NACE Standard RP0169-92
Item No. 21001

Standard
Recommended Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Approved August 1969
Revised January 1972
Revised September 1976
Revised January 1983
Revised April 1992
National Association of Corrosion Engineers
P.O. Box 218340
Houston, Texas 77218-8340
713/492-0535

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Foreword

This NACE standard recommended practice was prepared by NACE Task Group T-10-1, which is composed of corrosion control personnel from oil and gas transmission companies, gas distribution companies, power companies, corrosion consultants, and others concerned with corrosion control. This standard is issued by NACE under the auspices of Group Committee T-10 on Underground Corrosion Control.

The purpose of this recommended practice is to present procedures and practices for achieving effective control of external corrosion on buried or submerged metallic piping systems. These recommendations are also applicable to many other buried or submerged metallic structures. This recommended practice describes the use of electrically insulating coatings, electrical isolation, and cathodic protection as corrosion control methods. It contains specific provisions for the application of cathodic protection to existing bare, existing coated, and new piping systems. Also included are procedures for control of interference currents on pipelines. This recommended practice does not include corrosion control methods based on chemical control of the environment or on the use of electrically conductive coatings. For recommendations on control of internal corrosion, see NACE Standard RP0175 (latest revision), "Control of Internal Corrosion in Steel Pipelines and Piping Systems."

This recommended practice should be used in conjunction with the practices described in the following NACE standards and publications where appropriate (use latest revisions):

RP0572, "Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds";

RP0175, "Control of Internal Corrosion in Steel Pipelines and Piping Systems";

RP0675, "Control of External Corrosion on Offshore Steel Pipelines";

RP0177, "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems";

RP0285, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems";

RP0186, "Application of Cathodic Protection for Well Casings";

RP0286, "The Electrical Isolation of Cathodically Protected Pipelines";

RP0387, "Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications";

RP0188, "Discontinuity (Holiday) Testing of Protective Coatings";

TPC 11, "A Guide to the Organization of Underground Corrosion Control Coordinating Committees";

NACE Publication 10A190, "Measurement Techniques Related to Criteria for Cathodic Protection of Underground or Submerged Steel Piping Systems (as Defined in NACE Standard RP0169-83)";

NACE Publication 10B189, "Direct Current (DC) Operated Rail Transit and Mine Railroad Stray Current Mitigation";

NACE Item No. 54277, "Specialized Surveys for Buried Pipelines"; and

NACE Item No. 54276, "Cathodic Protection Monitoring on Buried Pipelines."

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

This recommended practice does not designate practices for every specific situation because of the complexity of conditions to which buried or submerged piping systems are exposed.

In NACE standards, the terms "shall" and "must" are used to state mandatory requirements. The term "should" is used to state that which is considered good and is recommended but is not absolutely mandatory. The term "may" is used to state that which is considered optional.

This standard was revised in 1992 by NACE Task Group T-10-1 and published under the auspices of Group Committee T-10. This standard was originally published in 1969, and revised by Group Committee T-10 in 1972, 1976, 1983, and now 1992.

This standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this NACE standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials.

Section 1: General

1.1 This recommended practice presents acknowledged practices for the control of external corrosion on buried or submerged steel, cast iron, ductile iron, copper, and aluminum piping systems under the following headings:

Section 1: General
Section 2: Definitions
Section 3: Determination of Need for Corrosion Control
Section 4: Piping System Design
Section 5: Coatings
Section 6: Criteria and Other Considerations for Cathodic Protection
Section 7: Design of Cathodic Protection Systems
Section 8: Installation of Cathodic Protection Systems
Section 9: Control of Interference Currents
Section 10: Operation and Maintenance of Cathodic Protection Systems
Section 11: Corrosion Control Records

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

1.2.1 New piping systems: Corrosion control by coating supplemented with cathodic protection, or by some other proven method, 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 pipelines in a manner that facilitates the use of in-line inspection tools.

1.2.2 Existing coated piping systems: Cathodic protection should be provided and maintained, unless investigations indicate that cathodic protection is not required.

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

1.3 The provisions of this recommended practice should 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 buried or submerged metallic piping systems. Such persons may be registered professional engineers or persons recognized as corrosion specialists or cathodic protection specialists by NACE if their professional activities include suitable experience in corrosion control of buried or submerged metallic piping systems.

1.4 Special conditions sometimes exist where cathodic protection is ineffective or only partially effective. Such conditions may include elevated temperatures, disbonded coatings, thermal insulating coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte. Deviation from the recommended practice may be warranted in specific situations provided that corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in the recommended practice have been achieved.

Section 2: Definitions[1]

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, which is normally metallic. The anode is usually the electrode where corrosion occurs and metal ions enter solution.)

Anodic Polarization: The change of the electrode potential in the noble (positive) direction resulting from the flow of current between the electrode and electrolyte.

Beta Curve: See Appendix A.

Cable: One conductor or more than one insulated from one another.

Cathode: The electrode of an electrolytic cell at which reduction occurs.

Cathodic Disbondment: The coating disbondment caused by the products of a cathodic reaction.

Cathodic Polarization: The change of electrode potential in the electronegative direction resulting from the flow of current between the electrolyte and electrode.

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

Coating: A dielectric material applied to a structure to separate it from the environment.

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

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

Continuity Bond: An intentional metallic connection that provides electrical continuity.

Corrosion: The deterioration of a material, usually a metal, by reaction with its environment.

Corrosion Potential: The mixed potential of a freely corroding pipe surface with reference to an electrode in contact with the electrolyte.

Corrosion Rate: The rate at which corrosion proceeds, expressed as either weight loss or penetration, per unit time.

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

Current Density: The current per unit area.

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

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

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: An electronic conductor used to establish electrical contact with an electrolyte part of a circuit.

Electro-Osmotic Effect: Passage of a charged particle through a membrane under the influence of a voltage. Soil or coatings may act as the membrane.

Electrolyte: A chemical substance or mixture containing ions that migrate in an electric field. For the purpose of this recommended practice, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic piping system, including the moisture and other chemicals contained therein.

Foreign Structure: Any structure that is not intended as a part of the system of interest.

Galvanic Anode: A metal which, because of its relative position in the galvanic series, provides protection to metal or metals that are more noble in the series, when coupled in an electrolyte.

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

Half Cell Reference Electrode: See "Reference Electrode."

Holiday: A discontinuity in the coating.

Impressed Current: Direct current supplied by a cathodic protection system utilizing an external power source.

In-Line Inspection: The inspection of a steel pipeline using an electronic instrument or tool that travels along the interior of the pipeline. (See Paragraph 6.3.3.)

Insulating Coating System: All components comprising the protective coating, the sum of which provides effective electrical isolation of the coated structure.

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

Interference Bond: A metallic connection designed to control electrical current interchange between metallic systems.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Isolation: See "Electrical Isolation."

