NORSOK STANDARD M-001

Rev. 3, Nov. 2002

Materials selection

Norwegian Technology Centre
Oscarsgt. 20, Postbox 7072 Majorstuen
N-0306 Oslo
NORWAY

Telephone: + 47 22 59 01 00
Fax: + 47 22 59 01 29
Email: norsok@nts.no
Website: www.nts.no/norsok

Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for existing and future petroleum industry developments.

The NORSOK standards are prepared to complement available international standards and fill the broad needs of the Norwegian petroleum industry. Where relevant NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

These standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001

The preparation and publication of the NORSOK standards is supported by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Manufacturing Industries). NORSOK standards are administered and issued by NTS (Norwegian Technology Centre).

Introduction

The provisions of this NORSOK standard are intended to comply with the requirements of the EC ”Pressure Equipment Directive” and the Norwegian implementation regulation ”Forskrift for trykkpåkjent utstyr” issued 9 June 1999. When this standard refers to the PED only, it is implicit that it also refers to the Norwegian implementation regulation.

The requirements given for materials by PED in its Annex I ”Essential Safety Requirements” section 4.1, are basically fulfilled provided the principles of material selection of this NORSOK standard are followed and documented.

The documentation requirement in PED Annex I section 4.3 of the materials used in main pressure retaining parts of equipment in PED categories II, III and IV, must take the form of a certificate of specific product control. This is fulfilled by the certification requirement given by the Material Data Sheets compiled in NORSOK M-630.

The PED requirements to specific material characteristics given in its Annex I section 7.5, are as follows:

- A steel is considered sufficient ductile if the elongation before rupture in a tensile test carried out by a standard procedure is not less than 14 %.
- The measured absorbed impact energy on an ISO V-notch test shall not be less than 27 J at the lowest scheduled operating temperature.

All the material grades given in the materials selection tables in this NORSOK standard and specified by the MDS compiled in NORSOK M-630 fulfil the material characteristics and documentation requirements specified by PED to piping category III, except the CMn-steel Type 235 defined by MDS C01 and C02, which in the current revision has no requirement to impact testing.

The PED requires that the manufacturer provide documentation of elements relating to compliance with the material specifications of the Directive in one of the following forms:

- By using materials which comply with a harmonised European standard
- By using materials covered by a European approval of materials (EAM)
- By a particular material appraisal (PMA).

The materials standards used in NORSOK Piping and Valve standard L-001 are not based on harmonised European standards or given an EAM. Therefore, a particular appraisal has to be made to confirm compliance to PED for each particular installation.

1 Scope

The scope of this standard is to provide general principles, engineering guidance and requirements for material selection and corrosion protection for all parts of offshore installations.

This document gives guidance and requirements for:

- Corrosion and material selection evaluations.
- Specific material selection where appropriate.
- Corrosion protection.
- Design limitations for candidate materials.
- Qualification requirements for new materials or new applications.

2 Normative references

The following standards include provisions which, through reference in this text, constitute provisions of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements of the standards referenced below.

API RP 17J	Specification for unbonded Flexible Pipe.
ASME B 31.3	Process Piping.
ASTM A 193	Specification for Alloy-Steel and Stainless Steel Bolting Materials for High- Temperature Service.
ASTM A 194	Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.
ASTM A 320	Specification for Alloy Steel Bolting Materials for Low-Temperature Service.
ASTM D 2992	Practice for Obtaining Hydrostatic or Pressure Design Basis for Fibreglass Pipe and Fittings.
BS MA 18	Salt Water Piping in Ships.
Det Norske Veritas	Guidelines for Flexible Pipes, 1987.
DNV RP B201	Metallic Materials in Drilling, Production and Process Systems.
DNV RP O501	Erosive wear in piping systems.
DNV OS F101	Submarine Pipeline Systems.
EC	Pressure Equipment Directive, 97/23/EC
EFC Publ. no. 16	Guidelines on Material Requirements for Carbon and Low Alloy Steels for H_2S Environments in Oil and Gas Production.
EFC Publ. no. 17	Corrosion Resistant Alloys for Oil and Gas Production. Guidance on General Requirements and Test Methods for H_2S Service.
ISO 898	Mechanical properties of fasteners.
ISO 13628 - 2	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 2: Flexible pipe systems for subsea and marine applications.
ISO 14692	Glass reinforced plastics (GRP) piping - Part 1: Application and materials, - Part 2: Qualification and manufacture - Part 3: System design - Part 4: Fabrication, installation and operation
MTI Manual No. 3	Guideline Information on Newer Wrought Iron and Nickel-base Corrosion Resistant Alloys, Phase 1, Corrosion Test Methods. (Appendix B, Method MTI-2).
NACE MR0175	Sulphide Stress Cracking Resistant Metallic Materials for Oilfield Equipment. (Will be superseded by ISO 15156.)
NS 3420	Beskrivelsestekster for bygg og anlegg (Specification texts for building and construction).
NS 3473	Concrete Structures. Design Rules.

