TECHNICAL SPECIFICATION

DESIGN OF CATHODIC PROTECTION SYSTEMS FOR OFFSHORE PIPELINES

(AMENDMENTS/SUPPLEMENTS TO DNV RP B401)

DEP 30.10.73.32-Gen.

July 1996

DESIGN AND ENGINEERING PRACTICE

PREFACE

DEP (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell International Oil Products B.V. (SIOP)
and
Shell International Exploration and Production B.V. (SIEP)
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Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

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APPENDICES

PART I INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design of cathodic protection systems for offshore pipelines.

This DEP may also be applied to submerged pipeline sections of on-shore pipelines.

Short "offshore" pipelines or pipeline sections (e.g. loading lines) may sometimes be protected by onshore based (impressed current) cathodic protection installations. For such installations reference is made to DEP 30.10.73.31-Gen.

This DEP is based on DNV Recommended Practice RP B401, 1993 edition. Part III of this DEP gives amendments and supplements to RP B401.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F" as defined in DEP 00.00.05.05-Gen.).

This DEP is intended to be used for new offshore pipeline construction projects in relation to oil and gas production facilities, oil refineries, chemical plants, gas plants and supply/marketing installations. This DEP is not intended to be used for retrofitting of cathodic protection systems on existing offshore pipelines.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, installation, and commissioning or management of a project or operation or maintenance of a facility. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorised to act for the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific Definitions

Anode Manufacturer/Supplier - the manufacturer/supplier of sacrificial anodes and related materials

Cathodic protection design Contractor - the party responsible for the design of the cathodic protection system and ultimately responsible for the functioning of the cathodic protection system.

Cathodic protection installation Contractor - the party responsible for the installation of the cathodic protection system in accordance with the design and with this DEP.

Coating breakdown factor - the ratio between the surface area of exposed metal due to coating breakdown and the total surface area under consideration. The factor is used to determine the average current density on coated metal from current densities compared with that for bare steel.

Conceptual design - early design phase, preceding detailed design.

Foreign structures/pipelines - metal structures, or pipelines other than the pipeline under consideration, in contact with the same electrolyte as the pipeline, and which (may) come under the influence of the pipeline's cathodic protection system. Foreign structures/pipelines may be owned by the Principal or other companies and may or may not be equipped with cathodic protection.

Pipe to (sea)water potential - the difference in electrochemical potential between a pipeline or foreign structure/pipeline and a specified reference electrode in contact with the electrolyte. Similar terms such as structure to (sea)water potential, pipe to electrolyte potential and pipe to soil potential are sometimes used as applicable in the particular context.

Requisition - the data/requisition sheet(s) DEP 30.10.73.94-Gen., to be used by the Principal and completed by the Contractor. A specimen copy for information is included in Appendix 1. The actual sheets can be found in the requisitioning binder (DEP 30.10.01.10-Gen.).

1.4 ABBREVIATIONS

Ag/AgCl	Silver/silver chloride as used for the Silver/silver chloride type of reference electrode.
$Cu/CuSO_4$	Copper/copper sulphate as used for the Copper/copper sulphate type of reference electrode.
AC	Alternating current
Ah/kg	Ampere-hours per kilogram
DC	Direct current
DNV	Det Norske Veritas
GRE	Glass reinforced epoxy
PE	Polyethylene
SCE	Saturated calomel electrode

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section is shown in brackets. Other documents referenced by this DEP are listed in (Part IV).

1.6 GUIDANCE FOR USE

Part III contains amendments/supplements which are directly related to equivalent sections in DNV RP B401. For clarity, the section numbering of DNV RP B401 has been used. Where sections in DNV RP B401 are referenced in this DEP, those sections as amended/supplemented by this DEP are meant. Sections in DNV RP B401 that are not amended/supplemented by this DEP shall remain valid as written.

PART II DESIGN PHILOSOPHY

1.1 GENERAL

Offshore pipelines shall be protected from sub-sea corrosion using a combination of external coatings and cathodic protection. The cathodic protection system shall be designed to maintain the exposed pipeline metal surfaces within an electrochemical potential range which controls corrosion within acceptable limits without causing material damage.

The recommended cathodic protection system for newly constructed offshore pipelines features bracelet-type sacrificial anodes. The use of impressed current is not recommended except where successfully in use for existing pipelines and for retrofit purposes when sacrificial systems are not feasible.

For offshore pipelines the pipe-to-sea water "ON" potential is used as a criterion for effective cathodic protection. "OFF" potentials may be applicable to impressed current systems in high-resistivity waters.

The cathodic protection system shall maintain the pipe-to-sea water potential of pipelines between - 800 and -1100 mV with respect to an Ag/AgCl reference cell.

The effect of cathodic protection on corrosion resistant steels and some high strength steels depends on the susceptibility of the material to hydrogen induced stress cracking. Practical potential levels obtained from cathodic protection systems using Zinc or Aluminium sacrificial anodes are such that polarisation more negative than the above overprotection limit is avoided. Therefore, the use of materials, welded or not welded, susceptible to hydrogen embrittlement within the specified potential range shall not be used in conjunction with cathodic protection. Magnesium anodes or impressed current cathodic protection shall not be used for high strength steels or corrosion resistant steels.

