Engineering Standard

SAES-X-600 31 August, 2004

Cathodic Protection of Plant Facilities

Saudi Aramco DeskTop Standards

Table of Contents

1 Scope

1.1 This standard prescribes the minimum mandatory requirements governing the design and installation of cathodic protection systems for the external surfaces of buried and submerged structures for plant facilities.

1.2 Plant facilities include but are not limited the following structures:

a. Buried pressurized piping including short sections at road crossings, dike crossings, or at connections to existing underground piping.

b. Buried non-pressurized piping containing a product that might pose a safety or environmental issue if leakage was to occur, i.e., gravity drain lines with H_2S.

c. Pipeline casings for pressurized piping at road or dike crossings.

d. The bottom or soil side of above ground storage tanks.

e. Buried storage tanks.

f. Metal piles, sheet piling and associated anchors.

g. Buried valves and fittings.

Commentary Notes:

1. *Non-pressurized buried hydrocarbon piping shall be electrically bonded to the CP systems, but does not need to comply with the protection levels detailed in 4.3.*

2. *Only buried portion of metal piles in areas with soil resistivities less than 500 ohm-cm shall be cathodically protected.*

3. *Water wells inside the plant facilities shall be protected as per SAES-X-700.*

4. *Catch basins and metal fittings and appurtenances associated with catch basins are outside the scope of this standard and do not require cathodic protection.*

1.3 This standard may not be attached to nor made part of purchase orders.

2 Conflicts and Deviations

2.1 The Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran shall resolve in writing any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

Referenced standards and specifications shall be the latest edition, revision or addendum unless otherwise stated.

The Desktop TIC and the Saudi Aramco Engineering Standards intranet web site contain the latest revisions of all standards and a listing of Standard Drawings. The Drawing Management System (DMS) contains Standard Drawing listings with the latest revision numbers. These Standard Drawings can also be accessed through the web enabled DMS QVP system at http://engdwg.aramco.com.sa.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*
SAEP-332	*Cathodic Protection Commissioning*

Saudi Aramco Engineering Standards

SAES-D-100	*Design Criteria of Atmospheric and Low-Pressure Tanks*
SAES-D-108	*Storage Tank Integrity*
SAES-P-104	*Wiring Methods and Materials*
SAES-P-111	*Grounding*
SAES-Q-001	*Criteria for Design & Construction of Concrete Structures*
SAES-X-300	*Cathodic Protection Marine Structures*
SAES-X-400	*Cathodic Protection of Buried Pipelines*
SAES-X-700	*Cathodic Protection of Onshore Well Casings*

Saudi Aramco Materials System Specifications

02-SAMSS-010	*Flanged Insulating Joints/Spools for Cathodic Protection*

17-SAMSS-004	*Conventional (Tap Adjustable) Rectifiers for Cathodic Protection*
17-SAMSS-005	*Cathodic Protection Phase Controlled Rectifiers*
17-SAMSS-006	*Galvanic Anodes for Cathodic Protection*
17-SAMSS-007	*Impressed Current Anodes for Cathodic Protection*
17-SAMSS-008	*Junction Boxes for Cathodic Protection*
17-SAMSS-017	*Impressed Current Cathodic Protection Cables*
32-SAMSS-005	*Manufacture of Atmospheric Tanks*

Saudi Aramco Standard Drawings

The following Saudi Aramco Standard Drawings outline specific methods of designing and installing cathodic protection systems.

AD-036132	*Termination Detail Cable Identification*
AA-036145	*Anode Cable Splice Junction Box*
AA-036157	*Galvanic Anode 3-Pin Test Station*
AB-036273	*Surface Marker Underground Electric Cable*
AB-036274	*5 Terminal Junction Box Details*
AB-036275	*12 Terminal Junction Box Details*
AA-036276	*Multi-purpose Junction Box Details*
AA-036277	*5 Terminal Bond Box Details*
AA-036346	*Surface Anode Bed Details - Horizontal and Vertical Anodes (Sheets 1&2)*
AA-036347	*20 Terminal Junction Box Details*
AA-036349	*3 Terminal Bond Box Details*
AA-036350	*2 Terminal Bond Box Details*
AB-036351	*Marker Plate Details*
AA-036352	*Galvanic Anodes for Road and Camel Pipeline Crossings Details of Installation*
AA-036355	*Tank Bottom Impressed Current Cathodic Protection*
AA-036378	*Rectifier Installation Details (Sheets 1&2)*

AB-036381	*Thermite Welding of Cables to Pipelines and Structures*
AB-036540	*Mounting Support Details for Junction Boxes*
AA-036629	*Anode Details for Hydrants and Risers from RTR or Plastic Mains*
AA-036637	*Bond Box Details for Manholes*
AB-036677	*An Overview (Architectural) Security & General Purpose Fencing*
AA-036678	*Security & General Purpose Fencing - Post & Fabric Details*
AE-036785	*Symbols for Cathodic Protection*
AA-036865	*CP Isolating Flanges*
AD-036874	*Direct Buried Electric Cable and Conduit*
AA-036905	*Details of Installation of New Bottoms and Cathodic Protection for Existing Welded and Riveted Tanks*
AB-036907	*Kilometer Marker & CP Test Stations for Buried Pipelines*

Saudi Aramco General Instruction

GI-0002.710	*Mechanical Completion and Performance Acceptance of Facilities*

3.2 Industry Codes and Standards

National Fire Protection Association

NFPA 70	*National Electrical Code (NEC)*

National Association of Corrosion Engineers

NACE RP0169	*Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
NACE RP0193	*External Cathodic Protection of Carbon Steel Storage Tank Bottoms*
NACE RP0285	*Corrosion Control of Underground Storage Tanks Systems by Cathodic Protection*

4 Design

4.1 Design Review and Approval

4.1.1 IT IS MANDATORY that proposed construction drawings and the related cathodic protection design information for every design package be submitted to the proponent cathodic protection organization and the Cathodic Protection & Coatings Unit of CSD for review and approval.

