PIP PLE00006
Cathodic Protection Systems for Pipelines
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

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1. **Scope**

This document provides guidance for the design and installation of cathodic protection systems to control and minimize external and internal corrosion of metallic pipelines buried or immersed in an electrolyte (e.g. an aqueous or soil environment). Appendix A contains well construction information. Appendix B contains typical installation details.

2. **References**

Applicable parts of the following industry codes and standards shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate. Code section references below are specific to the code editions in effect at the issuance of this Practice.

**Industry Codes and Standards**

- Institute of Electrical and Electronics Engineers (IEEE)
  - IEEE 81 - *Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System*

- International Organization for Standardization (ISO)
  - ISO 15589-1 - *Petroleum and Natural Gas Industries – Cathodic Protection of Pipeline Transportation Systems – Part 1: On-land Pipeline*

- National Association of Corrosion Engineers (NACE)
  - NACE RP0169 - *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
  - NACE SP0286 - *Electrical Isolation of Cathodically Protected Pipelines*

**Other References**

- A. W. Peabody - *Control of Pipeline Corrosion*

3. **Definitions**

**anode:** Electrode through which current flows into the electrochemical cell and through which negatively charged electrons flow to the external circuit. As such, the location at which oxidation or corrosion of the component occurs.

**cathode:** Electrode of an electrolytic cell at which reduction, the complementary process to oxidation, is the principal reaction. Also, the recipient of negatively charged electrons from the anode.

**cathodic protection (CP):** (1) Decrease of corrosion rate by shifting the corrosion potential of the electrode toward a less oxidizing potential by applying an external electromotive force; (2) Partial or complete protection of a metal from corrosion by making it a cathode, using either a galvanic anode or a DC impressed current.
cell: Electrochemical system consisting of an anode and a cathode immersed in an electrolyte. The anode and cathode may be separate metals or areas of dissimilar potential on the same metal. The cell includes the external circuit, which permits the flow of electrons from the anode toward the cathode.

coke: High carbon backfill used in anode beds

corrosion potential: Potential of a corroding surface in an electrolyte relative to the reference electrode under open-circuit conditions

electrolyte: Liquid, or the liquid component in a medium such as soil, in which electric current flows by the movement of ions

electrode: Conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte

galvanic anode: Electrode providing current for CP through galvanic action

groundbed: System of buried or immersed galvanic or impressed current anodes.

impressed current cathodic protection (ICCP): Type of CP system typically applied if there are elevated current requirements for protection against corrosion. ICCP is used in cases where the driving voltage is higher than the galvanic system or if there is a need for increased system control.

interference: Any change of the structure to electrolyte potential which is caused by foreign electrical sources. Interference is sometimes by design to permit the transfer of CP current between pipelines.

isolating joint: Electrically discontinuous connection between two lengths of pipe, inserted to provide electrical discontinuity between them (e.g., monolithic isolating joint, flange isolation kit, etc.)

natural potential: Structure to electrolyte potential measured with no CP applied.

owner: Party who owns the pipeline or facility where the CP system will be installed

pipeline: Underground metallic piping

polarization: Shift in the potential of an electrode (structure) from the equilibrium value because of current flow through its surface

protected structure: Structure to which CP is effectively applied

supplier: The party responsible for providing the CP system.

transformer rectifier: Device which converts alternating current (AC) to direct current (DC). The DC voltage derived in this way is used as a power source for ICCP systems.
4. Background

4.1 Corrosion related to lack of or insufficient CP can have catastrophic consequences. Corrosion damage causing loss of containment may seriously harm the environment, personal health and safety, production, revenue, and the owner’s reputation both locally and globally.

4.2 Metal that has been extracted from its primary ore (i.e., metal oxides or other free radicals) has a natural tendency to revert to that state under the action of oxygen and water. This action is called corrosion and the most common example is the rusting of steel. Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale.

