AS 2832.4—1994

Australian Standard®

Cathodic protection of metals

Part 4: Internal surfaces

This Australian Standard was prepared by Committee MT/14, Corrosion of Metals. It was approved on behalf of the Council of Standards Australia on 24 January 1994 and published on 18 April 1994.

The following interests are represented on Committee MT/14:

- Aluminium Development Council
- Australasian Corrosion Association
- Australasian Institute of Metal Finishing
- Australian Chamber of Commerce and Industry
- Australian Gas Association
- Australian Institute of Steel Construction
- Australian Pipeline Industry Association
- Australian Zinc Development Association
- AUSTROADS
- Bureau of Steel Manufacturers of Australia
- Department of Defence
- Division of Building, Construction and Engineering, CSIRO
- Electricity Supply Association of Australia
- Engineering and Water Supply Department, S.A.
- Heavy Engineering Research Association, New Zealand
- Railways of Australia Committee
- States electrolysis committees
- Telecom Australia

Additional interests participating in preparation of Standard:

- Corrosion consultants
- Gas and Fuel Corporation of Victoria
- Hunter Water Board
- Melbourne Water
- Office of Energy, N.S.W.
- Oil and gas producers
- Petroleum refineries
- State Electricity Commission of Victoria
- State Energy Commission of Western Australia
- Water Authority of Western Australia
- Water Resources Commission, Qld

This Standard was issued in draft form for comment as DR 91223.

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First published as AS 2832.4—1994.

Incorporating:
Amdt 1—1999

PUBLISHED BY STANDARDS AUSTRALIA
(STANDARDS ASSOCIATION OF AUSTRALIA)
1 THE CRESCENT, HOMEBUSH, NSW 2140
ISBN 0 7262 2832 4

PREFACE

This Standard was prepared under the direction of the Multitechnics Standards Policy Board by the Standards Australia Committee on the Corrosion of Metals, at the request of industry, to provide a Standard for guidance in the application and maintenance of cathodic protection to internal surfaces of metal pipes and vessels. It is not intended to be a complete cathodic protection design manual and those requiring further information should refer to the other Standards mentioned, to text books on the subject or to appropriate corrosion prevention specialists.

During the preparation of this Standard cognizance was taken of BS 7361, *Cathodic protection*, Part 1: *Code of practice for land and marine applications*, 1991 and account was taken of the regulations of the various State authorities which differ in their approach to cathodic protection.

This Standard forms one of the AS 2832 series of Standards which cover the cathodic protection of metals. Other Standards in the series are as follows:

AS	
2832	Cathodic protection of metals
2832.1	Part 1: Pipes, cables and ducts
2832.2	Part 2: Compact buried structures
2832.3	Part 3: Fixed immersed structures

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

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FOREWORD

Corrosion of a metal is an electrochemical reaction between the metal and its environment which results in wastage of the metal. Thus corrosion is a combination of chemical effects with an associated flow of electrical energy (corrosion current).

In many practical situations where it is impossible to change the nature of the environment, corrosion may be prevented by employing cathodic protection. This is achieved by applying an appropriate direct current flowing in opposition to the original corrosion current, thus preventing the natural tendency of the metal to react with its environment. In practice, the electrical potential of the metal at risk is used to judge whether adequate protection is being achieved.

To employ cathodic protection, a circuit is established by connecting a suitable source of direct current to the structure to be protected.

Two types of cathodic protection systems are available as follows:

(a) Galvanic anode systems, which employ metallic anodes that sacrifice themselves to provide the source of direct current for protection of the structure.

(b) Impressed current systems, which employ an external electrical power source of direct current for the protection of the structure.

Corrosion control for a structure should be considered at the conceptual design stage. Factors which affect the corrosion of metallic structures are listed in Paragraph A3 of Appendix A. The practices recommended in this Standard relate to steps that need to be taken following a decision to apply cathodic protection to a structure. These steps are as follows:

(i) Decide whether the structure should be coated. If the decision is to coat, then decide which particular coating system should be employed. If the structure is already installed, a determination should then be made of whether the nature and quality of the coating are compatible with cathodic protection.

(ii) Design the structure to be compatible with cathodic protection and to include cathodic protection facilities during construction. If the structure is already installed, determine the measures to be taken to apply cathodic protection effectively, and the facilities necessary for cathodic protection monitoring.

(iii) Design the cathodic protection system. If the structure is already installed, the design parameters may be measured and an optimum design provided. If the structure is not installed, a number of assumptions will be required for the estimation of design parameters.

(iv) Install the cathodic protection system.

(v) Commission the cathodic protection system after achieving a balance of cathodic protection current to enable the entire structure to be protected with minimum current, and with as uniform a potential over its surface as is practicable.

(vi) Monitor cathodic protection at regular intervals, adjusting the conditions of operation as necessary, and maintain complete records of its operation.

STANDARDS AUSTRALIA

Australian Standard

Cathodic protection of metals

Part 4: Internal surfaces

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard provides guidelines for the cathodic protection of internal surfaces of pipes and structures including heat exchangers, hot water systems, clarifiers, ballast and water storage tanks, cooling conduits and reservoirs, that are in contact with natural waters including seawater and waters of near neutral pH.

The Standard specifically covers the following subjects which relate to cathodic protection:

(a) The design of structures requiring cathodic protection.

(b) Coatings for use on internal surfaces.

(c) Criteria for the choice of cathodic protection potential.

(d) The design of cathodic protection systems.

(e) The installation of cathodic protection systems.

(f) The operation and maintenance of cathodic protection systems.

NOTES:

1 Guidance on the general use and design of cathodic protection systems and factors affecting the corrosion of internal surfaces are given in Appendix A.

2 This Standard employs conventional (positive) current flow, for consistency with accepted practice, and uses the potential sign conventions specified in AS 1852. In order to understand the various electrochemical reactions which occur at electrodes during cathodic protection, it should be recognized that electron flow occurs in the opposite direction to conventional currect flow.

1.2 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

STANDARDS

AS	
1056	Storage water heaters
1627	Metal finishing—Preparation and pretreatment of surfaces
1627.4	Part 4: Abrasive blast cleaning
1768	Lightning protection
1852	International Electrotechnical Vocabulary
2052	Metallic conduits and fittings
2053	Non-metallic conduits and fittings
2239	Galvanic (sacrificial) anodes for cathodic protection
2430	Classification of hazardous areas
3000	SAA Wiring Rules
3859	Guide to the effects of current passing through the human body

APPROVAL AND TEST SPECIFICATIONS

AS	
3100	General requirements for electrical equipment
3108	Particular requirements for isolating transformers and safety isolating transformers
3147	Electric cables—Thermoplastic insulated—For working voltages up to and including 0.6/1 kV

1.3 DEFINITIONS For the purpose of this Standard, the definitions below apply.

1.3.1 Anaerobic—lacking free oxygen.

1.3.2 Anode (in general)—an electrode placed in the electrolyte to apply cathodic protection to the structure.

1.3.3 Anode screen—a safety barrier surrounding a submerged anode for the prevention of electrical shock or shorting.

1.3.4 Anode shield—a protective covering of insulating material applied to a coated structure in the immediate vicinity of an anode to reduce local cathodic current density.

1.3.5 Back e.m.f.—an instantaneous open-circuit opposing voltage between an anode and cathode of an operating cathodic protection system.

NOTE: Back e.m.f. may have other definitions in other technologies.

1.3.6 Bond (electrical)—a metal connection between points on the same structure or on different structures.

1.3.7 Bond (coating)—adhesion between the coating materials and the substrate.

1.3.8 Cathode—the structure that is to be protected by cathodic protection.

1.3.9 Cathodic disbonding—detachment of a coating due to the effects of cathodic polarization.

1.3.10 Cathodic protection—the prevention or reduction of corrosion of metal by making the metal the cathode in a galvanic or electrolytic cell.

1.3.11 Copper/copper sulfate reference electrode ($Cu/CuSO_4$)—a reference electrode consisting of copper in a saturated solution of copper sulfate.

1.3.12 Corrosion—the deterioration of metal caused by its electrochemical reaction with its environment.

1.3.13 Corrosion cell anode—the electrode at which metal dissolution (corrosion) takes place.

1.3.14 Corrosion current—the current flowing in a corrosion cell, electrochemically equivalent to the anode and cathode reactions.

1.3.15 Current density (at anode)—current output of anode divided by anode surface area.

1.3.16 Current density (at cathode)—current flowing into cathode divided by the cathode surface area.

1.3.17 Current density (at coated cathode)—total current flow into cathode divided by the total surface area of the structure.

1.3.18 Earth (noun)—the conducting mass of the general body of the earth.

1.3.19 Earth (verb)—the act of connecting any conductor to earth.

1.3.20 Electrode—an electronic conductor that allows current to flow either to or from an electrolyte with which it is in contact.

1.3.21 Electrode potential—the measured potential of an electrode in an electrolyte relative to the potential of a reference electrode.

1.3.22 Electrolyte—a liquid, or the liquid component in a composite material such as soil, in which electric current may flow by the movement of ions.

1.3.23 Foreign (secondary) structure—a buried or submerged structure that may be subject to interference arising from the cathodic protection of a primary structure.

1.3.24 Galvanic action—a spontaneous electrochemical cell reaction in which a metallic anode in a dissimilar metal couple corrodes.

1.3.25 Galvanic anode—an electrode used to protect a structure by galvanic action.

1.3.26 Half-cell—(*see* reference electrode)

1.3.27 Impressed current—direct current supplied by an external power source to cathodically protect a structure.

1.3.28 Impressed current anode—the electrode connected to the positive terminal of an impressed current power supply.

1.3.29 Insulating joint—a joint which breaks electrical continuity in a structure, but does not affect the mechanical integrity.

