RECOMMENDED PRACTICE
DNV-RP-F103

CATHODIC PROTECTION OF SUBMARINE PIPELINES BY GALVANIC ANODES

OCTOBER 2010

DET NORSKE VERITAS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV service documents consist of amongst other the following types of documents:

— *Service Specifications.* Procedual requirements.
— *Standards.* Technical requirements.
— *Recommended Practices.* Guidance.

The Standards and Recommended Practices are offered within the following areas:

A) Qualification, Quality and Safety Methodology
B) Materials Technology
C) Structures
D) Systems
E) Special Facilities
F) Pipelines and Risers
G) Asset Operation
H) Marine Operations
J) Cleaner Energy
O) Subsea Systems

Any comments may be sent by e-mail to *rules@dnv.com*
For subscription orders or information about subscription terms, please use distribution@dnv.com
Computer Typesetting (Adobe Frame Maker) by Det Norske Veritas

CHANGES

- **General**

As of October 2010 all DNV service documents are primarily published electronically.

In order to ensure a practical transition from the "print" scheme to the "electronic" scheme, all documents having incorporated amendments and corrections more recent than the date of the latest printed issue, have been given the date October 2010.

An overview of DNV service documents, their update status and historical "amendments and corrections" may be found through http://www.dnv.com/resources/rules_standards/.

- **Main changes**

Since the previous edition (October 2003), this document has been amended, most recently in April 2008. All changes have been incorporated and a new date (October 2010) has been given as explained under "General".

CONTENTS

1. General

1.1 Introduction

1.1.1 Submarine pipelines are designed with an external coating as the primary system for corrosion control. Still, a cathodic protection (CP) system is normally provided as a back-up to account for any deficiency in the coating system. Such deficiencies may include holidays during coating manufacturing, damage to the coating during transportation and installation of coated linepipe, and mechanical damage or other coating degradation during operation of the pipeline. In defining the required capacity of the CP system, the design of the pipeline coating system is the primary factor.

Guidance note:

Pipeline coatings may have other objectives in addition to corrosion control, including mechanical protection, thermal insulation and/or anti-buoyancy. In its widest sense, the term "pipeline coating" includes "linepipe coating" (or "factory coating") applied on individual pipe joints in a factory, "field joint coating" (FJC) and "coating field repairs" (CFR). In addition to the design of the coating system, the quality control of its application is essential for its performance and thus also for CP design.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

1.1.2 Cathodic protection of pipelines can be achieved using galvanic (or "sacrificial") anodes, or impressed current from rectifiers. For submarine pipelines, galvanic anode systems are most commonly applied. Such systems have traditionally been designed as self-contained systems with all anodes installed directly on the pipeline itself (bracelet type anodes). However, the CP design in this document (as in ISO 15589-2) allows for CP by anodes installed on adjacent structures electrically connected to the pipeline such as platform sub-structures, subsea templates and riser bases.

For pipelines in CRA's susceptible to hydrogen induced stress cracking (HISC) by CP, this concept has the main advantage that the installation of anodes on the pipeline itself can be fully avoided for shorter lines.

Guidance note:

Apparently all failures of CRA pipelines due to HISC have been related to the welding of anodes to the pipeline causing stress concentrations, susceptible microstructure and defect coating. The concept of installing anodes on adjacent structures also has the advantage that the complete anode surfaces are exposed to seawater, increasing the anode electrochemical performance and the anode current output compared to those for anodes partly or fully covered by seabed sediments. Moreover, the potential for damage to the pipeline coating during installation is reduced.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

1.1.3 The design of pipeline CP systems is mostly carried out in two steps; conceptual and detailed CP design. The 'conceptual CP design' will typically include selection of anode material, tentative net mass and dimensions of anodes, and concept for fastening of anodes. The conceptual design shall further take into account potential detrimental effects of cathodic protection such as the pipeline materials' intrinsic susceptibility to hydrogen embrittlement by CP and the magnitude of local stresses induced during installation, commissioning and operation of the pipeline that may lead to damage by HISC. For this conceptual CP design, reference is made to the applicable sections of DNV-OS-F101 and ISO 15589-2 (see 1.3.1). During the 'detailed CP design' (i.e. as covered in this document), the final net anode mass and dimensions of anodes, and their distribution on the pipeline are defined.

1.2 Scope

1.2.1 This Recommended Practice (RP) has been prepared to facilitate the execution of detailed CP design and the specification of galvanic anode manufacturing and installation. While the requirements and recommendations are general, the document contains advice on how amendments can be made to include project specific requirements. The document can also easily be amended to include requirements/guidelines by a regulating authority, or to reflect the pipeline operator's general philosophy on pipeline corrosion control.

Guidance note:

It is recommended that any additional conservatism is introduced by use of a "design factor" rather than modification of one or more of the many design parameters used for CP calculations. For example, it may be specified that the design life shall be based on the maximum estimated lifetime of the pipeline multiplied with some constant larger than 1 (one).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

1.2.2 The document covers the detailed design of CP for submarine pipeline systems (see 1.3.1) using galvanic anodes, either Al - or Zn -based, and the manufacturing and installation of such anodes. For CP of subsea manifold templates, riser bases and other subsea structures where components of a pipeline system are electrically connected to major surfaces of structural C-steel, use of DNV-RP-B401 is recommended for CP design (see 1.5.3). For conceptual CP design, Sec.5 is applicable to preliminary calculations of the anode net mass and anode distribution. This RP is based on the sections in ISO 15589-2 that are applicable (see 1.3.1). For compliance with the general philosophy in DNV-OS-F101, primarily with respect to procedures for quality control, or for the purpose of clarification and guidance, some amendments are given. This RP further contains some formula for calculation of CP protective range from adjacent structures and minimum distance between pipeline anodes that are not included in the ISO standard. Default values for galvanic anode performance and design current densities that do not require any special qualification or field testing are also recommended.

1.2.3 By referring to specific pipeline coating systems for linepipe, field joints and field repairs in DNV-RP-F102 and DNV-RP-F106, and implementing the detailed requirements for the quality control of their manufacturing as defined in these documents, specific design parameters for calculation of current demands for CP are recommended in this RP. This is to enable a CP design without any arbitrary allowance for deficiencies associated with the design and quality control of such coatings, reducing the need for excessive conservatism in the design. In this RP, and contrary to ISO 15589-2, the current demands for cathodic protection are calculated for specific combinations of linepipe and field joint coating.

Guidance note:

In case certain deviations from the requirements to coating design and/or quality control of manufacturing in DNV-RP-F106 and DNV-RP-F102 are identified, the CP design parameters associated with pipeline coatings in this document (i.e. "coating breakdown factors") may still be applicable. However, the user of this document should then carefully assess the significance of any such deviations.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

1.2.4 Full conceptual design of CP (see 1.1.3 and 1.2.2), detailed design of impressed current CP systems, testing of galvanic anode material for the purpose of either qualification or quality control, and the operation of pipeline CP systems are not addressed in this document. For these items, reference is made to the general guidelines in DNV-OS-F101 and the more detailed recommendations in ISO 15589-1, -2.

1.2.5 Although considerations related to safety and environmental hazards associated with galvanic anode manufacturing and installation are of great importance, such are never-the-less beyond the scope of this document.

1.3 Objectives and use

1.3.1 This RP complies with the requirements, recommendations and guidelines in the applicable sections of ISO 15589-2. It is applicable to 'submarine pipeline systems' as defined in DNV-OS-F101, except risers above LAT for which cathodic protection is not efficient. For landfall sections protected by impressed current CP, reference is made to ISO 15589-1.

1.3.2 The document has two major objectives. It may be used as a guideline to pipeline operator's or their contractor's execution of detailed CP design, and to the specification of galvanic anode manufacturing and installation. It may also be used as an attachment to an inquiry or purchase order specification for such work. If Purchaser has chosen to refer to this RP in a purchase document, then Contractor should consider all requirements in this document as mandatory (see Sec. 3), unless superseded by amendments and deviations in the specific contract.