4.3 Metal lost by corrosion converts to positive ions and loses electrons through the metal. The electrons travel through the metal to an area where they react with the environment to balance the charge by forming negative ions in solution. This corrosion process is initially caused by:

a. Difference in natural potential in galvanic (i.e., bimetallic) couples;

b. Metallurgical variations in the state of the metal at different points on the surface; or,

c. Local differences in the environment, such as variations in the supply of oxygen at the surface. Oxygen rich areas become the cathode and oxygen depleted areas become the anode.

d. Interference

e. Induced current from other electrical power courses.

4.4 A combination of applying both a coating and CP results in the most practical and economical overall corrosion protection system and should be the primary principle for corrosion protection of immersed and/or buried structures operated by the owner. Most of the corrosion protection is provided by the coating while CP provides protection to deficiencies in the coating and enhances the integrity of the associated structure. As the coating degrades with time, the activity of the CP system continues to provide efficient protection of the pipe at defects in the coating. The initial design of the system should provide sufficient protection for when the coating is possibly degraded. A coated pipeline without CP can have accelerated corrosion at coating anomalies.

5. Design Scope

5.1 General

5.1.1 The CP system should be designed so that any external corrosion on the pipeline is mitigated and any adverse stray current effects on the pipeline or on foreign structures/pipelines are avoided. The design of CP systems should be carried out by a professional and experienced CP engineering contractor approved by the owner. For new construction projects, the design of the CP system should be an integral part of the total pipeline design. Pipeline isolation and a suitable pipeline coating system should be provided for in the pipeline design.

5.1.2 Cathodic protection systems should be installed within one year of the asset being placed in service.
5.1.3 If designing a CP system for retrofitting to an existing pipeline, certain repairs and modifications to the pipeline may be necessary to be in accordance with owner specifications and best practices. Other requirements may have to be determined by site investigations.

5.1.4 Personnel employed in the design and installation of CP systems for onshore pipelines should be suitably qualified in accordance with an internationally recognized standard or association (e.g. NACE) and be approved as competent by owner or owner’s agent. Cathodic protection designs should be subject to owner approval.

5.1.5 The location for installation should be predetermined to provide for the required AC power, obtainable ROW (if needed), and ample size to permit equipment access to install the ground bed. The presence of any foreign underground structures should be considered when identifying a location to minimize the possibility of stray current interference. The required ROW and any permits should be secured before installation.

5.1.6 For additional design information, see NACE RP0169 and A. W. Peabody’s book, Control of Pipeline Corrosion.

5.2 Initial Site Survey

To achieve an effective CP design for a pipeline system, a site survey should be performed to collect essential information on soil resistivity, geographical factors, the likelihood or the existence of stray currents and any other important features along the pipeline route.

Regardless of the type of CP system to be installed, two simple field tests should be conducted before beginning the system design.

5.2.1 Soil Resistivity

Soil resistivity should be determined for the specific area where the groundbed is to be installed. Even small differences in location can cause large differences in soil resistivity. Soil resistivity may be determined using any one of the following:

a. Soil box procedure
b. Wenner (4-pin) procedure
c. Single rod test procedure

IEEE 81 provides information on this testing.

5.2.2 Current Requirement

Whenever possible, a trial and error process using a temporary groundbed and a portable power supply should be used to determine the current required to protect the structure. The procedure is as follows:

a. Set up a temporary groundbed with ground rods and a temporary power supply,
b. Energize the system,
c. Perform an on-off survey over the structure to be protected,
d. Increase the current and repeat the survey,
e. Repeat Steps 3 and 4 until the structure is protected in accordance with established criteria.

If field testing the current requirement is not feasible, assume current requirements by using typical current densities for the geographical location and calculate current requirement for the area of the structure to be protected.

6. Systems

6.1 Galvanic Cathodic Protection System

6.1.1 Galvanic anodes are most efficiently used on electrically isolated coated structures. The current output of a galvanic anode installation is typically much less than an ICCP system. See Figure 1 for an example of a galvanic CP system arrangement.

6.1.2 Galvanic anode installations are typically used on underground structures in applications if CP current requirements are small and if earth resistances are acceptably low.