The cathodic protection system shall be designed for the full design life of the pipeline.

Electrical pipeline isolation between compatible sacrificial anode cathodic protection systems installed on platforms and pipelines is not required. Offshore pipelines shall, however, be electrically isolated from on-shore pipelines and shore installations, structures equipped with impressed current systems and structures operated by third parties.

For new construction projects, the design of the cathodic protection system shall be an integral part of the total pipeline design. The design of cathodic protection systems shall be carried out by a professional and experienced cathodic protection design Contractor approved by the Principal.

1.2 CONCEPTUAL DESIGN

The Contractor shall submit to the Principal a conceptual cathodic protection design for review and approval which shall include the documentation listed in (6). Only after such approval shall the Contractor commence detailed design (1.3).

In some cases (e.g. on small projects or standard projects) the Principal may request the Contractor to carry out both conceptual design and detailed design in one operation.

1.3 DETAILED DESIGN

The detailed design shall contain all information required for the procurement of cathodic protection equipment and for the construction, commissioning, and hand over of the cathodic protection system. The detailed design package shall contain the documentation listed in (9).

PART III AMENDMENTS/SUPPLEMENTS TO DNV RP401, 1993 EDITION

The design of cathodic protection systems for offshore pipelines shall be in accordance with DNV RP B401, 1993 edition with the following amendments/supplements. Section numbers in the text of this section correspond with the respective section numbers in DNV RP B401. Unmentioned sections remain valid as written.

2. SCOPE

Delete this section and refer to Part I, Section 1.1 of this DEP.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1 PARTIES AND RESPONSIBILITIES

Replace the definitions of the parties with the following:

The "Operator" is the Principal (1.3.1).

The "Designer" is the cathodic protection design Contractor (1.3.2).

The "Fabricator" is the anode Manufacturer/Supplier or the cathodic protection installation Contractor (1.3.2) as apparent from the context or as specifically indicated in the text.

5. GENERAL DESIGN CONSIDERATIONS

Add to the beginning of this section:

The contents of this section are to be regarded as background information only. They are technically valid but do not provide any direct guidance for designing the cathodic protection system.

For some related subjects forming part of the Shell design philosophy on cathodic protection of offshore pipelines, refer to (Part II) of this DEP.

6. DESIGN PARAMETERS

6.1 GENERAL

Replace this section by the following:

This section specifies the parameters to be applied for cathodic protection systems based on sacrificial anodes.

The Principal shall submit to the Contractor all technical information required to carry out the cathodic protection design. The required information should be transmitted using the requisition and shall include:

- detailed information on the pipeline to be protected (material, length, diameter, coating, scope limits, operating temperature, etc.);
- sea water conditions if available (geographical area, sea water properties, pipeline depth);
- the design life of the system;
- requirements on cathodic protection systems and/or materials;
- information on existing pipelines in close proximity of the new pipeline;
- information on existing cathodic protection systems (platforms, shore etc.) and electrical pipeline isolation;
- relevant drawings.

6.2 DESIGN LIFE

6.2.3 Replace this section by:

The cathodic protection shall be designed such that no planned retrofitting is required during the design life of the protected pipeline.

6.3 DESIGN CURRENT DENSITIES

6.3.6 Replace this section by:

The current density required to achieve full protection depends on the sea water temperature and the water flow velocities over the pipeline surface.

For the design of the cathodic protection system for non-buried offshore pipelines under the various sea water conditions, the values given in Table 1 shall be used as a minimum for both average and final current densities.

The data for "Temperate waters" are applicable to the North Sea and the Norwegian Sea up to a latitude of 70 degrees North.

Table 1 Design current densities for non buried offshore pipelines in different sea water conditions.

	Design current density, mA/m^2		
Sea water temperature	Low lateral water flow /turbulence	Moderate lateral water flow /turbulence	High lateral water flow/turbulence or depth < 20 m
> 20 °C (Tropical waters)	50	60	70
12-20 °C (Sub tropical waters)	60	70	80
7-12 °C (Temperate waters)	70	80	100
< 7 °C (Arctic waters)	90	100	120

6.3.9 Delete this section

6.3.10 Delete this section

6.3.11 Delete this section

6.3.12 Delete this section

Delete Table 6.3.3

6.3.13 Delete this section

6.3.14 Delete this section

6.3.15 Delete this section

6.3.16 Delete this section

6.3.17 Delete this section

6.4 COATING BREAKDOWN FACTOR

6.4.4 Delete this section

Delete Figures 6.4.1 to 6.4.4

Delete Table 6.4.1

6.4.5 Delete this section

6.4.6 Delete this section

6.4.7 Delete this section

6.4.9 Delete this section

6.4.10 Delete this section

6.4.11 Delete this section

6.5 PIPELINE COATINGS

6.5.3 Delete this section

6.5.4 Delete this section

6.5.5 Replace this section by:

The constants k_1 and k_2 used for calculating coating breakdown factors for cathodic protection design for offshore pipelines in accordance with 6.4.8 are given in Table 2 of this DEP.

