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Standard Guide for External Corrosion Protection of Ductile Iron Pipe Utilizing Polyethylene Encasement Supplemented by Cathodic Protection[1]

This standard is issued under the fixed designation G218; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide will discuss standard practices which have been successfully utilized in the field for over 35 years to provide external corrosion protection of polyethylene encased ductile iron pipe supplemented with cathodic protection (CP). This guide may also be used for ductile iron fittings, valves, and other appurtenances specific to ductile iron pipe systems. Case histories and publications reporting on the use of cathodic protection to supplement polyethylene encasement are included as an Appendix in this guide.

1.2 Other external corrosion control methods which have been used for ductile iron pipe include, but are not limited to: cathodic protection, metallic zinc coatings, bonded dielectric coatings, dielectric coatings with cathodic protection, and trench improvement. Detailed information on these methods of protection are available from other sources and are beyond the scope of this guide.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The most recent version of the following documents should be consulted as references by those using this guide:

2.2 *ASTM Standards:*[2]

A674 Practice for Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids
A746 Specification for Ductile Iron Gravity Sewer Pipe
D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
D882 Test Method for Tensile Properties of Thin Plastic Sheeting
D1709 Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method
D1922 Test Method for Propagation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method
D4976 Specification for Polyethylene Plastics Molding and Extrusion Materials
G51 Test Method for Measuring pH of Soil for Use in Corrosion Testing
G57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
G97 Test Method for Laboratory Evaluation of Magnesium Sacrificial Anode Test Specimens for Underground Applications
G187 Test Method for Measurement of Soil Resistivity Using the Two-Electrode Soil Box Method
G193 Terminology and Acronyms Relating to Corrosion
G200 Test Method for Measurement of Oxidation-Reduction Potential (ORP) of Soil
G215 Guide for Electrode Potential Measurement

2.3 *ANSI/AWWA Standards:*[3]

ANSI/AWWA C105/A21.5 Polyethylene Encasement for Ductile-Iron Pipe Systems

[1] This guide is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.10 on Corrosion in Soils.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

ANSI/AWWA C110/A21.10 Ductile-Iron and Gray-Iron Fittings
ANSI/AWWA C111/A21.11 Rubber Gasket Joints for Ductile Iron Pressure Pipe and Fittings
ANSI/AWWA C151/A21.51 Ductile-Iron Pipe, Centrifugally Cast, for Water
ANSI/AWWA C600 Installation of Ductile-Iron Mains and Their Appurtenances

2.4 *NACE International Standards:*[4]
SP0169 Control of External Corrosion on Underground or Submerged Metallic Piping Systems
SP0104 The Use of Coupons for Cathodic Protection Monitoring Applications
TM0497 Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems
Publication 05107 Report on Corrosion Probes in Soil or Concrete
Publication 10A292 Corrosion and Corrosion Control for Buried Cast- and Ductile-Iron Pipe

2.5 *ISO Standards:*[5]
ISO 8180 Ductile iron pipelines – Polyethylene sleeving for site application
ISO 8179 Part 1 Ductile iron pipes, fittings, accessories, and their joints – External zinc-based coating – Part 1: Metallic zinc with finishing layer

2.6 Various additional publication references related to specific topics discussed in this guide are included as Appendix X1.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *100 mV criterion*—a specific degree of cathodic polarization between the pipe surface and a stable reference electrode, both in contact with the electrolyte; the degree of polarization can be measured during formation or decay.

3.1.2 *–850 mV criterion*—the degree of polarized potential measured relative to a saturated copper/copper sulfate reference electrode, which is used to verify cathodic protection has been achieved.

3.1.3 *annealing oxide*—a layer of tenacious and complex oxides of iron and silicon formed on ductile iron pipe during the annealing process.

3.1.3.1 *Discussion*—See 5.3 of this guide.

3.1.4 *cathodic protection coupon*—a metal sample representing the pipeline at the site, used for cathodic protection testing, and having a chemical composition approximately the same as the pipe.

3.1.5 *ductile iron pipe*—see Section 5 of this guide.