6.1.3 Magnesium and zinc are the most commonly used galvanic anodes, with aluminum anodes used in specific applications. Uses of anode materials differ as follows:

a. Magnesium anodes are available in a variety of shapes and sizes, bare or prepackaged with the most popular being the 7.7 kg (17 lb) prepackaged anode. As a general guideline, one may assume magnesium anodes to be acceptable if soil resistivities are between 1,000 ohm-cm and 5,000 ohm-cm. Short block shapes are suitable for low resistivity areas, but long slender shapes should be used in higher resistivity areas.

b. Zinc anodes are also available in many shapes and sizes. They are appropriate in soils with very low resistivities (750 ohm-cm to 1500 ohm-cm). Favorable environments are sea water and salt marshes. Short block shapes are suitable for low resistivity areas, but long slender shapes should be used in higher resistivity areas.

c. Aluminum anodes are not typically used in earth burial applications. Some proprietary aluminum alloy anodes work well in sea water environments.

6.1.4 A test station should be installed with each galvanic anode or cluster of anodes. There should be two independent wires going from the test station to the pipeline and one wire going from the test station to the anode. This arrangement permits measuring pipeline potential with and without the anode being connected to the pipeline.

6.1.5 Advantages of a galvanic CP system include:

a. No external power source is required. Current is induced by the difference in voltage potential between the steel pipe and the sacrificial anode.

b. Easy field installation of the anode

c. Maintenance requirements are low

d. Low current in the system is less likely to cause stray current interference problems on other structures
e. If the current requirement is small, a galvanic system is more economical than an ICCP system

6.1.6 Disadvantages of a galvanic CP system include:

a. Low driving voltage -- in other words, the voltage potential is relatively small

b. Limited to use in low resistivity soils

c. Low maintenance requirement; easy to “set it and forget it” while the anode eventually disappears

d. Not an economical source for large amounts of CP current (e.g., large diameter pipelines)

e. Very little capacity to control stray current effects on the protected structure

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**Figure 1. Galvanic CP System**

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6.2 **DC Impressed Current Cathodic Protection (ICCP) System**

An ICCP system is used to protect large bare and coated structures and structures in high resistivity electrolytes. Design of an ICCP system should consider the potential for causing coating damage and the possibility of creating stray currents, which adversely affect other structures. See Figure 2 for an example of an ICCP system arrangement.

6.2.1 Advantages of a DC ICCP system:

a. Flexibility – the impressed current can affect large areas so groundbeds can be spaced further apart along the pipeline.

b. Applicable to a variety of systems prone to corrosion.

c. Current output may be controlled by designed potential.

d. Effective in high resistivity soils

e. Can be used for extensive pipeline networks
6.2.2 Disadvantages of a DC ICCP system:

a. Requirement of a power source. The rectifier/controller requires power through electrical lines or by alternative power sources (i.e., constant duty generator, solar power, or thermo-electric generator).

b. Operating costs include power usage supplied by electric power provider or fuel for generator or thermo-electric generator.

c. May cause interference on other structures.

d. Ground beds need to be periodically replaced.

![Figure 2. DC Impressed Current CP System](image)

7. Elements of CP System

7.1 Groundbeds

7.1.1 Groundbeds are elements in both galvanic and ICCP systems. Groundbed location should be determined early in the design process because its location may affect the choice of groundbed type. The following factors should be considered when choosing a groundbed location:

a. Soil resistivity

b. Soil moisture

c. Interference with other structures

d. Availability of power supply

e. Accessibility

f. Ability to limit or prevent vandalism or other damage

g. Availability of right of way

h. Proximity to structures requiring protection
7.1.2 Conventional groundbeds are typically used to distribute protective current over a broad area of the pipeline to be protected. These are typically called remote groundbeds because the pipeline is outside the anodic gradient of the groundbed caused by the discharge of current from the anodes to the surrounding soil.

7.1.3 Where subsurface impermeable layer (rock/shale) exist with low electrolyte quantity, consideration should be made for shallow well distribution.

7.1.4 Distributed anode groundbeds are used to reduce the potential for interference effects on neighboring structures. They are used to protect sections of bare or poorly coated pipelines. They are used in congested areas where electrical shielding might occur with other groundbeds.