Table 2 Constants (k_1 and k_2) for calculation of coating breakdown factors for different pipeline coatings.

COATING TYPE	k_1	k_2	example for 20 year design life $f_{c(average)}/f_{c(final)}$
Asphalt and concrete weight coating,	0.02	0.004	0.04 / 0.10
FBE + adhesive + Polyethylene or Polypropylene	0.02	0.002	0.04 / 0.06
Polychloroprene / EPDM	0.01	0.002	0.03 / 0.05
Thermally insulated pipelines	0.01	0.001	0.02 / 0.03
Fusion bonded epoxy coating without mechanical protection	0.05	0.005	0.10 / 0.20

The coating breakdown factors calculated using the above data do not include any allowance for excessive damage to pipeline coatings during fabrication or installation or for field joints intentionally left uncoated. If such conditions are anticipated, the affected surface area shall be estimated and included in design calculations (7.3/7.4) as bare metal surface.

6.6 SACRIFICIAL ANODE MATERIAL PERFORMANCE

6.6.1 Replace this section by:

The sacrificial anode shall be an indium-activated aluminium alloy or shall be a zinc alloy in accordance with US Mil.Spec. 18001-K.

6.6.3 Replace this section by:

The values given by DNV RP B401, table 6.6.1 may be used for the conceptual design. For detailed design the electrochemical efficiency shall be given by the anode manufacturer as valid for the design conditions (anode current density, operating temperature). It is, however, recommended that electrochemical efficiencies used in design calculations based on the data in Table 1 shall not exceed 2500 Ah/kg for Al-base materials and 750 Ah/kg for Zn-base materials.

6.6.4 In the second paragraph, replace "internal fluid temperatures" by "anode operating temperatures".

6.6.5 Add to this section:

For detailed design the closed circuit anode potential shall be given by the anode Manufacturer as valid for the design conditions (sea water conditions, operating temperature).

7. DESIGN TASK

7.2 SUB-DIVISION OF OBJECT

Replace this section by:

Pipelines may be divided into discrete sections, e.g. where changes in operating temperature or burial conditions occur. Care shall be taken to ensure that different cathodic protection systems (e.g. different anode types) are compatible and that no excessive current drains from one system into an adjacent system.

7.5 CURRENT DRAIN CALCULATIONS

Add to this section:

Offshore pipelines shall be isolated from other unprotected structures which could drain current from the pipeline's cathodic protection system.

7.9 DETAILED ANODE DESIGN

7.9.3 Add to this section:

Anodes to be mounted on pipelines without concrete weight coating shall be designed with a tapered shape or be provided with tapered end fittings as required for the pipe laying process. For thermally insulated lines, tapered anodes shall be installed over the top of the insulation to reduce the anode temperature.

7.9.5 Add to this section:

The surfaces of all bracelet anodes facing the pipeline coating and facing the concrete weight coating (if applicable) shall be coated with coal tar epoxy paint with a dry film thickness of 100 µm.

7.10 DISTRIBUTION OF ANODES

7.10.5 Add to this section:

Anode spacing exceeding 100 m shall be justified by attenuation calculations or other mathematical modelling.

7.11 ANODE MOUNTING AND PROVISIONS FOR ELECTRICAL CONTINUITY

7.11.2 Add to this section:

Welding shall be carried out using qualified procedures approved by the Principal.

7.11.5 Replace this section by:

For bracelet anodes which are designed to be clamped onto the pipeline coating, electrical connections shall be made using a minimum of two PE sheathed stranded cables. The cable shall have a cross-sectional area of at least 10 mm^2.

7.11.10 Add a new section:

Cable attachments to the pipeline shall be coated to the same standard as the pipeline coating system. On stainless steel pipes, similar stainless steel cable attachments shall be used. "Thermit" welding shall not be performed on stainless steel.

7.12 ENGINEERING DOCUMENTATION

Replace this section by:

7.12.1 Design documents

The **conceptual design** documents shall be submitted for approval by the Principal, covering the following requirements:

- a description of the basis of the design with reference to relevant project specifications, codes and standards;
- results of any pipeline route surveys that have been carried out;
- justification of the selected cathodic protection system and anode materials if the choice is made by the Contractor;
- calculations of surface area, current requirement, anode mass, resistance and numbers;
- for impressed current systems, a schematic diagram of the proposed cathodic protection system, pipeline attenuation calculations and an overview of the system capacity;
- if requested by the Principal, a draft monitoring plan complete with the proposed number and types of cathodic protection monitoring facilities, frequencies and acceptance criteria.

The **detailed design** documents shall be submitted to the Principal for approval before construction starts and shall cover the following requirements:

- final design calculations based on accurate Manufacturer/suppliers information about anode weight, dimensions, performance data etc.;
- a schedule of materials;
- a complete set of design drawings, including anode distribution, detailed anode design and construction;
- for impressed current systems, a wiring diagram and component and installation details;
- installation procedures;
- commissioning procedures;
- if requested by the Principal, an operation and maintenance manual, including the final monitoring plan.