Line Current: The direct current flowing on a pipeline.

Long-Line Corrosion Activity: Current flowing through the earth between an anodic and a cathodic area that returns along an underground metallic structure.

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

Pipe-to-Electrolyte Potential: The potential difference between the pipe metallic surface and electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Polarization: The deviation from the corrosion potential of an electrode resulting from the flow of current between the electrode and the electrolyte.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Reference Electrode: A reversible electrode with a potential that may be considered constant under similar conditions of measurement. (Examples: saturated copper-copper sulfate, saturated calomel, and silver-silver chloride.)

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

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

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

Sound Engineering Practices: Reasoning exhibited or based on thorough knowledge and experience, logically valid and having true premises showing good judgment or sense in the application of science.

Stray Current: Current in paths other than the intended circuit.

Stray Current Corrosion: Corrosion resulting from stray current transfer between the pipe and electrolyte.

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

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

Wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller gauge conductors (No. 10 Awg or smaller).

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

Section 3: Determination of Need for Corrosion Control

3.1 Introduction

3.1.1 The purpose of this section is to recommend practices for determining when an underground or submerged metallic piping system requires corrosion control.

3.1.2 Metallic structures, buried or submerged, are subject to corrosion. Adequate corrosion control procedures should be adopted to ensure metal integrity for safe and economical operation.

3.2 The need for 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, and operating, safety, and economic requirements. The absence of leaks alone is insufficient evidence that corrosion control is not required.

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 Appendix B);

3.2.1.2 Nature of the product being transported, the working temperature, temperature differentials within the pipeline causing thermal expansion and contractions, 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 foreign to the system.

3.2.2 Economic factors include the following:

3.2.2.1 Costs of maintaining the piping system in service for its expected life (see Appendix B);

3.2.2.2 Contingent costs of corrosion (see Appendix C); and

3.2.2.3 Costs of corrosion control (see Appendix D).

Section 4: Piping System Design

4.1 Introduction

4.1.1 The purpose of this section is to provide 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 recommendations should not be construed as taking precedence over recognized electrical safety practices.

4.2 Corrosion Control

4.2.1 Corrosion control must be a primary consideration during the design of a piping system. Materials selection and coatings are the first line of defense against corrosion. Because perfect coatings are not feasible, cathodic protection must be used in conjunction with coatings. For additional information, see Section 5 on "Coatings" and Section 6 on "Criteria and Other Considerations for Cathodic Protection."

4.2.2 New piping systems should be coated unless thorough investigation indicates that coatings are not required (see Section 5 on "Coatings").

4.2.3 Materials and construction practices that create electrical shielding should not be used on the pipeline. Pipelines should be installed at locations where proximity to other structures and subsurface formations will not cause shielding.

4.3 Electrical Isolation

4.3.1 Isolation devices such as flange assemblies, prefabricated joint unions, or couplings should be installed within piping systems where electrical isolation of portions of the system is required to facilitate the application of corrosion control. These devices should be properly selected for temperature, pressure, chemical resistance, dielectric resistance, and mechanical strength. Installation of isolation devices should be avoided or safeguarded in areas where combustible

atmospheres are likely to be present. Locations where electrical isolating devices should be considered include, but are not limited to, the following:

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

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

4.3.1.3 Inlet and outlet piping of in-line measuring and/or 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 of 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 a bare pipe; and

4.3.1.9 Locations where electrical grounding is used, such as motorized valves and instrumentation.

4.3.2 The need for lightning and fault current protection at isolating devices should be considered. Cable connections from isolating devices to arrestors should be short, direct, and of a size suitable for short-term, high-current loading.

4.3.3 Where metallic casings are required as part of the underground piping system, the pipeline should be electrically isolated from such casings. Casing insulators must be properly sized, spaced, and tightened securely on the pipeline to withstand insertion stresses without sliding on the pipe. Inspection should be made to verify that the leading insulator has remained in position. Concrete coatings on the carrier pipe could preclude the use of casing insulators. Consideration should 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 nor act as a shield to cathodic protection current.

4.3.4 Casing seals should be installed to resist the entry of foreign matter into the casing.

4.3.5 Where electrical contact would adversely affect cathodic protection, piping systems should be electrically isolated from supporting pipe stanchions, bridge structures, tunnel enclosures, piling, offshore structures, or reinforcing steel in concrete. However, piping can be attached directly to a bridge without isolation if isolating devices are installed in the pipe system on each side of the bridge to electrically isolate the bridge piping from adjacent underground piping.

4.3.6 Where 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 manufacturer's instructions.

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

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

4.3.9 Insulating type spacing materials should be used where it is intended to maintain electrical isolation between a metallic wall sleeve and the pipe.

4.3.10 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.

4.3.11 Based on voltage rating of AC transmission lines, adequate separation should be maintained between pipelines and electric transmission tower footings, ground cables, and counterpoise. Regardless of separation, consideration should always be given to lightning and fault current protection of pipeline(s) and personnel safety (see NACE Standard RP0177 [latest revision]).

4.4 Electrical Continuity

4.4.1 Non-welded pipe joints may not be electrically continuous. Electrical continuity can be ensured by the use of fittings manufactured for this purpose or by bonding across and to the mechanical joints in an effective manner.

4.5 Corrosion Control Test Stations

4.5.1 Test stations for potential, current, or resistance measurements should be provided at sufficient locations to facilitate cathodic protection testing. Such locations may include, but not be 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 Rectifier installations.

4.5.2 The span of pipe used for line current test stations should exclude:

4.5.2.1 Foreign metallic structure crossings;
4.5.2.2 Lateral connections;
4.5.2.3 Mechanical couplings or connections such as screwed joints, transition pieces, valves, flanges, anode or rectifier attachments, or metallic bonds; and
4.5.2.4 Changes in pipe wall thickness and diameter.

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

4.5.3.1 Test lead wires may be used for both periodic testing or 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) thermit welding process, (b) soldering, and (c) mechanical means.

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 environments.

4.5.3.4 Attachment by mechanical means is the least desirable method. Such a connection may loosen, become highly resistant, or lose electrical continuity.

4.5.3.5 The connection should be tested for mechanical strength and electrical continuity. All exposed portions of the 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 may 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 will be required. Flux residues may cause corrosion unless removed.

NOTE: The use of copper test lead wire may cause preferential galvanic attack on the aluminum pipe. Where copper wire or flux is used, care must be taken to seal the attachment areas against moisture. In the presence of moisture, the connection may 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.

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. The relative thickness of the wire and the pipe wall will dictate, 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 should 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 may be required, or self-produced, when brazing with some filler metals or soldering with some low-melting point soft solders. Since flux residues may cause corrosion, they should be removed.

Section 5: Coatings

5.1 Introduction

5.1.1 The purpose of this section is to recommend practices for selecting, testing and evaluating, handling, storing, inspecting, and installing coating systems for corrosion control on piping systems.