NORSOK Standards:

L-001	Piping and Valves
M-101	Structural Steel Fabrication
M-120	Material Data Sheets for Structural Steel
M-121	Aluminium Structural Materials
M-501	Surface Preparation and Protective Coating
M-503	Cathodic Protection Design
M-506	CO_2 Corrosion rate calculation model
M-601	Welding and Inspection of Piping
M-CR-621	GRP Piping Materials (will be renumbered M-621)
M-630	Material Data Sheets for Piping
M-650	Qualification of Manufacturers of Special Materials
M-710	Qualification of Non-metallic Sealing Materials and Manufacturers

3 Definitions and abbreviations

3.1 Definitions

C- glass	A special fibre type that is used for its chemical stability in corrosive environments.
Can	Verbal form used for statements of possibility and capability, whether material, physical or casual.
E-glass	The general purpose fibre that is most used in reinforced plastics.
ECR-glass	A modified E-glass fibre type with improved corrosion resistance against acids.
Free machining steel	Steel to which elements such as sulphur, selenium, or lead have been added intentionally to improve machinability.
Maximum operating temperature	The temperature in the equipment when the plant operates at unstable conditions, like control requirements, process flexibility and process upsets.
May	Verbal form used to indicate a course of action permissible within the limits of the standard.
Operating temperature	The temperature in the equipment when the plant operates at steady state condition, subject to normal variation in operating parameters.
Oxygen equivalent	ppb oxygen + 0.3 x ppb free chlorine.
PED	EC Pressure Equipment Directive
pH stabilisation	Increase in bulk pH to reduce corrosion in condensing water systems.
PRE	Pitting Resistance Equivalent, PRE = % Chromium + 3.3 x % Molybdenum + 16 x % Nitrogen.
Shall	Verbal form used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted, unless accepted by all involved parties.
Should	Verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain action is preferred but not necessarily required.

Definitions of descriptors used for metallic materials in this document are given in the table below.

Metallic Materials

Generic type	UNS	Typical alloy composition			
		% Cr	% Ni	% Mo	others
Carbon and low alloy steels					
235[1]					
235LT					
360LT					
3.5% Ni			3.5		
Martensitic stainless steels					
13Cr		13			
13Cr 4Ni		13	4		
SM13Cr		12	6	2	C<0.015%
S13Cr		12	6	2	
17 - 4 PH	S17400	17	4		
Austenitic stainless steels					
310	S31000	25	20		
316	S31600	17	12	2.5	C≤0.035
6Mo	S31254 N08925 N08926 N08367	20 20 20 21	18 25 25 24	6 6 6 6	N=0.2 Cu=1, N=0.2 N min. 0.15 N=0.2
904	N08904	21	25	4.5	Cu=1.5
Superaustenite	S34565	24	17	4-5	Mn=6 N=0.40-0.60
Duplex stainless steels					
22Cr	S32205 S31803	22	5.5	3	N
25Cr	S32550 S32750 S32760	25 25 25	5.5 7 7	3.5 3.5 3.5	N N N
Nickel base alloys					
Alloy C22	N26022	21	rem.	14	W=3
Alloy C-276	N10276	16	rem.	16	W=4
Alloy 625	N06625	22	rem.	9	Nb=4
Alloy 718	N07718	19	53	3	Nb=5
Alloy 800H/Alloy 800HT	N08810 / N08811	21	33	-	Al + Ti
Alloy 825	N08825	21	42	3	Ti
Co-base alloys					
Elgiloy	R30003	20	16	7	Co=40
MP-35-N	R30035	20	35	10	Ti, Co rem.
Copper base alloys					
Cu-Ni 90-10	C70600	-	10	-	Fe, Cu rem.
Cu-Ni 70-30	C71500	-	31	-	Fe, Cu rem.
NiAl bronze	C95800	-	4.5	-	9Al, Fe, Mn, Cu rem.
Gun metal	C90500	-	-	-	10Sn, Zn, Cu rem.
Titanium					
Ti grade 2	R50400	-	-	-	C max 0.10 Fe max 0.30 H max 0.015 N max 0.03 O max 0.25 Ti rem.