7.1.5 Deep anode groundbeds are remote to the pipeline by virtue of the vertical distance between anode and structure. Deep anode groundbeds therefore achieve results similar to remote surface groundbeds. A deep anode groundbed is an appealing choice if space is not available for a conventional groundbed or if surface soil has high resistivity and deeper strata exhibit low resistivities.

7.1.6 Shallow vertical groundbeds are typically used where space is limited.

7.1.7 See Appendix A for details of well construction, backfill selection and carbon backfill.

7.2 Power Supplies

Outside power sources are only required in ICCP systems. Where access to AC power is available, rectifiers are the most common power source for CP systems. The device rectifies alternating current into direct current. Each of several manufacturers offers a large array of options, most commonly in the following areas:

a. Enclosure type
b. Cooling type
c. Control type
d. Rectifying element
e. Circuit type
f. AC input
g. DC volts
h. DC amperes
i. Cable type

Where access to AC power is unavailable, solar cells with controller and battery can provide a dependable power supply in certain parts of the world where sun is abundant. A backup power supply is typically needed. Generators (engine, wind, or turbine powered) are used in special circumstances.

7.3 Anodes

7.3.1 Anode selection varies based on the type of CP system used. Magnesium, zinc, and aluminum anodes were previously discussed in Section 4.3.1.
7.3.2 Graphite anodes are one of the most typically used anodes for ICCP systems. Most common applications are to protect underground structures. Graphite anodes are suitable for deep vertical or shallow horizontal ground beds with carbonaceous backfill.

7.3.3 High silicon cast iron anodes are widely used in underground applications in both shallow and deep groundbeds. Specially formulated high silicon cast iron anodes are also used in seawater. Although the performance is improved with coke breeze, the use of coke breeze is not critical.

7.3.4 Platinized titanium anodes take advantage of the low consumption rate and high current density. Voltages in excess of 10 volts can result in severe pitting of the titanium core causing premature failure.

7.3.5 Platinized niobium/tantalum anodes also take advantage of the properties of platinum, but avoid the low driving voltage restriction of platinized titanium anodes. Breakdown of the niobium oxide film occurs at approximately 120 volts. Therefore, these anodes are used if high driving voltage is required.

7.3.6 Magnetite anodes are quite expensive but have an extremely long life. They are therefore an economical choice for some applications.

7.3.7 Mixed metal oxide anodes consist of a high purity titanium substrate with an applied coating consisting of a mixture of oxides. The titanium serves as a support for the oxide coating. The mixed metal oxide is a crystalline, electrically-conductive coating that activates the titanium and enables it to function as an anode. Applied on titanium, the coating has an extremely low consumption rate, measured in terms of milligrams per year. Because of this low consumption rate, the tubular dimensions remain nearly constant during the design life of the anode if a consistently low resistance anode is used. In areas with chloride in the soil, chloride or acid resistant insulation (e.g., Halar dual insulated wire) is recommended to prevent premature failure of the anode lead during operation.

7.4 Cathode
The pipe/pipeline/system being protected.

7.5 Electrical Isolation
For additional design and construction guidelines, see NACE SP0286. The measurement of the electrical resistance across isolation joints should be included in the CP monitoring program although this may be impractical once the isolation joint has been installed.

With regard to installation of isolating joints in flammable areas, spark gap encapsulation should be in accordance with the National Electric Code (NEC) and applicable site electrical regulations.

If possible, the isolation joint/kit should be isolated from the pipeline by a side valve.

7.6 Test Station
Test stations permit taking pipeline potential reading and measuring the current output of each galvanic anode. Test stations should be installed typically at one mile intervals and where the pipeline crosses another pipeline or other potential points of interference. Accessibility should be considered in selection of the locations of test stations.
7.7 Remote Monitoring and Current Interrupter

Remote monitoring / control with GPS synchronized current interrupter and reference electrode permit real time monitoring and adjustment, which permits the operator to provide real time adjustment to the CP. This type of system is valuable for pipeline systems in arid areas which require high current during normal operation but after a period of rain a substantially lower current is required to achieve protect. The current interrupter facilitates the performance of instant off surveys.