5.1.2 The function of coatings is to control corrosion by isolating the external surface of the underground or submerged piping from the environment, to reduce cathodic protection current requirements, and to improve current distribution. Coatings must be properly selected and applied, and the coated piping carefully handled and installed to fulfill these functions. Various types of coatings can accomplish the desired functions.

5.1.2.1 Desirable characteristics of coatings include the following:

5.1.2.1.1 Effective electrical insulator,

5.1.2.1.2 Effective moisture barrier,
5.1.2.1.3 Application to pipe by a method that will not adversely affect the properties of the pipe,
5.1.2.1.4 Application to piping with a minimum of defects,
5.1.2.1.5 Good adhesion to pipe surface,
5.1.2.1.6 Ability to resist development of holidays with time,
5.1.2.1.7 Ability to resist damage during handling, storage, and installation,
5.1.2.1.8 Ability to maintain substantially constant electrical resistivity with time,
5.1.2.1.9 Resistant to disbonding,
5.1.2.1.10 Resistant to chemical degradation,
5.1.2.1.11 Ease of repair,
5.1.2.1.12 Retention of physical characteristics,
5.1.2.1.13 Non-toxic to the environment, and
5.1.2.1.14 Resistance to changes and deterioration during aboveground storage and long distance transportation.

5.1.2.2 Typical factors to consider when selecting a pipe coating include:

5.1.2.2.1 Type of environment;
5.1.2.2.2 Accessibility of piping system;
5.1.2.2.3 Operating temperature of piping system;
5.1.2.2.4 Ambient temperatures during application, shipping, storage, construction, installation, and pressure testing;
5.1.2.2.5 Geographical and physical location;
5.1.2.2.6 Type of coating on existing pipe in the system;
5.1.2.2.7 Handling and storage;
5.1.2.2.8 Pipeline installation methods;
5.1.2.2.9 Costs; and
5.1.2.2.10 Pipe surface preparation requirements.

5.1.2.3 Pipeline coating systems shall be properly selected and applied to ensure that adequate bonding is obtained. Unbonded coatings can create electrical shielding of the pipeline that could jeopardize the effectiveness of the cathodic protection system.

5.1.3 Information in this section is primarily by reference to other documents. It is important that the latest revision of the pertinent reference be used.

5.1.3.1 Table 1 is a general listing of all references used, giving titles and sponsoring sources. In this table, each document is given a reference number for convenient use thereafter.

5.1.3.2 Table 2 is a listing of types of coating systems, showing the appropriate references for material specifications and recommended practices for application.

5.1.3.3 Table 3 is a grouping of references for general use during installation and inspection, regardless of coating type.

5.1.3.4 Table 4 is a list of coating system characteristics related to environmental conditions containing suggested laboratory test references for various properties.

5.1.3.5 Table 5 is a list of coating system characteristics related to design and construction, with recommended laboratory tests for evaluating these properties.

5.1.3.6 Table 6 lists the references that are useful in field evaluation of coating systems after the pipeline has been installed.

5.2 Storage, Handling, Inspection, and Installation

5.2.1 Storage and Handling

5.2.1.1 Coated pipe to be stored should be protected internally and externally from atmospheric corrosion and coating deterioration.

5.2.1.2 Damage to coating can be minimized by careful handling and by using proper pads and slings.

5.2.2 Inspection

5.2.2.1 Qualified personnel should keep every phase of the coating operation and piping installation under surveillance.

5.2.2.2 Surface preparation, primer application, coating thickness, temperatures, bonding, and other specific requirements should be checked periodically, using suitable test procedures for conformance with specifications.

5.2.2.3 The use of holiday detectors is recommended to detect coating flaws that would not be observed visually. The holiday detector should be operated in accordance with manufacturer's instructions and at a voltage level appropriate to the electrical characteristics of the coating system.

5.2.3 Installation

5.2.3.1 Joints, fittings, and tie-ins must be coated with a material compatible with the existing coating.

5.2.3.2 Coating defects should be repaired.

5.2.3.3 Materials used to repair coatings must be compatible with existing pipe coating.

5.2.3.4 The ditch bottom should be graded and free of rock or other foreign matter that can damage the coating or cause electrical shielding. Under difficult conditions, consideration should be given to padding the pipe or the ditch bottom.

TABLE 1 - Index of Coating References

Reference Number	Title	Source[1]
1	"Standard for Coal-Tar Protective Coatings and Linings for Steel Water Pipelines—Enamel and Tape—Hot-Applied"	ANSI/AWWA C-203-91
2	"Extruded Asphalt Mastic Type Protective Coatings for Underground Pipelines"	NACE RP0276-76
3	"Application and Handling of Wax-Type Protective Coatings and Wrapper Systems for Underground Pipelines"	NACE RP0375-75
4 (a)	"Material Requirements for Polyolefin Cold-Applied Tapes for Underground or Submerged Pipeline Coatings"	NACE MR0174-89
4 (b)	"Standard for Tape Coating for the Exterior of Steel Water Pipelines"	ANSI/AWWA C-214-89
4 (c)	"Standard for Cold-Applied Tape Coating for the Exterior of Special Sections, Connections and Fittings for Steel Water Pipelines"	ANSI/AWWA C-209-90
5 (a)	*Control of Pipeline Corrosion*, A.W. Peabody, pp. 9-18, 1967	NACE
5 (b)	"Application of Organic Coatings to the External Surface of Steel Pipe for Underground Service"	NACE RP0275-75
5 (c)	"Standard for Fusion-Bonded Epoxy Coatings for the Interior and Exterior of Steel Water Pipelines"	ANSI/AWWA C213-91
5 (d)	"Recommended Practices for Unprimed Internal Fusion Bonded Epoxy Coating of Line Pipe"	API RP 5L7-(1988)
5 (e)	"External Fusion Bonded Epoxy Coating for Steel Pipe and External Polyethylene Coating"	CSA-Z245.20M92
5 (f)	"External Protective Coatings for Joints, Fittings, and Valves on Metallic Underground or Submerged Pipelines and Piping"	NACE RP0190-90
6 (a)	"Extruded Polyolefin Resin Coating Systems for Underground or Submerged Pipe"	NACE RP0185-85
6 (b)	"Polyethylene Sheathing of Steel Tubes and of Steel Shapes and Fittings"	DIN 30 670
6 (c)	"Standard for Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines"	ANSI/AWWA C215-88
7	"High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation"	NACE RP0274-74
8	"Underground Corrosion," by M. Romanoff (reprint of National Bureau of Standards Circular 579, now out-of-print)	NACE #51270-P
9	"Standard Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel"	ASTM G12-83 (1988)
10 (a)	"Standard Test Method for Cathodic Disbonding of Pipeline Coatings"	ASTM G8-90
10 (b)	"Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial"	ASTM G19-88
10 (c)	"Standard Methods for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures"	ASTM G42-90
10 (d)	"Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings"	ASTM G95-87
11	"Standard Test Method for Water Penetration into Pipeline Coatings	ASTM G9-87