The design agency shall not issue drawings for construction that have not been approved in writing by the proponent cathodic protection organization and the Cathodic Protection & Coatings Unit of CSD.

4.1.2 The Supervisor of CSD/ME&CCD/Cathodic Protection and Coatings Unit and the Supervisor of the proponent cathodic protection organization shall indicate the completion of their review and approval of each Cathodic Protection drawing by signature. The signatures shall be placed in the "Review of Key Drawings" block of each Index X drawing. Alternatively, a list containing all approved project drawing numbers can be signed by the Supervisor of CSD/ME&CCD/Cathodic Protection and Coatings Unit and the Supervisor of the proponent cathodic protection organization to indicate their review and approval.

4.1.3 The design package submitted for review shall contain at minimum

a. The scope of work

b. Professionally drafted full size Index "X" CP drawings that:

- Detail each CP item by description and stock number if applicable
- Detail the proposed location for each piece of CP equipment including but not limited to rectifiers, anodes, junction boxes, bond stations, test stations, soil access holes, bonds to pipelines, insulating flanges and unions
- Detail and clearly illustrate an organized numbering system (sequential order) for test points and soil access boxes that begins at the top left corner of the cathodic protection layout drawing
- Detail and specifically identify all cathodic protection cables including all anode, structure, bond, and rectifier cables.

These details shall be shown on the One-Line Diagram for Impressed Current Cathodic Protection (ICCP) system

- Clearly identify the specific and individual cable routing and termination points within the respective test stations, junction boxes, bond boxes, and rectifiers

- Detail all cathodic protection equipment using the cathodic protection symbols as shown on Standard Drawing AE-036785 "Symbols for Cathodic Protection"

c. All calculations and applicable field data required to verify design compliance with the Saudi Aramco Cathodic Protection Engineering Standards. CSD's approval of the design calculations, using average soil resistivity values, does not relieve the designer of his responsibility of meeting the required potential criteria stated by this standard.

Commentary Notes:

Cathodic protection design considerations begin at the DBSP stage and should be reasonably developed by the Project Proposal stage. The Project Proposal should include all design considerations that can be developed without acquiring actual field measurement data, including proposed anode type(s) and sizing of the cathodic protection rectifier(s).

The 30% Detailed Design Package should present a complete and comprehensive cathodic protection system design including all required field measurement data, calculations, a detailed description of the proposed cathodic protection equipment, and a set of detailed drawings that illustrate the proposed placement of all cathodic protection equipment and the associated protected structures.

4.2 General

4.2.1 Design Philosophy

Unless otherwise specified in this standard, cathodic protection systems shall be designed using the "earth potential rise" method with distributed impressed current anodes or continuous impressed current anodes.

Exception:

An alternative design philosophy using a combination of remote and distributed anode beds may be more cost effective in some situations. Proposals for alternative cathodic protection designs may be submitted *for consideration to CSD. Proposals must be submitted with a complete and thorough economic comparison and shall be considered unacceptable unless pre-approved in writing by the proponent cathodic protection organization and the Supervisor of the Cathodic Protection and Coatings Unit of CSD.*

4.2.2 Protection Criteria

4.2.2.1 Potential Criteria

The potential criteria for the specific structures shall be achieved in the design by determining the number, placement, current loading, and length of the anodes required to achieve the necessary voltage gradient. The calculation method for this procedure shall use the "earth potential rise" equations detailed in Appendix 1 to achieve the potential criteria for the specific structure as detailed in the sections of this standard listed in Table 1.

Table 1 – Potential Criteria

Equipment Surface Description	Section
Buried Metal Pipelines	4.3.2
Isolated Buried Pipeline Casings	4.4.2
On Grade Tank Bottoms and Buried Tanks	4.5.3
Buried Valves, Hydrants, Monitors & Fittings	4.6.2
Metal Piles, Sheet Piling & Associated Anchors	4.7.2

Unless actual field data indicates otherwise "earth potential rise" calculations shall presume an initial structure potential of:

a) -0.250 volt ($Cu-CuSO_4$) for structures electrically continuous with bare stainless steel or copper piping, bare ground cables (copper or tinned), or copper or stainless steel ground rods.

b) -0.500 volt ($Cu-CuSO_4$) for structures that are not shorted to buried and bare copper or stainless steel structures, but may be electrically continuous with insulated ground cables, galvanized ground rods, or other galvanized or coated structures.

4.2.2.2 Current Density Criteria

Cathodic protection designs for a remote anode bed system or for the remote anode bed part of a combination of remote plus distributed anodes as discussed in 4.2.1 "Exception", shall provide the minimum current densities detailed in Table 2.