1.3.30 Interference—a significant change in current density on a foreign structure caused by a cathodic protection system; it may be detected by a resultant potential change on the structure.

1.3.31 Interrupter—a timing device which permits a cyclic on/off interruption to the flow of cathodic protection current.

1.3.32 Loop resistance—the total external circuit resistance at the output terminals of the cathodic protection impressed current rectifier.

1.3.33 Polarization—a change in the potential of a corroding metal from its natural steady state value (the corrosion potential), as a result of current flow.

1.3.34 Polarization cell—an electrochemical device which, at potential levels typical of cathodically-protected structures, has low impedance to alternating current but high impedance to direct current.

1.3.35 Primary structure—the structure which is subject to intentional cathodic protection.

1.3.36 Protective potential—the potential to which a metallic structure is reduced to achieve cathodic protection.

1.3.37 Protective current—the current made to flow into a metallic structure from its electrolytic environment, and which cathodically protects the structure.

1.3.38 Reference electrode—an electrode which has a stable potential in one or more electrolytes at a given temperature, thus enabling it to be used for the measurement of other electrode potentials.

1.3.39 Silver/silver chloride reference electrode (Ag/AgCl)—an electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions.

1.3.40 Stray current—current flowing through paths other than the intended circuit.

1.3.41 Structure—a metal surface in contact with an electrolyte.

1.3.42 Structure potential—the potential of a structure relative to that of a specified reference electrode situated in the electrolyte immediately adjacent to the structure.

1.3.43 Structure potential shift—a change in measured voltage of a metallic structure caused by the application of current from an external source.

1.3.44 Sulfate-reducing bacteria—a type of bacteria which is capable of reducing sulfate to sulfide in anaerobic, near-neutral soils and natural waters.

1.3.45 Test point—a nominated point on a structure for electrical contact.

SECTION 2 DESIGN OF STRUCTURES FOR CATHODIC PROTECTION

2.1 GENERAL This Section provides guidance for the design of structures to accommodate the application of internal cathodic protection.

Because some aspects of the design and construction of the structures can interfere with the corrosion prevention process, cathodic protection should become an integral part of the design stage. This will tend to minimize unnecessary and possibly costly modifications, and help to ensure the safe operation of the structure and maximize its economic life.

The design of the internal surfaces to be protected should be as open as possible, avoiding semi-enclosed compartments, deep recesses and shielded areas which may give rise to localized underprotection.

NOTE: Cathodic protection systems designed to provide protection to internal surfaces do not provide any protection to external surfaces. When protection to both internal and external surfaces is required, it is necessary to have two separate cathodic protection systems.

2.2 STRUCTURE COATING Cathodic protection may be applied to bare or coated surfaces. The following factors should be considered when determining whether the surface should be coated or remain bare:

(a) The magnitude of the current required to achieve protection is considerably less for coated surfaces. When surfaces are coated the cathodic protection installation may be smaller and less complex than that which would be required to protect uncoated surfaces. Longer life will result from a similarly designed sacrificial cathodic protection system used to protect coated surfaces.

(b) Uniformity of current distribution to an uncoated structure may be difficult to achieve, particularly if the structure contains deep recesses or shielded areas. Coating the structure may result in more uniform protective potentials.

(c) The protective current will penetrate further into recesses and corners when the water resistivity is low. If recesses are present and the water has high resistivity, coating is strongly recommended.

(d) The ability to apply and maintain the coating.

(e) Areas not continuously immersed in water may receive only partial protection from a cathodic protection system. The degree of protection depends on many factors including water composition, the relative immersed and non-immersed periods, the tendency of the surface to dry out during non-immersed periods and the protective potential when immersed. Typical examples of variable immersion occur in ship ballast tanks and water supply storage tanks. Coatings should be applied in these areas if maximum protection is required.

2.3 INTERFERENCE WITH FOREIGN STRUCTURES Systems installed for the cathodic protection of internal surfaces only do not cause stray current external to the protected structure. Therefore interference with foreign external structures is not a problem and special design considerations to mitigate interference are not necessary. For this reason, regulatory authorities do not generally require formal approval and registration of these internal cathodic protection systems.

2.4 ISOLATION OF STRUCTURES IN CONTACT WITH THE INTERNAL ELECTROLYTE In most cases all of the immersed metallic areas in contact with the internal electrolyte will require protection, and metallic isolation from other structures, or other portions of the structure in contact with the common internal electrolyte, will not be required. In some cases, however, isolation may be desirable or necessary, e.g. a stainless steel ladder or the presence of a major area of non-ferrous metal in the common electrolyte will significantly increase the protective current requirement, if not isolated.

NOTE: As interference corrosion is possible on electrically isolated components, consideration should be given to the means for its mitigation.

Metallic isolation may be achieved by the use of flange insulating assemblies, couplings, monolithic joints or custom-designed insulation.

2.5 METALLIC CONTINUITY It is important that all surfaces requiring protection are in reliable low resistance metallic contact. Slipring bonding facilities or similar are necessary if protection is to be applied to rotating components such as pump impellers or rotating arm clarifiers, except where galvanic anodes are directly connected to the rotating component.

2.6 FITTINGS TO SUPPORT ANODES AND MONITORING EQUIPMENT Provision should be made at the time of structure design for anode support fittings. These may comprise brackets, through-the-wall sockets or flanges, or other custom-designed components. Consideration should also be given to providing access for anode inspection and replacement.

Potential monitoring facilities are also desirable. For structures where the interior is not readily accessible, facilities should be provided for the placement of a portable or a permanent reference electrode and may comprise reference electrode access ports. They may include the provision of cable support fittings and suitable hardware.

2.7 VENTING With impressed current systems, chlorine or oxygen is generated at the anode. These gases may be wholly dissolved in the water, but in extreme cases may also form gas bubbles or enter a vapour space above the water. With galvanic or impressed current systems insoluble hydrogen gas may be generated at the structure surface. Depending on the structure geometry, the provision of venting for these gases may need to be considered.

SECTION 3 COATINGS FOR USE WITH CATHODIC PROTECTION

3.1 GENERAL This Section provides guidance on the use of coatings on the internal surfaces of structures which are to be cathodically protected.

Coatings assist in the corrosion control of structures in several ways, as follows:

(a) They inhibit corrosion by providing an adherent film with a high resistance to ionic transport.

(b) They reduce the current requirements for cathodic protection by providing an electrically insulating film.

(c) Their use can be extended to provide corrosion protection to non-immersed parts of the structure.

(d) They can extend the effective coverage from a given anode.

Although high costs are involved with the initial coating procedure, the application of coatings will lead to a considerable reduction in cathodic protection power consumption.

Coatings are considered to be an integral part of any cathodic protection system. In most situations, coatings provide the primary corrosion protection system, with cathodic protection providing back-up corrosion protection of the structure at points where failure of the coating, or damage to the coating, has occurred.

Economic decisions on whether to use coatings with cathodic protection should be taken on the following grounds:

(i) The anticipated life of the structure.

(ii) The maintenance costs of both cathodic protection and coating over the life of the structure, in present value dollars.

(iii) The method of operation of the internal surface. For example, a tank with a constantly fluctuating water level and subjected to turbulent flow conditions will be less easily protected with cathodic protection than a constantly immersed, non-turbulent surface.

The practicality of recoating an internal surface during the life of a structure will be dependent on its accessibility.

3.2 COATING PROPERTIES

3.2.1 General The prime function of a coating is to provide an electrically-insulating barrier between the structure and its environment.

Coatings on internal surfaces are fully immersed in a liquid environment for all or part of their life. Because internal surfaces often are not very accessible, the application and curing properties of a coating and the practicality of coating repair are important factors.

Desirable features of coatings for internal immersed surfaces are as follows:

(a) Resistance to chemical degradation.

(b) Resistance to deterioration at the operating temperature of the structure.

(c) High electrical resistance and dielectric strength under continuous service.

(d) Resistance to the permeation of water.

(e) Compatibility with the level of cathodic protection required (resistance to cathodic disbondment).

(f) Long-term adhesion to the structure.

(g) Resistance to attack by marine or freshwater organisms.

(h) Sufficient strength to resist service conditions including changes in environment caused by fluctuating fluid levels and temperatures.

(i) Mechanical strength and resistance to pinholing, cracking and spalling.

(j) Ability to be repaired in the field.

(k) Resistance to degradation by ultraviolet light for the period of exposure during transport, storage and installation.

(l) Resistance to mechanical damage and abrasion from handling, installation, and service conditions, e.g. the cleaning of a reservoir.

(m) Where applicable, suitability for use with potable water.

Table 3.1 gives typical properties for coatings commonly used on internal surfaces.

3.2.2 Application and curing properties The degree of surface preparation required for an acceptable coating is important. It is good practice to blast clean surfaces prior to coating application (see AS 1627.4), however this may not be possible on certain interior surfaces, and a more surface tolerant coating will be required. This restriction may also be important in the choice of repair materials.

NOTE: For immersed conditions, the general performance of any coating applied without proper surface preparation is likely to be markedly inferior to that of a coating applied after the correct treatment.

The application and curing mechanisms of the coating should be considered both in terms of obtaining an even thickness over all areas, and safety, particularly if the coating releases solvent.

It is important to allow sufficient time for the coating to fully cure before the structure is placed into service.

3.2.3 Chemical properties The coating is required to be resistant to chemical degradation by the liquid in which it is immersed taking into account the chemical concentration range expected in service. Sufficient alkali resistance is required to withstand alkaline cathodic reaction products.

The coating must not contaminate the surrounding liquid; this is particularly important in the case of potable water. It should be resistant to entomological, bacterial, and fungal attack.

3.2.4 Physical properties The coating is required to be compatible with cathodic protection and needs to have a high dielectric strength to resist the applied potential. The coating adhesion is of prime importance to prevent the occurrence of delaminations and blistering. The coating thickness affects the electrical resistance, vapour and ionic transfer rates and should be as thick as is practicable.

