



Corrosion Protection of Steel Offshore Units and Installations

May 2006

**Guidance Note
NI 423 DT R01 E**

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MARINE DIVISION

GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine Division (the "Society") is the classification ("Classification") of any ship or vessel or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- issues Certificates, Attestations and Reports following its interventions ("Certificates");
- publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as "Certification".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as "Services". The party and/or its representative requesting the services is hereinafter referred to as the "Client". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisalment given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisalment is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisalment or cause to modify its scope.

2.4. - The Client is to give to the Society all access and information necessary for the performance of the requested Services.

ARTICLE 3

3.1. - The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are not a code of construction neither a guide for maintenance or a safety handbook.

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the Code of Ethics of the Members of the International Association of Classification Societies (IACS).

3.4. - The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- conducts surveys at the place of their construction;
- classes Units and enters their class in its Register;
- surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder, respectively.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - **If the Services of the Society cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee.**

The Society bears no liability for indirect or consequential loss such as e.g. loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - **Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.**

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. hereabove subject to compliance with 2.3. hereabove and Article 8 hereunder.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - **Overdue amounts are increased as of right by interest in accordance with the applicable legislation.**

8.3. - **The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.**

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit;
- copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society Member of the International Association of Classification Societies (IACS) in case of the Unit's transfer of class;
- the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units are passed on to IACS according to the association working rules;
- the certificates, documents and information relative to the Units classed with the Society may be reviewed during IACS audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France.

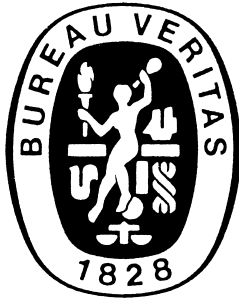
12.3. - **Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.**

ARTICLE 13

13.1. - **These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.



INFORMATION NOTE NI 423

Corrosion Protection of Steel Offshore Units and Installations

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SECTION 3	PROTECTION OF SPLASH ZONE
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SECTION 1

GENERAL

1 Scope

1.1 Application

1.1.1 The present Guidance Note applies to mobile units, fixed platforms, floating units, underwater pipelines, underwater production facilities, buoys and anchoring systems attached to the sea bed. Chains, cables and anchors are excluded.

1.1.2 It provides guidelines for the prevention and control of corrosion on steel structures, appurtenances and equipment of units or installations operating in a marine environment.

1.2 Zones

1.2.1 Corrosive environments offshore are often categorized as marine atmosphere, splash zone, tidal zone, fully submerged zone and mud zone. However, within the present Guidance Note, only the three following zones are separately considered (see definition in [3]):

- the atmospheric zone
- the splash zone
- the submerged zone.

1.3 Reference documents

1.3.1 Recognised international standards

Reference is given to the following International Standards, which are assumed to be complied with, in addition to requirements of this Guidance Note:

- ISO 13173: 2001 - Cathodic protection for steel offshore floating structure.
- ISO 15589-2: 2004 - Petroleum and natural gas industries - Cathodic protection of pipeline transportation systems - part 2 : offshore pipelines.
- ISO 12473: 2002 - Specimen dimensions and procedures for shear testing resistance spot, seam and embossed projection welds.

2 Miscellaneous definitions

2.1

2.1.1 The following definitions are considered throughout the present Guidance Note:

- **acidity**: presence of an excess of hydrogen ions over hydroxyl ions (see also "pH value")
- **alkalinity**: presence of an excess of hydroxyl ions over hydrogen ions (see also "pH value")

- **anaerobic**: lack of free oxygen. In the present Guidance Note, this term refers to the state of the electrolyte adjacent to the metal
- **anchor pattern**: roughness of a surface on which a coating is intended to be applied
- **anode**: electrode at which an oxidation process occurs;
- **anode shield**: synonym of "dielectric shield"
- **anodic area**: means the part of a metal surface which acts as an anode
- **blistering** (of paint film): formation of swellings on the surface of an unbroken paint film by moisture, gases, or the development of corrosion products between the metal and the paint film
- **bond**: piece of metal conductor, either rigid or flexible, usually made of copper, connecting two points on the same structure or on different ones, in order to prevent any appreciable change in the potential of one point with respect to the other
- **coating breakdown factor (K)**: anticipated relative reduction in cathodic current density due to the application of an electrically insulating coating. K is a function of coating properties, operation parameters and time.
K is equal to:
 - $K=0$: the coating is totally electrically insulating
 - $K=1$: the coating has no protective properties.
- **calcareous deposit**: layer mainly consisting of a mixture of calcium carbonate and magnesium hydroxide deposited on surfaces protected by a cathodic protection system in sea water due to the increased pH adjacent to the protected surface
- **cathode**: electrode of an electrolytic cell at which a reduction process occurs; it is usually the area which is not corroding
- **cathodic area**: part of a metal surface which acts as a cathode
- **cathodic disbonding**: failure of adhesion between a coating and a metallic surface which is directly attributable to the application of cathodic protection
- **cathodic protection**: technique to reduce the corrosion of the structure to insignificant rate by causing a direct current to flow from its electrolyte environment into the entire metal surface
- **cell**: complete electrolytic system including a cathode and an anode in electrical contact with an intervening electrolyte
- **continuity bond**: bond designed and installed specifically to provide electrical continuity. This bond may be permanent or temporary, e.g. during the course of a modification or repair (see also "bond")