1.3.3 CP design, anode manufacture and anode installation are typically carried out by three different parties (all referred to as Contractor in this RP). The party issuing a contract (Purchaser) may be either the installation contractor or Owner. For definition of contacting parties and associated terms, see Sec.3.

1.3.4 Besides any reference to this document in a 'purchase document' (see definition in Sec. 3), the information given in 1.3.5 to 1.3.7 (intended as a check-list) shall be enclosed, as applicable to the detailed CP design, anode manufacturing and anode installation, respectively.

1.3.5 For cathodic protection detailed design:

- conceptual design report, if completed (5.1)
- relevant data from pipeline design basis, including e.g. information on pipe material and dimensions, installation conditions, internal fluid temperature, marine environmental conditions, degree of burial or rock-dumping, linepipe and field joint coating design, design life (5.1)
- requirements to documentation and verification, including schedule for supply of documentation (5.7).

1.3.6 For anode manufacturing:

- anode material type (i.e. Al- or Zn-base) and any detailed requirements to chemical composition of anode material (6.5.1)
- outline anode drawing (including anode cores) with tentative tolerances (5.7.1)
- project specific requirements to pre-production qualification testing (PQT), including schedule for notification and supply of documentation, number of anodes to be cast and tested destructively for each casting mould (6.3)
- any special requirements to 'manufacturing procedure specification' (MPS) (6.2.1) or 'inspection and testing plan' (ITP) (6.4.2)
- requirements for frequency of destructive testing during production, and for verification of bracelet anode tab positions by measurements and/or anode fit-up test on a dummy pipe sample (6.6.3)
- any specific requirements to Contractor's management of non-conformities and concession requests (6.6.7)
- retaining of anode material specimens (6.6.1)
- requirements to marking of anodes (6.7)
- any specific requirements to handling, storage and shipping of anodes (6.8)
- project specific requirements to final documentation, including schedule for supply (6.7).

1.3.7 For anode installation:

- anode installation design requirements, including anode drawing (tentative from CP conceptual or detailed design report, subsequently to be replaced by anode manufacturer's drawing)
- design premises affecting anode installation, e.g. linepipe dimensions, type of linepipe coating, pipeline installation concept
- location of anodes in relation to pipe ends and field joints (7.6.3)
- any special requirements to qualification of anode installation (PQT), including e.g. verification of anode integrity during pipeline installation, application of in-fill and repair of linepipe coating, as relevant (7.3)
- any special requirements to quality control, e.g. use of IPS (7.2.1) and 'daily log' (7.4.2)
- any specific requirements to handling and storage of anodes and materials for anode installation (7.5.3)
- project specific requirements to final documentation, including schedule for supply (7.8.3).

1.4 Structure of document

1.4.1 Requirements and recommendations for detailed cathodic protection design, anode manufacturing and anode installation are contained in Sec. 5, 6 and 7, respectively.

1.5 Relation to DNV-OS-F101 and other DNV documents on pipeline corrosion control

1.5.1 DNV-OS-F101 "Submarine Pipeline Systems", Sec. 8, gives general guidelines to the conceptual and detailed design of CP systems and contains some requirements and recommendations associated with anode manufacturing and installation, in addition to pipeline coatings. Inspection of CP systems in operation is addressed in Sec. 10 of the same document.

1.5.2 DNV-RP-F106 "Factory Applied Coatings for External Corrosion Control" and DNV-RP-F102 "Pipeline Field Joint Coating and Field Repair of Linepipe External Coatings" provide detailed requirements to the manufacturing of pipeline coatings.

1.5.3 DNV-RP-B401 "Cathodic Protection Design" (2005) covers CP of other offshore structures than pipelines. However, it is applicable for certain components of a pipeline system like those installed on manifold templates and riser bases (see 1.3.1).

2. References

2.1 DNV (Det Norske Veritas)

DNV-OS-F101	Submarine Pipeline Systems
DNV-RP-B401	Cathodic Protection Design
DNV-RP-F106	Factory Applied External Pipeline Coatings for Corrosion Control
DNV-RP-F102	Pipeline Field Joint Coating and Field Repair of Linepipe External Coating

2.2 EN (European Standards)

EN 10204	Metallic Products – Types of Inspection Documents

2.3 ISO (International Organisation for Standardization)

ISO 8501-1	Preparation of Steel Substrate Before Application of Paint and Related Products – Visual Assessment of Surface Cleanliness. – Part 1: Rust Grades and Preparation Grades of Uncoated Steel Substrates and of Steel Substrates After Overall Removal of Previous Coatings.
ISO 8503-2	Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Substrates. – Part 2: Method for the Grading of Surface Profile of Abrasive Blast-Cleaned Steel – Comparator Procedure
ISO 10474	Steel and Steel Products – Inspection Documents
ISO 10005	Quality Management – Guidelines for Quality Plans
ISO 13847	Petroleum and Natural Gas Industries- Pipeline Transportation Systems – Welding of Pipelines
ISO 15589-1	Petroleum and Natural Gas Industries- Cathodic Protection of Pipeline Transportation Systems – Part 1: Onshore Pipelines (see 1.3.1)
ISO 15589-2	Petroleum and Natural Gas Industries- Cathodic Protection of Pipeline Transportation Systems – Part 2: Offshore Pipelines (see 1.3.1)

3. Terminology and Definitions

Owner	party legally responsible for design, construction and operation of the pipeline
Purchaser	party (Owner or main contractor) issuing inquiry or contract for engineering, manufacturing or installation work, or nominated representative
Contractor	party to whom the work has been contracted
shall	indicates a mandatory requirement
should	indicates a preferred course of action
may	indicates a permissible course of action
agreed agreement	refers to a written arrangement between *Purchaser* and *Contractor* (e.g. as stated in a contract)
report and notify	refers to an action by *Contractor* in writing
accepted acceptance	refers to a confirmation by *Purchaser* in writing
certificate certified	refers to the confirmation of specified properties issued by *Contractor* or supplier of coating materials according to EN 10204:3.1.B, ISO 10474:5.1-B or equivalent.
purchase document(s)	refers to an inquiry /tender , or a purchase/contract specification, as relevant
manufacture manufacturing	refers to work associated with anode manufacturing and installation, including qualification of a MPS (i.e. PQT) and WPS

4. Abbreviations and Symbols

4.1 Abbreviations

CDS	Coating Data Sheet
CFR	Coating Field Repair
CP	Cathodic Protection
CR	Concession Request
CRA	Corrosion Resistant Alloy
FJC	Field Joint Coating
HISC	Hydrogen Induced Stress Cracking
HV	Vicker Hardness
IPS	Installation Procedure Specification (see 7.2)
ITP	Inspection and Testing Plan (see 6.4.2)
LAT	Lowest Astronomical Tide
LE	Liquid Epoxy
MIP	Manufacturing and Inspection Plan (see 6.4.2)
MPS	Manufacturing Procedure Specification (see 6.2)
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinylchloride
PQT	Pre-Production Qualification Testing (see 6.3)
RP	Recommended Practice
SMYS	Specified Minimum Yield Stress
WPQ	Welding Procedure Qualification
WPS	Welding Procedure Specification

4.2 Symbols for CP design parameters

References within brackets refer to paragraphs in this document where the design parameters are defined.