The coating should be stable at the service temperature, and at any expected temperature variations.

The coating should have adequate mechanical strength, particularly when cyclic wet and dry conditions may cause cracking and spalling. Good abrasion resistance may be an important property in turbulent conditions.

3.3 COATING CHOICE The choice of a generic coating type for a particular application is necessarily a compromise between the physical and chemical properties (see Table 3.1), and other factors including availability and economic considerations. In some applications, the choice of coating type is dictated by normal industry practice, and relevant Standards (e.g. AS 1056 recommends the use of vitreous enamel in cathodically-protected domestic hot water storage tanks). For potable water applications, only materials which have been specifically tested and approved by a relevant authority should be used, e.g. coal tar epoxy is no longer used for potable water service due to concerns about contamination of the water with undesirable chemical components.

When a choice of coating has been made, the test requirements of the relevant product Standard should be utilized to ensure that the proprietary product chosen is of acceptable quality. Correct application techniques and requirements for appropriate field testing of the coated structures are normally specified in the product Standard.

TABLE 3.1

TYPICAL PROPERTIES OF COATING SYSTEMS USED ON INTERNAL SURFACES WITH CATHODIC PROTECTION

Coating system	Dry film thickness mm	Ability to resist					Compatibility with cathodic protection	Suitability for potable water	Max. working temperature °C
		Mechanical damage	Bacteria and fungi	Alkaline conditions	UV light*	Water permeation†			
Coal tar epoxy	0.3–0.6	Medium	High	Medium	Unsuitable‡	High	Medium	Unsuitable	50
Chlorinated rubber	0.2–0.4	Medium	Medium	Medium	Medium	High	Low	Medium	40
Epoxy	0.3–3.0	Medium	Medium	High	Unsuitable‡	High	Medium	Medium	50−100
Polyester	0.75–4.0	Medium	Medium	Low	Medium	High	Low/ medium	High	40
Vinyl ester	1.5–4.0	Medium	Medium	Medium	High	High	Low	High	40
Vinyl/VR3	0.15–0.25	Medium	Medium	Low/ medium	High	High	Low/ medium	High	40
Vitreous enamel	0.15–0.8	Low	High	High	High	High	High	High	95

* Applies to roofless tanks.

† Care should be taken when selecting a coating system which will be exposed to hot water.

‡ Chalking results.

SECTION 4 CRITERIA FOR CATHODIC PROTECTION

4.1 GENERAL Many metals are protected from corrosion by the application of direct current which maintains the potential sufficiently negative with respect to its environment to prevent corrosion. Direct current is provided by the use of galvanic anodes, or by means of an impressed current system. The potential of a structure with respect to its environment can give a reliable indication of the degree of protection being provided.

The potential criteria to provide protection are given in Clauses 4.2 and 4.3, however other potential criteria may be used, provided that their efficacy has been established.

NOTE: It is important that sufficient tests be carried out to ensure that the entire structure conforms with the appropriate potential criterion.

This Standard recommends the use of copper/copper sulfate reference electrodes for measuring potentials.

Reference electrodes such as silver/silver chloride, calomel, lead/lead chloride, metallic zinc, lead or steel, may be used as alternatives to copper/copper sulfate provided their relativity to this reference electrode in the environment has been established.

NOTES:

1 Where a silver/silver chloride reference electrode is of the type which has the central billet directly exposed to the electrolyte in which it is immersed, rather than being encapsulated in a chloride ion-rich electrolyte, the protection criteria will vary with the change in concentration of chloride ions present, requiring appropriate correction to the measured value. This type of silver/silver chloride reference electrode is used mainly in seawater where the chloride ion concentration is substantially constant.

2 Copper/copper sulfate reference electrodes should not be used in waters containing a high level of chloride as chloride diffusion into the electrode will affect its potential.

3 Electrolyte movement affects both oxygen access and also physical erosion of the corrosion film. With some metal/environment conditions, an increase in temperature may increase the corrosion activity, however this may reduce the oxygen availability. The interpretation of corrosion conditions requires significant expertise and is required prior to the application of cathodic protection.

4 A comparison of the structure/electrolyte potentials obtained using various reference electrodes is given in Appendix B.

4.2 POTENTIAL CRITERIA FOR FERROUS VESSELS The accepted practices for the protection of internal surfaces of ferrous vessels, including vessels with fittings which are cathodic to steel, e.g. brass, copper and bronze fittings, are as follows:

(a) *For oxygenated conditions at 25°C* The potential at all surfaces should be equal to, or more negative than, −850 mV with respect to a copper/copper sulfate reference electrode.

(b) *Where anaerobic bacteria are present at 25°C* The potential at all surfaces should be equal to, or more negative than, −950 mV with respect to a copper/copper sulfate reference electrode.

(c) *For other conditions* For environmental conditions which include low pH, elevated temperatures, aggressive chemicals, or a combination of these, the potential criteria may vary widely and need to be individually established for the system under consideration. Caution is also required as the potential of the reference electrode may vary due to the effects of these conditions.

4.3 POTENTIAL CRITERIA FOR MIXED METALLIC STRUCTURES The accepted practice for the protection of the internal surfaces of mixed metallic structures is to maintain a negative (cathodic) voltage, at least equal to that required for the most anodic metal, between all structure surfaces and the reference electrode.

4.4 OVERPROTECTION If potentials are excessively negative, coating disbondment or, in the case of high strength steels, hydrogen embrittlement may occur. The level of potential a structure can tolerate is dependent on the coating type, the structural material and the environment.

SECTION 5 DESIGN OF CATHODIC PROTECTION SYSTEMS

5.1 GENERAL This Section includes guidelines for the design of cathodic protection systems for internal surfaces.

The design of a cathodic protection system should use the criteria given in Section 4 with the aim of generating uniform potentials over the entire internal surface. In practice, satisfactory protection can often be achieved with wide variations of potential.

NOTE: In general, State regulations are not applicable to the cathodic protection of internal surfaces.

The relevant requirements of AS 2239, AS 3000, AS 3100, AS 3108 and AS 3147, are applicable for conductor current ratings and the protection of circuits and transformers.

5.2 SAFETY PRECAUTIONS For personnel safety, the open-circuit voltage of a cathodic protection power supply should not exceed 50 V d.c. Consideration should be given to the following electrical hazards:

(a) The effects of lightning, both on the protected structure and via the electricity distribution system (personnel protection aspects are specifically covered in AS 1768).

(b) Electrical gradients resulting from impressed current systems occurring in water around fully and partially submerged anodes and in waterways adjacent to anode installations.

NOTE: Paralysis and respiratory failure may result if a person comes in contact with electric field strengths greater than 3 V/m in water (see AS 3859). Should the design result in a possible electric field strength exceeding this value in waters located close to impressed current anodes, warnings should be given and access to such areas prevented by shielding or by other means.

5.3 CHOICE OF SYSTEM—IMPRESSED CURRENT OR GALVANIC ANODES The decision on the type of cathodic protection system to be installed requires careful consideration. Parameters which may affect the decision include the following:

(a) *Coating effectiveness* The more effective the protective coating, the lower will be the cathodic protection current requirements. Low cathodic protection current requirements favour the use of galvanic anodes. For long life structures where the coating cannot be maintained, the effects of coating breakdown should be considered.

(b) *Economic considerations* It is generally more economical to protect a large structure by impressed current. However, specific civil engineering requirements, maintenance problems, or operational needs may override primary cathodic protection economics in favour of specially-designed high-capacity galvanic systems.

(c) *Electrolyte resistivity* Galvanic anodes have a fixed, low, driving voltage with respect to the protected metal and, in high resistivity electrolytes, cannot produce sufficient current output. The use of an impressed current system may be more economical for such electrolytes.

Galvanic anodes are infrequently used in electrolytes where the resistivity is in excess of 75 Ω.m unless the components are effectively coated.

(d) *Control* An impressed current system has the advantage of increased flexibility of location and ease of control. With such a system, anodes can be more remotely located allowing problems arising from coating defects and submerged short-circuits to be more readily traced. In contrast, a galvanic anode system requires less frequent monitoring, and is self-regulating.

5.4 CABLES

5.4.1 General All cables should comply with the requirements of AS 3147. Where additional protection from mechanical damage is required, cables may be located in conduit complying with AS 2052 or AS 2053, or be in the form of armoured cabling. Specific environments may dictate the use of alternative cable materials.

Cable insulation should be resistant to attack by rodents and insects and, in marine or immersed installations, attack by marine or other bacteriological organisms.

All cable terminations and joints should be designed to be of brazed, crimped, bolted, welded or soldered construction.

Joints in cables should be kept to a minimum. Because long-term electrical integrity is necessary, all immersed cable joints are required to be totally waterproofed to prevent the ingress of moisture. This is mandatory for joints in impressed current anode cables.

5.4.2 Anode, cathode and test cables The types of insulated cables used for cathodic protection systems include the following:

(a) Impressed current anode cables to carry d.c. positive supply.

(b) Primary structure (cathode) cables to carry d.c. negative supply.

(c) Cables to galvanic anodes.

(d) Test cables connected as follows—

  (i) to the structure; and

  (ii) to reference electrodes.

NOTE: Cables colour-coded with green and green/yellow combinations are to be used exclusively for safety earthing applications in impressed current cathodic protection systems.

5.4.3 Test cables

5.4.3.1 *Construction* Test cables should be of stranded construction, be manufactured from copper, comply with the requirements of AS 3147, and have a minimum conductor cross-sectional area of 1.5 mm^2.

Test cables subject to mechanical damage should be protected by enclosure in conduit or ducting, or by some other suitable means.