Table 2 – Minimum Surface Current Densities

Equipment Surface Description	*Current Density (mA/m²)*
Copper Ground Rods	50
Stainless Steel Ground Rods (driven)	20
Bare Tinned Copper Cable	70
Bare Copper Cable	150
Bare Steel (buried)	20
Polyethylene Tape	1.25
Liquid Applied Epoxy	0.75
Fusion Bond Epoxy	0.10

Consult CSD for current density requirements for other coatings such as three-layer PE, or specialized high temperature coatings.

4.2.3 Design Life

4.2.3.1 The minimum design life for impressed current and galvanic anode systems shall be 20 years.

4.2.3.2 The design life for a galvanic system shall be calculated using parameters from Table 3 and the equation detailed below:

$$\left[\frac{\text{Total Weight of All Anodes (kgs) X Utilization Factor}}{\left\{\text{Consumption Rate x}\left(\dfrac{\text{Anode Open Circuit Potential - Protected Potential}}{\text{Resistance of All Anodes}*}\right)\right\}}\right] \geq \text{20 Years}$$

* Use the lowest measured resistivity for the planned installation depth of the anodes based on the finished grade levels at the site, for the life calculation of a galvanic anode bed system.

Table 3 – Galvanic Anode Material Properties

Anode Material	Consumption Rate *(kg/A-Y)*	Potential *(mV) (Cu/CuSO₄)*
Aluminum	3.7	-1100
Magnesium	7.7	-1700
Zinc	11.8	-1100

Commentary Note:

The consumption rates detailed in Table 3 have been corrected for efficiency. A utilization factor of 0.85 shall be used unless specified otherwise in design documents.

4.2.3.3 The design life for an impressed current distributed anode system shall be calculated using parameters detailed in Table 4 and the following equation:

$$\left[\frac{\text{Anode Weight (kgs.)}}{\{\text{Anode Consumption Rate x Anode Current Capacity}\}}\right] \geq 20\ \text{Years}$$

The design life for an impressed current remote anode system shall be calculated using parameters detailed in Table 4 and the following equation:

$$\left[\frac{\text{Total Anode Weight (kgs.)}}{\{\text{Anode Consumption Rate x Rectifier Rated Current Capacity}\}}\right] \geq 20\ \text{Years}$$

Table 4 – Impressed Current Anode Consumption Rates and Maximum Current Densities

Anode Material	Consumption Rate *(kg/amp-y)*	Maximum Current Density *(mA/cm²)*
HSCI	0.45	0.7
Mixed Metal Oxide or Polymeric Anodes	As per the manufacturer recommendation	As per the manufacturer recommendation

Commentary Note:

The consumption rates detailed in Table 4 have been corrected for efficiency and utilization factor. Shortening of the effective anode length due to an end cap at the cable end of the anode shall be neglected in the theoretical calculation of anode current capacity.

4.2.3.5 The impressed current anodes most commonly used by Saudi Aramco are as listed in Table 5 below.

Table 5 – Impressed Current HSCI Anode Data

Type	Dimensions	Weight	Current Capacity
TA-4	95 mm x 2133 mm	38.6 kg	4.45 amps/anode
TA-5A	121 mm x 2133 mm	79.4 kg	5.67 amps/anode

4.2.4 Soil Resistivity Surveys

4.2.4.1 **Distributed Anode Bed:** Conduct soil resistivity or soil conductivity measurements over a representative sample of the distributed anode installation locations. Ensure that the readings are taken for the planned installation depths of the anodes based on the finished grade levels at the site.

4.2.4.2 **Remote Surface Anode Bed:** Conduct soil resistivity or soil conductivity measurements at 10-meter intervals over the full length of the proposed surface anode bed location. Consult with CSD for design alternatives if the soil resistivities over the length of the proposed anode bed vary by more than 100%.

4.2.4.3 **Remote Deep Anode Bed:** Soil resistivity or soil conductivity measurements for deep anode beds are recommended but not mandatory. The Supervisor of the Cathodic Protection & Coatings Unit of ME&CCD/CSD in consultation with the Groundwater Protection Division will determine the final bore hole depth and anode placement based on the drill stem resistance and test anode resistance measurements measured during drilling of the anode hole.

4.2.5 DC Power Supply

4.2.5.1 Install the rectifiers in non-hazardous areas where possible and use oil-immersed rectifier units (Type OA per 17-SAMSS-004 or 17-SAMSS-005) inside hydrocarbon plant areas, in all locations that are within 30 meters of hydrocarbon plant perimeter fencing (outside), and within 1 km of a coastline.

Exception:

The DC power supply for a grid or continuous impressed current anode CP system can be air cooled (NEMA 4X) and need not comply with the requirements of 17-SAMSS-004 & 005 but shall be supplied by a Saudi Aramco approved manufacturer.

4.2.5.2 DC power supplies shall have a maximum rated output voltage of no greater than 100 volts. The sizing of the rectifier shall be optimized and based on the overall circuit resistance. Rectifier sizes other than those listed in SAMSS category 17 can be used, but must be approved by the

Supervisor of the Cathodic Protection and Coatings Unit of CSD, and shall be supplied by a Saudi Aramco approved manufacturer. The power supply shall be sized to compliment the specific anode requirements and must be suitably classified for the area of installation.