Note 1: This material does not comply with PED-requirements concerning documentation of impact toughness if specified according to NORSOK M-630

3.2 Abbreviations

AFFF	Aqueous Film Forming Foams.
AWS	American Welding Society.
CRA	Corrosion Resistant Alloy.
CSCC	Chloride induced stress corrosion cracking.
CTOD	Crack Tip Opening Displacement.
EC	European Commission.
EFC	European Federation of Corrosion.
GRP	Glass fibre Reinforced Plastic.
HAZ	Heat affected zone.
MDS	Material Data Sheets.
MTI	Materials Technology Institute of the Chemical Process Industries.
NACE	NACE International.
NTS	Norsk Teknologistandardisering.
PED	EC Pressure Equipment Directive.
PMA	Particular material appraisal.
PRE	Pitting Resistance Equivalent.
SCC	Sulphide stress cracking.
SMYS	Specified Minimum Yield Strength.
UNS	Unified Numbering System.

4 General principles for material selection and corrosion protection

4.1 Material selection

Material selection shall be optimised, considering investment and operational/maintenance costs, such that overall costs are minimised while providing acceptable safety and reliability. As a minimum, the following shall be considered:

- Corrosivity, taking into account specified operating conditions including start up and shut-down conditions.
- Design life and system availability requirements.
- Failure probabilities, failure modes and failure consequences for human health, environment, safety and material assets.
- Inspection and corrosion monitoring possibilities.

For the final materials selection the following additional factors shall be included in the evaluation:

- Priority shall be given to materials with good market availability and documented fabrication and service performance.
- The number of different materials shall be minimised considering stock, costs, interchangeability and availability of relevant spare parts.

Deviations from materials selections specified in this standard may be implemented if an overall cost, safety and reliability evaluation shows the alternative to be more beneficial. Such deviations may include replacing CRAs with carbon steel and implementing supplier's standard materials.

4.2 Corrosivity and corrosion protection

4.2.1 Internal corrosion allowance

For carbon steel piping, a corrosion allowance of 3 mm shall be used, unless higher corrosion allowances are required.

Recommendation:
For submarine pipeline systems a maximum corrosion allowance of 10 mm is recommended as a general upper limit for use of carbon steel. Carbon steel can be used in pipelines where calculated inhibited annual corrosion rate is less than 10 mm divided by design life. Otherwise corrosion resistant alloys, solid or clad or alternatively flexible pipe, should be used. For pipelines with dry gas or non-corrosive fluids, no corrosion allowance is required. Corrosion during installation and testing prior to start-up shall be considered.

4.2.2 Corrosivity evaluations in hydrocarbon systems

Evaluation of corrosivity shall as a minimum include:

- CO_2-content.
- H_2S-content.
- Oxygen content and content of other oxidising agents.
- Operating temperature and pressure.
- Organic acids, pH.
- Halide, metal ion and metal concentration.
- Velocity, flow regime and sand production.
- Biological activity.
- Condensing conditions.

A gas is considered dry when the water dew point at the actual pressure is at least 10°C lower than the actual operation temperature for the system. Materials for stagnant gas containment needs particular attention.

The evaluation of CO_2 corrosion should be based on the NORSOK standard M-506. When the total content of organic acids exceeds 100 ppm and the partial pressure of CO_2 is less than 0.5 bar, use of NORSOK standard M-506 can lead to under-prediction of the corrosion rate. Corrosion inhibitors should always be used in such conditions, and relevant amounts of organic acids must be included in the testing for corrosion inhibitor selection. In gas systems with low condensation rates M-506 may give conservative corrosion rates.