7.12.2 Material schedules

A complete schedule of materials to be used for the installation of the cathodic protection system shall be issued to demonstrate that all materials to be procured are in accordance with this DEP. This schedule shall include the required quantities and grades of all materials to construct the cathodic protection system and the proposed Manufacturers/Suppliers.

The Contractor shall include in the material schedule a list of proposed monitoring equipment required to carry out regular surveys of the cathodic protection system (10.5).

The Contractor shall also include a list of proposed tools and spare parts required for maintenance of the system during the first 5 years of operation.

7.12.3 Installation procedures

Full construction details and installation procedures of the cathodic protection system shall be provided to ensure that the system will be installed in accordance with this DEP.

The installation of the cathodic protection system shall start only after approval of the installation procedures by the Principal.

7.12.4 Commissioning procedures

Commissioning procedures shall be provided to prove that the installed cathodic protection system is in accordance with the design.

They shall include as a minimum:

- procedures for the testing of pipeline isolation;
- procedures for energising cathodic protection hardware;
- requirements for polarisation of the pipeline;
- procedures for the measurement of adequate protection levels (potentials);
- procedures for interference testing if applicable;
- documentation on anode fabrication and testing;
- required format of the commissioning report.

7.12.5 Operating and maintenance manual

If requested by the Principal, an operating and maintenance manual shall be provided to ensure that the cathodic protection system is well documented and that operating and maintenance procedures are available for the future operator.

This document shall contain:

- a description of the system and system components;
- the commissioning report (7.12.4);
- as-built drawings;
- Manufacturer/Supplier documentation;
- a schedule of all monitoring facilities;
- potential criteria for the system;
- the monitoring plan including procedures, schedules and equipment for each of the types of monitoring facilities installed on the pipeline;
- guidelines for the safe operation of the cathodic protection system.

8. MANUFACTURING OF SACRIFICIAL ANODES

8.2 QUALIFICATION OF ANODE MANUFACTURING

Replace this section by:

Anode manufacturing shall be carried out according to a qualified procedure. Anodes shall be pre-qualified by the Manufacturer in accordance with (Appendix 3) of this DEP before they can be approved for the application.

As part of the pre-qualification requirements, anode manufacturers shall submit the following data for the approval of the Principal:

- anode/core preparations;
- casting precaution measures;
- chemical composition ranges;
- potential and capacity limits;
- surface defects (visual inspection);
- anode to core bonding (destructive test);
- weight and dimensional tolerances;
- certification/documentation format.

8.3 STANDARDS

Replace this section by:

Requirements for manufacturing of anodes are given in NACE RP 0492-92 for offshore pipeline bracelet anodes.

9. INSTALLATION OF SACRIFICIAL ANODES

9.3 DOCUMENTATION

Add new section:

9.3.3 Installation procedures (7.12.3)

10. IMPRESSED CURRENT CATHODIC PROTECTION SYSTEMS

10.1 GENERAL

Add new section:

10.1.4 Impressed current cathodic protection systems are not recommended for offshore pipelines. Impressed current cathodic protection may only be considered for the following cases:

- on short pipelines which terminate at platforms which have impressed current systems installed;
- as a retrofit system on pipelines with sacrificial anode failures, excessive anode consumption or excessive coating deterioration;
- on short pipelines where an impressed current system may be operated from shore (e.g. loading lines).

Full justification shall be given when impressed current is proposed (see Part II).

Pipelines protected by impressed current shall be electrically isolated at both ends from foreign structures/pipelines.

10.2 CURRENT SOURCES AND CONTROL

10.2.1 Replace this section by:

Transformer/rectifiers shall comply with DEP 30.10.73.31-Gen., however, on offshore platforms additional safety requirements may be applicable.

Separate negative connections shall be installed for each pipeline, independent of any negative connection to the platform or any land based installation. Negative connections shall be terminated in a control box equipped with control resistors and shunts to regulate and measure protective current to each pipeline.

10.4 SYSTEM DESIGN

10.4.3 Replace this section by:

To ensure adequate protection at remote points on the pipeline, pipeline attenuation calculations or similar modelling shall be carried out to ensure that the whole pipeline length can be protected from the point of installation of the impressed current system.

10.4.9 Replace the first sentence by:

Pipelines protected by impressed current shall be electrically isolated at both ends from foreign structures/pipelines.

10.5 MONITORING EQUIPMENT

Replace this section by the following:

10.5.1 Monitoring plan

A monitoring plan shall be written as part of the design and the required monitoring facilities for this plan shall be installed. Required facilities depend on specific pipeline parameters such as pipeline length, water depth and the underwater access related to the burial conditions.

Such a monitoring plan shall include as a minimum:

- the required type of measurements such as pipe-to-sea water potentials, anode potentials, anode current outputs, visual inspection of anode dimensions, pipeline isolation testing, impressed current output, etc.;
- the locations where these measurements are to be carried out;
- the required monitoring installations and equipment to carry out such surveys;
- a description of the techniques to be used, such as divers, remotely operated vehicles, trailing wires, towed fish techniques etc. This description shall also include the methods of accurately locating the pipeline and the construction-phase requirements concerning the acquisition of navigation data for this purpose;
- the frequency with which each type of measurement should be performed.