8. Installation

Before installation of the groundbed, ensure all permits have been received. A water permit is frequently required. This permit typically details the water table isolation strategy to ensure ground water is not contaminated. Also look for other interferences (pipelines, structures, electrical, etc.).

8.1 General

8.1.1 Deep well ground beds are typically drilled with truck-mounted rotary drilling equipment. Typical equipment circulates water-based drilling mud to maintain well integrity and remove downhole cuttings. Compressed air circulation systems may be advantageous in limited situations where downhole formations permit their use. Installation procedures are critical, so use only experienced and qualified drillers.

8.1.2 For deep well installations, resistance logging should be conducted before loading to determine anode placement in the lower resistance area of the hole.

8.1.3 Before installing any materials, all anodes should be inspected for damage and indications of proper connection. Any damaged anodes are not to be used. All cables should be inspected for damage to the coating and continuity before installation.

8.1.4 As previously mentioned, deep well anode columns are ordinarily drilled with direct mud rotary equipment. After reaching desired depth, downhole mud slurry should be thinned to nearly the viscosity of fresh water to permit proper carbon settlement around anodes. Thinning is performed by pumping potable water from the bottom up through the mud circulation system until it returns to surface in well bore. Accurate well thinning is critical to system installation.

8.1.5 Drillers familiar with proper thinning procedures should be used. Higher downhole fluid viscosities provide more resistance to caving of formations but slow carbon settlement. Lower viscosities speed carbon settlement but can lead to caving of downhole formations. Caving formations can bridge in well bore or settle around anodes. These conditions prevent carbon settlement around anodes, which can significantly decrease system performance and life. A casing may be required where the cathodic well goes through a strata that has potable water.

8.1.6 After thinning, the drill pipe is removed from the well to permit system loading. Vent pipe is typically lowered first and tied into position. Anodes are lowered by their attached wires to the desired elevation and tied off at the surface. After anodes are placed at desired elevations, carbon backfill is poured or pumped downhole from the bottom up. Anode resistance logging before, during, and after
carbon backfill provides proof of proper carbon settlement. Settlement of top-loaded granular carbons typically occurs within one hour. Settlement of pumped fluid carbons typically takes 6 to 12 hours. Total settlement should occur before backfilling of the inactive column.

8.2 Testing

If the installation is complete and the system has been energized, polarity tests should be conducted to verify the proper connection of the circuits.

The general testing procedure should first attach the volt meter positive terminal to the pipeline, then attach the negative terminal to the reference electrode. This should produce a negative potential.

9. Required Documentation

9.1 From Owner

Owner should include in the contract documents all technical information required to carry out the CP design.

This information should include a minimum of:

a. Detailed information on the pipeline to be protected (length, diameter, coating, scope limits, etc.)

b. Required design life of the CP system, typically equal to the design life of the pipeline

c. Requirements on CP systems and/or materials,

d. Relevant drawings (pipeline route, existing systems, foreign structures/pipelines), and

e. Applicable environmental and operating conditions for the CP equipment

9.2 From Supplier

A basic CP design should be submit to the owner for review and approval that should include:

a. Documentation listed in the first seven bullet items in Clause 13.1.1 of ISO 15589-1,

b. Justification of the selected CP system and anode materials,

c. Summary of the used formulae and standards,

d. System current requirement calculations (if performed by supplier),

e. Historical operating performance of the existing CP system (if any) and/or performance of other nearby CP systems in similar service (if any) that were used as the basis of the design, e.g., changes in current demand with time, coating condition, anode performance, etc., and

f. Any other information regarded as pertinent to this stage of the design. Only after such approval should the detailed design begin. In some cases (e.g., on small projects or standard projects), the owner may request the supplier to carry out both basic design and installation.
When the project is complete, the following documents should be a part of the construction document records for the project:

a. Permits
b. Driller’s Hole Log
c. As Builts
d. Rectifier Inspection
e. Exposed Pipe Report
f. Location of Test Stations