5.4.3.2 *Insulation colours* Colours for test cable insulation on any one installation should be permanently identified and should preferably comply with a uniform colour code. Where this is not specified, it is recommended that insulation colours be as follows:

(a)	To primary structure:	black
(b)	To reference electrode:	white
(c)	For other uses:	blue

5.4.4 Impressed current anode cables

5.4.4.1 *Construction* Impressed current anode cables should be suitably protected, where necessary, against mechanical damage because failure of the cable insulation may lead to:

(a) Electrical shorting of the anode to the structure.

(b) Failure of the cable due to accelerated corrosion in immersed conditions.

Additional protection may be achieved by the use of double insulation or by placing the anode cable in conduits or ducts.

Because anode cables may be subject to attack from a high chlorine environment found near some anodes, it is important that the cable insulation and sheathing be resistant to such an environment, or otherwise be suitably oversheathed or protected.

Commonly used insulants are:

(i) PVC (insulant or sheathing) with dimensions in accordance with AS 3147, but unfilled and containing a minimum of colourant and plasticizer.

NOTE: Sheathing material conforming to AS 3147 contains filler and is unsuitable.

(ii) Polyethylene cable insulation not less than 1.5 mm thick; this should have an outer sheathing of a black, ultraviolet-resistant grade of polyethylene.

5.4.4.2 *Cable identification* It is important that anode cables have a different colour, preferably with red insulation, or constructional appearance to that of cathode cables, and that all cables in a system can be identified by differences of construction, insulation, sheathing, or permanent marking.

5.4.5 Galvanic anode cables Cables are supplied with galvanic anodes in accordance with the requirements of AS 2239.

5.5 CHECK LIST FOR INITIAL SURVEYS The following check list is applicable to new and existing structures, and sets out items of information needed for the design of a cathodic protection system, before initial surveys and tests are carried out:

(a) Complete layout plans and specifications of structure and materials of construction which also show the location and position of test points and full details of any insulating joints or sections that may require bonding, or special consideration.

(b) Details of the liquid in contact with the internal surface.

(c) Details and location of any previously-installed cathodic protection systems on the structure, including details of test points and the position of anodes.

(d) Full technical details of the type and quality of coatings used on the immersed surface, and of the results of any tests carried out to assess their integrity.

(e) Ability of the owner of the structure to maintain the cathodic protection system, especially where it is intended to use civil, electrical or mechanical staff to operate the system.

(f) Nature and location of any existing or proposed electrical earthing, electrical surge control, and potential equalization.

(g) Any known hazardous areas, as defined in AS 2430.

(h) Availability of electricity supply.

5.6 DETERMINATION OF CATHODIC PROTECTION CURRENT REQUIREMENTS

5.6.1 General The current capacity of an installed cathodic protection system is dependent on the achievement and maintenance of the appropriate criteria for protection for all discrete modules of the structure, as described in Section 4. In complex structures, the effects of bonding on operational safety, telemetry and incidental corrosion control may require careful consideration.

To minimize interference effects, overprotection should be avoided (see Clause 4.4).

5.6.2 Basic procedures The following steps should be followed in the design of any cathodic protection system:

(a) Determine the exposed immersed surface area requiring cathodic protection (see Clause 5.6.3).

(b) Select the required current density to be applied to achieve the nominated cathodic protection potentials specified in Section 4 (see also Clause 5.6.4).

(c) From the two values determined in Items (a) and (b), calculate the current capacity requirement of the installed cathodic protection system (see Clause 5.6.5).

(d) For a distributed anode system, calculate the current output of one anode (impressed current or sacrificial), and determine the total number of anodes required to supply the calculated current (see Clause 5.6.6).

(e) For a galvanic anode system, calculate the galvanic anode mass requirements (see Clause 5.6.7).

(f) Complete the detailed engineering design of the system.

5.6.3 Determination of immersed surface area The total exposed surface area of the structure is calculated from structural drawings and should take into account all additional immersed metallic appurtenances in electrical contact with the structure, since these will also draw current from the designed system. Examples of appurtenances are ladders and pipe inlets. For structures where the immersed surface area may vary, e.g. high level potable water tanks, the total area should be taken as the maximum area that can be immersed.

At the completion of the calculation, the surface area should be increased by an appropriate factor to account for items including missed areas, surface roughness, weld beads and clamps, and for minor design changes affecting new structures. This factor may be of the order of 10%.

5.6.4 Determination of current density requirements The current required for cathodic protection is related to the following environmental factors:

(a) The temperature of the electrolyte.

(b) The oxygen availability at the structure surface.

(c) The oxygen and moisture permeability of the coating.

(d) The effective area of exposed bare structure metal.

(e) The velocity of the electrolyte.

(f) The resistivity of the electrolyte.

Based on experience, the above factors should be considered when estimating the current density required to give protection. For bare surfaces, particularly those immersed in seawater and other relatively high conductivity electrolytes, there is no single average current density figure that can be assumed, as the current density required for the maintenance of protection changes with time, with a greater current being required to achieve protection than is necessary to maintain it. This is partly due to the potential change that occurs at the cathode, and partly to the effect of chemical compounds precipitated at the cathode. If the electrolyte has a tendency to support biological activity, e.g. sulfate-reducing bacteria, such activity may affect the current density requirement.

In very high conductivity environments, the following current densities should be estimated:

(i) The initial current density required to achieve polarization.

(ii) The average current density over the life of the structure.

(iii) The final peak current density at the end of the design life of the structure taking into account periodic variations.

For existing structures, the current densities required to achieve protection can be established by a field test or, where this is not possible, by estimation. Typical current densities (CDs) used in designs for bare steel at ambient temperature are given in Table 5.1.

The current density required to protect exposed metal which has resulted from breakdown of a coating may be estimated using Equation 5.6(1).

$$CD_{\text{coated}} = CD_{\text{bare metal}} \times \text{\% of surface effectively bare} \qquad \ldots\ 5.6(1)$$

TABLE 5.1

TYPICAL CURRENT DENSITY REQUIREMENTS FOR THE PROTECTION OF BARE STEEL IMMERSED IN VARIOUS TYPES OF WATER

Water type	Resistivity Ω.m	Initial CD mA/m^2	Average CD mA/m^2	Final peak CD mA/m^2
Fresh water (potable)	>20	50	50	50
Brackish water and sewage	0.5−20	50−100	20−100	20−100
Seawater	<0.5	120	60−90	60−90

NOTE: These values may need to be varied by an order of magnitude or more depending on temperature and turbulence.

The amount of coating breakdown that will occur is related to the type of coating, the service conditions and the length of time in service. It is probable that no better than a 99% perfect coating is achievable on a new structure. In general, the thicker the coating, the lower the amount of breakdown that will occur within a given period. Values for coating breakdown with time are best estimated for the particular environment in which the structure is to be placed.

NOTE: Some steel structures including potable water reservoirs are manufactured with a lining of cement-mortar on the floor. Such floors behave in a similar manner to bare steel and in order to lower the current density requirements to a practical level, it may be necessary to provide an organic barrier coating over the cement.

5.6.5 Calculation of the current capacity The current capacity for a cathodic protection system is the product of the calculated surface area and the required current density.

Where a structure is coated, an estimate of likely coating deterioration (as a percentage) for the required structure life is made and the corresponding system current determined by multiplying the end-of-life current density by the structure surface area.

5.6.6 Anode layout design Anodes for protecting internal surfaces are normally installed singly and distributed within the electrolyte, according to the geometry of the internal surface to be protected.

Anodes should be immersed in the electrolyte in a manner which ensures that the potentials are maintained as evenly as possible over the internal surfaces to be protected. The distribution and number of anodes are dependent on the structure dimensions and the total current density requirements.

The separation of each anode from the structure should be sufficient to ensure that potentials at the adjacent structure surface do not become excessive. For the calculation of the appropriate anode-to-structure separation, see Clause 5.7.2.

For the design of a distributed anode system, it is necessary to calculate the resistance of each anode to the electrolyte, and thus determine the amount of current that can be provided.

The resistance of the anode to the electrolyte is determined from the electrolyte resistivity and the anode dimensions, using a suitable equation. For example, for a long slender anode immersed to a depth at least equal to the anode length, the following equation applies (modified Dwight equation):

$$R = \frac{\rho}{2\pi L}\left(\ln\frac{8L}{d} - 1\right) \qquad \ldots 5.6(2)$$

where

R = resistance of anode to electrolyte, in ohms

ρ = electrolyte resistivity, in ohm metres

L = anode length, in metres

d = anode equivalent diameter, in metres

$$= \sqrt{\frac{4ab}{\pi}}$$

and where

a = mean anode width, in metres

b = mean anode breadth, in metres

For a slab anode:

$$R = \frac{\rho}{2(a + b)} \qquad \text{. . . 5.6(3)}$$

At the end of the anode life, the anode dimensions will have decreased; this particularly applies to sacrificial anodes. To ensure that adequate output is available at the end of anode life, it may be necessary to base the calculation of the anode output current on the reduced anode dimensions. For sacrificial anodes it is common to allow for 90% radial consumption and 10% longitudinal consumption of the active material.

Anode output current can then be determined using the following equation:

$$I = E/R \qquad \text{. . . 5.6(4)}$$

where

I = output current, in amperes

E = anode driving voltage, in volts

R = resistance of anode to electrolyte, as calculated using Equation 5.6(3), in ohms

For impressed current systems, the anode driving voltage (E_{ic}) is equal to the maximum operating voltage of the transformer/rectifier (E_{tr}), minus the voltage drop in the cables due to the passage of the current (E_{cable}), minus a back electromotive force of approximately 2 V between the polarized anode and the cathode, i.e.

$$E_{\mathrm{ic}} = E_{\mathrm{tr}} - E_{\mathrm{cable}} - 2 \qquad \text{. . . 5.6(5)}$$

For galvanic anodes, the driving voltage (E_{ga}) is equal to the anode open circuit potential (E_{a}), minus the polarized structure potential (E_{s}), i.e.

$$E_{\mathrm{ga}} = E_{\mathrm{a}} - E_{\mathrm{s}} \qquad \text{. . . 5.6(6)}$$

Typical open-circuit potentials of galvanic sacrificial anodes are given in Table 5.2.