3.1.6 *enhanced linear low density (ELLD) polyethylene encasement film*—film extruded from virgin linear low density polyethylene raw material with additives designed to control generalized corrosion and microbiologically induced corrosion (MIC).

3.1.7 *ER probe*—an ER (electrical resistance) corrosion measurement probe that has been adapted for use in soil-side applications (also known as SCP – soil corrosion probe).

3.1.8 *free-corrosion coupon (also known as native coupon)*—a coupon that is immersed in the soil or aqueous environment adjacent to the structure but is not connected to the structure.

3.1.9 *high-density, cross-laminated (HDCL) polyethylene film*—film extruded from virgin high-density polyethylene raw material, which is then molecularly oriented by stretching; the final product is then formed by two single-ply layers of the film that are then laminated together with their orientations at 90° to one another using molten, high-density, virgin resin.

3.1.10 *linear low-density (LLD) polyethylene film*—film extruded from virgin linear low-density polyethylene raw material.

3.1.11 *LPR probe*—a linear polarization resistance (LPR) probe which determines the corrosion rate on its metal electrode or electrodes by measuring the polarization resistance under the application of a small applied potential, typically 10 to 20 mV, above the free corroding potential of the electrode or electrodes; the probe elements are generally made of the same or similar material as the structure to be monitored.

3.1.12 *polyethylene encasement*—polyethylene material, in tube or sheet form, that is used to encase ductile iron pipe and fittings for the purposes of corrosion protection or stray current mitigation, or both.

3.1.12.1 *Discussion*—See Section 6 of this guide.

3.1.13 *shopcoat*—the standard external coating for ductile iron pipe as described in ANSI/AWWA C151/A21.5; it consists of a painted coating approximately 1 mil (0.025 mm) thick which is normally applied to the outside of ductile iron pipe and fittings.

3.1.13.1 *Discussion*—See 5.4 of this guide.

3.2 General terminology and acronyms relating to corrosion are defined in Terminology G193.

4. Significance and Use

4.1 This guide provides basic information on the application of cathodic protection to polyethylene encased ductile iron pipe for engineers, owners, water companies, corrosion consultants, ductile iron (DI) pipe manufacturers and others who have an interest in providing underground corrosion protection to ductile iron pipe.

4.2 There are many publications, standards, recommended practices, and specifications for the application of coatings and cathodic protection to steel pipe. However, the metallurgy, chemistry, physical properties, surface composition and texture, coating requirements and electrical continuity of standard production ductile iron pipe are significantly different than those of steel pipe, and coating and cathodic protection specifications written specifically for steel pipe may not be directly applicable to ductile iron pipe. The latest revision of a

[4] Available from NACE International (NACE), 15835 Park Ten Pl., Houston, TX 77084, http://www.nace.org.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

commonly accepted cathodic protection specification (NACE SP0169) states the following in the forward: "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 non-adhered polyethylene encasement (refer to NACE Publication 10A292)." It is the purpose of this guide to summarize publications, case histories, and studies which are available regarding cathodic protection installations of polyethylene encased ductile iron pipe to give the reader guidance on this unique method of protection.

4.3 This guide may be utilized with galvanic or impressed current cathodic protection.

4.4 This guide is written specifically for ductile iron pipe and does not apply to any other type of piping material. It may also be used for ductile iron fittings, valves, and appurtenances specific to ductile iron piping systems.

4.5 This guide references requirements for vendor provided information which should be requested and reviewed by the user.

5. Ductile Iron Pipe (DIP)

5.1 *Metallurgy*—Ductile iron is a novel ferrous product containing approximately 93 % iron (Fe), with sufficient carbon (C) and silicon (Si) to qualify as a eutectiferous material. It has been treated in the liquid state so as to cause the majority of the carbon to occur as substantially equiaxed particles appearing as spheroids or nodules in the as-cast structure of the pipe. Ductile irons can be viewed as a family of alloys which combine the principal advantages of gray cast iron with the engineering advantages of steel; that is, good fluidity, castability, machinability, great strength, toughness, and ductility. Ductile iron pipe is typically specified to meet the minimum requirements of ANSI/AWWA C151/A21.51 and Specification A746.