9.3 General

The basic design documentation should include:

a. Results of any site surveys and soil investigations that have been carried out
b. Results of any current drainage tests that have been carried out for the retrofitting of CP on existing pipelines
c. Any requirements for modifications with respect to existing pipeline systems such as minimum electrical separation or coating repairs
d. Calculations of current requirements, potential attenuation, electrical resistance and current output of groundbeds
e. Description of system including a schematic diagram of the proposed CP system
f. List of the number and types of CP monitoring facilities
g. Any sensitivities in the CP system that require special attention
h. Schedule of materials including recommended spares
i. Set of design drawings, and
j. Set of installation procedures

9.4 Construction Details and Installation Procedures

Full construction details and installation procedures of the CP system should be documented to ensure that the system is installed in accordance with ISO 15589-1. These should include:

a. Procedures for the installation of DC voltage sources, groundbeds, cables, test facilities, and cable connections to the pipeline
b. Procedures for all tests required to demonstrate that the quality of the installation is in accordance with the requirements
c. Construction drawings including but not limited to plot plans, locations of CP systems and test facilities, cable routing, single-line schematics, wiring diagrams and groundbed construction and civil works, and
d. Procedures to ensure safe systems of work during the installation and operation of the CP system
9.5 Commissioning Documentation

After the successful commissioning of the CP system, the following should be compiled in a commissioning report:

a. As-built layout drawings of the pipeline including neighboring structures or systems that are relevant to the effective CP of the pipeline;
b. As-built drawings, reports and other details pertaining to the CP of the pipeline;
c. Records of the interference tests (if any) carried out on neighboring structures;
d. Voltage and current at which each CP system was initially set and the voltage and current levels to be used during future interference tests. The location and type of interference-current sources (if any);
e. Records of the pipe-to-soil potentials at all monitoring stations before and after the application of CP.
f. Equipment manufacturer’s documentation and operating instructions.

9.6 Inspection and Monitoring Documentation

The results of all inspection and monitoring checks should be recorded and evaluated. They should be retained for use as a baseline for future verifications of CP effectiveness and maintained for the life of the pipeline.

9.7 Operating and Maintenance Documentation

An operating and maintenance manual should be developed to ensure that the CP system is well documented and that operating and maintenance procedures are available for operators. This document should include:

a. Description of the system and system components
b. Commissioning report
c. As-built drawings
d. Manufacturer’s documentation
e. Schedule of all monitoring facilities
f. Potential criteria for the system
g. Monitoring plan
h. Monitoring schedules and requirements for monitoring equipment
i. Monitoring procedures for each of the types of monitoring facilities installed on the pipeline, and
j. Guidelines for the safe operation of the CP system

9.8 Maintenance Records

For maintenance of the CP facilities, the following information shall be recorded:

a. Repair of rectifiers and other DC power sources
b. Repair or replacement of anodes, connections and cables
c. Maintenance, repair and replacement of coating, isolating devices, test leads and other test facilities

d. Rectifier oil testing records

e. Drainage stations, casing and remote monitoring equipment

10. **Safety and Integrity Concerns**

10.1 The CP system should be in accordance with all applicable safety standards and regulations.

10.2 For onshore ICCP systems, the transformer rectifier DC voltage should not be greater than 50 volts for safety reasons.

10.3 If there is a possibility of AC induced currents on a structure or pipeline, appropriate remedial actions should be executed to safeguard personnel.

10.4 Over-polarization of the structure can cause the evolution of hydrogen gas at the surface of steel and stainless steels. This can cause hydrogen induced embrittlement and cracking. The material hardness and microstructure are important factors in this aspect.

10.5 Another hazard generated by hydrogen evolution is the potential for the buildup of hydrogen gas in confined spaces, which may present a risk of explosion. To avoid these hazards, the following measures should be taken:

   a. Structure to electrolyte potential should be kept less negative than the threshold value at which hydrogen evolution is not significant.

   b. Include adequate venting to prevent the buildup of hydrogen.

   c. Magnesium alloy anodes should not be installed in areas where hydrogen build up may occur.