- **copper/copper sulphate reference electrode:** reference electrode consisting of copper in a saturated copper sulphate solution; this electrode can become polluted by chlorides after a long term service in sea water
- **corrosion:** chemical or electrochemical reaction of a metal with its environment, resulting in its progressive degradation or destruction
- **corrosion product:** chemical compound or compounds produced by the reaction of a corroding metal with its environment
- **corrosion specialist:** person who, by reason of his education and/or experience is qualified to evaluate and solve problems related to the corrosion of materials. In the present Guidance Note, corrosion specialist refers to the one who is qualified in the control of corrosion in marine environments
- **current:** rate of flow of electrical charge carriers in the direction of net transport of positive charges (in a metallic conductor, this is the opposite direction of the electron flow), expressed in amperes (A) or milliamperes (mA)
- **current density:** current flowing to or from a unit area of an electrode surface
- **depolarisation:** removal of factors resisting the flow of a current in a cell
- **dielectric shield:** electrically non-conductive and alkali-resistant material such as organic coating, plastic sheet, or pipe, which is placed, in a cathodic protection system, between an anode and adjacent cathode to minimize the risk of hydrogen damage to the latter and to improve current distribution
- **doubler plate:** additional plate used to provide extra strength at a point of anode attachment to a structure
- **driving voltage** (sacrificial anodes system): difference between the structure/electrolyte potential and the anode/electrolyte potential
- **electrode:** conductor of the metallic class (including carbon) by means of which current passes to or from an electrolyte
- **electrolyte:** chemical substance or mixture, usually liquid, containing ions that migrate in an electric field
- **electro-negative:** applied to a metallic electrode, means that its potential is negative with respect to another metallic electrode in the system
- **electro-positive:** applied to a metallic electrode, means that its potential is positive with respect to another metallic electrode in the system
- **foreign structure:** any metallic structure which is not intended to be part of the concerned system
- **galvanic anode** (sacrificial anode): metal which, because of its relative position in the galvanic series corrodes and provides galvanic protection to metal or metals which are more noble in the series when coupled in an electrolyte. These anodes are the current source in sacrificial anodes cathodic protection systems
- **HAT:** highest astronomical tide, as obtained from site data
- **holiday:** discontinuity in a protective coating which exposes the metal surface to the environment
- **impressed current:** direct current supplied by a device employing a power source external to the electrode system of a cathodic protection system
- **interference current** (stray current): in its broadest sense, direct current flowing through paths other than the intended circuit. In the present Guidance Note, interference current means current discharged to the electrolyte from a structure which may be either not an intended part of circuit, or an intended part of circuit not adequately connected to the current source
- **IR drop:** voltage drop across a current carrying resistance (which can be the electrolyte) in accordance with Ohm's law
- **"J" tube:** curved tubular conduit designed and installed on a structure to support and guide one or more pipeline risers or cables
- **LAT:** lowest astronomical tide, as obtained from site data
- **mill scale:** heavy oxide layer formed during manufacturing, hot fabrication or heat treatment of metals and alloys
- **mud line:** ocean floor at the concerned location; synonyms: sea floor, sea bed and sea bottom
- **mud zone:** zone lying under the mud line
- **MWL:** mean water level as obtained from site data
- **passivation:** phenomenon occurring when the surface of a metal or alloy susceptible to corrosion reaches a state where its electrochemical behaviour becomes less reactive and its corrosion rate is reduced. This is the result of the formation of a protective film
- **pH value:** scale used to indicate the concentration of hydrogen ions in an electrolyte
- **pitting:** localized form of corrosion whereby a number of cavities, never in the form of cracks, are formed in the surface
- **Pitting Resistance Equivalent Number (PREN):** an empirical relationship to predict the pitting resistance of austenitic and duplex stainless steel. It is expressed as:

$$PREN = \%Cr + 3.3\% (Mo + 0.5W) + 16 \%N$$
- **polarization:** deviation from the open circuit potential of an electrode resulting from the passage of current
- **protected structure:** structure to which cathodic protection is applied
- **protection current:** current made to flow into a metallic structure from its electrolytic environment in order to effect cathodic protection of this structure
- **protection potential:** the less negative level to which the potential of a metallic structure, with respect to a reference electrode in an electrolytic environment, has to be depressed in order to effect cathodic protection of this structure
- **protective coating:** dielectric material adhering to or bonded to a structure to separate it from its environment in order to provide corrosion protection
- **reference electrode** (also called reference half-cell): reversible electrode the open circuit potential of which is constant under similar conditions of measurement. It is used for measuring the potentials of other electrodes

- **riser:** section of pipeline extending from the ocean floor up to the offshore unit or installation
- **saturated calomel electrode (SCE):** reference electrode consisting of mercury and mercurous chloride (calomel) in a saturated solution of potassium chloride; this electrode is mainly used for calibration of other reference electrodes
- **silver-silver chloride reference electrode:** reference electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions, e.g. the Ag/AgCl/sea water electrode; this electrode is frequently used for underwater potential measurements
- **standard hydrogen reference electrode:** reference electrode consisting of an electro-positive metal, such as platinum, in an electrolyte containing hydrogen ions at unit activity and saturated with hydrogen gas under a pressure of one standard atmosphere
- **structure/electrolyte potential:** difference in potential between a structure and a specified reference electrode in contact with the electrolyte at a point sufficiently close to (but without actually touching) the structure to avoid error due to the voltage drop associated with any current flowing in the electrolyte
- **sulphate-reducing bacteria (SRB):** group of bacteria found in most soils and natural waters, but active only in near neutral and anaerobic conditions. They reduce sulphates in their environment, with the production of sulphides
- **tidal zone:** zone lying between LAT and HAT
- **unprotected structure:** structure to which no cathodic protection or no coating is applied
- **utilization factor:** proportion of anode material on an anode which may be consumed before the anode ceases to provide a current output as specified in the design
- **voltage:** electromotive force, or a difference in electrode potentials, expressed in volts (V) or millivolts (mV).

3 Definition of zones

3.1 General

3.1.1 Concerned zones are steel surfaces of the unit or installation exposed to marine corrosive environment.

3.2 Submerged zone

3.2.1 The submerged zone is the zone permanently under water or, in other words, downwards from LAT for fixed installations, and from the normal working condition water line for mobile or floating units. For fixed installations or bottom-supported mobile units, it includes the portion of the structure buried below the sea bottom level. For floating units, it includes the bottom and side areas up to maximum summer load line or maximum scantling draft if no load line mark is assigned.

3.2.2 For floating unit, the waterballast tanks are to be considered as “submerged zone” in this Guidance Note.

3.3 Splash zone

3.3.1 The splash zone is the zone of the unit or installation which is alternatively in and out of water because of wind, wave, tide, and, for mobile units, unit's motions. Surfaces which are wetted only during major storms are excluded from splash zone.

3.3.2 The exact location and vertical extent of the splash zone is generally determined at the design stage of unit or installation, as it depends upon environmental conditions corresponding to the site of installation of the fixed installation, or those expected to be met by the mobile unit, and used for its design.

3.3.3 The splash zone is usually considered as extending:

- from 3 m below LAT level to 5 m above HAT level for fixed platforms (these values varying from site to site)
- from 3 m below to 5 m above water line at draught corresponding to normal working condition for mobile units.

3.4 Atmospheric zone

3.4.1 The atmospheric zone is the zone of the unit or installation which extends upwards from the splash zone i.e. above the level reached by the normal swell, and exposed to sun, wind, spray and rain.

4 Corrosion protection systems

4.1 Submerged zone

4.1.1 Steel corrosion of the external areas of submerged zone is to be controlled by the installation of cathodic protection systems, i.e. sacrificial anodes system or impressed current system. In some cases, corrosion protection of the submerged zone can be provided by appropriate coating systems, supplemented by one of the above mentioned cathodic protection systems.

4.1.2 As concerned with steel corrosion on the internal areas of submerged zone:

- a) Corrosion may be expected to be negligible on the internal surfaces of structures in compartments which are considered to be sealed and where no renewal of the electrolyte is possible
- b) In compartments where presence and circulation or renewal of sea water is possible in normal conditions, as for example waterballasts in floating units, cathodic protection using sacrificial anodes combined with adequate coating systems is to be used
- c) In closed flooded compartments where bacteria may develop or where the electrolyte may be renewed, cathodic protection using sacrificial anodes combined with adequate coating systems is to be considered. Injection of chemicals (oxygen scavenger and bactericides) can be used in such compartment (i.e. permanent ballast) provided approval by Flag and Coastal State.