12 (a)	"Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)"	ASTM G17-88
12 (b)	"Standard Test Method for Rubber Property-Durometer Hardness"	ASTM D2240-91
13	"Standard Test Method for Shrinkage Factor of Soils"	ASTM D427-83 (1990)
14 (a)	"Standard Test Method for Resistance of Plastics to Chemical Reagents"	ASTM D543-87
14 (b)	"Test Method for Resistance of Plastics to Chemical Reagents," Federal Test Standard No. 406A, Method 7011, January 1982	General Services Administration
14 (c)	"Standard Test Method for Chemical Resistance of Pipeline Coatings"	ASTM G20-88
15 (a)	"Standard Test Method for Thermal Endurance of Rigid Electrical Insulating Materials"	ASTM D2304-91
15 (b)	"Standard Practice for Determining the Effect of Overbaking on Organic Coatings"	ASTM D2454-91
15 (c)	"Standard Test Methods for Evaluating Coatings for High Temperature Service"	ASTM D2485-91
16 (a)	"Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi"	ASTM G21-90
16 (b)	"Test Method for Mildew Resistance of Plastics by Mixed Culture Method," Agar Medium, Federal Test Standard No. 406A, Method 6091, January 1982	General Services Administration
17	"Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings"	ASTM G11-88
18	"Standard Test Method for Abrasion Resistance of Pipeline Coatings"	ASTM G6-88
19	"Standard Test Method for Specific Bendability of Pipeline Coatings"	ASTM G10-83 (1988)
20	"Standard Test Method for Adhesion of Organic Coatings by Scrape Adhesion"	ASTM D2197-86 (1991)
21 (a)	"Standard Test Method for Impact Resistance of Pipeline Coatings (Limestone Drop Test)"	ASTM G13-89
21 (b)	"Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)"	ASTM G14-88
22 (a)	"Standard Test Methods for Joints, Fittings, and Patches in Coated Pipelines"	ASTM G18-88
22 (b)	"Standard Method for Evaluating Pipeline Coatings and Patch Materials"	ASTM G55-88

(1) Addresses of Sources:

ASTM, 1916 Race St., Philadelphia, PA 19103. Telephone (215) 299-5400.
American Petroleum Institute (API), 1120 L St. NW, Washington, DC 20005. Telephone (202) 682-8375.
American Water Works Association (AWWA), 6666 West Quincy Ave., Denver, CO 80235. Telephone (303) 794-7711.
National Association of Pipe Coating Applicators (NAPCA), Commerce National Bank Bldg., 333 Texas St., Shreveport, LA 71101-3673. Telephone (318) 227-2769.
General Services Administration, Business Service Center, Washington, DC 20025. Telephone (202) 472-2205.
National Association of Corrosion Engineers (NACE), P.O. Box 218340, Houston, TX 77218-8340. Telephone (713) 492-0535.
U.S. Government Printing Office, Washington, DC 20420. Telephone (202) 783-3238.
Canadian Standards Association (CSA), 178 Rexdale Blvd., Toronto, Ontario, Canada M9W 1R3. Telephone (416) 747-4000.
Deutsches Institute fur Normung (DIN), Postfach 1107, D-1000 Berlin 30, Federal Republic of West Germany.

TABLE 2 - Generic Coating Systems With Material Requirements and Recommended Practice for Application [1]

Item No.	Generic Coating System	Reference No. (See Table 1)
1	Coal Tar	1
2	Asphalt	2
3	Wax	3
4	Prefabricated Films	4
5	Fusion Bonded Epoxy Coatings	5
6	Polyolefin Coatings	6

[1]NOTE: Many other references are available and this table is not comprehensive. Listing does not constitute endorsement of any coating system in preference to another. Omission of a system may be due to unavailability of reference standards or lack of data.

TABLE 3 - Reference for General Use in the Installation and Inspection of Coating Systems for Underground Piping

Item No.	Reference	Reference No. (See Table 1)
1	Application of Organic Pipeline Coatings	1, 2, 3, 5
2	Film Thickness of Pipeline Coatings	9
3	Inspection of Pipeline Coatings	7

TABLE 4 - Coating System Characteristics Relative to Environmental Conditions [1]

Item No.	Environmental Factor	Recommended Test Methods[2] (See Table 1 for Reference)
1	General Underground Exposure with or without Cathodic Protection	5, 10
2	Resistance to Water Penetration and Its Effect on Choice of Coating Thickness	11
3	Resistance to Penetration by Stones in Backfill	12, 21
4	Soil Stress	8, 13
5	Resistance to Specific Liquid not Normally Encountered in Virgin Soil	14
6	Resistance to Thermal Effects	15
7	Suitability of Supplementary Materials for Joint Coating and Field Repairs	10, 11, 12
8	Resistance to Micro-organisms	16

[1]NOTE: Apply only those factors pertinent to the installation.
[2]No specific criteria are available. Comparative tests are recommended subject to evaluation as supplementary information only.

TABLE 5 - Coating System Characteristics Related to Design and Construction

Item No.	Design and Construction Factor	Recommended Test Methods[1] (See Table 1 for Reference)
1	Yard Storage, Weathering	17
2	Yard Storage, Penetration Under Load	12
3	Handling Resistance, Abrasion	18
4	Handling Resistance, Impact	21
5	Field Bending Ability	19
6	Driving Ability (Resistance to Sliding Abrasion)	18, 20
7	Special Requirements for Mill-Applied Coating	1, 2, 3, 4, 5, 6
8	Special Requirements for Application of Coating Over the Ditch	1, 2, 3, 4, 5
9	Backfill Resistance	21
10	Resistance to Thermal Effects	10, 15
11	Suitability of Joint Coatings and Field Repairs	5, 10, 11, 22

[1] No specific criteria are available. Comparative tests are recommended subject to evaluation on basis of any tolerable compensating measures that may be required.

TABLE 6 - Methods for Evaluating In-Service Field Performance of Coatings

Item	Title or Subject of Method	Reference No. (See Table 1)	Basis for Rating
1	Rate of Change in Current Required for Cathodic Protection	8	Comparison of initial current requirement with subsequent periodic determination of current requirement
2	Inspection of Pipeline Coating	7	(a) With cathodic protection: no active corrosion found (b) Without cathodic protection: no new holidays showing active corrosion
3	Cathodic Disbondment	10	Purpose is to obtain data relative to specific conditions for comparison with laboratory data

5.2.3.5 Pipe should be lowered carefully into the ditch to avoid coating damage.

5.2.3.6 Care should be taken when backfilling so that rocks and debris will not strike and damage the pipe coating.

5.2.3.7 Care shall be exercised when using materials such as loose wrappers, nonconducting urethane foam, and rock shield around pipelines as protection against physical damage or for other purposes, because these materials may create an electrical shielding effect that would be detrimental to the effectiveness of cathodic protection.