NOTE: For impressed current systems, monthly transformer/rectifier reading is recommended together with an annual potential survey; for sacrificial systems an annual isolation check is recommended and pipe/anode potential measurements are recommended after one year and every five years thereafter.

A conceptual plan shall be included in the conceptual design (7.12.1) together with a list of proposed monitoring facilities. The final plan shall be part of the operating and maintenance manual.

10.5.2 Pipeline end monitoring stations

As a minimum, monitoring facilities shall be provided at both ends of the pipeline. For short pipelines (<5 km) this may be sufficient but for longer pipelines intermediate stations may be necessary.

For non-isolated pipelines terminating on a platform, this facility shall consist of a safe location close to the riser where there is vertical access to the sea water and where a dedicated contact point to the pipeline has been installed or marked to enable reproducible monitoring.

For isolated pipelines the monitoring point on the seaward side of the isolating joint serves as the potential monitoring point.

For sub-sea pipelines at landfalls, a test post shall be installed at or near the landfall with two cables connected to the pipeline. If the isolating joint is close to the landfall, then the seaward test point on the isolating joint may be used instead of this test post.

For pipelines protected by impressed current, at least one potential monitoring point shall be installed at the most remote point from the transformer/rectifier or at the mid-point between two transformer/rectifiers.

10.5.3 Permanent underwater monitoring facilities

Where access to a pipeline is not possible because the water is too deep or the pipeline is buried, the installation of a permanent reference electrode system with remote read-out shall be considered. Such a system may be wired into the platform, but normally a self contained unit that can be remotely interrogated is preferred. The Contractor shall propose a suitable system.

10.5.4 Test facilities at isolating joints/flanges

At all isolating joints/flanges, two cables shall be connected to either side of the joint or flange. All cables shall be separately terminated in one test post or junction box with suitable facilities to install direct or resistive bonds. The test box shall be installed in a convenient, safe location close to the riser where there is vertical access to the sea water to enable reproducible monitoring.

The cables to either side of the isolating joint shall be identified by colour coding or tags.

10.5.5 Drain point test facilities

At the drain points of impressed current systems each negative connection to the pipeline shall be provided with current measurement facilities. For single pipelines the ammeter built into the current source may suffice. Where multiple negative connections are installed, separate shunts and blocking diodes shall be provided, installed in a distribution box.

At the drain point a potential monitoring station (10.5.2) shall be installed using a separate test cable connected to the pipeline for the measurement of the drain point potential.

10.5.6 Miscellaneous monitoring facilities

The Contractor may propose other test facilities which he considers necessary for cathodic protection monitoring. Such test facilities may include in-line current measurement facilities, etc.

10.7 DOCUMENTATION

Replace this section by:

Documentation shall be in accordance with (7.12)

11. INSPECTION AND MONITORING OF CATHODIC PROTECTION

11.1.1 Add to this section:

More detailed requirements for monitoring are given in Section (10.5) as amended by this DEP.

PART IV REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Requisitioning binder	DEP 30.10.01.10-Gen.
Design of cathodic protection systems for onshore buried pipelines	DEP 30.10.73.31-Gen.
Data/requisition sheet for Design of cathodic protection system for offshore pipelines (contained in requisitioning binder DEP 30.10.01.10-Gen.)	DEP 30.10.73.94-Gen.

AMERICAN STANDARDS

Specification for substitute ocean water	ASTM D1141

Issued by:
American Society for Testing of Materials
1916 Race Street
Philadelphia, PA 19103-1187
USA.

Metallurgical and inspection requirements for offshore pipeline bracelet anodes	NACE RP 0492

Issued by:
National Association of Corrosion Engineers
1440 South Creek
Houston, TX 77084
USA

NORWEGIAN STANDARDS

DNV recommended practice cathodic protection design	DNV RP B401 1993 edition

Issued by:
Det Norske Veritas Industri Norge AS
PO Box 300, N-1322 Høvik
Norway.

APPENDIX 1 SPECIMEN COPY OF REQUISITION SHEET

A specimen copy of sheet 1 of the data/requisition sheet DEP 30.10.73.94-Gen. is shown below. The latest revision of this sheet (and its continuation sheet) shall be used and can be found in the Requisitioning binder (DEP 30.10.01.10-Gen.).