5.2 *Joints*—Joints are the device by which an essentially leak-free connection is produced between two lengths of ductile iron pipe. The joint may be mechanical, push-on, or restrained, and is typically specified to meet minimum requirements of ANSI/AWWA C111/A21.11. Bolts used for securing mechanical joints are also typically specified to conform to the requirements of the same standard, and pipe with other types of joints specified to comply with the joint dimensions and weights agreed upon at the time of purchase.

5.3 *Annealing Oxide*—Modern production practices for ductile iron pipe include an annealing heat treatment to allow the material to achieve the optimum balance of material properties. When iron or steel are heat treated in air an oxide film is formed. Unlike mill scale on carbon steel which flakes away, the annealing oxide on ductile iron pipe exhibits a tenacious layer that adheres to the base metal due to the presence of silicon in the oxide structure. Under burial conditions, pores in the annealing oxide film become plugged by relatively insoluble corrosion products. This oxide film protects the underlying metal as long as the oxide layer is protected from the introduction of other species, like chlorides, which can result in partial dissolution of the oxide. Intact polyethylene encasement of the pipe resists introduction of chlorides and other compounds from contacting this protective oxide layer on the pipe surface.

5.4 *Shopcoat*—An exterior coating approximately 1 mil (0.025 mm) thick is normally applied on the outside of ductile iron pipe and fittings. AWWA and ASTM specifications call for the finished coating to be continuous, smooth, and strongly adherent to the pipe. While primarily applied for esthetic purposes, studies have shown asphaltic and other shopcoats do offer limited corrosion protection in conjunction with the annealing oxide and have been shown to reduce current requirements on CP systems (X1.2, X1.18). Shopcoats have also been shown to be compatible with metallic zinc coatings on ductile iron pipe, and have been reported to improve the life and performance of these coatings (X1.3).

5.5 *Metallic Zinc Coating*—Prior to the application of the shopcoat, a metallic zinc coating is sometimes applied to the exterior of ductile iron pipe for external corrosion protection. It is normally applied in accordance with ISO 8179 Part 1 utilizing arc spray or flame spray methods. The metallic zinc coating is typically applied on top of the inherent annealing oxide layer on ductile iron pipe. In severely corrosive soils, metallic zinc coating is normally utilized in conjunction with polyethylene encasement, or an enhanced polyethylene encasement, and may be used with or without additional external cathodic protection (X1.5).

6. Polyethylene Encasement

6.1 *Description and Properties:*

6.1.1 *General Description*—Polyethylene encasement has been the primary asset preservation method utilized for gray and ductile iron pipe since 1958. In the 60+ years of use, over 300 million feet of iron pipe have been installed with polyethylene encasement and over 300 miles of encased pipe installed with supplemental cathodic protection (X1.1, X1.5).

6.1.2 *Mechanisms of Protection:*

6.1.2.1 Polyethylene encasement is an engineered corrosion control system for ductile iron pipelines. The film is manufactured using specially designed virgin material with specific minimum thickness and mechanical requirements, for example, tensile strength, elongation, propagation tear resistance, impact resistance, and dielectric strength, which are specified in national and international standards. In those standards, recycled polyethylene is specifically proscribed from use in the manufacture of the film. Protection is achieved by encasing the pipe with a tube or sheet of loose polyethylene at the trench during the pipe installation process. Once installed, polyethylene encasement acts as an unbonded film, which prevents direct contact of the pipe with the corrosive soil. It also limits the electrolyte available to support corrosion activity to the moisture that might be present in the thin annular space between the pipe and wrap. Although polyethylene encasement is not a watertight system, in typical installations, the weight of the earth backfill and surrounding soil after installation normally prevents any significant exchange of groundwater between the wrap and the pipe (X1.1). Although some groundwater will typically seep beneath the wrap, the water's corrosive characteristics are depleted by initial corrosion reactions, usually reduction of oxygen in the presence of water to form hydroxyl ions. In areas of fluctuating water table or tidal action, additional installation procedures are described in ASTM and AWWA standards to minimize water exchange under the wrap.