10.6 Electrochemical reactions at the surfaces of impressed current anodes in brine or seawater can result in the evolution of chlorine gas, which is highly toxic and corrosive. This gas can corrode anode leads causing premature failure. If this gas is allowed to collect in confined spaces, it may present a hazard to personnel and materials.
Appendix A: Well Construction Information
A.1 Well Construction

A.1.1 To eliminate anode current leakage up the inactive column, the upper section of deep anodes should be backfilled with nonconductive materials. Materials include PVC casing, sand, gravel, and cement. Sand bridges easily during installation and is not recommended. Depth of inactive column depends on current distribution requirements. Pea gravel backfill above the active column can increase the probability for ground water recharge. However, long columns of porous backfill can lead to comingling of aquifers with differing water qualities.

A.1.2 All deep ground beds should include a nonporous sanitary well seal in upper section of inactive column. Depth of seal should be 3 m (10 ft) minimum and may include cement, concrete, and specially formulated bentonite. The exact depth may be dictated by the local regulatory agency.

A.1.3 Conductor casings may be required to prevent caving of surface formations during installation.

A.1.4 Steel casing should be removed from inactive column within 15.2 m (50 ft) of active column. PVC casings can be left in the inactive column, but should be cemented into place to provide sanitary well seal. Top of casings should be sealed to prevent surface runoff that could lead to contamination of downhole aquifers. Size the well diameter to provide 50 mm (2 in) minimum annular space around outside diameter of casing for proper seal placement.

A.1.5 In potentially contaminated formations, surface casing should be cemented into place before drilling active column. This should eliminate cross contamination during installation and operation of anode system.

A.2 Backfill Selection

Backfill selection should be based on a consideration of the following coke characteristics:

a. Resistivity, or more significantly in-situ bulk resistivity determines how well the objective of the carbon backfill is achieved.

b. Specific gravity affects compact settling. A high specific gravity helps to ensure compact settling.

c. Carbon content of the backfill material determines the anode system life.

d. Particle sizing determines the amount of contact between anode and backfill. For optimum contact, particle size should be small relative to the anode diameter. Very small (i.e., less than 7.5 microns) particles should be avoided because they are high in ash content.

e. Particle shape affects how well the backfill settles and the tendency for the backfill to trap gases. A spherical shape is preferred over flat, irregularly shaped particles.

A.3 Carbon Backfill

A.3.1 The carbon backfill serves as a sacrificial buffer between the anode and the reaction environment. Carbon backfill is used to accomplish three major goals:

a. Maintain stability of the excavation (i.e., hole)
b. Serve as the primary anodic reaction surface

c. Lower resistance-to-earth of the system

A.3.2 The primary objective of the carbon backfill is to electronically conduct the current discharged from the anode surface to the carbon-earth interface where the electrochemical reaction can occur with least impact on the anode.

A.3.3 Metallurgical coke is low in carbon content, porous and therefore low in specific gravity, and high in ash and volatiles content. These three characteristics cause metallurgical coke to have a relatively high resistivity. Metallurgical coke is not suitable for deep anode groundbed installations.

A.3.4 Petroleum coke should be calcined (i.e., heat treated). Before calcination, petroleum coke is nonconductive and is therefore not suitable for backfill.
Appendix B: Examples of Installation Details
The following notes apply to Figures B1 through B3:

a. The lead wire from the pipeline to the rectifier should be looped around the pipeline with slack at both ends in the connecting wire from pipe to anode to minimize potential for the cadweld to be pulled from the pipeline.

b. A separate test lead should run from the pipeline to the test station located at the rectifier/controller. This permits direct reading of the pipe current, validating the connection to the pipeline from the rectifier/controller.

c. The anodes with their lead wires should be laid out and marked before installation.
Figure B1. Deep Type Installation
Figure B2. Conventional Groundbed – Vertical Single Trench Anode Installation
Figure B3. Conventional groundbed – horizontal single trench anode installation