A_c (m²)	surface area (5.2.1)
a	constant (5.2.7)
b	constant (5.2.7)
D (m)	linepipe outer diameter (5.6.4)
d (m)	linepipe wall thickness (5.6.5)
$E_a°$ (V)	design closed circuit anode potential (5.5.1)
$E_c°$(V)	design protective potential (5.5.1)
E'_c (V)	global protection potential (5.6.3)
ΔE_A (V)	electrolytic voltage drop (5.6.9)
ΔE_{Me} (V)	metallic voltage drop (5.6.3)
ε (A·h/kg)	anode electrochemical capacity (5.4.1)
f_{cm}	mean coating breakdown factor (5.2.5)
f_{cf}	final coating breakdown factor (5.3.2)
f'_{cf}	mean final coating breakdown factor (5.6.4)
I_{af} (A)	final anode current output (5.5.1)
I_c (A)	current demand (5.2.1)
I_{cm} (A)	mean current demand (5.2.1)
I_{cm} (tot) (A)	total mean current demand (5.2.9)
I_{cf} (A)	final current demand (5.3.1)
I_{cf} (tot) (A)	total final current demand (5.3.1)
i_{cm} (A/m²)	design mean current density (5.2.3)
L (m)	length of pipeline to be protected from one anode (5.6.3)
L_{tot} (m)	length of pipeline section (5.6.9)
M (kg)	total net anode mass (5.4.1)
M_a (kg)	individual net anode mass (5.6.9)
N	number of anodes (5.5.3)
R_{Me} (ohm)	metallic resistance (5.6.3)
R_{af} (ohm)	anode final resistance (5.5.1)
r	ratio: length of cutbacks (2 off) to linepipe coating per pipe joint (5.6.4)
ρ_{Me} (ohm·m)	resistivity of linepipe material (5.6.5)
t_f (years)	design life (5.2.6)
u	anode utilisation factor (5.4.2)

5. Cathodic Protection Detailed Design

5.1 General

5.1.1 The detailed design of a pipeline CP system is normally preceded by a conceptual design activity (see 1.1.3), during which the type of CP system and type of galvanic anode material to be used (i.e. unless an impressed current CP system was selected) have been defined. A concept for anode attachment will normally also be selected, considering requirements for the integrity of anodes during pipeline installation and provision of electrical connection of anode material to the pipeline. If no CP conceptual report has been prepared, then the premises and basic concepts for detailed CP design shall be defined by Purchaser in some other reference document (see 5.1.3). This information shall be included in an inquiry (ref. 1.3.5)

5.1.2 The pipeline conceptual design will normally define the generic type of pipeline coatings to be utilised for linepipe and pipeline components, and for coating of field joints. Based on this, it is common practice to carry out a preliminary calculation of current demands for cathodic protection and the associated total net mass of anode material required, resulting in a preliminary sizing and distribution of individual anodes (see 1.1.3).

5.1.3 In addition to the conceptual CP design report (if completed), the project design basis should contain all project specific input parameters for the execution of detailed CP design. Purchaser should ensure that the valid revision of the design basis is available to Contractor during the design work.

5.1.4 The design calculations in this section are in accordance with ANNEX A of ISO 15589-2, giving some amendments for the purpose of clarification or to facilitate selection of CP design parameters. (The above standard is sometimes referred to as "the ISO standard" or "the standard" in the text of this RP).

5.1.5 All electrochemical potentials associated with CP in this section refer to the Ag / AgCl / seawater reference electrode. (The potential of this reference electrode is virtually equivalent to that of the standard calomel electrode).

5.2 Calculation of mean current demand for cathodic protection

5.2.1 For the detailed CP design, a pipeline should normally be divided into sections based on variations in fluid and environmental parameters (e.g. fluid temperature and burial conditions) that affect the 'current demand' I_c for CP.
The 'mean current demand', I_{cm} (A) for a specific pipeline 'surface area' A_c is calculated from:

$$I_{cm} = A_c \cdot f_{cm} \cdot i_{cm} \qquad (1)$$

(f_{cm} and i_{cm} are defined below)

5.2.2 In this RP, the surface area associated with field joint coating at girth welds shall be calculated separately and the associated current demand according to equation (1) is then added to the current demand for the pipeline covered by linepipe coating and for any pipeline components with other types of coating.

Guidance note:
For CP calculations, a minimum cut-back length of 0.20 m should be applied. As the surface area associated with field joints is only a few percent of the total pipe area, it is not actually necessary to subtract the FJC area when calculating the current demand for surfaces with linepipe coating.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.3 In equation (1) above, i_{cm} is the 'design mean current density', i.e. the mean cathodic current density of an assumed bare metal surface exposed to the environment; i.e. seawater or marine sediments (see Guidance Note to 5.2.4). "mean" refers to an average value for the design life.

5.2.4 Table 5.1 gives recommended mean design current densities for buried and non-buried pipelines (or sections of a pipeline) as a function of the fluid temperature but independent of depth. "Buried" refers to pipeline sections to be subjected to trenching and backfilling. Pipelines (or pipeline sections) to be installed in very soft soil for which complete self-burial can be demonstrated (e.g. by calculations) may also be considered as "buried", however, sections for which incomplete self-burial is expected shall always be considered as "non-buried" for calculation of current demand. Pipeline sections without trenching but covered by rock / gravel dumping may further be considered as "buried". The design current densities in Table 5-1 are applicable for pipelines with linepipe coating and FJC / CFR as defined in DNV-RP-F106 and DNV-RP-F102, respectively. For any pipeline components or parts of pipelines designed without such coatings, default values of 0.100 A/m^2 and 0.050 A/m^2 are recommended for non-buried and buried items, independent of surface temperature and depth. It is then presumed that any such areas constitute a minor surface area (maximum 2%) compared with the overall surface area (pipe section) to be protected. For any larger surfaces, DNV-RP-B401 is recommended for calculations of CP current demands. The design current densities in this paragraph are applicable to CRA as well as CMn-steel linepipe and ordinary C-steel.

Table 5-1 Recommended design mean current densities (in A/m^2) as a function of internal fluid temperature

Exposure Condition	Internal Fluid Temperature (°C)			
	≤ 50	>50 - 80	>80 - 120	>120
Non-Buried*)	0.050	0.060	0.070	0.100
Buried*)	0.020	0.025	0.030	0.040

*) see definition in 5.2.4

Guidance note:
The design current densities in Table 5-1 are applicable independent of geographical location and depth but should be considered as *minimum* values. Based on special considerations, the Owner/Purchaser may chose to specify higher design values than those in Table 5-1.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:
The current demand associated with cathodic protection of pipelines is related to "leakage" of current at pores and narrow cracks or crevices in the coating, primarily in connection with field joints. Hence, there is no direct exposure of steel surfaces to seawater and the temperature at the metal / electrolyte interface is close to that of the internal fluid temperature. The cathodic current is then primarily related to hydrogen evolution, even for unburied pipeline sections, whilst reduction of dissolved oxygen has a minor contribution to the cathodic reaction. As a consequence, seawater parameters affecting oxygen supply (e.g. dissolved content of oxygen and seawater flow), hydrostatic pressure and seawater ambient temperature are less important. The cathodic current is primarily determined by diffusion and migration processes in the pores and crevices and the electrolytic resistivity. For pipelines operating above ambient seawater temperature, the temperature of the internal fluid, having a major effect on diffusion/migration processes and electrolytic conductivity, is the decisive factor for the current demand.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.5 f_{cm} in equation (1) is a dimensionless factor (≤1) termed 'mean coating breakdown factor', describing the assumed capability of the coating to reduce the current demand for cathodic protection. (See also Guidance Notes to 5.2.7, 5.3.1 and 5.3.2). "mean" refers to an average value for the design life.

5.2.6 The mean coating breakdown factor f_{cm} is given by the equation:

$$f_{cm} = a + 0.5 \cdot b \cdot t_f \qquad (2)$$

where t_f (years) is the 'design life'. a and b are defined below.

Guidance note:

The design life to be used for CP detailed design shall be defined by Purchaser and should be a conservative estimate of the maximum expected lifetime of the pipeline. Any significant period of time between installation and start of operation shall be included.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.7 a and b in equation (2) are constants. Table A.1 and A.2 in Annex 1 give recommendations for constants to be used for specific combinations of linepipe coating and FJC systems as defined in DNV-RP-F106 and DNV-RP-F102, respectively, and for the maximum operating temperatures indicated in the tables. These constants further assume that any damage to the linepipe coating is repaired (CFR) in accordance with DNV-RP-F102 prior to installation, and that the compatibility of installation systems with the linepipe and FJC has been verified by testing or calculations. Furthermore, it is assumed that the pipeline is protected by weight coating, burial or rock / gravel dumping as required to avoid damage in operation causing significant exposure of bare metal.