5.6.7 Galvanic anode mass requirement The mass of anode material required to provide protection current for a given period of time can be calculated using the following equation:

$$m = \frac{ZIt}{Du} \qquad \text{. . . 5.6(7)}$$

where

m = mass of anode, in kilograms

Z = theoretical anode consumption rate, in kilograms per ampere year (see Note 1)

I = anode output current, in amperes

t = time, in years

D = anode current efficiency (see Note 2)

u = anode utilization factor (see Note 3)

NOTES:

1 Theoretical anode consumption rates, in kg/A.year, are as follows:

(a) Magnesium: 4.0.
(b) Zinc: 10.7.
(c) Aluminium: 3.0.

2 The anode current efficiency is the useful charge in ampere hours, which may be obtained from the metal in practice, compared with the theoretical value of the charge.

The anode current efficiency is dependent on factors such as anode alloy composition, output current density and electrolyte chemistry.

Typical anode current efficiency values are as follows:

(a) Magnesium: 0.2 to 0.5
The anode current efficiency value for magnesium is typically 0.5 when the anode is operating at its maximum output as limited by its resistance to ground. The efficiency may be considerably lower if the output is reduced to below this level owing to resistance or polarization of the cathode.
(b) Zinc: 0.85 to 0.95
(c) Aluminium: 0.8 to 0.9

3 The utilization factor is applied to take account of material which is not consumed at the end of the useful life of the anode. Typical values range between 0.8 and 0.9.

The average polarized current density requirement (see Table 5.1) should be used to calculate the anode mass, which should then be compared with the anode numbers calculated for the initial and final current outputs, as detailed above. The largest calculated value should be selected.

TABLE 5.2
TYPICAL PROPERTIES OF GALVANIC ANODES

Anode type	Open circuit potential, V	Typical anode consumption rate in seawater
	Reference electrode Cu/$CuSO_4$	kg/A.year
Aluminium	−1.10 to −1.20	3.5
Zinc	−1.1	12
Magnesium:		
(a) high potential	−1.7	7
(b) low potential	−1.5	7

5.7 ANODE ARRANGEMENTS

5.7.1 General Anodes should be placed where they will achieve the desired spread of protection for all the immersed surfaces of the primary structure. The placement of anodes will depend upon a number of factors including the following:

(a) Site accessibility and availability.

(b) The electrolyte resistivity.

(c) The structure layout and location.

(d) The extent of structure coating.

(e) The geometric layout of the structure.

(f) The need to avoid excessive potential variations in the structure by maintaining appropriate anode separation.

(g) Whether any parts of the structure require a higher current density (e.g. the presence of more electropositive metals).

5.7.2 Calculation of appropriate anode to structure separation Anodes should be located at appropriate positions to ensure that potentials at adjacent primary structure surfaces do not become excessive.

In a homogeneous electrolyte, the relationship between potential and distance of an operating anode to the primary structure, is given by the following equation:

$$d = \frac{I\rho}{2\pi V} \qquad \ldots 5.7(1)$$

where

d = distance from anode to primary structure, in metres
I = current output of anode, in amperes
ρ = electrolyte resistivity, in ohm metres
V = potential at a distance d metres from the anode, relative to remote earth, in volts

NOTE: This equation will give only approximate results when the electric field is distorted by the physical shape of the primary structure or when the electrolyte is inhomogeneous.

The minimum desirable separation of an anode from a structure can be calculated from this equation by substituting a maximum allowable value for V. The value of V should not exceed 1.0 V at the primary structure.

In some situations the anodes are required to be placed deliberately close to the primary structure to provide very localized protection.

EXAMPLE: Where the anode current is 10 A and the electrolyte resistivity is 0.25 Ω.m, the minimum spacing from the anode to the primary structure (for a maximum potential of 1 V) is calculated as follows:

$$d = \frac{10 \times 0.25}{2 \times \pi \times 1} \approx 400 \text{ mm}$$

5.7.3 Positioning of anodes

5.7.3.1 *Positioning of galvanic anodes* Galvanic anodes may be attached to the structure by either the anode core insert or by a cable of appropriate size (see Note to Clause 5.7.3.2).

Anodes which are to be installed flush with the structure may be attached to the structure by either of the following methods:

(a) Welding of the anode core to the structure.

(b) The use of structure studs/nuts to attach the anode core.

5.7.3.2 *Positioning of impressed current anodes* Anodes for impressed current systems may be installed singly or in groups from a single power source. Depending on the site layout, anodes are normally arranged for optimum uniform current distribution, and have the maximum possible spacing between each other and from the structure.

Anodes which are in close proximity to a coated steel structure should be provided with an adequate dielectric shield, designed so that the potential at the periphery of the shield does not exceed −1.2 volts with reference to a copper/copper sulfate electrode.

In the case of cantilever anodes, which are generally rod-shaped and project from the structure, obstruction of the active anode surface can be avoided by using an adequate shroud length to prevent build-up of a calcareous deposit on the structure surface.

NOTE: For safety reasons, suspended anodes, other than light anodes of platinized titanium or mixed metal oxides which are specifically designed to be suspended by their cable tails, should be supported by a suitable rope of polypropylene, or of similar material, to prevent the anode cable bearing the anode weight.

5.8 ANODE MATERIALS, APPLICATION AND OPERATING CHARACTERISTICS

Anode materials are classified according to their end use, as impressed current anodes, or as galvanic (sacrificial) anodes. When selecting anodes, consideration should be given to the possible toxic effects of alloying elements on humans and fish.

Typical environments and operating characteristics of anodes are given in Table 5.3.

5.9 POWER SUPPLY CONSIDERATIONS

5.9.1 Sources of direct current Where impressed current systems are being considered, it is necessary to have a direct current power supply which may be obtained from such sources as the following:

(a) Mains (a.c.) power supply.

(b) Engine-driven generators.

(c) Alternative sources, e.g. solar, wind and gas.

The simplest system to produce a fixed voltage of unfiltered output may comprise a transformer with a suitable rectifier, the current depending upon the total circuit resistance and the back e.m.f.

5.9.2 Equipment The equipment and wiring is required by regulatory authorities to comply with AS 3000, AS 3100, AS 3108 and AS 3147, as appropriate.

NOTES:

1 If an impressed current system utilizing waveform chopping circuitry to obtain variable d.c. output is used, it is essential to ensure that any radio frequency (RF) emanation from the structure or equipment is within allowable limits and does not cause interference with other electrical equipment.

2 Reduction of the a.c. ripple (smoothing) may be required for special purposes such as the suppression of electrical interference to telecommunication lines, data or signalling circuits.

3 Reduction of the a.c. ripple may also be required where platinized titanium anodes are used.

4 Surge protection should be fitted to power sources as appropriate.

5 For the safety of divers or other personnel in close proximity to the anodes, the electrical field strength in the water should be kept below 3 volts per metre and a.c. ripple limited to not more than 5% r.m.s. (see AS 3859).

Where anode/cathode resistance varies, current control-voltage adjustment may either be manual or fully automatic.

It is prudent to provide the equipment with sufficient power capacity to give it a capability for coping with unknown factors such as changes in electrical resistivity.

5.9.3 Calculation of voltage requirements The approximate d.c. voltage requirement can be calculated by multiplying the total loop resistance by the required current and adding the back e.m.f. This d.c. output voltage should not exceed 50 V d.c. for safety reasons (see Clause 5.2).

TABLE 5.3

TYPICAL ENVIRONMENTS AND OPERATING CHARACTERISTICS OF ANODES FOR CATHODIC PROTECTION

Description of anode	Typical environment for cathodic protection application	Typical environment resistivity Ω.m	Typical current density A/m²	Approximate consumption kg/A.year*†	Relevant reference Standard
Galvanic anodes					
Zinc	All waters	0.2 to 15	Controlled by total circuit resistance	12	AS 2239
Aluminium	Seawater	0.2 to 4		3.5	AS 2239
Magnesium	Potable water	5 to 75		7	AS 2239
Impressed current anodes					
Platinized titanium/niobium	Sea or potable water	0.2 to 75	100 to 1000	1×10^{-5}	—
Silicon iron‡	All waters	0.2 to 75	5 to 40	0.3 to 1	—
Magnetite	All waters	0.2 to 75	3 to 60	<0.1	—
Scrap steel	All waters	10 to 200	0.1 to 1	10	—
Mixed metal oxides	All waters	0.2 to 200	60 to 750	1×10^{-6}	—

* With the exception of steel, the *impressed* current anodes listed do not obey Faraday’s law, the dissolution rate being less. However, the consumption rate increases if the current densities listed are exceeded, or the environmental conditions are unsuitable. For platinized titanium, voltages across any bare titanium/electrolyte interface should not exceed 8 V in chloride environments.

† Higher consumption rates may occur at temperatures above 40°C. Zinc anodes may be unsuitable for use in waters warmer than 45°C.

‡ The composition of silicon iron typically includes chromium to resist high-chloride environments.

5.10 SYSTEM DESIGN DOCUMENTATION Following the design of the cathodic protection system, it is necessary that suitable documentation be prepared to provide a permanent record which can be updated as necessary when construction is complete.

Documentation of the proposed system should be drawn up in the form of plans to acceptable engineering standards using appropriate signs and symbols.