4.2.6 Anodes

4.2.6.1 Unless specified otherwise in this document, impressed current anode materials for soil applications shall be high silicon cast iron complying with 17-SAMSS-007 and shall use design parameters as detailed in Table 4.

4.2.6.2 Galvanic anode materials for soil applications shall be manufactured in accordance with 17-SAMSS-006. Designs using galvanic anodes shall comply with the design parameters detailed in Table 3.

4.2.6.3 In asphalt, paved areas, or tightly compacted marl areas, conventional impressed current anodes shall be vented according to Standard Drawing AA-036346. Vent openings shall be above-grade if product spill could contaminate the anode backfill.

4.2.7 Cables

4.2.7.1 Cathodic protection cables shall be manufactured in accordance with 17-SAMSS-017.

4.2.7.2 The minimum size for the primary positive and negative DC cables from the rectifier shall be 25 mm^2 (#4 AWG).

4.2.7.3 All cathodic protection cables including the primary positive and negative cables shall be sized to comply with the most recent edition of the National Fire Protection Association NFPA 70, National Electric Code (NEC).

Commentary Note:

> *Use Table 310-16, Column for 90°C rated cables of the latest NEC Handbook to calculate the ampacity of HMWPE cables, and consider an ambient temperature of 40°C.*

4.2.8 Structure Electrical Continuity

4.2.8.1 Install dedicated bonds to all structures influenced by the impressed current anode systems to ensure electrical continuity back to the cathodic protection rectifier. Make all cable connections to structures according to Standard Drawing AB-036381.

4.2.8.2 Cables installed for, or associated with electrical grounding or electrical ground continuity purposes shall not be used to achieve the required electrical continuity for cathodic protection.

4.2.8.3 Identify and locate all bonding connections on the cathodic protection drawings.

4.2.9 Resistors for Current Distribution Control

Electrical resistors shall not be used for current distribution control.

4.2.10 Bonding

4.2.10.1 All buried metal structures influenced by cathodic protection systems shall be electrically continuous. Install continuity bonds between all buried structures requiring cathodic protection that are not welded together. Make all bond cable terminations between structures in an above-grade approved electrical enclosure constructed according to one of the following Standard Drawings AA-036276, AA-036277, AA-036349, AA-036350, and AA-036637. Make bond connections for manholes according to Standard Drawing AA-036637.

4.2.10.2 The bond conductor shall be sized to achieve a voltage drop across the conductor of less than 0.05 volt and shall be minimum 16 mm^2 (#6 AWG).

4.2.10.3 Make all cable connections to structures according to Standard Drawing AB-036381.

4.2.10.4 Install a test lead on all buried bonded structures in addition to the bond cable. Terminate the test lead in the bond box on its own individual terminal.

4.2.10.5 If an above ground bond box will interfere with the operation of the plant, a flush mounted bond box installed according to Standard Drawing AA-036637 may be used provided the cathodic protection proponent organization concurs in writing.

4.2.11 Electrical Isolation

4.2.11.1 Insulating flanges, insulating joints or spools, or other electrical isolating devices are not allowed except to limit protective current flow between plant facilities and off-plot pipelines, and for short pipeline sections less than 500 meters long protected by a galvanic anode system.

Exceptions:

1. *Fire water systems at office buildings may be electrically isolated.*

2. *Isolation flanges may also be used to electrically isolate protected and non-protected piping sectios to prevent loss of CP current.*

4.2.11.2 Do not install isolating devices in areas classified as hazardous locations.

4.2.11.3 Do not install isolating devices in any buried or submerged portions of a pipeline.

4.2.11.4 Provide an above-grade bond box for all isolating devices. Construct the box according to Standard Drawings AA-036277, AA-036349 or AA-036350.

Exception:

An above grade bond box is not required for an isolation devices mentioned in Section 4.2.11.1.

4.2.11.5 Use an insulation flange kit selected from Standard Drawing AA-036865 to construct the insulated flange. Construct the flange according to 02-SAMSS-010.

4.3 Buried Metal Pipelines

4.3.1 Design Philosophy

The cathodic protection system for a buried metal pipeline shall be designed using the "earth potential rise" method with distributed impressed current anodes and the relative equations detailed in Appendix 1.

Exception:

Paragraphs 4.2.1 & 4.3.4.4 - Exception.

4.3.2 Protection Criteria

The negative pipe-to-soil potential shall be:

a. A minimum of -1.0 volt and a maximum of -3.0 volts, with reference to a copper/copper sulfate electrode and the current on, or,

b. if all of the protective current can be interrupted, a potential of either -0.850 volt off, or

c. a 100 mV polarization shift between the instant off potential and either the native state potential (for initial commissioning only) or the depolarized state potential. The maximum time allowed for the depolarized state potential to occur is 7 days.

4.3.3 DC Power Supply

The DC power supply shall comply with section 4.2.5 of this standard.

4.3.4 Anode Beds

4.3.4.1 The number and size requirements for the anodes shall be determined based on providing a sufficient potential gradient over the entire length of the respective pipeline to achieve the protection criteria.

4.3.4.2 The resistance to ground of a distributed anode bed does not need to compliment the rated resistance of the rectifier, however, the combined current capacity of the anodes shall be equal to or greater than the rectifier rated current.