Guidance note:

The constant a defines the assumed initial capability of the coating to reduce the current demand for cathodic protection, whilst the constant b defines the assumed degradation of this capability over time ("coating breakdown") although the coating may appear visually unaffected. The constants a and b defined in Tables A.1 and A.2 are rough estimates based on practical experience and engineering judgement. This is reflected by the accuracy of the numbers recommended.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.8 For any pipeline components protected by "ordinary" marine coating systems based on e.g. liquid epoxy or polyurethane (dry film thickness ≥ 150μm), default values of 0.10 and 0.03 are recommended for a and b respectively. These default values further presume a surface cleanliness of A/B Sa 2 1/2 and surface roughness grade Medium according to ISO 8501-1 and ISO 8503-2, respectively. The current demand of surfaces without pipeline coatings as defined in DNV-RP-F106 and DNV-RP-F102 shall be calculated using the design current densitiy default values defined in 5.2.4. The use of such default values presumes that any such areas constitute a minor surface area (maximum 2%, see 5.2.4) compared with the overall pipeline surface area.

5.2.9 Based on the design current densities and coating breakdown factors as defined above, the current demand contributions from coated linepipe, field joints and any pipeline components with "ordinary" marine coating are calculated individually according to equation (1) and then added to make up the 'total mean current demand' I_{cm}(tot) (A).

Guidance note:

ISO 15589-2 recommends constants a and b in eqn (2) for general types of pipeline coating systems assuming that the reduction of current demand for CP (i.e. per surface area) is the same for linepipe and FJC (quote: field joints having a quality equivalent to factory-applied coatings).

This RP, however, refers to specific combinations of linepipe and FJC coating and takes into account their relative surface area (eqn. 9). The calculated FJC coating breakdown factor may then be 3-30 times higher than for the linepipe coating. For certain combinations of parent and linepipe coating, the calculated overall coating breakdown using the constants in Annex 1 may be significantly lower than in the ISO standard.

This is justified by the specific requirements to coating design and quality control of coating application in the referenced DNV-RP-F102 and DNV-RP-F106; the ISO standard referring to the generic type of coating (e.g. fusion bonded epoxy) or purpose of coating (e.g. thermal insulation) and to (quote:) commonly applied industry standards.

The constants recommended in Annex 1 are only applicable if the actual coating specifications are in general compliance with the referred DNV RP's. However, for certain combinations of coating systems (e.g. asphalt and coal tar enamel plus FJC based on tape or sleeves with infill), the CP system can readily be designed so that the current demands of both standards are fulfilled (see also Guidance notes to 5.4.1 and 5.6.9).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.3 Calculation of Final Current Demand for Cathodic Protection

5.3.1 The 'total final current demand', I_{cf}(tot) (A) for a specific pipeline section is calculated by adding the contributions from coated linepipe, field joints and pipeline components calculated from:

$$I_{cf} = A_c \cdot f_{cf} \cdot i_{cm} \qquad (3)$$

as described in 5.2 above.

Guidance note:

The design "initial" and "final" current densities as defined in DNV-RP-B401 refer to the anticipated current demand (at a fixed protection potential of - 0.80 V) for the initial polarisation of a bare steel surface, and for re-polarisation of a bare steel surface that has become depolarised due to the mechanical removal of surface layers (calcareous deposits), respectively. For pipelines coated with the systems defined in DNV-RP-F106 and DNV-RP-F102, the requirement to such polarising capacity is not considered relevant and i_{cm} is used in equation (3). This approach is applicable also to pipelines (or pipeline sections) with minor areas (maximum 2%) coated with other types of coating (see 5.2.8).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.3.2 The 'final coating breakdown factor' f_{cf} is given by the equation:

$$f_{cf} = a + b \cdot t_f \qquad (4)$$

using the a and b constants in Table A.1 and A.2 in Annex 1.

Guidance note:

It is the coating breakdown factor used for CP design that in the main determines the magnitude of the calculated current demand. Compared to this factor, the effect of variations of other design parameters such as design current densities and those associated with the anode performance is relatively small (See also Guidance note to 5.2.9).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.4 Calculation of total anode net mass to meet mean current demand

5.4.1 Using the calculated total mean current demand I_{cm} (tot), the 'total net anode mass' M (kg) required is calculated from:

$$M = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \qquad (5)$$

where u (dimension less), is the anode 'utilisation factor' and ε in (A·h/kg) is the 'electrochemical capacity' of the anode material. ("8760" is the number of hours per year).

Guidance note:

The total net anode mass calculated from eqn. (5) may be considered as an absolute minimum value. If a default anode distance of 300 m is adopted (5.6.1), typical bracelet anode dimensions will normally give a significantly higher anode mass to be installed. Any excess anode mass installed can be utilised as a contingency in case the calculated current demand was underestimated due to e.g. pipeline components not included in the current demand calculations, or unforeseen mechanical damage to the coating during installation and/or operation, or if the design life of the pipeline is extended. (For inclusion of contingency in pipeline CP design, see Guidance note to 1.2.1).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.4.2 The anode utilisation factor u (dimensionless) shall be selected according to ISO 15589-2, Sec. 7.4; i.e. maximum 0.80 for bracelet anodes, and maximum 0.90 for elongated stand-off type of anodes placed on other subsea structures for protection of the pipeline.

Guidance note:

u depends on the anode core arrangement and for special anode designs, the actual value may be smaller than the default values defined above. Candidate anode manufacturers should be consulted in such cases.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.4.3 According to ISO 15589-2, the anode material electrochemical capacity (ε) used for CP design shall take into account the effect of the estimated anode current density according to Sec. A.9 in Annex A of the standard. The ISO standard further requires that the use of data according to Table 4 shall be documented by long term testing according to Annex B of the standard. It is recommended in this RP that if data for Al-Zn-In anodes (meeting the compositional requirements in Table 5 of the ISO standard) at the applicable temperature and anode current density are not at hand, the data in Table 4 of the ISO standard shall be used, multiplied by a design factor of 0.8 (dimensionless). As an example, this will give 2,000 Ah/kg and 1,600 Ah/kg for anodes exposed to seawater and marine sediments, respectively, at anode surface temperatures up to 30°C. The data for zinc anode materials (meeting the compositional requirements in Table 6 of the ISO standard) in Table 4 of the standard are applicable also at low current densities. The temperature limits for Al-Zn-In and Zn anodes in the ISO standard (Table 4) shall apply, see 5.4.4 below.

Guidance note:

Data on anode electrochemical efficiency from laboratory examinations will typically result in values close to the theoretical limit (e.g. >2,500 Ah/kg for Al-Zn-In material). This is due to the relatively high anodic current densities that are utilized for testing. Such data shall not replace the recommended design values for electrochemical capacity. The use of higher electrochemical efficiency than the default values defined above should be justified by long term testing according to Annex B of the ISO standard.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.4.4 For anodes on pipelines defined as "non-buried" for calculation of current demand (see 5.2.4), the electrochemical capacity for anodes "immersed in seawater at anode surface temperature ≤30°C" as defined in Table 4 of the ISO standard are applicable (i.e. according to 5.4.3), also if the fluid temperature is higher than 30°C. For anodes on "buried" sections (5.2.4), the internal fluid temperature may be used as a conservative estimate of the anode surface temperature. As an alternative, the anode surface temperature may be estimated by heat transfer calculations taking into account any thermal insulation applied between anode and steel surface, in addition to environmental parameters.