Appropriate documentation may include the following:

(a) A report of the proposed design and layout, including electrolyte resistivity and current drainage surveys, if applicable. The report should include design calculations, assumptions made in the design and an explanation of any departures from normal practice. It should also include full and adequate drawings and specifications to allow construction to proceed. The report should typically include the following information:

   (i) Structural details from which the wetted surface area can be calculated.

   (ii) Details and location of the cathodic protection unit and the power supply.

   (iii) The location of test points, individually identified.

   (iv) The location of any bonding to other structures.

(v) A detailed plan of anode installations, including anode type, mass, dimensions and distribution.

(vi) The location of any reference electrodes, and their types.

(vii) Installation instructions.

NOTE: Documentation may need to be updated in the light of changes which occur during construction.

(viii) The location of insulating joints, and any insulation of structure sections in the protected area, or in other structures, if applicable. This will not normally be encountered in the cathodic protection of immersed internal surfaces.

(ix) Possible sources of external interference currents which may affect the proposed system.

NOTE: A list of administering authorities which should be consulted if the control of interference currents is required, is given in Appendix C.

(b) Documentation required by State and local government regulatory authorities, if applicable. This documentation is not generally required for immersed internal surfaces.

(c) Advice to the electricity supply authorities regarding the need for power supply.

SECTION 6 INSTALLATION OF CATHODIC PROTECTION SYSTEMS

6.1 GENERAL This Section outlines recommended procedures for the installation of systems for the cathodic protection of internal surfaces.

Where required by regulatory authorities, it should be confirmed that the necessary approvals have been sought and obtained.

The installer should be thoroughly familiar with the specifications for the works, and should ensure that all works are completed in accordance with good industrial practice and the relevant specifications. Departures from design specifications should be approved and permanently recorded for future reference.

Installation of all electrical work is required to be carried out in accordance with AS 3000 and AS 3100, as appropriate, local electricity regulations, or other relevant Standards.

Care should be exercised to ensure that cables and other components are protected from damage during installation. All cable connections need to provide reliable long-term low-resistance electrical contact.

6.2 MATERIALS AND EQUIPMENT ACCEPTANCE TESTS

6.2.1 General Because of the inaccessible nature of much of the cathodic protection equipment in service, it is advisable to confirm prior to shipment to site and prior to installation, that materials and equipment comply with the appropriate specification or Standard. Clauses 6.2.2 to 6.2.4 indicate the types of checks and tests which should be undertaken to avoid protracted delays while replacements are sought or repairs are undertaken.

6.2.2 Anodes Galvanic and impressed current anodes should be inspected to ensure that the following criteria are met:

(a) Freedom from critical damage.

(b) Electrical security and continuity of connections.

(c) Anode-to-core continuity.

(d) Correct metal mass.

(e) Correct profile.

(f) Compliance of galvanic anodes with AS 2239.

The insulation of all impressed current anode cable tails should be inspected for the presence of nicks, cuts or other forms of damage which could cause premature failure of the system.

6.2.3 Cables Cables should be inspected to ensure that they are of the correct construction for the intended application.

6.2.4 Transformer/rectifier equipment Testing should be carried out prior to acceptance of a transformer/rectifier unit, to confirm compliance with the written specification and to ensure that the equipment is suitable for the intended purpose. Electrical output and insulation tests should be carried out in accordance with AS 3108.

The following tests should also be carried out on transformer/rectifier equipment:

(a) Polarity checks to ensure that output terminals are correctly identified.

(b) Visual inspection to ensure that all rectifier and surge protection equipment, and all specified current outputs, have been provided.

(c) A step-by-step check of the unit output against calculated load to ensure that the control pattern is suitable.

(d) Functional tests of any time switches installed.

(e) Functional tests of any other special equipment fitted.

6.3 INSTALLATION OF GALVANIC ANODE SYSTEMS The common methods of installation of galvanic anodes are as follows—

(a) by direct attachment to the internal part of the structure; or

(b) by suspension in the electrolyte from the structure using a cable or a rigid metal support; the cable is connected to the structure above water.

In all cases, the anode should be in reliable long-term low-resistance metallic contact with the structure. This may be achieved by the use of fusion joints, bolted connections, or by direct screwing into the structure surface. Ensure that corrosion resistant materials are used and the joints are effectively insulated (wrapped).

Before immersion of the anodes, it is necessary to remove any material wrapped around them. The anodes should not be painted and, where necessary, should be protected from accidental paint application.

> CAUTION: THE ADEQUATE SUPPORT OF ANODES IS NECESSARY TO AVOID POSSIBLE CABLE FAILURE.

6.4 INSTALLATION OF IMPRESSED CURRENT SYSTEMS

6.4.1 Anodes and cabling Impressed current anodes should not be directly attached to the internal part of the structure. They are required to be insulated from the structure and, in all cases, the electrical connection is to the positive terminal of the d.c. power source.

Because anodes are often brittle or have thin film electrodeposited coatings, care should be exercised to ensure that they are not damaged during handling.

Certain anodes are specifically designed for suspension by their cable tails, and may be lowered into position by the cable. Other anodes generally of the direct immersion type, may require to be lowered into position by separate ropes, as their cable tails are designed for electrical purposes only and not for mechanical suspension. The installation drawings should be checked before commencement of anode installation.

Cable supports should be corrosion resistant and located so that the cable insulation does not become abraded due to cable movement from wind or electrolyte forces. Cable routes should also avoid areas of likely damage from physical operations on the structure.

Cable joints should be completely waterproofed using an appropriate cable-jointing compound. Waterproofing is particularly important on the positive side of an impressed current system to prevent localized rapid corrosion and subsequent failure of the corrosion protection system.

> NOTE: Proper cleaning (degreasing and abrading) of the insulation is necessary to ensure that a watertight bond is achieved between the insulation and the cable-jointing compound. Where repairs are carried out, a minimum of 50 mm of cable insulation should be applied to each side of the repaired cable joint.

Anode to cable tail encapsulation for immersed anodes is generally fitted at the factory. Prior to installation the encapsulation should be carefully inspected for any faults or handling damage during transit.

Anodes which project from support pipes or require centreing through insulating sleeves may require inspection after installation.

WARNING: WHERE UNDERWATER DIVING INSPECTION OR MAINTENANCE IS LIKELY, STRUCTURES SHOULD HAVE WARNING NOTICES DISPLAYED ADVISING OF THE DANGER OF ELECTRICAL GRADIENTS NEAR THE ANODES AND THE NEED TO SWITCH OFF THE SYSTEM PRIOR TO DIVING.

CAUTION: SIGNS SHOULD BE DISPLAYED INDICATING THE PRESENCE OF ANY IMMERSED CABLES OR ANODE SUPPORT ROPES WHICH ARE NOT PHYSICALLY PROTECTED.

Anodes and their support cables on structures located in flowing fluids should be designed to withstand vibration and impact.

6.4.2 Transformer/rectifier Requirements of relevant Standards and local authorities should be observed during the installation of a transformer/rectifier especially with regard to a.c. input, cabling, and positioning.

After installation of a unit, it is important that the following be checked:

(a) The input and output terminals are correctly identified, and the structure cable is connected to the negative output terminal prior to connection to the electricity supply.

NOTE: When electricity is connected, correct polarity and loop resistance should be verified by energizing the unit, and checking that the structure potential is shifted in the negative direction.

(b) The oil level is correct (if the unit is oil-cooled).

(c) The fuse ratings are correct.

6.5 REFERENCE ELECTRODES If permanent reference electrodes are installed for the measurement of the structure-to-electrolyte potential, it is important that they are continually immersed when in use.

Reference electrodes should be located in accordance with the design requirements. Each reference cell should be wired to a termination position by a separate and isolated conductor, insulated from the structure and the electrolyte and protected by continuous conduit. The separate conductors can be installed together using multicore cable.

It is essential that reference cell wiring is electrically shielded between the structure exit point and the termination position.

SECTION 7 OPERATION AND MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

7.1 GENERAL This Section outlines procedures and practices for operation and maintenance of cathodic protection systems used for the protection of internal surfaces.

Electrical measurements and inspections are necessary to ensure that initial protection of the structure has been established in accordance with applicable criteria and that each part of the cathodic protection system is operating satisfactorily.

It is important for subsequent system checks to be carried out to ensure that the structure remains protected and, if changes are noted, that action is taken to return the internal surface to a protected condition.

Most cathodically-protected internal surfaces are coated. Wherever the metal surface of a coated structure is exposed, the condition of the coating should be noted, and the coating repaired appropriately, if necessary.

7.2 MEASURING TECHNIQUES All instruments used for determining electrical values should be of an appropriate type and be of the required accuracy. They should be maintained in good working condition at all times.

Reference electrodes, other than copper/copper sulfate, may be used provided their relationship with copper/copper sulfate reference electrodes is either known or established prior to each series of measurements.

Permanent reference electrodes should be checked regularly against an independent or master reference electrode to ensure that their potential has not drifted from their standard value.

The structure potential is measured by connecting the positive terminal of a high-impedance voltmeter (at least 1 megohm) to the structure, usually at a test point. The negative terminal is connected to a reference cell which is positioned as near as practicable to the immersed surface of the structure (see Figure 7.1).

Because accurate measurement of the structure potential requires the reference to be located at the surface of the structure, the reference electrode may be carried by a remotely operated vehicle or be permanently installed at various areas of the structure (such as areas of complex geometry or where shielding can occur). Accurate readings of the structure potential can then be related to readings taken with a reference electrode placed adjacent to the side of the structure.

Care should be taken to ensure that the structure component to which the measuring voltmeter is connected is not carrying a substantial cathodic protection current. With impressed current systems, in particular, parts of the structure may be carrying a large current and hence may cause a significant voltage drop error in the measurement.

7.3 COMMISSIONING SURVEY The commissioning survey should include the following tests and measurements to ensure that the structure is protected in accordance with the design criteria, and that all equipment is correctly installed and functioning correctly:

(a) Measurement of structure potential at all test points, both before and after energization of the cathodic protection system.