6.1.2.2 Once the available dissolved oxygen in the moisture or groundwater between the pipe and the wrap has been consumed, further corrosion activity is effectively halted, and a uniform environment created around the pipe. This, in turn, helps eliminate the formation of localized corrosion cells that typically occur on the surface of a pipe exposed to a non-homogeneous soil environment. Additionally, the polyethylene film provides an essentially impermeable barrier that restricts the access of additional oxygen to the pipe surface and the diffusion of corrosion products away from the pipe surface (X1.9). The film also has a high dielectric strength that mitigates the pick-up of stray electrical currents and minimizes current required for cathodic protection applications (X1.7). To summarize, polyethylene encasement isolates the pipe from the soil and replaces a corrosive non-homogeneous environment (soil) with a non-corrosive homogeneous environment (passivated water) (X1.8, X1.9).

6.1.2.3 To enhance corrosion protection of linear low density polyethylene encasement, incorporation of an anti-microbial and a corrosion inhibitor into the film at the time of manufacture can be considered as an improvement to traditional polyethylene encasement. The anti-microbial is designed to control microbiologically induced corrosion (MIC) which may occur in some environments, and the corrosion inhibitor is designed to control the initial corrosion rate until the deoxygenation process takes place under the film. This material is commercially available and is described in 6.2.3.

6.1.3 *Polyethylene Encasement with Cathodic Protection*—Polyethylene encasement has been used successfully in conjunction with cathodic protection and this combination is discussed in Section 9 (X1.1, X1.2, X1.4, X1.5, X1.6, X1.7, X1.8, X1.10, X1.11, X1.12, X1.13, X1.14, X1.16, X1.17). The primary purpose of cathodic protection is to provide protection to the pipe surface at areas of unrepaired damage to the encasement. Polyethylene encasement with an anti-microbial has also been used in conjunction with cathodic protection to address MIC concerns at areas under the encasement where the cathodic protection currents may not reach (X1.4, X1.5, X1.16). As both standard polyethylene and enhanced polyethylene films meet the dielectric requirements of Practice A674, cathodic protection design and operation requirements are typically the same for both types of film.

6.2 *Physical Properties*—Physical properties and test methods are described in detail in Practice A674. They include thickness, tensile strength (machine and transverse direction), elongation (Test Method D882), dielectric strength (Test Method D149), impact resistance (Test Methods D1709), and propagation tear resistance (Test Method D1922).

6.2.1 *Linear Low-Density (LLD) Polyethylene Film*—Polyethylene film described in Specification D4976 is categorically described as Group 2 (linear) with a density of 0.910 to 0.925 g/cm^3 and dielectric strength, volume resistivity of 10^{15} ohm-cm, minimum.

6.2.2 *High-density Cross Laminated (LLD) Polyethylene Film*—Polyethylene film described in Specification D4976 as in 6.2.1 except with density of 0.940 to 0.960 g/cm^3.

6.2.3 *Enhanced Linear Low-density Polyethylene Film*—Linear low density polyethylene film as described in 6.2.1 utilizes additives designed to control generalized corrosion and microbiologically induced corrosion (MIC). These additives utilize a specifically engineered co-extruded polyethylene matrix as the carrier.

7. Inspection, Testing, and Verification of Polyethylene Encasement

7.1 *Materials:*

7.1.1 *Polyethylene Film*—Only virgin polymers meeting the minimum properties described in Practice A674, Table 1 for linear-low density polyethylene film, or Table 2 for high-density cross laminated polyethylene film, are considered to be compliant with this guide. These properties are summarized in 6.2 of this guide. Virgin polyethylene polymers are critical as some non-virgin polymers or films containing post-consumer waste products (that is, recycle polyethylene) can contain deleterious materials such as biodegradable elements, binders, starches, and other components which can affect film properties, cause deterioration with time, or serve as food sources for bacteria associated with MIC, or combinations thereof. Non-compliant polyethylene films may not only degrade with time, but generally do not meet all the minimum physical requirements for new film and are difficult to install without significant damage.