Guidance note:

The use of Al-Zn-In or Zn based anode alloys for surface temperatures higher than 80°C and 50°C, respectively, shall be qualified by realistic long-term testing. However, it is recommended primarily to avoid such temperatures by application of heat insulation between anode and, pipe wall or by installing anodes freely exposed to seawater whenever practical. Hence, cathodic protection of a relatively short "buried" section can readily be provided by adjacent anodes on "non-buried" sections.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.5 Calculation of total anode current output to meet final current demand

5.5.1 Based on the total net anode mass (M) for the pipeline or pipeline section calculated from equation (5) and the pipeline outer diameter (including coating), a tentative pipeline anode dimension can be defined. The 'final anode current output' I_{af} (A) of an anode (with tentative dimensions) at the end of its design life shall be calculated in accordance with ISO 15589-2, Annex A, Sec. A.7 using the equation

$$I_{af} = \frac{(E_c^\circ - E_a^\circ)}{R_{af}} \qquad (6)$$

where E_a°(V) is the 'design closed circuit anode potential'. The design values in Table 4 of the ISO standard shall apply. E_c° (V) in equation (6) is the 'design protective potential' of the linepipe material to be protected (see 5.6.11) and R_{af} (ohm) is the 'final anode resistance'. Equation (6) assumes that the metallic resistance in the pipeline is much smaller than the 'anode electrolytic resistance' R_{af}. This assumption is applicable to all types of pipelines with pipeline coatings as defined in DNV-RP-F106 and DNV-RP-F102 and with a distance from the anode of up to 300 m as a minimum.

Guidance note:

The design protective potential (E_c°) as defined in 5.6.11 is applicable also when a more negative protection potential is aimed for during operation of the pipeline. Hence, I_{af} is calculated to ensure sufficient polarizing capacity of the CP system based on R_{af} and using the design protective potential as a default value for definition of the driving voltage.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.5.2 The final anode resistance R_{af} in equation (6) shall be calculated according to Annex A, Sec. A.8 of ISO 15589-2. For pipelines defined as "non-buried" in 5.2.4, the ambient temperature seawater resistivity is applicable for calculation of R_{af}. The seawater resistivity (annual average) may be estimated based on Fig. 1 in Annex A of the ISO standard. For buried pipeline anodes, an actually measured soil resistivity should be applied, corrected for any annual temperature variations. As an alternative, a default value of 1.5 ohm·m may be used.

5.5.3 From the final (individual) anode current output (I_{af}), and the 'total final current demand' I_{cf}(tot) for cathodic protection of a pipeline section, the required number (N) of anodes becomes

$$N = \frac{I_{cf}(tot)}{I_{af}} \qquad (7)$$

in accordance with Annex A, Sec. A.7 of the ISO standard. This exercise may involve some adjustment(s) of the initially selected (tentative) anode dimensions and re-iterative calculations in order to meet the requirements for both total net anode mass M and 'total final anode current output' ($N \cdot I_{af}$).

5.6 Distribution of anodes

5.6.1 In ISO 15589-2, Sec. 7.1 a default maximum anode distance of 300 m is advised for pipeline CP design. It is presumed in the standard that this distance will ensure sufficient anode current output in the event an adjacent anode is lost such that the actual anode distance becomes 600 m. For larger distances than 300 m (i.e. by design), the effect of the metallic resistance in the pipe wall shall be taken into account.

Guidance note:

For medium and long distance export pipelines with concrete coating, the concept of using pre-installed anodes and with a default maximum distance of 300 m is adequate for most purposes (See Guidance note to 5.4.1). Except for very long design lives (> 30 years), a typical bracelet anode size (i.e. convenient for casting) will then give an installed anode net mass that exceeds the calculated required net anode mass.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.2 According to this RP, short pipelines (<10-30 km approximately depending on the design and operating conditions) may be protected by installing anodes on subsea structures located at the pipeline termination(s) and to which the pipeline is electrically connected. Examples of such structures are subsea production templates, riser bases and platform substructures. Anodes (elongated type) may also be installed on a dedicated structure (sledge) with a cable connection for electrical continuity to the pipeline. Calculations of anode current output from such anode arrangements shall take into account the significance of a voltage drop in the cable connection and any interaction between closely spaced anodes affecting their electrolytic resistance (i.e. "anode resistance" according to 5.5.2).

Guidance note:

Also the ISO 15589-2 encourages CP of short pipelines by anodes located at each end of the pipeline. To calculate the protective length of such anodes, this standard recommends so-called attenuation calculations contained in an Annex A. These formulas are fairly complicated and contain the pipe-to-electrolyte insulation resistance as the most critical parameter and which (quote:) should be selected based on practical experience. This RP, however, offers a simplified approach with specification of all required design parameters.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.3 The length of a pipeline L (m) that can be protected by anodes located on a secondary structure (with excess CP capacity, see 5.6.8) is determined by the 'global cathodic potential' E'_c (V) at this structure, the design protective potential $E_c°$ (V) of the linepipe material and the 'metallic voltage drop' ΔE_{Me} (V) associated with the electrical current I_{cf} in the pipeline and its 'metallic resistance' R_{Me} (ohm). It follows from Ohm's law:

$$\Delta E_{Me} = E_c° - E'_c = R_{Me} \cdot I_{cf} \qquad (8)$$

5.6.4 The total cathodic current entering the pipe section of L becomes:

$$I_{cf} = L \cdot D \cdot \pi \cdot f'_{cf} \cdot i_{cm} \qquad (9)$$

where

D (m) is the linepipe outer diameter

f'_{cf} (dimensionless) is the 'final coating breakdown factor' calculated as a mean value for linepipe and field joint coating according to

$$f'_{cf} = f_{cf}\,(\text{linepipe}) + r \cdot f_{cf}\,(\text{FJC}) \qquad (10)$$

where r is the ratio of the lengths of the cutbacks and the linepipe coating for the specific pipeline or pipeline section.

Guidance note:

The length of cut-back refers to the corrosion protective coating. For cutbacks with length < 0.20 m, a default minimum value of 0.20 m is recommended. With this default value, and for a pipeline section with all joints of 12 m length approximately, r = 0.033 and $f'_{cf} = f_{cf}$ (linepipe) + 0.033 f_{cf} (FJC).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.5 The metallic resistance R_{Me} is calculated from:

$$R_{Me} = \frac{L \cdot \rho_{Me}}{\pi \cdot d \cdot (D - d)} \qquad (11)$$

where d (m) is the pipe wall thickness and ρ_{Me} (ohm·m) is the resistivity of the linepipe material.

5.6.6 Assuming that the cathodic current is largely uniformly distributed on L, and inserting equation (9) and equation (11) in equation (8):

$$\Delta E_{Me} = E_c° - E'_c = \frac{L^2 \cdot \rho_{Me} \cdot f'_{cf} \cdot i_{cm} \cdot D}{2 \cdot d \cdot (D - d)} \qquad (12)$$

and L becomes

$$L = \sqrt{\frac{2 \cdot \Delta E_{Me} \cdot d \cdot (D - d)}{\rho_{Me} \cdot D \cdot f'_{cf} \cdot i_{cm}}} \qquad (13)$$

The above equation gives a simplified method to assess the voltage drop associated with a cathodic current in a pipeline.

5.6.7 In case the cathodic current is expected to be unevenly distributed along L, it may be assumed conservatively that all current enters at L such that

$$L = \sqrt{\frac{\Delta E_{Me} \cdot d \cdot (D - d)}{\rho_{Me} \cdot D \cdot f'_{cf} \cdot i_{cm}}} \qquad (14)$$

5.6.8 For cathodic protection by anodes on coated subsea structures freely exposed to seawater, a design global protection potential (E'_c) of - 0.95 V is recommended as a reasonably conservative default value. For structures with major areas in bare steel (e.g. platform sub-structures) - 0.90 V is recommended as a default value.

Guidance note:

A pipeline CP design based on anodes located on adjacent structures must ensure that the CP systems of these structures are sufficiently robust. Hence, towards the end of the life of a CP system, the global protective level may decrease to values less negative than those assumed above. For new structures, the CP system can be designed with an additional conservatism (e.g. extended CP design life). For an existing structure with marginal CP capacity, monitoring of the global protection potential and ultimately retrofitting of anodes may be required. (Note also that even with dedicated pipeline anodes, a pipeline electrically connected to structures with marginal CP may suffer premature anode consumption and ultimately underprotection.)