  NOTE: Following the application of cathodic protection, the potential level of the structure may change with time owing to polarization and, to ensure that the structure potential is in the desired range, it may be necessary to carry out several potential measurements over a given time. In tanks containing fluids of relatively high resistivity, it is recommended that ‘OFF’ potentials are measured to minimize voltage gradient errors for impressed current systems.

(b) A check for correctness of polarity of electrical circuits, i.e. positive to anode and negative to structure.

(c) A functional test of all test points, to ensure correct installation/operation.

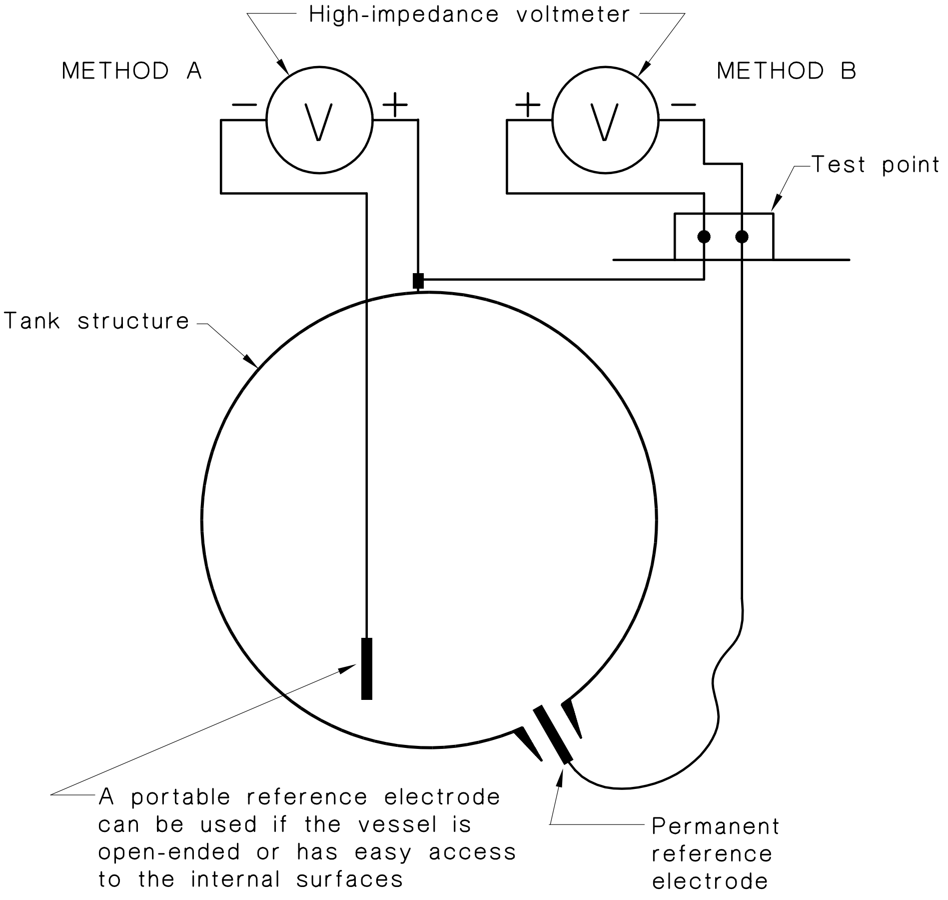
(d) For impressed current systems, the measurement of circuit resistance.

(e) The current required to provide protection.

(f) The voltage output of the impressed current system.

(g) A test for continuity between internal fittings and the tank body.

Data from the survey should be recorded and retained for future reference.



NOTES:

1 Method A employs a portable reference electrode.

2 Method B employs a permanent reference electrode.

3 The polarity shown is for digital, off-set zero and centre-zero voltmeters.
When using direct reading voltmeters the test leads need to be reversed to obtain negative potential readings.

FIGURE 7.1 ALTERNATIVE METHODS FOR MEASURING INTERNAL STRUCTURE POTENTIALS

7.4 CATHODIC PROTECTION POTENTIAL SURVEYS Cathodic protection potential surveys should be carried out at time intervals determined from a consideration of the system parameters, including the type of cathodic protection system, the nature of the environment and the structure operating conditions. The frequency at which it is necessary to recheck any system depends ultimately upon the history of the structure and other structures containing similar liquids. As a starting point, a complete survey and an inspection of the protection system should be carried out at yearly intervals.

7.5 EQUIPMENT MAINTENANCE CHECKS

7.5.1 For impressed current systems Equipment checks for impressed current systems should be carried out at regular intervals, typically monthly.

Functional checks on equipment should be carried out to determine changes in the following parameters:

(a) Rectifier current output and voltage.

(b) Structure potential.

(c) Potential of controlling reference electrodes, if installed.

Electrical equipment, including rectifiers, transformers and switchgear, should be kept clean to ensure adequate cooling. More comprehensive electrical maintenance checks may be needed on an annual basis, e.g. unit efficiency checks, cable checks for damage and resistance checks on all cable joints. The periodic cleaning of permanent reference electrodes may also be necessary.

7.5.2 For galvanic anode installations For galvanic anode installations, it is difficult to specify detailed procedures for maintenance because of the variety of structures involved.

The frequency and extent of inspection will depend upon such considerations as the likelihood of disturbance by other agencies, and the possibility of additions and alterations to the structure.

Wherever practical, link boxes should be included in the installation so that current measurements can be carried out to check anode operation.

7.6 STRUCTURE INSPECTIONS Where the surfaces of internal structures are exposed for any purpose, they should be examined for corrosion and, if coated, the condition of the coating should be assessed and recorded as part of the history of the system.

Any coating damage should be made good prior to the recommissioning of the structure.

7.7 RECORDS Records can be used to demonstrate the operational history at any time during the working life of a cathodic protection system. For this reason it is recommended that records be retained for the life of the structure.

Information should be recorded for the following operations:

(a) *Commissioning and installation* The information should include the following items:

    (i) Design documentation.

    (ii) Results of potential surveys.

    (iii) Results of equipment checks.

    (iv) The location of any test points added to the system.

    (v) The coating material and application procedures.

(b) *Inspections* The following information should be included:

  (i) Dates of surveys.

  (ii) System output voltages and currents (impressed systems).

  (iii) Potential survey data.

  (iv) For anode replacements: types, locations and dates of replacement.

  (v) Any damage to the structure, and nature and extent of repairs carried out.

  (vi) The condition of coating at failure points, and remedial action taken.

  (vii) The locations of any structure corrosion observed and, if possible, the causes of corrosion. Details of repair methods.

  (viii) Details of any alterations made to the structure.

(c) *Equipment maintenance* The following information should be included:

  (i) Details of any repairs to, or replacement of, any cathodic protection equipment.

  (ii) Location and identification of any new equipment added to the system.

APPENDIX A

GUIDANCE ON THE GENERAL USE OF CATHODIC PROTECTION

(Informative)

A1 SCOPE This Appendix describes the basic components of both the galvanic and the impressed current cathodic protection systems, and lists the factors which may affect the rate of corrosion of internal metallic surfaces.

A2 GENERAL COMPONENTS OF CATHODIC PROTECTION INSTALLATIONS The general components of a cathodic protection system employing galvanic anodes as the current source to protect internal surfaces, are shown schematically in Figure A1.

The general components of an impressed current cathodic protection system are shown schematically in Figure A2. This system employs a mains-operated or other source of power with a relatively permanent anode.

In either system, correct polarity is required to achieve protection of the structure. With proper design and operation, both systems are capable of completely preventing the corrosion of any metallic surface in contact with the electrolyte for as long as sufficient current flow is maintained.

A3 FACTORS AFFECTING THE CORROSION OF METALLIC STRUCTURES Most metal surfaces in contact with electrolytes are subject to corrosion. Factors which affect the rate of corrosion of a given metal include the following:

(a) *The environment surrounding the structure* The characteristics of the environment surrounding the structure are affected by the following properties:

   (i) Resistivity.

   (ii) pH value.

   (iii) Concentration of dissolved salts.

   (iv) Presence of microbiological species, and their state of activity.

   (v) Degree of aeration.

(b) *Environment factors* Environment factors may include:

   (i) Presence of aqueous growth.

   (ii) Fouling.

(c) *Climatic and intermittent wetting factors* Factors which are affected by climate and cause intermittent wetting include:

   (i) Temperature at the metal surface.

   (ii) Velocity of the liquid in a structure.

   (iii) Liquid level fluctuations.

(d) *Operating conditions of the structure* Factors which affect operating conditions of the structure include the following:

   (i) Minimum, maximum and average temperature of the metal surface.

   (ii) Magnitude and frequency of temperature fluctuations.

   (iii) Stress level of the structure, and magnitude and frequency of stress variations.

(e) *Other factors* Other factors which affect the corrosion rate of a metal or metallic structure include the following:

   (i) Deterioration of any protective coating.

   (ii) Coupled dissimilar metals in contact with the electrolyte.

   (iii) Abrasion.

   (iv) Erosion.

   (v) Structure design, e.g. the formation of crevices.

   (vi) Metallurgical condition of the structure.

The total effect of these factors on the corrosion rate can generally not be assessed until the structure is in service. Even then a complete assessment may not be possible because the corrosive effects of many of these factors may vary daily or seasonally, and the variation may not be repeatable or predictable. The effects of these factors may vary over short distances across the structure and at different depths, so that different conditions may exist at the top and the bottom of the structure. Some of the factors can have combined effects greater than the sum of individual effects. The uncertainty of individual results, and the complexity in making an accurate assessment of the combined results, may give rise to an inaccurate evaluation of corrosion rates.