7.1.1.1 *Quality Control and Inspection*—Practice A674 requires the manufacturer of polyethylene film for corrosion protection encasement of ductile iron pipe systems to have a documented Quality Control System or a current compliance certificate from an accredited Quality Auditing organization to assure that it complies with all requirements of the standard.

7.1.1.2 *Manufacturer's Statement*—Practice A674 requires the film manufacturer, the film distributor, or both, to maintain accessible quality records for a minimum period of one year from date of manufacture. In lieu of the above records, the manufacturer may elect to test a customer selected film sample provided that proof of manufacturer and the date of manufacture (DOM) are verifiable to the sample.

7.1.1.3 *Freedom from Defects*—Practice A674 requires the polyethylene film to be manufactured and used in accordance with the standard, not be made from recycled materials, and to be clean, sound, and without defects.

7.2 *Installation – Polyethylene Encasement Installation*—Installation practices are described in Practice A674. Failure to follow these installation practices can significantly limit the effectiveness of the installed polyethylene encasement system. Enhanced LLD Polyethylene Encasement installation practice per this guide encompasses all of the practice defined in Practice A674 and should include manufacturers defined installation practice as well. Recommended installation practices are also described in ANSI/AWWA C105/A21.15 and ANSI/AWWA C600.

8. Cathodic Protection

8.1 *Description*—Cathodic protection is an electrochemical technique used to reduce the corrosion rate of a metal surface by making it the cathode of an electrochemical cell. When a metallic structure, such as ductile iron piping, comes in contact with an electrolyte, through burial or other means, anodic and cathodic areas may form at the metallic surface exposed to the electrolyte, which creates local electrochemical cells. At anodic areas, current flowing from the structure through the electrolyte causes corrosion. At cathodic areas, current flowing from the soil to the metallic surface causes a significant drop of the local corrosion rate. Therefore, cathodic protection can make a structure cathodic by forcing the current to flow through the electrolyte, from an external anodic site to every exposed areas of this structure. CP can be used in conjunction with coatings or wrappings in order to minimize to exposed area of a pipe, therefore reducing the total current required to achieve adequate polarization of the structure. Cathodic protection systems can be subcategorized into two distinct techniques: (*1*) galvanic anode CP systems, and (*2*) impressed current CP systems.

8.2 *Galvanic Anode CP Systems*—In galvanic anode CP systems, current is generated by connecting to the structure a less noble (or more active) metal. The driving voltage (difference of potential between the anode and the structure) depends on the nature of the anode. Typical materials used for galvanic anodes underground are magnesium and zinc. Aluminum anodes have sometimes been used for special environments such as salt water.

8.2.1 *Galvanic Anodes*—Galvanic anodes for use with polyethylene encasement are typically recommended to be of quality material and to comply with all design requirements which include, but not be limited to composition, electrode (oxidation potential), and electrical charge (ampere hours) obtained per unit mass of specimen consumed. Test Method G97 may be used to verify magnesium anode properties.

8.3 *Impressed Current CP Systems*—In impressed current CP systems, the structure is connected to a more noble metal, and the current is forced to circulate from the anode to the cathode (in the electrolyte) by an external power source such as a transformer rectifier or batteries. The driving voltage therefore depends on the power source used and can easily be adjusted. Many different materials can be used as impressed current anodes such as high silicon cast iron, graphite, mixed metal oxide, platinum, etc.

8.4 *Accepted Criteria*—Accepted cathodic protection criteria utilized on regulated pipelines are discussed in Section 10. Although ductile iron pipe are typically not considered for regulated pipelines such as oil and gas lines, much of the same criteria for verifying adequate cathodic protection has been utilized (X1.2, X1.4, X1.5, X1.6, X1.8, X1.10, X1.11, X1.12, X1.13, X1.17).