4.3.4.3 If impressed current anodes are placed within 50 meters of a thrust anchor, then two additional impressed current anodes shall be installed within 15 meters of the anchor, and placed on opposite sides of the anchor. If impressed current anodes are installed, galvanic anodes are not required for the thrust anchor.

Commentary Note:

> *Cathodic protection requirements for thrust anchors on pipelines exiting or entering the plant are covered in SAES-X-400.*

4.3.4.4 Galvanic anodes may be used to protect short (less than 500 meters) buried sections of coated piping; provided the following conditions are met:

a. All parts of the piping are greater than 100 meters from the closest impressed current rectifier.

b. The piping is not shielded by other structures and no other structures (concrete, plastic, wood, and metal) are within 6 meters of the piping.

c. The piping is not electrically continuous with any other buried uncoated structure.

The cathodic protection design shall be based on calculation of the current requirement for the short section of buried pipeline, and determination of the required number and size of galvanic anodes to achieve that current for the minimum life requirement.

4.3.5 Monitoring

4.3.5.1 Provide a test station according to Standard Drawing AB-036907 for measuring pipe-to-soil potentials at:

a. Insulated cased crossings

b. Paved road crossings

c. Thrust-bored road crossings

d. Negative connections to underground piping

e. Buried bond connections

f. Other locations as required by operational needs.

4.3.5.2 The maximum spacing between test stations or risers used for test stations is 100 meters.

4.3.5.3 Piping risers may be used for test stations provided they are labeled and identified as test points on the Cathodic Protection Layout Drawings and on the riser.

4.3.5.4 Install soil access test holes, according to Standard Drawing AB-036907, in concrete and asphalt (paved) areas directly over the top of the pipe or structure to be monitored. In these concrete or asphalt areas, install one soil access hole at each of the following locations:

a. One midway between each pair of anodes.

b. One over the structure closest to each anode.

c. One at the beginning and one at the end of each pipeline segment.

d. One at each metallic hydrant, metallic riser or metallic valve that is part of a non-metallic piping system.

e. One at each test station or riser used as a test station.

4.3.6 Bonding, Electrical Continuity, and Electrical Isolation

Bonding, electrical continuity, and electrical isolation shall comply with sections 4.2.7, 4.2.8, 4.2.9, 4.2.10 and 4.2.11 of this standard.

4.4 Isolated Buried Pipeline Casings

4.4.1 Design Philosophy

The cathodic protection system for a buried metal pipeline casing shall be:

a. Designed using the "earth potential rise" method for casings of normally buried metal pipelines protected by impressed current anodes, or,

b. designed using galvanic anodes for casings of normally above grade pipelines that are cased for crossings such as at roads or dikes.

Commentary Note:

A dedicated DC power supply for an isolated pipeline casing will seldom be more cost effective than galvanic anodes. However, in situations where there is an existing impressed current system with spare capacity, it may be cost effective to install supplemental impressed current anodes for the casing with a dedicated negative drain cable from the casing to the rectifier via a negative junction box.

4.4.2 Protection Criteria

The negative pipe-to-soil potential shall be:

a. A minimum of -1.0 volt and a maximum of -3.0 volts, with reference to a copper/copper sulfate electrode and the current on, or,

b. if all of the protective current can be interrupted, a potential of either -0.850 volt off, or

c. a 100 mV polarization shift between the instant off potential and either the native state or the depolarized state potential. The maximum time allowed for the depolarized state potential to occur is 7 days.

4.4.3 DC Power Supply

The DC power supply shall comply with section 4.2.5 of this standard.

4.4.4 Anodes for Pipeline Casings

4.4.4.1 Impressed Current Anodes

4.4.4.1.1 The number and size requirements for the anodes shall be determined based on providing a sufficient potential gradient over the entire length of the respective pipeline casing to achieve the protection criteria.

4.4.4.1.2 The resistance to ground of the anode bed does not need to compliment the rated resistance of the rectifier, however, the combined current capacity of the anodes shall be equal to or greater than the rectifier rated current.

4.4.4.2 Galvanic Anodes

4.4.4.2.1 Install the number of anodes specified in Table 6. Use 27.2 kgs (60 lbs) magnesium anodes for soil resistivities greater than 500 ohm-cm. Use 22 kgs (48.5 lbs) or 50 kgs (110.23 lbs) zinc anodes for soil resistivities equal to or less than 500 ohm-cm.

4.4.4.2.2 Galvanic anodes shall be connected to the casing through galvanic anode (3-pin) junction boxes.

Table 6 – Galvanic Anodes for Coated Casings that are Electrically Isolated

Casing Diameter *(inches)*	Number of Casings	Casing Length *(meters)*	Number of Anodes
Less than 12	1 – 3	Less than 15	2 on one end
12 to 35	1 – 3	Less than 15	2 on each end
36 or larger	1 – 3	Less than 15	3 on each end
Less than 12	1 – 3	15 to 30	2 on each end
12 to 35	1 – 3	15 to 30	2 on each end
36 or larger	1 – 3	15 to 30	2 on each end plus 2 in the middle

Notes:

- The above table is for groups of casings that are spaced no more than 6 meters from each other.
- For groups of casing greater than 3, divide the number of casings by 3 and multiply the number of anodes in the table by the result of this division. Round up to the next whole number for fractional results.
- For casings not addressed by this table, such as bare casings or casings longer than 30 meters, a site-specific design must be completed that considers soil resistivity, total current requirement, and anode life. The supervisor of the Cathodic Protection and Coatings Unit must concur with the proposed design.