For b) and c), the possibility to provide thickness increments of steel should be also considered.

Note 1: Impressed current system is only permitted on external part of the structure. This system is not permitted for closed compartment such as waterballast tanks in floating units.

4.2 Splash zone

4.2.1 Steel corrosion in the splash zone is to be controlled by the following means:

- application of particular protective coating systems
- in addition for tubular structures:
fitting of steel wear plates (doubler plates, often applied as welded wrap) or use of structural members with addi-

tional wall thickness for corrosion and erosion allowance.

Steel wear plates are to be sufficiently thick to compensate the anticipated corrosion and wear of the structure during the whole expected life of the unit or installation. They are generally coated or sheathed for additional corrosion protection.

- density current as defined in Sec 2, [3.2.2] is to be increased by 10% in the splash zone.

4.3 Atmospheric zone

4.3.1 Steel corrosion in the atmospheric zone should be controlled by the application of suitable protective coating systems.

SECTION 2

PROTECTION OF SUBMERGED ZONE

1 General

1.1

1.1.1 The purpose of using cathodic protection is to control the corrosion of metallic surfaces in contact with electrolytes.

2 Criteria for cathodic protection

2.1 Protection potential

2.1.1 Cathodic protection is effective if the reaction of oxidation of iron is not possible.

2.1.2 The purpose of [2.1.1] is achieved when the steel electrode potential is lowered below the protection potential of -800 mV versus Ag/AgCl sea water reference electrode, which can be considered as a protection criterion.

This value includes the IR drop across the steel/water interface but does not include the IR drop in sea water.

Under anaerobic conditions where micro-biologically assisted corrosion may occur, a potential of -900 mV versus Ag/AgCl/sea water reference electrode is to be considered as the criterion.

Under particular conditions of pH, temperature or pressure, the potential criterion should be adjusted according to the thermodynamic laws.

2.1.3 In addition, negative limits for potential are to be settled by taking into account the hydrogen stress cracking susceptibility of steel and coating disbonding possibility, if any.

If the structure reaches too negative a potential, the cathodic protection may cause penetration of hydrogen, resulting in metal embrittlement, and subsequently inducing the propagation of cracks. The risk is significantly greater for high strength steels.

Steels with a specified minimum yield strength (R_{eG}) not exceeding 500 N/mm², these phenomena can occur at potentials (V) lower than -1100 mV versus Ag/AgCl/sea water reference electrode.

Anaerobic environments with presence of sulphate-reducing bacteria and sulphide increase the possibility of high strength steels to suffer from hydrogen stress cracking.

2.1.4 Tab 1 gives recommended limits for steel potential.

2.1.5 Use of cathodic protection outside these limits ($R_{eG} > 500$ N/mm² or/and $V < -1100$ mV) is to be considered by the Society on a case by case basis.

Table 1 : Steel potential limits versus Ag/AgCl sea water

Material	Upper limit (mV)	Lower limit for bare steel (mV)
Carbon steel		
• aerated seawater	-800	-1100
• non aerated seawater	-900	-1100
Austenitic stainless steel		
• $PREN \geq 40$	-300 (1)	-1100
• $PREN < 40$	-500 (1)	-1100
Duplex stainless steel	-500 (1)	(2)
Martensitic stainless (13% Cr) steel	-500 (1)	(2)
(1) For stainless steels, the minimum negative potentials apply for aerobic and anaerobic conditions (2) Depending on strength, specific metallurgical condition and stress level encountered in service, these alloys can be susceptible to hydrogen embrittlement and cracking. If a risk of hydrogen embrittlement exists, then potentials more negative than -800 mV is to be avoided.		

2.1.6 Other standard reference electrodes may be substituted to the Ag/AgCl/sea water reference electrode. Tab 2 lists these electrodes with their voltage equivalent to -800 mV referred to Ag/AgCl/sea water reference electrode.

Table 2 : Steel potential upper limit versus other reference electrodes

Electrode	Potential (mV) equivalent to -800 mV vs Ag/AgCl
Saturated Cu/CuSO ₄ (1)	-850
High purity zinc ASTM B418-80 type II	$+250$
Zinc MIL Spec A-18001 H	$+250$
Saturated calomel	-780
(1) is to remind that the saturated Cu/CuSO ₄ is not stable for long term immersion service.	

2.1.7 The silver-silver chloride reference electrode potential is affected by the temperature and the chloride concentration (i.e. the resistivity) of the sea water in which the electrode is immersed.