	Data / requisition sheet for Design of Cathodic Protection System for Offshore Pipeline				Project Name: Project Number: Order/Enquiry No.	
1	**PIPELINE DATA**					
2	Pipeline Name/Code	:				
3	Pipeline Route	:				
4	Product(s) Transported	:				
5	Year of Construction	:				
6	Design Life	:	years			
7	Pipeline Length	:	m			
8	Nominal Diameter	:	inches	Outside diameter :	mm	
9	Wall Thickness	:	mm			
10	Pipeline Material	:				
11	Design Temperature	:	°C			
12	External Corrosion	Type :				
13	Coating	Thickness :	mm			
14	External Weight	Type :				
15	Coating	Thickness :	mm			
16	Pipeline Burial		Buried	Not Buried		
17						
18	**CATHODIC PROTECTION DATA**					
19	Design Scope	:	Conceptual	Detailed	Both	
20	Site Survey	:	Required	By Contractor	By Others	
21	Electrical Isolation	:	Beginning	End	Both	
22	Type of System	:	Impressed Current	Sacrificial		
23	Anode Material	:	Aluminium	Zinc		
24	End Installations	Beginning	Impressed Current	Sacrificial	None	
25		End	Impressed Current	Sacrificial	None	
26	Monitoring Facilities	: Not Required		Required	Type :	
27						
28	**ENVIRONMENT DATA**					
29	Geographical Area	:				
30	Pipeline Depth	:	m			
31	Sea Water Temperature	Value	°C			
32		Source	Site Measurement	Estimated	Other Project	
33	Sea Water Salinity	Value	g/l			
34		Source	Site Measurement	Estimated	Other Project	
35	Sea Water Resistivity	Value	Ohm.cm			
36		Source	Site Measurement	Estimated	Other Project	
37	Sediment Resistivity	Value	Ohm.cm			
38		Source	Site Measurement	Estimated	Other Project	
39	Sea Water Lateral Flow / Turbulence		Low	Moderate	High	
40						
41	In shaded boxes, use 'Y', 'N', or a 'Check Mark' to indicate selection					
42						
43						
44						
45	**INFORMATION TO BE SUBMITTED WITH THE TENDER**					
46	Completed data requisition sheet DEP 30.10.73.94-Gen. (i.e. all data fields not already completed by the Principal).					
47						
48						
49						
50						
51						
52	**REMARKS AND/OR DESCRIPTION OF REVISIONS**					
53	Cathodic Protection system design shall comply with DEP 30.10.73.32-Gen					
54						
55						
56						
	Made by	Date	EQUIPMENT		Rev letter	
	Checked by	Date	PLANT		Date	
					Sign	
	Appr by	Date	CONSIGNEE		Sheet No 1 of ___	
	Eng by				Equipm No	
	Principal				Req No	

DEP 30.10.73.94-Gen., sheet 1 dated 06-96

APPENDIX 2 DESIGN EXAMPLES

This appendix gives two example design calculations for sacrificial anode cathodic protection following the steps given in section 7 of DNV RP B401. Reference is made to the relevant sections where parameters are defined and calculation formulae are given.

Example 1: Non buried North Sea pipeline,
Example 2: Buried South China sea pipeline.

Design Step	Reference	Parameter	Pipeline 1	Pipeline 2	Unit
General Collect pipeline data	7.1	Pipeline route/location	Southern North sea	South China Sea	
		Pipeline length	25000	10000	m
		Nominal diameter	24	18	inch
		Outside diameter	0.610	0.457	m
		Wall thickness	12	9	mm
		Corrosion coating	Bitumen	PE	
		Coating thickness	5	3	mm
		Weight coating	Concrete	Concrete	
		Weight coating thickness	25	20	mm
Service data		Pipeline temperature	30	20	°C
		Design life, t_r	25	20	years
Environmental data		Sea water temperature	8	20	°C
		Burial conditions	open water	trenched in sand	
		Sea water/sediment resistivity, ρ	0.25	1.4	Ω.m
		Pipeline depth	25	15	m
Subdivision of object	7.2	Divide pipeline in temp/depth zones, calculate for each zone. This example one zone.			
	7.10.5	Define anode spacing and calculate for one anode, modify spacing depending on results	100	50	m
Surface area calculation	7.3	Area between mid-points, A_c = diameter x π x spacing	191	72	m^2
		Coating breakdown factor for this coating	bitumen/ concrete	PE	
	Table 2	k_1 =	0.02	0.02	
	Table 2	k_2 =	0.004	0.002	
	6.4.8	average, $f_{c(average)}$	0.07	0.04	
	6.4.8	final, $f_{c(final)}$	0.12	0.06	

Design Step	Reference	Parameter	Pipeline 1	Pipeline 2	Unit
Current demand calculations	7.4	Determine current density	moderate waters, high lateral flow	buried pipeline	
	Table 1	Current density (open water), i_c	100		mA/m^2
	6.3.7	Current density (buried), i_c		20	mA/m^2
	6.3.8	Incl. allowance for temp >25 °C	105	20	mA/m^2
	7.4.2/3	Average current, $I_{c(average)}$	1.407	0.057	A
	7.4.2/3	**Final current demand, $I_{c\ (final)}$**	2.412	0.086	A
Anode selection	7.6	Select bracelet anode type, size to fit pipeline, adjust after calculation	Zinc	Zinc	
	7.6.2	Anode thickness = concrete thickness	0.025	0.02	m
		Internal diameter = pipe outside diameter + 2 x coating thickness	0.62	0.46	m
		External diameter = internal diameter + 2 x concrete thickness	0.67	0.50	m
Electrochemical data	DEP II, 1.1	Protection potential, $E^o{}_c$	-800	-800	mV
	Table 6.6.2	Anode potential, $E^o{}_a$	-1000	-950	mV
		Driving voltage, ΔE^o	200	150	mV
	Table 6.6.1	Anode current capacity (efficiency),ε	700	700	Ah/kg
	Table 6.9.1	Utilisation factor, u	0.8	0.8	
Anode mass calculation required	7.7	Calculate anode mass, m,	550	18	kg
for design life and for this spacing		density (zinc)=	6920	6920	kg/m^3
		Anode volume = mass / density	0.080	0.003	m^3
		Anode cross section = ¼ π (od^2-id^2)	0.051	0.030	m^2
		Anode length = Volume / cross section	1.57	0.09	m
Number of anodes	7.8				
	6.7.7	Final anode surface area, A	3.06	0.12	m^2
	Table 6.7.1	Final anode resistance, R_a	0.045	1.250	Ω
	7.8.2	**Final current output, I_a**	4.44	0.12	A
		Final current demand from 7.4	2.41	0.09	A
	7.8.7	**Check final output > final demand**	**OK**	**OK**	
		Number of anodes, = line length / spacing	250	200	