4.4.5 Monitoring

Monitoring shall comply with section 4.3.5 of this standard.

4.4.6 Bonding and Electrical Continuity

Bonding and electrical continuity, shall comply with sections 4.2.7, 4.2.8, and 4.2.10 of this standard.

At crossing locations involving more than one casing, the casings shall be bonded together if influenced by impressed current anodes. If galvanic anodes provide the only cathodic protection influence on the casings, then bonding the pipelines together is not required.

4.5 On Grade Tank Bottoms - Soil Side

4.5.1 New Tanks - CP Design Philosophy

4.5.1.1 The cathodic protection system shall be designed in accordance with the requirements for new tanks detailed in Standard Drawing AA-036355.

4.5.1.2 New tanks shall be designed with an impressed current grid system or continuous distributed anode system placed directly beneath the tank and designed to ensure a relatively uniform current distribution that maintains all points on the tank bottom within the required protection criteria limits.

Exception:

New tanks with a diameter of 10 meters or less may use a galvanic continuous or grid type anode system, or conventional prepackaged galvanic anodes placed between the tank bottom and a dielectric barrier.

Commentary Note:

In case of a tank(s) containing high temperature product(s) that could make the soil environment under the tank bottom to be very dry and non-corrosive, then the need for a CP system to protect such tank(s) should be evaluated in consultation with CSD. If a CP system is considered to be not required, then an Engineering Standards Waiver request should be processed to document that the long term corrosion protection needs of the tank(s) will be met over the operating life of the tank(s).

4.5.2 Existing Tanks - CP Design Philosophy

It is up to the proponent organization to evaluate the corrosion history of the subject tank and make the decision on the need to install a cathodic protection system. If the decision is to install a cathodic protection system, then the following shall be applied:

4.5.2.1 The cathodic protection system shall be designed in accordance with the requirements for existing tanks detailed in Standard Drawing AA-036355.

4.5.2.2 The anode configuration for existing tanks requiring new impressed current cathodic protection systems, or upgrades to existing impressed current cathodic protection systems shall be designed using impressed current distributed anodes placed around the perimeter of a tank.

Commentary Note:

Existing tanks that require anode upgrades and have an oily sand foundation mixture or asphalt or concrete foundation pad will not receive complete cathodic protection in areas where the oily sand mixture collects water at the interface between the tank bottom and the oily sand. Consideration should be given to removing the oily sand wherever economically viable.

4.5.2.3 Existing tanks requiring new tank bottoms that will be installed above the existing bottom without removal of the existing bottom shall be cathodically protected with galvanic anodes in accordance with Standard Drawing AA-036905.

4.5.3 Protection Criteria - Tank Bottoms and Buried Tanks

For new tank bottom CP system installation, the negative structure-to-soil potential shall be measured at 1 meter intervals through a slotted monitoring tube installed beneath the tank, and through access holes in the ring wall. The protection criteria for tank bottoms and buried tanks shall be:

a. A minimum of -1.0 volt and a maximum of -3.0 volts, with reference to a copper/copper sulfate electrode and the current on, or

b. if all of the protective current can be interrupted, a potential of either -0.850 volt off, or

c. a 100 mV polarization shift between the instant off potential and either the native state (for initial commissioning only), or the depolarized state potential.. The maximum time allowed for the depolarized state potential to occur is 7 days.

4.5.4 DC Power Supply - Tank Bottoms

The DC power supply shall comply with section 4.2.5 of this standard (see exception item in 4.2.5.2).

4.5.5 Anodes - Tank Bottoms

4.5.5.1 For an existing tank, anodes shall be placed a minimum of ¼ tank diameter away from the tank shell. The circumferential spacing between anodes shall be less than 30 meters in Bulk plants or other facilities with minimal underground structures, and less than 20 meters in Tank Farms or other process type areas with more extensive underground facilities.

4.5.5.2 Mixed metal oxide, or polymeric anodes shall be used for new tank designs. The design concept shall be pre-approved in writing by the Proponent and the Supervisor of the CP&CU of CSD. The anode specifications and manufacturer must also be pre-approved in writing by the RSA for cathodic protection anodes.

4.5.5.3 Impressed current anodes for existing tanks, and galvanic anodes shall comply with section 4.2.3.

4.5.5.4 The resistance to ground of the anodes can be greater than the rated resistance of the rectifier, however, the combined current capacity of the anodes shall be equal to or greater than the rectifier rated current.

4.5.6 Monitoring

4.5.6.1 For a new tank bottom, monitoring shall be through access tubes through tank ring walls, and slotted monitoring tubes under the tank bottom according to Standard Drawing AA-036355.

4.5.6.2 For an existing tank with distributed anodes outside the perimeter of the tank, monitoring shall be through access tubes through the ring wall, as per Standard drawing AA-036355, detail 6.

4.5.7 Bonding and Electrical Continuity

A dedicated negative cable shall be connected directly between each tank protected and the rectifier providing current to that tank. Connect multiple tanks to the rectifier through a negative junction box.