If the ratio between the partial pressure of CO_2 and H_2S is less than 20, or the partial pressure of H_2S is higher than 0.5 bar, the calculation model in M-506 is not applicable.

pH stabilisation can be used in condensed water systems to reduce the corrosion rate. pH stabilisation is only applicable in combination with glycol in sweet systems. NORSOK standard M-506 does not apply for this case, and a corrosion rate of 0.1 mm/year shall be used for design purposes, unless field or test data are available. The effect of corrosion inhibitors shall be included as an inhibitor efficiency.

Corrosion inhibitors shall not be used to reduce corrosion of carbon or low alloy steels in production wells, subsea trees and subsea piping systems.

Use of corrosion inhibitors in topside process systems is not recommended, but can be used provided the inhibitor in each process stream satisfies the inhibitor supplier's minimum recommended concentration. In the design an inhibitor efficiency of maximum 75% in relation to the calculated corrosion rate in the prediction model, should be used.

For pipelines, an inhibitor efficiency of up to 90% can be used. The inhibitor efficiency includes the effect of glycol and/or methanol injection and shall be related to the corrosion rate calculated according to NORSOK standard M-506. The corrosion rate in the inhibited fluid shall be documented by corrosion tests unless relevant field or test data are available.

In pipeline systems carrying hydrocarbons with condensed water, the corrosivity may be reduced by application of inhibitors in combination with pH adjustment as an alternative to inhibitors alone. The combined effect of inhibitors and pH adjustment shall be qualified and documented by corrosion tests unless relevant documentation exists.

Vessel materials for topside oil separation and gas treating systems shall be selected based on the same corrosivity criteria as for topside hydrocarbon piping systems. Vessels manufactured in solid CRAs, internally CRA clad or weld overlayed, will not need additional internal corrosion protection systems.

Galvanic corrosion between CRA equipment and the vessel wall in internally paint coated carbon steel vessels shall be addressed in case of coating damages. As a minimum CRA support brackets shall be painted. Other protection methods like cathodic protection should be considered.

Possibility for "sour" service conditions during the lifetime shall be evaluated. Sour service is defined according to EFC Publication no. 16 for carbon steel and NACE MR0175 for CRAs and Titanium alloys. Requirements to metallic materials in "sour" service shall comply with NACE MR0175 standard with

amendments given in this standard. Qualification testing shall be in accordance with EFC Publication no. 16 for carbon steel and EFC Publication no. 17 for CRAs.

Drying or use of corrosion inhibitors shall not relax the requirement to use "sour" service resistant materials if the conditions otherwise are categorised as "sour" by the above documents.

If sand production and/or particles from well cleaning and squeeze operations are expected, an erosion evaluation shall be carried out. The evaluation should be based on DNV RP-O-501.

4.2.3 External corrosion protection

The external atmospheric environment shall be considered wet with the condensed liquid saturated with chloride salts. Material selection and surface protection shall be such that general corrosion is cost effectively prevented and chloride stress corrosion cracking, pitting and crevice corrosion are prevented.

Carbon steel shall always have surface protection to the external environment. Additional corrosion allowance or other means of protection are required for installations in the splash zone.

Corrosion resistant alloys should not be coated, except under insulation and pipe clamps or when submerged in seawater. Stainless steels may be coated at elevated temperature to reduce the probability for chloride induced stress corrosion cracking. Submerged small bore stainless steel piping need not be coated. Coating of stainless steel used in HVAC channels and exhaust ducts should be evaluated in each case.

Corrosion protection in the splash zone for permanently installed equipment shall consist of coating and corrosion allowance calculated as follows:

- Corrosion allowance for carbon steel in the splash zone with thin film coating: minimum 5 mm. For design lives more than 17.5 years: Corrosion allowance = (design life –X years) x 0.4 mm/year, where X = 5 for thin film coating and X = 10 for thick film coating. Thick film coating is understood as an abrasion resistant coating with thickness of minimum 1000 micron and applied in minimum 2 coats or layers.
- Corrosion allowance for carbon steel and SM13Cr risers: minimum 2 mm in combination with minimum 12 mm vulcanised chloroprene rubber. At elevated temperature the corrosion allowance shall be increased by 1 mm per 10°C increase in operating temperature above 25°C.
- Stainless steel risers: minimum 12 mm vulcanized chloroprene rubber.