APPENDIX 3 ELECTROCHEMICAL TEST PROCEDURES FOR SACRIFICIAL ANODES

1. INTRODUCTION

Sacrificial anodes used for offshore cathodic protection (platforms, pipelines etc.) require prequalification testing before they can be approved for the application.

The objective of the tests is to assess the compliance of the anode material's passivation and current capacity properties with the design data submitted by the manufacturer. The suitability of the anode material for a particular design shall be judged from case to case using the above information.

Potentiostatic tests are to be carried out to measure the anode material's tendency to passivation.

Galvanostatic tests are to be carried out to determine the anode material's current capacity and its susceptibility to intergranular corrosion.

When both tests have been passed, the anode material has been qualified.

This document describes the test procedures of these tests, to be carried out by a nominated test laboratory.

Each test shall be carried out in duplicate. Both results shall be acceptable for the material to pass the test.

The tests shall be carried out on test samples, fully representative for the proposed type of anode material.

2. ANODE DESIGN DATA

The following design data shall be submitted by the supplier of the anode:

- the manufacturer's name and the type and/or trade name of the anode material;
- the anode material standard specification if applicable (e.g. MIL-A-18001K);
- the nominal chemical composition ranges of the anode material;
- the date of manufacture and heat number of the test samples;
- a full chemical analysis of the anode sample materials;
- the nominal free corroding potential of the anode material in mV vs. SCE;
- the maximum and minimum design current density of the anode material in mA/cm^2;
- the nominal design current capacity of the anode material in Ah/kg.

3. TEST ENVIRONMENT

The test environment shall be either artificial sea-water or clean fine silica sand soaked in artificial sea-water.

The sea-water shall be prepared in accordance with ASTM D1141 with the exception of the addition of magnesium salts. The indicated quantity of MgCl shall be replaced by the stoichiometric equivalent in NaCl (viz. 3889 g MgCl in stock solution 1 shall be replaced by 3803 g NaCl).

The sand water mixture shall be prepared by washing the sand with de-ionised water, drying the sand and pouring it into the required volume of sea-water, leaving about 1 cm water above the sand.

The volume of sea-water shall be sufficient to avoid contamination of the sea-water with corrosion products from the samples, produced during the test and to avoid changes in concentration due to normal evaporation losses. Minimum volumes are given in the test procedures below.

4. TEST TEMPERATURE

The test temperature shall be selected to simulate the actual operating temperature of the anode to be encountered in the field and shall be agreed with the Principal before the tests are carried out.

For the North Sea and for seas in similar climates a temperature of 5 °C should be used unless otherwise specified. For other seas a test temperature of 20 °C should be used unless otherwise specified.

For the use of anodes at elevated temperatures, e.g. to protect hot pipelines, the test temperature should be 50, 70 or 90 °C, whichever is the next higher than the operating temperature.

The temperature of the test solution shall be thermostatically controlled and for elevated temperatures measures shall be taken to avoid water evaporation, e.g. by using closed containers and reflux condensers.

Tests at 20 °C may be carried out without thermostatic control at room temperature provided that this temperature is between 18 and 22 °C and the minimum and maximum temperature are measured during the tests.

5. SAMPLE IDENTIFICATION

The anode samples shall be cut or machined from two different blocks of anode material from the same melt or from different melts.

Each sample shall be provided with a unique identification code e.g. by engraving in the embedding material.

6. ANODE PASSIVITY TEST PROCEDURE

6.1 Procedure

A sample of anode material is provided with an electrical test lead and embedded in a suitable resin. The exposed test surface shall be in one plane. The exposed surface area shall be between 150 and 400 mm^2 and shall be accurately measured and reported.

NOTE: Sample size of dia=16mm, L=20mm is recommended, surface area of circular section=201 mm^2.

Prior to the test, the test surface is ground using 180 grit abrasive paper.

For each test sample a minimum of 1 litre of test solution is prepared.

The sample is immersed in the test environment and the free corroding potential is determined with respect to a Saturated Calomel Electrode (SCE) or a Silver/Silverchloride (Ag/AgCl) reference electrode.

When testing at elevated temperatures the temperature of the reference electrode shall be kept at room temperature by using a salt bridge. The reference electrode system shall be provided with a Haber Luggin capillary positioned about 1 millimetre from the sample's surface. An auxiliary (counter) electrode shall be a bright platinum mesh or another inert material of approximately 10 square centimetres placed opposite the test surface.