5.2.3.8 Where a pipeline comes above ground, it must be cleaned and coated, or jacketed with a material suitable for the prevention of atmospheric corrosion.

5.3 Methods for Evaluating Coating Systems

5.3.1 Established Systems Proven by Successful Use

5.3.1.1 Visual and electrical inspection of in-service pipeline coatings should be used to evaluate the performance of a coating system. These inspections can be conducted wherever the pipeline is excavated or at bell holes made for inspection purposes.

5.3.2 Established or Modified Systems for New Environments

5.3.2.1 This method is intended for use where coating systems will continue to be used and are qualified under Paragraph 5.3.1, but where application will be extended to new environments or where it is desired to revise a system to make use of new developments.

5.3.2.1.1 The use of applicable material requirements, material specifications, standards, and recommended practices for application, as given in Table 2, is recommended.

5.3.2.1.2 The use of applicable references in Table 3 is recommended unless previously covered in applicable references in Table 2.

5.3.3 New Coating System Qualification

5.3.3.1 The purpose of this method is to qualify a new coating material by subjecting it to laboratory tests appropriate for the intended service. After laboratory tests have been conducted and indicate that the coating system appears to be suitable, application and installation are conducted in accordance with recommended practices. In-service field performance tests are made to confirm the success of the previous steps. The steps of the method are: (1) laboratory tests, (2) application under recommended practices, (3) installation under recommended practices, and (4) in-service field performance tests. If good results are obtained after five years, only Steps 2 and 3 are required thereafter.

5.3.3.1.1 Applicable sections of Tables 4 and 5 are recommended for the initial laboratory test methods.

5.3.3.1.2 Applicable sections of Tables 2 and 3 are recommended for conditional use during Steps 2 and 3.

5.3.3.1.3 During a period of five years or more, the use of the evaluation methods given in Table 6, Item 1 or 2 is recommended. The test method in Item 3 may be used as a supplementary means for obtaining data for correlation with laboratory tests.

5.3.4 Method for Evaluating a Coating System by In-Service Field Performance Only

5.3.4.1 The purpose of this method is to qualify a coating system where none of the first three methods given in Paragraph 5.3 have been or will be used. It is intended that this method should be limited to minor pilot installations.

5.3.4.1.1 The use of at least one of the first two methods given in Table 6 is recommended on the basis of at least one investigation per year for five consecutive years.

Section 6: Criteria and Other Considerations for Cathodic Protection

6.1 Introduction

6.1.1 This section lists criteria and other considerations for cathodic protection that will indicate, when used either separately or in combination, whether adequate cathodic protection of a metallic piping system has been achieved (see also Section 1, Paragraphs 1.2 and 1.4).

6.1.2 The effectiveness of cathodic protection or other corrosion control measures can be affirmed by visual observation, measurements of pipe wall thickness, or by use of internal inspection devices. Because such methods sometimes are not practical, meeting any criterion or combination of criteria in this section is evidence that adequate cathodic protection has been achieved. When excavations are made for any purpose, the pipe should be inspected for evidence of corrosion and/or coating condition.

6.1.3 The criteria in this section have been developed through laboratory experiments and/or verified by evaluating data obtained from successfully operated cathodic protection systems. Situations may exist where a single criterion for evaluating the effectiveness of cathodic protection may not be satisfactory for all conditions. Often a combination of criteria is needed for a single structure.

6.1.4 Sound engineering practices shall be used to determine the methods and frequency of testing required to satisfy these criteria.

6.1.5 Corrosion leak history is valuable in assessing the effectiveness of cathodic protection. Corrosion leak history by itself, however, shall not be used to determine whether adequate levels of cathodic protection have been achieved unless it is impractical to make electrical surveys.

6.2 Criteria

6.2.1 It is not intended that persons responsible for corrosion control be limited to the criteria listed below. Criteria that have been successfully applied on existing piping systems can continue to be used on those piping systems. Any other criteria used must achieve corrosion control comparable to that attained with the criteria herein.

6.2.2 Steel and Cast Iron Piping

6.2.2.1 Corrosion control can be achieved at various levels of cathodic polarization depending on the environmental conditions. However, in the absence of specific data that demonstrate that adequate cathodic protection has been achieved, one or more of the following shall apply:

6.2.2.1.1 A negative (cathodic) potential of at least 850 mV with the cathodic protection applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement.

NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

6.2.2.1.1.1 Measuring or calculating the voltage drop(s);

6.2.2.1.1.2 Reviewing the historical performance of the cathodic protection system;

6.2.2.1.1.3 Evaluating the physical and electrical characteristics of the pipe and its environment; and

6.2.2.1.1.4 Determining whether or not there is physical evidence of corrosion.

6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.

6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.

6.2.2.2 Special Conditions

6.2.2.2.1 On bare or ineffectively coated pipelines where long line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient.

6.2.2.2.2 In some situations, such as the presence of sulfides, bacteria, elevated temperatures, acid environments, and dissimilar metals, the criteria in Paragraph 6.2.2.1 may not be sufficient.

6.2.2.2.3 When a pipeline is encased in concrete or buried in dry or aerated high resistivity soil, values less negative than the criteria listed in Paragraph 6.2.2.1 may be sufficient.

6.2.2.3 PRECAUTIONARY NOTES

6.2.2.3.1 The earth current technique is often meaningless in multiple pipe rights-of-way, in high resistivity surface soil, for deeply buried pipe, in stray current areas, or where local corrosion cell action predominates.

6.2.2.3.2 Caution is advised against using polarized potentials less negative than -850 mV for cathodic protection of pipelines when operating pressures and conditions are conducive to stress corrosion cracking (see references on stress corrosion cracking at the end of this section).

6.2.2.3.3 The use of excessive polarized potentials on coated pipelines should be avoided to minimize cathodic disbondment of the coating.

6.2.2.3.4 Polarized potentials that result in excessive generation of hydrogen should be avoided on all metals, particularly higher strength steel, certain grades of stainless steel, titanium, aluminum alloys, and prestressed concrete pipe.

6.2.3 Aluminum Piping

6.2.3.1 The following criterion shall apply: A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.3.2 PRECAUTIONARY NOTES

6.2.3.2.1 Excessive Voltages: Notwithstanding the minimum criterion in Section 6.2.3.1, if aluminum is cathodically protected at voltages more negative than -1200 mV measured between the pipe surface and a saturated copper/copper sulfate reference electrode contacting the electrolyte and compensation is made for the voltage drops other than those across the pipe-electrolyte boundary, it may suffer corrosion as the result of the buildup of alkali on the metal surface. A polarized potential more negative than -1200 mV should not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment.