Coating system selections for pipelines, structures and topside equipment shall make due consideration to structural design, operating conditions and conditions during storage and installation. The coating systems selection and requirements to application are covered by NORSOK Standard M-501 for structures and topside equipment.

The following areas/conditions shall be subject to special evaluation:

- Coatings for areas in the splash zone.
- Use of thermally sprayed aluminium coating for elimination of maintenance coating.
- Coatings for passive fire protection.
- Coatings for bolts and nuts, flanges, machined surfaces of valves, etc. For such applications wax coatings should be considered.
- Coating and/or insulation when connecting aluminium, stainless steel, carbon steel and other materials where galvanic corrosion may occur.

Cathodic protection shall be used for all submerged, metallic materials, except for materials which are immune to seawater corrosion. Surface coating shall in addition be used for components with complex geometry and where found to give cost effective design.

Recommendation:
The extent and type of coating shall be determined by the following factors:

- Cost savings due to reduced anode weight.
- Required coating to obtain rapid polarisation, including use of shop primers only.
- Required coating quality to obtain low coating breakdown.
- Accessibility for coating application.
- Cost saving by not coating weld areas.

The cathodic protection design shall be based on NORSOK Standard M-503. Welded connections are recommended for subsea applications. The electrical continuity to the cathodic protection system shall be verified by actual measurements for all components and parts not having a welded connection to an anode.

Any component permanently exposed to seawater and for which efficient cathodic protection can not be ensured, shall be fabricated in materials immune to corrosion in seawater. Exceptions are components where corrosion can be tolerated. Material selection should take into account probability for, and consequence of, component failure.

Recommendation:
The following materials are regarded as immune to corrosion when submerged in seawater at ambient temperature:

- Alloy 625 and other nickel alloys with equal or higher PRE value.
- Titanium alloys
- GRP.
- Other materials, provided adequately documented.

Ambient seawater temperature is related to normal North Sea water temperatures.

Note: Stainless steels Type 6Mo and Type 25Cr duplex are borderline cases and should not be used for creviced connections without cathodic protection when their material temperature exceeds ambient seawater temperature. Threaded connections are particularly susceptible to crevice corrosion.

4.2.4 Corrosion protection of closed compartments

For completely closed seawater filled compartments in carbon steel, e.g. in jacket legs, J-tubes and caissons, etc. no internal corrosion protection is needed.

For compartments with volume to area ratios exceeding 1 m^3/m^2 and a possible but restricted sea water exchange (e.g. subsea installations), treatment with oxygen scavenger can be used as an alternative to cathodic protection. For compartments with volume to area ratios less than 1 m^3/m^2, internal protection may not be necessary.

Closed structural compartments which are not filled with water need no internal corrosion protection if the compartments are completely sealed off by welding, or there is a proven gas tight gasket in any manhole or inspection covers.

4.2.5 Insulation, topside applications

Thermal insulation for topside applications shall be avoided to the extent possible, and only be used if required for safety or processing reasons. Piping and equipment which have to be insulated shall be coated in accordance with NORSOK Standard M-501.

The requirement for coating under insulation also includes CRAs. Titanium alloys need not be coated even if insulated.

The design of insulation for structures, vessels, equipment, piping systems etc. shall ensure drainage at low points, and access in areas where maintenance and inspection are required. Heat tracing shall to the extent possible be avoided in conjunction with stainless steel materials.

4.2.6 Galvanic corrosion prevention

Wherever dissimilar metals are coupled together in piping systems, a corrosivity evaluation shall be made. If galvanic corrosion is likely to occur, there are the following methods to mitigate it:

- Apply electrical insulation of dissimilar metals. Possible electrical connection via pipe supports, deck and earthing cables must be considered.
- Install a distance spool between the dissimilar metals so that they will be separated by at least 10 pipe diameters from each other. The distance spool may be either of a solid electrically non-conducting material, e.g. GRP, or of a metal that is coated internally with an electrically non-conducting material, e.g. rubber. The metal in the distance spool should be the most noble of the dissimilar metals.