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.9 If CP is to be provided by bracelet anodes, and the default value of maximum 300 m according to 5.6.1 shall not apply, then the maximum distance between successive anodes may be calculated using equation (17) below. For a pipeline section with a length of L_{tot} (m) to be protected by N bracelet anodes, the maximum distance between anodes becomes 2L:

$$2L = \frac{L_{tot}}{N} \qquad (15)$$

L may be calculated taking into account both the electrolytic voltage drop ΔE_A (V) and the metallic voltage drop ΔE_{Me} for which the following relation applies:

$$\Delta E_A + \Delta E_{Me} = E_c° - E_a° \qquad (16)$$

Inserting equation (7), equation (12) and equation (15) into equation (16), L becomes:

$$L = \frac{d \cdot (D-d)}{\rho_{Me} \cdot D \cdot f'_{cf} \cdot i_{cm}} \cdot \left\{ -\frac{2 \cdot R_{af} \cdot I_{cf}(tot)}{L_{tot}} + \sqrt{\frac{4 \cdot R_{af}^2 \cdot I_{cf}^2(tot)}{L_{tot}^2} + \frac{2 \cdot \rho_{Me} \cdot i_{cm} \cdot f'_{cf} \cdot D}{d \cdot (D-d)} \cdot (E_c^\circ - E_a^\circ)} \right\} \quad (17)$$

If the loss of an anode is taken into account, the maximum anode distance to provide sufficient anode current output becomes L in stead of 2L.

It is subsequently to be confirmed that the individual net anode mass M_a (kg) meets the total net anode mass requirement (M):

$$N \cdot M_a = M \qquad (18)$$

Guidance note:

The minimum anode distance (L) calculated from eqn. (17) may be considered as an absolute minimum value and not an optimum distance. The definition of distance between bracelet anodes (i.e. other than the default value of 300 m recommended in 5.6.1) will be dependant on the anode design, the installation concept (onshore/offshore installation) and the minimum net anode mass required (see 5.4.1).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.10 The following default values for specific electrical resistivity (ρ_{Me}) of the linepipe material (applicable to all practical pipeline operating temperatures) and to be used for calculation of L are recommended:

- CMn-steel linepipe	0.2 10^{-6}·ohm·m
- Type 13Cr linepipe	0.8 10^{-6}·ohm·m
- Type 22Cr/25Cr linepipe	1.0 10^{-6}·ohm·m

5.6.11 The following design protective potentials $E_c°$ are recommended for calculation of L according to (13), (14) and (17) :

- For CMn steel linepipe	- 0.80 V
- For martensitic stainless steel type 13 Cr linepipe	- 0.60 V
- For ferritic-austenitic (duplex) stainless steel linepipe	- 0.50 V

The potentials above refer to a Ag/AgCl/seawater reference electrode and are applicable to both buried and unburied pipelines.

Guidance note:

Ordinary Al-Zn-In and Zn anode materials may provide protection potentials approaching a negative limit of -1.15 and -1.05 V respectively. It may be decided during the conceptual pipeline design (see 1.1.3) to restrict such negative potentials to avoid or reduce the potential for hydrogen embrittlement of susceptible pipeline materials. This can be achieved by special anode alloys or installation of diodes, however, practical experience from such potential control is largely lacking.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.7 Documentation of completed CP detailed design

5.7.1 The following documentation shall be contained in the CP detailed design report:

— References to relevant codes, standards and project specifications (including revision number).
— Calculation of average and final current demands for individual sections of the pipeline.
— Calculation of total anode net mass for the individual sections, to meet the average current demand(s).
— Selection of bracelet anode and/or anodes on adjacent structure as concept for CP of the pipeline.
— Calculations of pipeline metallic resistance to verify the feasibility of CP by anodes on adjacent structure(s) as the final CP concept or a bracelet anode spacing exceeding the default maximum value of 300 m recommended in ISO 15589-2 (i.e. if any of these options apply).
— Calculation of final anode current output to verify that the final current demand can be met for the individual sections of the pipeline.
— Number of anodes for the individual pipeline sections, and resulting total net anode mass to be installed on each section.
— Outline drawing(s) of anodes with fastening devices and including tentative tolerances.

Guidance note:

Purchaser should consider carrying out a third party verification of the detailed CP design documentation. Anode design may have major implications for pipeline installation and should be reviewed and accepted by installation contractor.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6. Anode Manufacturing

6.1 General

6.1.1 This section covers the manufacturing of galvanic anodes, including preparation of anode cores. The requirements and guidelines in this section are in compliance with those in ISO 15589-2, Sec. 8 and Sec. 9, giving some amendments, mostly related to quality control. This section is primarily intended for manufacturing of pipeline (bracelet type) anodes. For manufacture of other anodes located on adjacent structures electrically connected to the pipeline and intended for pipeline CP, see DNV-RP-B401.

6.2 Manufacturing procedure specification

6.2.1 All work associated with the manufacturing of galvanic anodes, including any qualification of the manufacturing procedure by 'pre-production qualification testing' (PQT, see 6.3) shall be described in a 'manufacturing procedure specification' (MPS). This document shall include as a minimum:

— specification of anode core materials
— receipt, handling and storage of materials
— maximum and/or minimum contents of anode material alloying elements and max contents of impurity elements
— detailed anode drawing, with anode inserts, including tolerances
— welding procedure specification and reference to qualification test (WPQ) for welding of anode cores, and qualification requirements for welders
— preparation of anode cores prior to casting
— anode casting, including control of temperature and addition of alloying elements
— inspection and testing of anodes
— coating of bracelet anode surface facing pipeline, if applicable
— handling, storage and shipping of anodes
— marking, traceability and documentation.

Anode chemical composition limits, detailed anode drawing and procedures for the last 2 items are all subject to acceptance by Purchaser.

6.2.2 Purchaser may specify that detailed procedures for testing/inspection and other information relevant to quality control are included in the MPS, e.g. detailed procedures for inspection and testing, handling of non-conformances (6.6.6) and concession requests (6.5.6).

6.3 Pre-production qualification testing (PQT)

6.3.1 The primary objective of the 'pre-production qualification testing' (PQT) is to verify that the MPS is adequate to achieve the specified anode properties. Of particular interest are those aspects that require destructive testing and hence cannot be frequently verified during regular production. The PQT shall use the specific materials and equipment as for regular production.

Guidance note:

It is recommended that the requirement for a PQT of pipeline bracelet anodes is not waived, that the PQT is performed in due time prior to start of the production, and that it is witnessed by a competent person representing Purchaser.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.3.2 Specific requirements to the PQT, including e.g. number of anodes to be cast for each mould and inspected (including those for destructive examination), schedule for notification and reporting, shall be specified in the purchase documents.

6.3.3 An MPS and an 'inspection and test plan' (ITP, see 6.4.2) specific for the PQT, together with a detailed schedule for anode casting, inspection and/or testing, and reporting shall be submitted to Purchaser in a timely manner (as per the purchase document) prior to start-up of the qualification activities.

6.3.4 Data sheets and calibration certificates for instruments essential to quality control (e.g. temperature sensors) shall be available for Purchaser's review during the PQT.

6.3.5 Results from all inspection, testing and calibrations during qualification, recordings of essential operational parameters for casting and material certificates shall be compiled in a PQT report. Unless otherwise agreed, the report shall be accepted by Purchaser prior to start of production.

6.4 Quality control of production

6.4.1 Prior to start-up of regular production, Contractor shall submit the following documents to Purchaser for acceptance:

— a project specific MPS updated to reflect the process parameters used during the completed and accepted PQT
— a project specific 'inspection and testing plan' (ITP) updated to reflect the process parameters used during the completed and accepted PQT
— a 'daily log' format (see 6.6.9).
— a description of responsibilities of personnel involved in quality control.