6.2.3.2.2 Alkaline Conditions: Aluminum may suffer from corrosion under high pH conditions and application of cathodic protection tends to increase the pH at the metal surface. Therefore, careful investigation or testing should be made before applying cathodic protection to stop pitting attack on aluminum in environments with a natural pH in excess of 8.0.

6.2.4 Copper Piping

6.2.4.1 The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.5 Dissimilar Metal Piping

6.2.5.1 A negative voltage between all pipe surfaces and a stable reference electrode contacting the electrolyte equal to that required for the protection of the most anodic metal should be maintained.

6.2.5.2 PRECAUTIONARY NOTE

6.2.5.2.1 Amphoteric materials that could be damaged by high alkalinity created by cathodic protection should be electrically isolated and separately protected.

6.3 Other Considerations

6.3.1 Methods for determining voltage drop(s) shall be selected and applied using sound engineering practices. Once determined, the voltage drop(s) may be used for correcting future measurements at the same location providing conditions, such as pipe and cathodic protection system operating conditions, soil characteristics, and coating quality, remain similar. (Note: Placing the reference electrode next to the pipe surface may not be at the pipe-electrolyte interface. A reference electrode placed at a coated pipe surface may not significantly reduce soil voltage drop in the measurement if the nearest coating holiday is remote from the reference electrode location.)

6.3.2 When it is impractical or considered unnecessary to disconnect all current sources to correct for voltage drop(s) in the pipe-electrolyte potential measurements, sound engineering practices should be used to ensure that adequate cathodic protection has been achieved.

6.3.3 Where feasible and practicable, in-line inspection of pipelines may be helpful in determining the presence or absence of pitting corrosion damage. Absence of corrosion damage or the halting of its growth may indicate adequate corrosion control. The in-line inspection technique, however, may not be capable of detecting all types of corrosion damage, has limitations in its accuracy, and may report as anomalies items that are not corrosion. For example, longitudinal seam corrosion and general corrosion may not be readily detected by in-line inspection. Also, possible thickness variations, dents, gouges, and external ferrous objects may be detected as corrosion. The appropriate use of in-line inspection must be carefully considered.

6.3.4 Situations involving stray currents and stray electrical gradients may exist that require special analysis. For additional information, see Section 9, "Control of Interference Currents."

6.4 Alternative Reference Electrodes

6.4.1 Other standard reference electrodes may be substituted for the saturated copper/copper sulfate reference electrode. Two commonly used reference

electrodes are listed below along with their voltage equivalent (at 25°C [77°F]) to -850 mV referred to a saturated copper/copper sulfate reference electrode:

6.4.1.1 Saturated KCl calomel reference electrode: -780 mV; and

6.4.1.2 Saturated silver/silver chloride reference electrode used in 25 ohm-cm seawater: -800 mV.

6.4.2 In addition to these standard reference electrodes, an alternative metallic material or structure may be used in place of the saturated copper/copper sulfate reference electrode if the stability of its electrode potential is ensured and if its voltage equivalent referred to a saturated copper/copper sulfate reference electrode is established.

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Section 7: Design of Cathodic Protection Systems

7.1 Introduction

7.1.1 The purpose of this section is to recommend procedures for designing cathodic protection systems that will provide effective corrosion control by satisfying one or more of the criteria listed in Section 6 and exhibiting maximum reliability over the intended operating life of the systems.

7.1.2 In the design of a cathodic protection 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 will ensure safe installation and operation.

7.1.2.2 Specification of materials and installation practices to conform to latest edition of applicable codes, National Electrical Manufacturers Association (NEMA)[2] Standards, National Electrical Code (NEC),[3] appropriate international standards, and NACE recommended practices.

7.1.2.3 Selection and specification of materials and installation practices that will 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, which can cause detrimental effects on foreign buried or submerged metallic structures.

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

7.1.2.6 Special consideration should be given to the presence of sulfides, bacteria, disbonded coatings, thermal insulating coatings, elevated temperatures, shielding, acid environments, and dissimilar metals.

7.1.2.7 Excessive levels of cathodic protection that can cause coating disbondment and possible damage to high strength steels as a result of hydrogen evolution should be avoided.

7.1.2.8 Where amphoteric metals are involved, care should be taken so that high pH conditions are not established that could cause cathodic corrosion of the metal.

7.2 Major objectives of cathodic protection 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 cathodic protection are efficiently attained;

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

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

7.2.4 To provide adequate allowance for anticipated changes in current requirements with time;

7.2.5 To install anodes where the possibility of disturbance or damage is minimal; and

7.2.6 To provide adequate monitoring facilities to test and evaluate the system performance.

7.3 Information Useful for Design

7.3.1 Useful piping system specifications and practices include the following:

7.3.1.1 Route maps and atlas sheets,
7.3.1.2 Construction dates,
7.3.1.3 Pipe, fittings, and other appurtenances,

7.3.1.4 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 cathodic protection systems,
7.3.2.2 Possible interference sources (see Section 9),
7.3.2.3 Special environmental conditions,
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, and
7.3.2.7 Feasibility of electrical isolation from foreign structures.

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 Coating integrity,
7.3.3.6 Cumulative leak history,
7.3.3.7 Interference currents,
7.3.3.8 Deviation from construction specifications, and
7.3.3.9 Other maintenance and operating data.

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

7.4 Types of Cathodic Protection Systems

7.4.1 Galvanic Anode Systems

7.4.1.1 Galvanic anodes can be made of materials such as alloys of magnesium, zinc, or aluminum. The anodes are connected to the pipe, either individually or in groups. Galvanic anodes are limited in current output by the anode-to-pipe driving voltage and the electrolyte resistivity.

7.4.2 Impressed Current Anode Systems

7.4.2.1 Impressed current anodes can be of materials such as graphite, high silicon cast iron, lead-silver alloy, precious metals, or steel. They are connected with an insulated cable, either individually or in groups, to the positive terminal of a direct current source, such as a rectifier or generator. The pipeline is connected to the negative terminal of the direct current source.

7.5 Considerations influencing selection of the type of cathodic protection 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 may preclude the use of galvanic anodes;

7.5.3 Effects of cathodic protection interference currents on adjacent structures that may limit the use of impressed current cathodic protection 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 aspects.

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; and

7.5.8 Electrical resistivity of the environment.

7.6 Factors Influencing Design of Cathodic Protection Systems

7.6.1 Various anode materials have different rates of deterioration when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current output, the anode life will depend on the environment and anode material, as well as the anode weight and the number of anodes in the cathodic protection system. Established anode performance data may be used to calculate the probable deterioration rate.

7.6.2 Data on the dimensions, depth, configuration of the anodes, and electrolyte resistivity may be used to calculate the resultant resistance-to-electrolyte of the

anode system. Formulas and graphs relating to these factors are available in the literature and from manufacturers.