8.5 *Installation of Cathodic Protection System*—Design and installation of cathodic protection systems are beyond the scope of this guide. Cathodic protection systems should be designed and installed by a trained and certified professional engineer, NACE corrosion specialist, or NACE cathodic protection specialist. During design of the CP system, it should be recognized that properly installed, undamaged polyethylene encasement shields the ductile iron pipe from cathodic protection currents. The primary purpose of applying cathodic protection to polyethylene encased ductile iron pipe is to provide cathodic protection to damaged areas of the encasement.

9. Need for Polyethylene Encasement with Cathodic Protection

9.1 *Description/Discussion*—The appendix of Practice A674 includes a detailed description of soil survey tests, observations, and interpretations used to determine if polyethylene encasement is recommended. In addition to these areas, some installations may need polyethylene encasement supplemented with cathodic protection. These include but are not limited to: (*1*) installations where soils are corrosive and there is a concern that areas of damage to the encasement may not be repaired, (*2*) areas of high density stray current where stray current mitigation is needed, and (*3*) "uniquely severe" soils as described in Practice A674.

9.2 *Site Assessment*—There are many factors which must be considered when evaluating the potential for external corrosion during a site assessment. Some of these factors are discussed in the following sub-sections. Testing should only be accomplished by qualified personnel who are experienced in soil analysis and evaluation of conditions potentially corrosive to ductile iron pipe.

9.2.1 *Soils*—The most common tests normally conducted to evaluate soil corrosivity include resistivity (Test Methods G57 and G187), oxidation-reduction potential (Test Method G200), pH (Test Method G51), presence of sulfides/sulfates, presence of chlorides, moisture content, and presence of corrosion related bacteria.

9.2.2 *Stray Current*—Sources of stray electrical currents include but are not limited to: cathodic protection systems, cathodically protected pipelines, electric railways, welding equipment, direct current transmission systems, and mine transportation equipment. Normally, the amount of stray current influence from cathodic protection systems is insignificant for galvanic CP systems but can be significant for impressed current systems. Analysis and mitigation of stray current environments should be conducted by a trained and certified professional engineer, NACE corrosion specialist, or NACE cathodic protection specialist.

9.2.3 *Environmental Conditions*—Certain soils and environmental conditions are known to be potentially corrosive to iron pipe based on experience and thus do not require evaluation. These include but are not limited to: coal, cinders, muck, peat, mine wastes, and landfill areas high in foreign materials.

9.2.4 *Likelihood of Future Changing Conditions over Projected Life Span*—It should be recognized and considered during design that environmental conditions may change over the projected life span of the system. One such example is the addition of road salts on roadways for de-icing purposes. This practice will normally change a relative non-corrosive soil to a very corrosive environment over time. Installation of new pipelines with cathodic protection systems, roads, industries, etc. may also change environmental conditions.

9.3 *Risk Assessment:*

9.3.1 *General*—An engineer or certified corrosion professional should perform a risk assessment considering the areas described in 9.1 and 9.2. Selection of the proper corrosion control method and design should be project specific and should address the likelihood and consequence of corrosion failure (X1.1, X1.7, X1.15).

9.3.2 *Implications of Failure*—Although the proper treatment and transport of water and wastewater are critical components of maintaining a healthy society, the implications or risks associated with the failure of a water or wastewater piping system are generally not as severe or life threatening as a failure in an oil, fuel, or gas pipeline (X1.11). For these reasons, corrosion control systems are not federally regulated in the water and wastewater industry as they are in the energy industry. Risk associated with failures in a water or wastewater piping system are generally related to water loss, possible reduction in water quality, property damage, disruption of fire protection systems, temporary disruption of service to customers, sink hole development, and traffic re-routing. Potential risk of failure in wastewater piping systems may also include environmental contamination of soil and waterways, health concerns, environmental fines and/or mandates, and extensive clean-up costs. While all of these risks/consequences of failure are potentially severe, rarely does a failure in a water or wastewater piping system result in the loss of life. Rather, the primary reasons for installing and maintaining a cathodic protection system on water or wastewater piping are typically for economic, sustainability, and reliability issues rather than safety concerns.