6.4.2 The ITP shall meet the general requirements of ISO 10005, Sec. 5.10. It shall be in tabular form, defining all quality control activities associated with receipt of materials, preparation of anode cores, casting, inspection, testing and marking of anodes. The activities shall be listed in consecutive order, with each activity assigned a unique number and with reference to the applicable codes, standards and Contractor's procedures or work instructions that shall apply for the specific project. Furthermore, frequency and/or extent of inspection and testing, acceptance criteria and actions in the case of non-conformances shall be defined in the plan. The ITP shall further contain a column for inspection codes, (e.g. inspection, witnessing and hold points) indicating the involvement of Contractor, Purchaser and any 3rd party. It is good practice to include a reference to the applicable reporting form or document, and to refer to the specific equipment or tools to be used for verification.

Guidance note:

It is recommended that the ITP also reflects the relevant manufacturing steps, in addition to the inspection and testing activities, all in the consecutive order they occur during production. Such a document is sometimes referred to as a 'manufacturing and inspection plan' (MIP).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.4.3 The MPS, ITP, and 'daily log' shall be in English, unless otherwise agreed.

6.4.4 Procedures and work instructions referenced in the ITP, and applicable acceptance criteria, shall be available to all persons concerned with the associated work and in their normal language.

6.4.5 Purchaser shall have the right to inspect any activity associated with the work throughout production and to carry out audits of Contractor's QA / QC system. Purchaser shall identify any hold points for witnessing in the ITP and inform Contractor accordingly.

6.5 Materials and casting

6.5.1 Purchaser should specify compositional limits (alloying and impurity limits) for sacrificial anode materials.

Guidance note:

"Typical" chemical compositions for Al-Zn-In and Zn base anode materials are given in ISO 15589-2, Clause 8.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.5.2 Contractor shall verify that all materials received for anode manufacturing are in accordance with the specified requirements. The verification may include actual testing or review of supplier's certificates. Review of certificates and any verification testing to be performed by Contractor shall be included in the ITP. Any materials checked and found non-conforming shall be marked and quarantined.

6.5.3 Materials, welding, surface preparation and final inspection of anode cores and any coating of bracelet anode sides facing the pipeline shall comply with ISO 15589-2, Clause 8.

6.5.4 Materials to be used for surface preparation and coating shall be contained in their original packing until use and shall be adequately marked, including:

— manufacturer's name and location of manufacture
— material type and product designation
— batch/lot number
— date of manufacturing (and shelf life, if applicable)
— manufacturing standard (if applicable)
— instruction for storage and handling (including health and safety notes).

6.5.5 Contractor shall ensure that any materials for coating and surface preparation are stored and handled so as to avoid damage by environment or other effects. Supplier's recommendations for storage and use shall be readily available for Purchaser's review.

6.5.6 All work associated with preparation of anode cores and casting of anodes shall be carried out according to the qualified MPS, describing equipment and procedures to be used. Once the MPS have been qualified, any changes shall be formally accepted by Purchaser through a 'concession request' (CR).

6.5.7 Equipment for monitoring of process parameters critical to quality (e.g. temperature sensors) shall be calibrated at scheduled intervals as specified in the ITP (6.4.2).

6.5.8 All anodes produced shall be traceable to certificates for anode core materials, and to coating materials, if applicable.

6.6 Inspection and testing of anodes

6.6.1 Chemical composition of produced anodes shall be verified at a frequency as defined in ISO 15589-2, Sec. 9.2. For spectrometric analyses of anode chemical composition, reference standards with a chemical composition (i.e. for the specified contents of alloying and impurity elements) certified by an independent party shall be used. Purchaser shall have the right to require anode sample material for verification testing in an independent laboratory, or to present samples for testing by Purchaser. Purchaser may further specify that Contractor shall retain sample material for any additional chemical analyses and/or electrochemical testing.

6.6.2 For verification of anode dimensions and weight, visual examination of anode surfaces for cracks/pores, destructive testing for internal defects and testing of electrochemical performance, including frequency of testing and acceptance criteria, reference is made to ISO 15589-2, Sec. 9.3 -9.9.

Guidance note:
As far as practical, acceptance criteria for surface defects shall be defined in MPS/MIP in quantitative terms.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.6.3 Any requirements for additional destructive testing of anodes during production and fit-up tests for verification of bracelet anode tab locations (e.g. fit-up test on dummy pipe sample) shall be specified in purchase order. Purchaser shall have the right to select anodes for such batch wise testing.

Guidance note:
Anode tabs refer to parts of anode cores protruding from the anode surface and to be used for anode fastening.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.6.4 Failures during testing which are obviously due to defective sampling or operational errors of testing equipment may be disregarded and testing repeated on the same anode.

6.6.5 In case of failure during fractional testing (e.g. destructive testing of one per 50 anodes), the preceding and following anodes shall be tested individually until at least 3 successive anodes are acceptable.

6.6.6 In case of repeated failures to meet specified properties, production shall be discontinued and Contractor shall issue a 'non-conformance report' and the cause of the failure shall be determined. Non-conforming anodes (individual or lots) shall be marked and quarantined.

6.6.7 All data from inspection and testing of anodes and calibration of testing and monitoring equipment shall be noted in the 'daily log'. For anode specific data, reference shall be made to the unique anode number or batch (6.7.2). The log shall be up-dated on a daily basis and shall be available for Purchaser's review at any time during manufacturing.

6.7 Documentation and marking

6.7.1 Specific requirements to marking and documentation format shall be specified in purchase document. Contractor's marking shall be descried in the MPS and included as a specific activity in the ITP.

6.7.2 All results from inspection and testing during qualification and production shall be documented and be traceable to a unique anode number (or batch of anodes as applicable), certificates for anode core materials and coating materials, if applicable. For specific requirements to a 'daily log', see 6.6.7.

6.7.3 Contractor shall issue an inspection document corresponding to the requirements given in EN 10204 or ISO 10474, inspection certificate 3.1.B.

6.7.4 Purchaser may specify special requirements to final documentation; e.g. format and schedule.

6.8 Handling, storage and shipping of anodes

6.8.1 Anodes shall be handled and stored such that damage to anode material and tabs is avoided, and in accordance with any special requirements in purchase documents. A procedure shall be contained in the MPS and is subject to acceptance by Purchaser.

6.8.2 Any special requirements for packaging or other means of protection of anodes for shipping shall be defined in the purchase documents.

7. Anode Installation

7.1 Design of anode attachment

7.1.1 The scope of this section is limited to the installation of pipeline anodes (bracelet type). For pipelines (or sections of pipelines) to be protected by anodes installed on adjacent structures, the project specifications for anode installation on such structures will apply. The requirements and guidelines in this section are in general compliance with those in ISO 15589-2, Sec. 10, giving some amendments, primarily related to quality control.

Guidance note:
For pipeline bracelet anodes to be installed on top of the pipeline coating, the design of anode installation devices should be addressed already during the pipeline conceptual design and completed during the detailed design. Purchaser of anodes should consider the need for verification of the final anode design by the installation contractor prior to casting of anodes.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

7.1.2 Anode fastening by fusion welding to either linepipe or pressure containing components in 'corrosion resistant alloys' (CRA) should preferably be avoided (even if doubler plates are applied). Electrical contact to the pipeline is then to be provided using thermite (alumino-thermic) welding, brazing or explosion welding. The heat input from a thermite or welding process shall be controlled so that excessive heat input is prevented. If welding is applied for fastening of anodes, the WPQ shall ensure that the maximum hardness in the heat affected zone does not exceed 300 HV or 350 HV for ferritic/martensitic and ferritic-austenitic (duplex) linepipe materials, respectively.

7.1.3 Bracelet anodes shall be attached to the pipe by bolting or welding of anode core tabs (see Guidance Note to 6.6.3). For any bolting materials to be used, specified minimum yield strength (SMYS) shall not exceed 720 MPa.