4.6 Buried Valves and Fittings

4.6.1 Design Philosophy

Cathodic protection for small buried isolated metallic structures that are part of a non-metallic piping system, such as valves and risers shall be protected using galvanic anodes, in accordance with Standard Drawing AA-036629.

Exception:

For buried metallic fittings used in non-metallic firewater systems, a supplemental (additional) coating system using APCS-113c or APCS-108 over top of the original shop or factory applied coating system may be applied as an alternative to galvanic anodes.

4.6.2 Protection Criteria

The design of the cathodic protection system shall achieve a minimum structure-to-soil potential for isolated buried metal structures of -1.0 volt with reference to a copper/copper sulfate electrode and the current on.

4.7 Metal Piles, Sheet Piling and Associated Anchors

4.7.1 Design Philosophy

Design cathodic protection for metal piles using impressed current (remote or distributed anode system) or galvanic anode systems. If a remote impressed current system or a galvanic anode system is used, the current requirements for all metallic buried structures that are electrically continuous with the protected structure must be considered.

4.7.2 Protection Criteria

The minimum structure-to-soil potential for design purposes shall be:

a. Water: The structure-to-water potential for sheet piling shall be a minimum of -0.90 volt, with reference to a silver chloride electrode.

b. Soil: The structure-to-soil potential for piling shall be a minimum of -0.85 volt, with reference to a copper/copper sulfate electrode and the current on.

4.7.3 DC Power Supply

If an impressed current cathodic protection system is used, the DC power supply shall comply with section 4.2.5 of this standard.

4.7.4 Bonding and Electrical Continuity

Impressed current designs for pile systems require electrical continuity between all piles within a common structure.

5 Installation

5.1 Galvanic Anodes

5.1.1 Install galvanic anodes vertically or horizontally.

5.1.2 Do not pick up or lower the anode using the anode cable.

5.1.3 Refer to 5.4.5 below for inspection and repair of galvanic anode cable leads. Instructions given in 5.2.1.2 below are for impressed current anodes, and do not apply to galvanic anode cable leads.

5.2 Impressed Current Anodes

5.2.1 Do not roll, pull or twist the anode and anode cable or lower the anode, with the anode cable or perform any other action that may strain the cable where the cable protrudes from the anode.

5.2.2 Number and install the distributed anodes in sequential order left to right and from top to the bottom of the layout drawing. Durably tag the anode cables at the termination point inside the anode lead junction box according to Standard Drawing AD-036132 to indicate the anode number.

5.2.3 Inspect the ICCP anode cables for below grade usage for insulation damage just before installation. Conduct the inspection with a pulse type holiday detector set at 18,000 volts DC. Saudi Aramco or it's designated agent shall witness the inspection. Do not use anodes with the cables that fail the dielectric test.

5.2.4 Do not use repaired anode cables, repaired anodes, or anodes with repaired anode-to-cable connections.

Exception:

> *You may repair an anode cable provided all splices are made in above ground junction boxes. Two boxes are required with one box at each end of the repaired section of cable. New cable of similar or larger size to the anode cable shall then be installed to connect the two boxes. Use cable splice boxes constructed according to Standard Drawing AA-036145.*

5.2.5 For a remote anode bed the designated Saudi Aramco design or construction agency shall verify the proper anode burial depth, and where practical mark the exact location of the anode bed on site to correlate with the location of the soil resistivity survey.

5.2.6 Each impressed current anode shall be connected to the positive circuit of the respective rectifier through an individual anode lead wire connected through a dedicated shunt mounted in an appropriately sized anode junction box.

Each junction box shall be constructed according to one of the following Standard Drawings: AB-036274, AB-036275 or AA-036347 and Saudi Aramco Materials System Specification 17-SAMSS-008.

Exception:

Shunts are not required for the individual anode connection in the individual anode boxes (GUB boxes) installed at the tank shell (Standard Drawing AA-036355, Sheet 1).

5.2.7 Install the anodes according to Standard Drawing AA-036355, or Standard Drawing AA-036346. The cathodic protection design shall provide the hole depth and other installation details that are job specific.

5.3 Rectifier AC Power Source

5.3.1 Provide AC power input to the rectifier through a fused disconnect switch or circuit breaker. Enclose the device in a enclosure with an externally operable handle mechanism in accordance with SAES-P-104. Mount the device in an accessible location approximately 1.8 meters above grade and within 3 meters of the rectifier. Rate the circuit breaker or the fused disconnect for approximately 125% rating of the rectifier rated input current.

5.3.2 If there is more than one negative or positive cable to connect to the rectifier, make the multiple connections in a positive or negative junction box constructed according to Standard Drawing AA-036276.

5.3.3 Install rectifiers according to Standard Drawing AA-036378. Where fences are required, install them according to Standard Drawings AB-036677 and AA-036678.

5.4 DC Cables

5.4.1 Install all plant area buried DC cables in trenches constructed according to Standard Drawing AD-036874.

5.4.2 Identify all underground DC cables (anode, bond, positive, and negative) with cable route markers constructed and installed according to Standard Drawings AB-036351 and AB-036273.

5.4.3 Inspect positive cables for insulation damage immediately prior to the burial of the cables. Conduct the inspection with a pulse type holiday detector set at 18,000 volts DC. Repair of the insulation for buried positive cable by any method is prohibited. Above-grade repair connections for anode bed positive cables in splice boxes are acceptable. See Standard Drawing AA-036145 for cable splice box details.