- Apply a non-conducting coating on the most noble of the dissimilar metals. The coating shall extend at least 10 pipe diameters into the most noble pipe material.
- Apply corrosion allowance on the less noble metal, e.g. in hydrocarbon systems.
- Install internal sacrificial anodes through access fittings near the interface, e.g. resistor controlled cathodic protection. This works only when the system is filled up with a conductive liquid, and special precautions during commissioning and shut-in is required.

Recommendation:
At galvanic connections between dissimilar materials without isolation/distance spool, it can be assumed that the local corrosion rate near the interface is approximately 3 times higher than the average corrosion rate, decreasing exponentially away from the interface within a length of 5 pipe diameters. This should be used to establish the magnitude of the corrosion allowances. Particular systems may have higher corrosion rates depending on area ratio and material combinations.

For connections between copper alloys and stainless steel/nickel alloys/titanium, the use of easily replaceable spools with added wall thickness shall be evaluated.

In hydrocarbon systems, isolating spools shall be avoided and transitions shall normally be made in dry, inhibited or other areas with low corrosivity.

For connections between aluminium and steel the following shall apply:

- Bolts, nuts and washers shall be stainless steel type 316.
- The direct contact between aluminium and carbon steel shall be prevented by application of an insulation system, e.g. an organic gasket or equivalent. Alternatively the two materials may be separated by a 1 mm stainless steel barrier.
- If the environment can be defined as dry and non-corrosive, no special precautions are required, except that the contacting surface of the carbon steel shall be coated.
- If stainless steel bolts or screws are threaded into aluminium, a suitable thread sealant shall be applied to the threads to prevent ingress of water and corrosion of the threads.

Direct connection between aluminium and copper alloys shall be avoided.

4.2.7 Carbon steel welds

For pipe systems with corrosive service the welds shall be compatible with the base material in order to avoid local corrosion of weldment and heat affected zone.

Welds in submarine flowline and pipeline systems for corrosive hydrocarbons shall be qualified by corrosion testing under simulated operating conditions with and without corrosion inhibitors as a part of weld procedure qualifications, unless relevant documentation exist.

For systems with “sour service” requirements the Ni content shall be less than 2.2%.

Welding consumables for water injection systems shall have a chemical composition according to NORSOK standard M-601 or have a composition which is documented not to give preferential corrosion in weld/heat affected zone.

4.3 Weld overlay

Weld overlay on carbon steel shall be in accordance with table 2. In corrosive hydrocarbon systems weld overlay with Alloy 625, defined as AWS ERNiCrMo3, giving minimum 3 mm thickness as-finished, may replace homogeneous corrosion resistant materials. The maximum iron content at the finished surface shall be 15 weight per cent in systems where oxygen is excluded (hydrocarbon service) and 10 weight per cent elsewhere (e.g. subsea for prevention of crevice corrosion).

Where weld overlay is used to prevent crevice corrosion in seawater systems, alloys with documented crevice corrosion resistance in the as weld overlayed condition shall be used. The maximum temperature shall be documented.

Recommendation:

The use of MTI test procedure, MTI Manual No. 3, is recommended for documentation of crevice corrosion resistance, using a tightening torque of 2 Nm. The selected tightening torque has been established based upon recent results.

The extent of weld overlay for hardfacing shall be as specified in relevant data sheets and shall be performed in accordance with requirements in NORSOK standard L-001. In corrosive service the hardfacing material as applied on the substrate shall have documented corrosion resistance.

4.4 Chemical treatment

Corrosion inhibitors, scale inhibitors, oxygen scavenger or other chemicals can be used to reduce corrosion in process, fresh water and seawater systems etc. The efficiency in the specified service shall be proven and documented as well as the compatibility with other chemicals to be used.

Biocides can be used in process, injection water systems etc. to prevent bacterial growth and possible microbiologically induced corrosion problems.

4.5 Corrosion monitoring

Design of corrosion monitoring systems shall be based upon criticality evaluations taking appropriate note of probability of failure/damage and the consequences. Such systems shall at least be evaluated for carbon steel pipelines and flowlines, carbon steel hydrocarbon piping and cathodic protection systems.