Guidance note:
It is recommended that the integrity of bracelet anodes attached by clamping on top of the linepipe coating is verified by calculations or testing, simulating maximum shear stresses during installation operations.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

7.1.4 Materials to be used for cables and cable connections shall comply with the requirements in ISO 15589-2. The design shall ensure that anode cables are protected, e.g. by use of suitable infill materials, during transportation of pipe joints with anodes attached and the subsequent pipeline installation. Damage to linepipe coating due to fastening of anodes shall be repaired (ref. DNV-RP-F102).

7.2 Installation procedure specification

7.2.1 All work associated with the installation of galvanic anodes on pipelines, including any qualification of the manufacturing procedure by a 'pre-production qualification test' (PQT) shall be described in an 'installation procedure specification' (IPS). This document shall include, as a minimum:

— specification of materials and equipment to be used, including certificates and material data sheets
— receipt, handling and storage of anodes and materials for anode installation

- detailed drawing of anode installation, including tolerances
- inspection and testing of anode fastening
- documentation of design, materials and inspection records.

7.3 Pre-production qualification testing (PQT)

7.3.1 The primary objective of the 'pre-production qualification test' (PQT) is to verify that the IPS is adequate to achieve the specified properties. Of particular interest are those aspects that require destructive testing and hence cannot be frequently verified during regular production. Furthermore, it shall be demonstrated that anode installation does not damage any adjacent coating.

7.3.2 All welding and/or brazing procedures associated with anode installation shall be qualified according to ISO 13847 limiting hardness and copper penetration at the fusion line. Only qualified welders and/or operators of brazing equipment shall be used.

7.3.3 An IPS specific for the PQT, together with a detailed schedule shall be submitted to Purchaser in a timely manner (as per purchase document) prior to start-up of the qualification activities.

7.3.4 Results from all inspection, testing and calibrations during qualification, welding procedure qualification tests, material data sheets and certificates, manuals for brazing equipment and any other relevant items shall be compiled in a PQT report. Unless otherwise agreed, the report shall be accepted by Purchaser prior to start of production.

7.4 Quality control during production

7.4.1 Prior to start-up of anode installation, Contractor shall submit to Purchaser for acceptance a project specific IPS, updated to reflect the process parameters used during the completed PQT.

7.4.2 For more complicated anode installation work; e.g. involving repair of linepipe coating, the following additional documentation shall be included:

- a project specific 'inspection and testing plan' (ITP) for production
- a 'daily log' format (see 6.6.7)
- a description of responsibilities of personnel involved in quality control.

7.5 Receipt and handling of anodes and materials for installation

7.5.1 Prior to installation, all anodes supplied by Purchaser shall be inspected by Contractor to confirm no significant damage or other adverse effects. Non-conforming anodes and other materials shall be quarantined.

7.5.2 Contractor shall ensure that anodes and other materials for anode installation are stored and handled so as to avoid damage by environment or other effects. Supplier's recommendations for storage and use shall be readily available for Purchaser's review.

7.5.3 Purchaser may specify special requirements to verification and handling of received anodes and installation materials.

7.6 Anode installation

7.6.1 All work associated with anode installation shall be carried out according to the qualified IPS and WPS, describing equipment and procedures to be used. Once the IPS / WPS have been qualified, any changes shall be formally accepted by Purchaser through a CR.

7.6.2 The location of anodes in relation to pipe ends or field joints shall be as specified (or accepted) by Purchaser. For anodes to be installed on concrete coated pipes, provisions shall be made to prevent any electrical contact between anodes and the steel reinforcement (to be addressed in IPS).

7.6.3 Any repair of linepipe coating and application of infill materials associated with anode installation should be carried out according to the applicable sections of DNV-RP-F102.

7.7 Inspection and testing of anode installation

7.7.1 Inspection of anode installation shall include visual examination of welds and brazed connections. The integrity of each thermite welded or brazed electrical connection shall be tested by a sharp blow with a 1 kg hard rubber headed hammer.

7.7.2 For inspection of any linepipe coating repairs, reference is made to DNV-RP-F102. Any spillage of infill on the anode surface shall be removed.

7.8 Documentation

7.8.1 For documentation to be provided prior to start of production, see 7.2, 7.3 and 7.4.1 above.

7.8.2 The final documentation shall contain certificates for installation materials (including welding and/or brazing consumables) and reports from all inspection and testing.

7.8.3 Purchaser may specify special requirements to final documentation; e.g. format and schedule.

8. ANNEX 1 Recommendations for Coating Breakdown Factors

Table A.1: Recommendations for constants "a" and "b" to be used for calculation of coating breakdown factors associated with specific linepipe coating systems as defined in DNV-RP-F106.

(Maximum temperatures refer to continuous operation and are indicative only. Manufacturer's recommendations shall always apply. For coatings with an inner layer of FBE and operating temperatures above 90°C, adequate properties shall be documented by pre-qualification and/or PQT. The same applies for polychloroprene based coatings at operating temperatures above 90°C)

Linepipe Coating Type	*DNV-RP-F106 CDS*	*Concrete Weight Coating*	*Max. Temperature (°C)*	*a x100*	*b x100*
Glass Fibre Reinforced Asphalt Enamel	No. 5	yes	70	0.3	0.01
Glass Fibre Reinforced Coal Tar Enamel	No. 6	yes	80	0.3	0.01
Single or Dual Layer FBE	No. 1	yes	90	1	0.03
3-layer FBE/PE	No. 2	yes	80	0.1	0.003
3-layer FBE/PP	No. 3	no	110	0.1	0.003
Multi-Layer FBE/PP	No. 4	no	140	0.03	0.001
Polychloroprene	No. 7	no	90	0.1	0.01

Note: x100 in the heading of the two column to the right means that all figures in these columns have been multiplied by a factor of 100; i.e. before use in eqns. (2) or (4), the numbers shall be multiplied with a factor 10^{-2}.

Table A.2: Recommendations for constants "a" and "b" to be used for calculation of coating breakdown factors associated with specific field joint coating systems, with and without infill, as defined in DNV-RP-F102.

(Maximum temperatures refer to continuous operation ad are indicative only. Manufacturer's recommendations shall always apply. For coatings with an inner layer of FBE and operating temperatures above 90°C, adequate properties shall be documented by pre-qualification and/or PQT. The same applies for polychloroprene based coatings at operating temperatures above 100°C)

FJC Type (DNV-RP-F102 FJC System)	*Infill Type (DNV-RP-F102 System)*	*Max. Temperature (°C)*	*Examples of Compatibility with DNV-RP-F106 Linepipe Coating System*	*a x100*	*b x100*
None	II (PU), III (Concrete) or IV (PP)		CDS no 1, 2, 5, 6 with concrete, CDS no. 4	30	3
1A Adhesive Tape or Heat Shrink Sleeve (PVC/PE backing) with mastic adhesive	I (Mastic), II or III	70	CDS no 5 and 6 with concrete	10	1
2A Heat Shrink Sleeve (Backing + adhesive in PE, LE primer)	II or III	70	CDS no. 2 with concrete	3	0.3
2B Heat Shrink Sleeve (Backing + adhesive in PP, LE primer)	none	110	CDS no. 3	3	0.3
3A FBE	none	90	CDS no. 1	3	0.3
3B FBE with PE Heat Shrink Sleeve	II or III	80	CDS no. 2 with concrete	1	0.03
3C FBE with PP Heat Shrink Sleeve	None or II	140	CDS no. 3	1	0.03
3D FBE, PP adhesive and PP (wrapped, extruded or flame sprayed)	None or II	140	CDS no. 3 or 4	1	0.03
4A Polychloroprene	none	90	CDS no. 7	1	0.03

Note: x100 in the heading of the two column to the right means that all figures in these columns have been multiplied by a factor of 100; i.e. before use in eqns. (2) or (4), the numbers shall be multiplied with a factor 10^{-2}.