Exception:

Visual inspection is adequate for the galvanic anode cable.

5.4.4 Limit buried main positive cable runs (e.g., between rectifier and anode bed junction box) to 150 meters. Make all splices in above-grade splice boxes. For sections of cable between 150 meters and 300 meters in length, locate the splice box approximately at the midpoint. See Standard Drawing AA-036145 for cable splice box details.

5.4.5 Negative cables and bond cables to be used for buried service need to be only checked visually for obvious insulation defects. Repair cables with visible insulation damage with 3 half-lap layers of plastic vinyl tape over 3 half-lap layers of rubber tape.

5.4.6 Use thermite welds for all negative drain cable and bond connections to steel pipes and structures according to Standard Drawing AB-036381.

5.4.7 Above-grade cables shall be armored or run in covered cable trays or steel conduit. Negative cables attached to above-grade structures may extend out of the conduit for up to 500 mm between the conduit and the structure connection.

5.5 Grounding Conductors

Follow the requirements of SAES-P-111 for grounding conductors installed in areas under the influence of cathodic protection.

5.5.1 Insulate buried bare copper conductors crossing a pipeline or piping for a minimum of 6 meters on each side of the pipeline crossing. The insulation may be PVC conduit, coated cable or other approved method.

5.5.2 Do not use bare copper conductors when running parallel within 3 meters of a buried pipeline or piping.

5.6 Test Stations, Bond Boxes and Junction Boxes

5.6.1 Install test stations, bond boxes, and junction boxes on supports constructed according to Standard Drawing AB-036540. Show all test stations and box locations on the design and construction drawings.

5.6.2 Identify all cables inside test stations, bond boxes, and junction boxes with durable tags according to Standard Drawing AD-036132. Label the cable and the terminals to indicate the structures to which they are connected.

Exception:

Cable identification is not required inside one pin test station.

5.6.3 Install an inside and outside nameplate for all junction and bond boxes indicating the identifying number of the structure and/or the rectifier unit to which they are connected. If specified in the design documents by the proponent organization, a location schematic shall be engraved on the nameplate of the positive and negative junction boxes.

5.6.4 The location of the negative drain junction box for multiple structures should be based on an analysis in the design stage, for the current distribution/balancing requirements of the CP system.

5.6.5 Grounding is not required for CP test stations, bond boxes, or junction boxes.

5.7 Electrical Area Classification

All electrical equipment used in CP installations shall comply with the requirements of the electrical area classification of the location in which it will be installed".

5.8 Concrete Foundations and Footings

Construct concrete foundations, footings and supports according to Saudi Aramco Engineering Standard SAES-Q-001.

5.9 Fencing and Guardrails

5.9.1 Do not locate rectifiers inside electrical substations or other fenced areas that are not normally accessible to cathodic protection operating and maintenance personnel, unless the fencing around the area is modified with a separate entry to allow access to the rectifier.

5.9.2 Install guardrails for unfenced rectifiers and junction boxes for protection against vehicular traffic, as required, per Standard Drawing AA-036378.

6 Commissioning and Inspection

6.1 Commissioning

Achieve cathodic protection within 30 (thirty) days of commissioning of the facility. For new or upgraded CP systems, conduct all pre-commissioning and commissioning in accordance with GI-0002.710 and SAEP-332.

6.2 Inspection

Before the start of construction, the construction agency shall notify Project Inspection and/or the proponent Operations Inspection Unit so that full inspection coverage can be provided during construction and especially during anode installations. The Construction agency shall provide test data sheets to the inspection agency for review at least three days, but not more than one week, prior to the start of construction.

7 Records

The Design agency or Construction agency shall update all Construction Drawings for any field modifications to the original design to show the detailed "as-built" cathodic protection system. The as-built drawings shall accurately illustrate the type and location of cathodic protection equipment & cables including every cathodic protection rectifier, cable, junction box, bond box, negative cable termination, anode, etc. The Design agency or Construction agency shall provide copies of these updated drawings to the cathodic protection proponent department and the Consulting Services Department within sixty (60) days of project completion. Reported corrections (if any) shall be completed and resubmitted within thirty days.

	Revision Summary
28 April, 2004	Major revision.
30 June, 2004	Editorial revision.
31 August, 2004	Minor revision.

Appendix I – Earth Potential Rise Formulas

For a Single Vertical Anode

$$\Delta V_x = \frac{0.5 \times I \times \rho}{\pi \times L}\left[\ln \frac{\sqrt{L^2 + x^2} + L}{x}\right]$$

For a Single Horizontal Anode

$$\Delta V_x = \frac{I \times \rho}{\pi \times L}\left[\ln \frac{\sqrt{(0.5L)^2 + x^2 + h^2} + 0.5L}{\sqrt{x^2 + h^2}}\right]$$

Where:

ΔV_x	=	Earth potential change (volts) at distance "x" from the anode
I	=	Current flow (amperes) from the anode
ρ	=	Soil resistivity (ohm-cm)
L	=	Anode length (cm)
x	=	Horizontal distance (cm) from the anode to a given point on the structure
h	=	Depth of burial (cm) to the centerline of the anode