When stabilised, the free corroding potential Eo is recorded.

Using a potentiostat, the potential of each of the samples is now controlled at various potentials more positive than the free corrosion potential (Eo) in the following sequence:

Period 1: Eo+50 mV

Period 2: Eo+100 mV

Period 3: Eo+200 mV

Period 4: Eo+100 mV

The duration of each period shall be between 66 and 72 hours.

During the test the position of the tip of the Haber Luggin capillary may have to be adjusted if high corrosion rates are encountered.

The current required to maintain the test potential shall be recorded continuously during the test.

The minimum current and the average current over the last 24 hours of each period shall be determined from these measurements. The average current is determined by calculating the arithmetic mean of the current values at the times 24, 18, 12, 6 and 1 hour before the end of each test period.

The applied current densities are determined by dividing the measured currents by the sample surface area.

The current densities for each of the test potentials are plotted against time.

The minimum and average current densities are plotted against the applied potential.

6.2 Pass/fail criteria

The sample passes the anode passivity test :

- if the average current density during three or four of the test periods is not less than the minimum design current density

and

- if the average current density during test period 4 is not less than 50% of the average current density during test period 2

and

- if the minimum current density is not less than 50% of the average current density during the last 24 hours of any of the test periods.

In all other cases the test has been failed.

7. ANODE CURRENT CAPACITY TEST PROCEDURE

7.1 Procedure

A cylindrical sample of anode material is provided with an electric lead. The lead contact shall be sealed using a suitable epoxy resin.

The total mass of the sample shall be sufficient to last for at least three times the duration of the test based on the actual current capacity.

The shape of the sample shall be such to maintain the same exposed surface area (within 10%) throughout the test.

The exposed surface area should be accurately known (approximately 10 cm^2).

NOTE: Typical test sample sizes are dia = 5mm, L=62.5mm or dia=10mm, L=30mm)

The anode surface shall be prepared before the test as follows:

Aluminium anodes are etched in a 10% aqueous sodium hydroxide solution for one minute, rinsed in tap water, cleaned for five seconds in a 10% solution of nitric acid, rinsed in tap water, rinsed with acetone and dried in air.

Zinc anodes are etched for one minute in a saturated aqueous solution of ammonium chloride, rinsed in tap water, rinsed with acetone and dried in air.

The sample is weighed before exposure.

The samples are placed in a cylindrical steel container, diameter 15 cm, height 25 cm which functions as an auxiliary electrode. The container is filled with the test environment (sea-water or sand in sea-water) and an SCE or Ag/AgCl reference electrode is installed with the tip of the Haber Luggin capillary 1 mm from the sample surface.

A constant direct current is passed between the container and the sample such that the sample is subjected to an anodic current. The current is adjusted to obtain a current density on the exposed surface of the sample of 0.2 mA/cm^2 (current approximately 2 mA) for exposure in sea-water and of 0.05 mA/cm^2 (0.5 mA) for exposure in mud (sand/sea-water).

The minimum test duration shall be 30 days.

During the tests the potential of the samples shall be measured at least twice a day or by continuous registration.

At the end of the test the samples are cleaned by hosing off with tap water, etched as before the test, rinsed with tap water, rinsed with acetone and dried in air.

The samples are weighed and the weight loss is determined. The total charge passed through the sample is determined in ampere-hours (Ah) and the current capacity is calculated, expressed in Ah/kg.

The sample shall be examined metallographically for the presence of intercrystalline corrosion. For this investigation the cylindrical sample shall be cut in the axial direction, ground using fine (720 grit) abrasive paper and etched with an appropriate etchant.

Photographic evidence of the surface shall be produced (enlargement 10x).

7.2 Pass/fail criteria

The sample passes the anode capacity test:

- if the measured current capacity of the anode material is not less than the design capacity specified by the supplier

and

- if the measured potential shows no excursions of more than 50 mV more positive than the average potential during the test and more than 100 mV more positive than the free corroding potential, Eo, as determined in the Passivity test.

If there is an indication of intergranular corrosion of the sample the test shall be repeated for a duration of 90 days, the results of which shall satisfy the above requirements. In all other cases the test has been failed.

8. TEST REPORT

A test report shall be produced in duplicate and shall contain at least the following information:

- all design data as required in section (2);
- reference to or a copy of these procedures;
- the date and place of manufacturing and a description of the sample preparation;
- the name and place of the test facilities and the name of the person responsible for the testing;
- the name of the Company representative who witnessed the test;
- a description of the test apparatus and (if applicable) brand names and types of the equipment used;
- a list of all measured and calculated current density, potential and weight values and/or copies of relevant recorder charts or graphs;
- the current density/potential graphs, current density/time graphs and the potential/time graphs as described in the test procedures;
- micrographs of the sections of the samples made during the metallographic examination;
- any other observations made during the tests which are regarded as relevant for supporting the conclusions;
- conclusion drawn from the test results with the pass/fail result as described above.

The final report shall be signed by the responsible person of the test laboratory and, if applicable, by the company representative(s) witnessing the tests.