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

7.6.4 Galvanic anode performance in most soils can be improved by using special backfill material. Mixtures of gypsum, bentonite, and anhydrous sodium sulfate are most commonly used.

7.6.5 The number of impressed current 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, and natural or manufactured graphite.

7.6.6 In the design of an extensive distributed 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 in order to achieve efficient corrosion control at the extremities of the protected structure.

7.6.7 Where it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current groundbed to deliver the required current, suitable provisions should 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 Where it is anticipated that electro-osmotic effects could impair the ability of the impressed current ground bed to deliver the required current output, suitable provisions should 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 may further reduce the electro-osmotic effect.

7.7 Design Drawings and Specifications

7.7.1 Suitable drawings should 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 buried or submerged metallic structures.

7.7.2 Layout drawings should be prepared for each impressed current cathodic protection installation, showing the details and location of the components of the cathodic protection 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 cathodic protection system.

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[2]National Electrical Manufacturers Association (NEMA), 2101 L St., N.W., Washington, DC 20037.
[3]National Fire Protection Association, Battermarch Park, Quincy, MA 02269.

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Section 8: Installation of Cathodic Protection Systems

8.1 Introduction

8.1.1 The purpose of this section is to recommend procedures that will result in the installation of cathodic protection systems that achieve protection of the structure. The design considerations recommended in Sections 4 and 7 should be followed.

8.2 Construction Specifications

8.2.1 All construction work on cathodic protection systems should be performed in accordance with construction drawings and specifications. The construction specifications should be in accordance with recommended practices in Sections 4 and 7.

8.3 Construction Supervision

8.3.1 All construction work on cathodic protection 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 corrosion control.

8.3.2 All deviations from construction specifications should be noted 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 for assurance that it is not damaged.

8.4.1.3 Other galvanic anodes, such as unpackaged "bracelet" type or ribbon, 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 should be inspected and, if damaged, repaired before the anodes are installed.

8.4.2 Installing Anodes

8.4.2.1 Anodes should be installed according to construction specifications.

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

8.4.2.3 Where anodes in bracelet form are used, pipe coating beneath the anode should be free of holidays. Care should be taken to prevent damage to the coating when installing bracelet anodes. After applications of concrete (if used) to pipe, all coating and concrete should be removed from anode surface. If reinforced concrete is used, there must be no metallic contact between anode and reinforcing mesh or between reinforcing mesh and pipe.

8.4.2.4 Where 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 and Handling

8.5.1.1 The rectifier or other power source should be inspected to ensure that internal connections are mechanically secure and that the unit is free of damage. Rating of the direct current power source should comply with the construction specification. Care

should be exercised in handling and installing the power source.

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

8.5.1.3 All cables should be carefully inspected to detect defects in insulation. Care should be taken to avoid damage to insulation on cable. Defects in the cable insulation must be repaired.

8.5.1.4 Anode backfill material should conform to specifications.

8.5.2 Installation Provisions

8.5.2.1 A rectifier or other power source should be installed so that the possibility of damage or vandalism is minimized.

8.5.2.2 Wiring to rectifiers shall comply with local and national electrical codes and requirements of utility supplying power. An external disconnect switch should be provided in the AC circuit. A rectifier case shall be properly grounded.

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

8.5.2.4 Impressed current anodes can be buried vertically, horizontally, or in deep holes (see NACE Standard RP0572 [latest revision]) as indicated in construction specifications. Backfill material should be installed to ensure that there are no voids around anodes. Care should be exercised during backfilling to avoid damage to the anode and cable.

8.5.2.5 The cable from the rectifier negative terminal to pipe should be 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. After the direct current power source has been energized, suitable measurements should be made to verify that these connections are correct.

8.5.2.6 Underground splices on header (positive) cable to the groundbed should be kept to a minimum. Connections between header and anode cables should be mechanically secure and electrically conductive. If buried 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 when installing 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 cable is installed in trench. Cable can be installed by plowing if proper precautions are taken.

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

8.6 Corrosion Control Test Stations, Connections, and Bonds (see Paragraph 4.5, "Corrosion Control Test Stations")

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

8.6.2 All buried or submerged lead wire attachments should be coated with an electrically insulating material, compatible with the pipe coating and wire insulation.

8.6.3 Test lead wires should be color coded or otherwise permanently identified. Wires should be installed with slack. Damage to insulation should be avoided and repairs made if damage occurs. Test leads should not be exposed to excessive heat and sunlight. Aboveground test stations are preferred. 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 should be mechanically secure, electrically conductive, and suitably coated. Bond connections should be accessible for testing.

8.7 Electrical Isolation

8.7.1 Inspection and electrical measurements should ensure that electrical isolation is adequate (see NACE Standard RP0286 [latest revision]).

Section 9: Control of Interference Currents

9.1 Introduction

9.1.1 The purpose of this section is to recommend practices for the detection and control of interference currents. The mechanism and detrimental effects are described.

9.2 Mechanism of Interference Current Corrosion (Stray Current Corrosion)

9.2.1 Interference current corrosion on buried or submerged metallic structures differs from other causes of corrosion damage in that the direct 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 direct current source not metallically bonded to the affected structure.

9.2.1.1 Detrimental effects of interference currents usually occur at locations where the currents transfer between the affected structures and the electrolyte.

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

9.2.1.3 Coatings may become disbonded at the areas where voltage gradients in the electrolyte force current on the affected structure. However, as the coating becomes disbonded, a larger area of metal may be exposed, which would increase the demand for a cathodic protection current. This disbondment may create shielding problems.

9.2.2 The severity of corrosion resulting from interference 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 and density of the current;

9.2.2.3 Quality of the coating or absence of a 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 interference currents include the following:

9.2.3.1 Direct current: cathodic protection rectifiers, thermoelectric generators, direct current electrified railway and transit systems, coal mine haulage systems and pumps, welding machines, and other direct current power systems;

9.2.3.2 Alternating current: alternating current power systems and alternating current electrified railway systems; and

9.2.3.3 Telluric current.

9.3 Detection of Interference Currents

9.3.1 During 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-electrolyte potential changes on the affected structure caused by the foreign direct current source;

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

9.3.1.3 Localized pitting in areas near or immediately adjacent to a foreign structure; and

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

9.3.2 In areas where interference currents are suspected, appropriate tests should be conducted. All affected parties shall be notified before tests are conducted. (Notification should be channeled through corrosion control coordinating committees, where they exist. (See NACE Publication TPC 11.) Any one or combination of the following test methods can be used.

9.3.2.1 Measurement of structure-electrolyte potentials with recording or indicating instruments;

9.3.2.2 Measurement of current flowing on the structure with recording or indicating instruments;

9.3.2.3 Development of beta curves to locate the area of maximum current discharge from the affected structure (see Appendix A); and

9.3.2.4 Measurement of the variations in current output of the suspected source of interference current and correlations with measurements obtained in Paragraphs 9.3.2.1 and 9.3.2.2.