9.3.3 *Areas of High Risk*—Areas with a high risk of failure may include but are not limited to: hospitals and health care facilities, single source transmission mains, heavily congested areas, river crossings, deep bury installations, under heavily traveled roadways, under airport runways, power plants, under railroad crossings, certain industrial facilities, and other areas based on economic and reliability considerations.

9.3.4 *Historical Performance*—Historical performance of old iron or metallic pipelines in the area of new pipelines to be installed can provide valuable information and guidance regarding the corrosivity of the soil and expected performance of pipe with and without corrosion protection. Whenever possible, a review of historical performance of metallic pipelines in the area should be considered in the risk analysis and design of corrosion protection systems for new pipelines.

9.3.5 *Potential Third-party Damage*—In spite of all efforts to properly design, install, and maintain a cathodic protection system, the risk always exists regarding the possibility of damage by a third party. This may include but not be limited to: cutting of anode, anode bed, or test station connection wires by third party excavation or brush cutting, vandalism of rectifiers, installation of other underground facilities between anodes or anode beds and the pipe, and loss of power to rectifiers. Future installation of other nearby cathodically protected pipelines may also result in stray current interference problems.

10. Cathodic Protection Criteria

10.1 *General*—The most generally utilized criteria for cathodic protection (to ferrous materials) is described in Section 6 of NACE SP0169 (formerly RP0169) developed by NACE International (National Association of Corrosion Engineers) – Houston, Texas. Although the criteria included in that standard were developed in 1969 primarily for the regulated Oil and Gas Industry, and the scope of that document states that it does not include corrosion control methods based on the use of non-adhered polyethylene encasement, portions of this document have been successfully applied to gray and ductile iron pipe for decades (X1.6). Publications and case histories have documented the successful use of the polyethylene encasement plus CP corrosion control strategy to protect over 300+ miles of ductile iron pipe constructed over the last 30+ years (X1.1, X1.6). Many of these case histories are referenced and summarized in Appendix X1 of this guide. 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. Numerous case histories document ductile iron pipe encased in polyethylene encasement with CP have met this benchmark (X1.1, X1.5, X1.6, X1.8, X1.10, X1.16). Electrical resistance corrosion probes are sometimes installed under polyethylene encasement to verify the effectiveness of the polyethylene encasement + CP system (refer to Section 11) (X1.5, X1.8, X1.9, X1.10, X1.14, X1.16, X1.18, X1.19).

10.2 *Criteria*—The two most commonly utilized criteria for determining adequate cathodic protection for iron or steel piping, or both, are (*1*) a structure-to-electrolyte potential of –850 mV or more negative as measured with respect to a saturated CSE (copper/copper sulfate) reference electrode (that is, –850 mV criterion), and (*2*) a minimum of 100 mV of cathodic polarization (that is, 100 mV shift criterion). Of these two methods, the one which has been utilized most often for verifying effective cathodic protection of polyethylene encased ductile iron pipe is the 100 mV cathodic polarization criterion (that is, 100 mV shift) (X1.11). Detailed discussions and descriptions of cathodic protection instrumentation and measurement procedures are beyond the scope of this guide. For this information, the reader is referred to Guide G215 and NACE TM0497. As stated in the NACE standard, "The provisions of this standard shall be applied by personnel who have the knowledge and understanding of the fundamentals of cathodic protection of buried and submerged metallic piping systems acquired by education and related practical experience."

10.2.1 *Cathodic Polarization of 100 mV (that is, 100 mV Shift Criterion)*—The 100 mV shift from the native potential of the pipe may be measured as the formation or the decay of polarization between the native potential of the pipe and the polarized CP potential.

10.2.2 *–850 mV Potential Criterion*—Structure-to-electrolyte potential of –850 mV or more negative with respect to a saturated copper/copper sulfate (CSE) reference electrode. To meet this requirement, potential measurements are allowed to be taken either as a direct measurement of the polarized potential or a current applied potential. However, if a current