Cathodic protection should be evaluated as a means of controlling corrosion on internal surfaces, together with other methods such as the use of internal linings, corrosion resistant material selection and design, and water treatment procedures. The application of cathodic protection requires the services of a trained and experienced corrosion engineer.

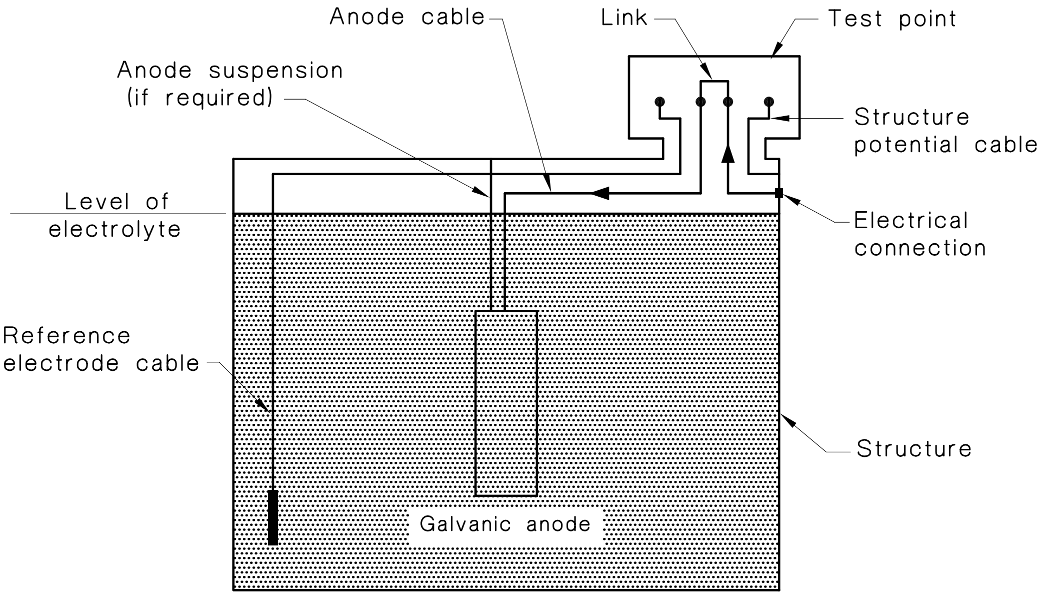


FIGURE A1 CATHODIC PROTECTION OF THE INTERNAL SURFACE OF A STRUCTURE USING A SACRIFICIAL GALVANIC ANODE SYSTEM (SCHEMATIC)

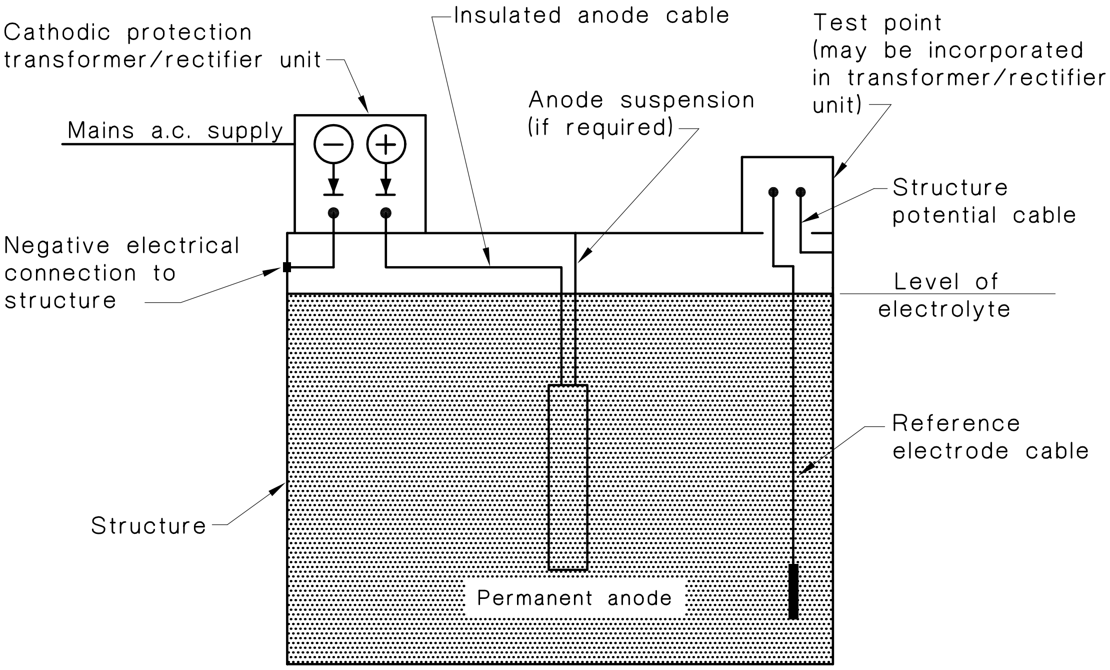


FIGURE A2 CATHODIC PROTECTION OF THE INTERNAL SURFACE OF A STRUCTURE USING AN IMPRESSED CURRENT SYSTEM (SCHEMATIC)

APPENDIX B

COMPARISON OF STRUCTURE/ELECTROLYTE POTENTIALS OBTAINED WHEN MEASURED WITH VARIOUS REFERENCE ELECTRODES

(Informative)

B1 SCOPE Figure B1 and Table B1 may be used to enable a comparison to be made between the potentials of a number of reference electrodes.

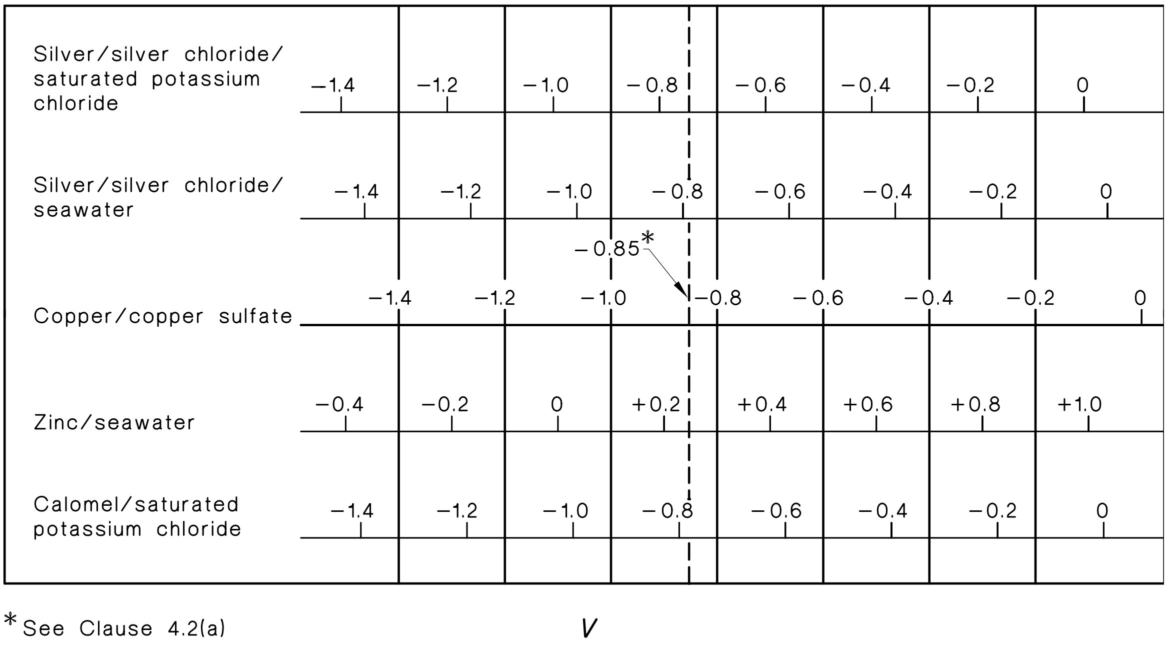


FIGURE B1 COMPARISON OF STRUCTURE/ELECTROLYTE POTENTIALS (*V*) MEASURED WITH VARIOUS REFERENCE ELECTRODES

TABLE B1

POTENTIALS OF VARIOUS ELECTRODES MEASURED AGAINST A SATURATED Cu/CuSO$_4$ ELECTRODE

Type of electrode	Potential at 25°C mV
Ag/AgCl/Seawater	−66
Ag/AgCl/KCl (saturated)	−91
Zinc/Seawater	−1 106
Hg/Hg$_2$Cl$_2$/KCl(saturated)	−74

APPENDIX C

CONTROL OF INTERFERENCE CURRENTS—LIST OF ELECTROLYSIS COMMITTEES

(Informative)

State	State electrolysis committee
A.C.T.	A.C.T. Electrolysis Committee C/- ACTEW PO Box 366 CANBERRA CITY A.C.T. 2601
N.S.W.	New South Wales Electrolysis Committee PO Box 536 ST LEONARDS N.S.W. 2065
N.T.	The Managing Director The Power and Water Authority PO Box 1921 DARWIN N.T. 0800
Qld	Queensland Electrolysis Committee C/- Queensland Electricity Commission 61 Mary Street BRISBANE Qld (GPO Box 10, BRISBANE Qld 4001)
S.A.	South Australian Electrolysis Committee C/- PO Box 206 KILKENNY S.A. 5009
Tas.	The Chief Electrical Inspector The Hydro-Electric Commission 4-16 Elizabeth Street HOBART Tas. 7000
Vic.	Victorian Electrolysis Committee Electrolysis Technical Subcommittee (both) C/- State Electricity Commission of Victoria GPO Box 2765Y MELBOURNE Vic. 3001
W.A.	None at present, refer to: State Energy Commission of Western Australia 365 Wellington Street PERTH W.A. (GPO Box L921 PERTH W.A. 6001)