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. These methods may be used individually or in combinations.

9.4.2 Design and installation of electrical bonds of proper resistance between the affected structures is a technique for interference control. The bond electrically conducts interference current from an affected structure to the interfering structure and/or current source.

9.4.2.1 Uni-directional control devices, such as diodes or reverse current switches, may be required in conjunction with electrical bonds if fluctuating currents are present. These devices prevent reversal of current flow.

9.4.2.2 A resistor may be necessary in the bond circuit to control the flow of electrical current from the affected structure to the interfering structure.

9.4.2.3 The attachment of electrical bonds can reduce the level of cathodic protection on the interfering structure. Supplementary cathodic protection may then be required on the interfering structure to compensate for this effect.

9.4.2.4 A bond may not effectively mitigate the interference problem in the case of a cathodically protected bare or poorly coated pipeline that is causing interference on a coated pipeline.

9.4.3 Cathodic protection current can be applied to the affected structure at those locations where the interfering current is being discharged. The source of cathodic protection current may be galvanic or impressed current anodes.

9.4.4 Adjustment of the current output from interfering cathodic protection rectifiers may resolve interference problems.

9.4.5 Relocation of the ground beds of cathodic protection rectifiers can reduce or eliminate the pick-up of interference currents on nearby structures.

9.4.6 Rerouting of proposed pipelines may avoid sources
of interference current.

9.4.7 Properly located isolating fittings in the affected structure may reduce or resolve interference problems.

9.4.8 Application of coating to current pick-up area(s) may reduce or resolve interference problems.

9.5 Indications of Resolved Interference Problems

9.5.1 Restoration of the structure-electrolyte potentials on the affected structure to those values which existed prior to the interference.

9.5.2 Measured line currents on the affected structure which show that the interference 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 eliminated at the location of maximum exposure (see Appendix A).

Section 10: Operation and Maintenance of Cathodic Protection Systems

10.1 Introduction

10.1.1 The purpose of this section is to recommend procedures and practices for energizing and maintaining continuous, effective, and efficient operation of cathodic protection systems.

10.1.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria and that each part of the cathodic protection system is operating properly. Conditions that affect protection are subject to change. Correspondingly, changes may be required in the cathodic protection system to maintain protection. Periodic measurements and inspections are necessary to detect changes in the cathodic protection system. Conditions may exist where operating experience indicates that testing and inspections need to be made more frequently than recommended herein.

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

10.1.1.3 Where practicable and determined necessary by sound engineering practice, a detailed (close interval) potential survey should be conducted to: (a) assess the effectiveness of the cathodic protection system; (b) provide base line operating data; (c) locate areas of inadequate protection levels; (d) identify locations likely to be adversely affected by construction, stray currents, or other unusual environmental conditions; or, (e) select areas to be monitored periodically.

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

10.2 A survey should be conducted after each cathodic protection system is energized and/or adjusted to determine whether the applicable criterion or criteria from Section 6 have been satisfied.

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

10.4 Inspection and tests of cathodic protection facilities should be made to ensure their proper operation and maintenance as follows:

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

10.4.2 All impressed current protective facilities should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Longer or shorter intervals for monitoring may 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 may be appropriate.

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

10.5 Where pipe has been uncovered, it should be examined for evidence of corrosion and, if coated, for condition of the 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 where periodic test and inspections indicate that protection is no longer adequate. These measures may include the following:

10.7.1 Repair, replace, or adjust components of cathodic protection systems;

10.7.2 Provide supplementary facilities where additional protection is necessary;

10.7.3 Thoroughly clean and properly coat bare structures if required to attain cathodic protection;

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

10.7.5 Remove accidental 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 cathodic protection of the pipeline outside of the casing due to reduction of protective current to the pipeline.

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

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

Section 11: Corrosion Control Records

11.1 Introduction

11.1.1 The purpose of this section is to describe corrosion control records that will document in a clear, concise, workable manner, data that is pertinent to the design, installation, operation, maintenance, and effectiveness of corrosion control measures.

11.2 Relative to the determination of the need for corrosion control, the following should be recorded:

11.2.1 Corrosion leaks, breaks, and pipe replacements; and

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

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

11.3.1 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 corrosion control measures taken.

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

11.4.1 Results of current requirements 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 corrosion control facilities, the following should be recorded:

11.5.1 Installation of cathodic protection 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 Specifications 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;

11.5.2.2.1 Type of switch or equivalent device; and

11.5.2.2.2 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 cathodic protection have been satisfied.

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

11.7.1 Maintenance of cathodic protection 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 coating, isolating devices, test leads, and other test facilities.

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

Appendix A - Interference Testing

A *beta curve* is a plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate), versus values of corresponding structure-to-soil potentials at a selected location on the affected structure (abscissa). If the correlation is reasonably linear, the plot will indicate whether the affected structure is receiving or discharging current at the location where the structure-to-soil potential was measured. Dynamic interference investigation involves many beta curve plots to search for the point of maximum interference current discharge. Interference is resolved when the correlation of maximum current discharge has been changed to a correlation that shows that current pickup is being achieved in the exposure area by the corrective measures taken. These corrective measures may be accomplished by metallic bonding or other interference control techniques.

For more information on the field techniques commonly used, refer to NACE Publication 56-12 "Contributions of J.M. Pearson to Mitigation of Underground Corrosion," and NACE Publication 10B189, "Direct Current (DC) Operated Rail Transit and Mine Railroad Stray Current Mitigation."

Appendix B - Method for Determining Probable Corrosion Rate and Costs of Maintaining Service

Maintenance of a piping system may include repairing corrosion leaks and reconditioning or replacing all or portions of the system.

In order to make estimates of the costs involved, it is necessary to 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:

(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 surrounding a piping system: resistivity, pH, and composition. 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 where environmental conditions are similar. Consideration should be included in such a study of possible environmental changes such as might result from irrigation, spillage of corrosive substances, pollution, and seasonal changes in soil moisture content.

(c) Investigation for corrosion on a piping system by visual inspection of the pipe and/or by instruments which 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, soil studies, structure-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 may help to determine the existence of corrosion.

Appendix C - Contingent Costs of Corrosion

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.

Appendix D - Costs of Corrosion Control

The usual costs for protecting buried or submerged metallic structures are for complete or partial cathodic protection or for coatings supplemented with cathodic protection. Other corrosion control costs include:

(a) Relocation of piping to avoid known corrosive conditions (This may include installing lines above ground);
(b) Reconditioning and coating the piping system;
(c) Use of corrosion-resistant materials;
(d) Use of selected or inhibited backfill;
(e) Electrical isolation to limit possible galvanic action; and
(f) Correction of conditions in or on the pipe that might accelerate corrosion.