5 Material selection for specific applications/systems

5.1 Introduction

This clause gives requirements to material selection for specific areas and systems. The selections are based upon contemporary North Sea practice and available technology.

All bulk materials for piping systems and structural components shall comply with relevant NORSOK Material Data Sheets. Note that it is the manufacturer's responsibility to confirm that the materials used comply with PED requirements. Material selections are given below and limitations for material alternatives are given in clause 6.

5.2 Drilling equipment

The materials used in drilling equipment shall be in compliance with relevant ISO standards. The material selection for drilling equipment should be in accordance with general requirements in this document.

5.3 Well completion

All well completion materials, including elastomers and polymeric materials, shall be compatible with produced/injected fluid. In addition, the materials shall as a minimum be compatible with the following well intervention fluids with additives for relevant exposure duration:

a) Completion and packer brine fluids
b) Mud acids (HCl - hydrochloric acid, HF - hydrofluoric acid)
c) Stimulation fluids
d) Scale inhibitors
e) Methanol

Material selection for well completion is given in table 1.

Polymers shall satisfy the requirements given in 6.4.

Titanium alloys shall not be used in permanently installed well completion equipment, when hydrofluoric acid or pure methanol (less than 5% water) are planned to be used.

Flow couplings shall be used at transitions between CRA and low alloy tubing materials to allow for galvanic corrosion in injection wells. The sealing surface of couplings to be used should not be located in areas expected to be affected by corrosion. Alternatively, internal baked phenolic coating can be considered. For production wells, flow couplings may be evaluated for use upstream and downstream of components causing obstructions to fluid flow, such as for downhole safety valves.

For hydraulic control lines for downhole safety valves, stainless steel type 316 shall not be used above 60°C. All materials shall have external thermoplastic sheathing resistant in the downhole environment. Clamps for cables and hydraulic control lines can be made in carbon or low alloy steel if the design allows for expected degree of corrosion.

The following is excluded from the scope of PED: well-control equipment used in the petroleum, gas or geothermal exploration and extraction industry and in underground storage which is intended to contain and/or control well pressure. This comprises the wellhead (Christmas tree), the blow out preventers (BOP), the piping manifolds and all their equipment upstream.

Table 1 - Material selection for wells

Well type	Tubing and liner	Completion equipment (Where different from tubing/liner)	Note
Production	13Cr is Base Case. See table 5 for design limitations.		1
	Low alloy steel. (Option for systems with low corrosivity/short lifetime.)	13Cr	1, 2
	13% Cr and 15% Cr alloys modified with Mo/Ni (S13Cr), duplex and austenitic stainless steels and nickel alloys are options for high corrosivity		3
Deaerated seawater injection	Low alloy steel	UNS N09925, Alloy 718 22Cr or 25Cr duplex	2, 4, 7
Raw seawater injection	Low alloy steel with GRP or other lining	Titanium. See also table 5.	5, 8, 9
	Low alloy steel for short design life	Titanium. See also table 5.	8, 9
	Titanium. See table 5 for design limitations.		9
Produced water and aquifer water injection.	Low alloy steel	13Cr (Limitations as for tubing for this service)	1, 2, 6
	Low alloy steel with GRP or other lining	13Cr (Limitations as for tubing for this service)	1, 5
	13Cr. Provided oxygen < 10 ppb, see also table 5.		1
	22Cr duplex, Alloy 718, N09925. Provided oxygen < 20 ppb.		
Gas injection	Material selection shall be as for production wells and shall follow the guidelines in 4.2.2.		
Alternating injection and combination wells	Material selection shall take into account that the corrosion resistance of different material alternatives will differ for various media.		

NOTES

1 For fluids with a partial pressure of H_2S above 0.1 bar or pH below 3.5, 13Cr shall have a maximum SMYS of 560MPa (80 ksi). Limiting the strength is generally recommended to avoid hydrogen stress cracking caused by hydrogen formed by galvanic corrosion of the casing.
2 Low alloy steel with approximately 0.5% Cr and proper corrosion allowance for tubing. Use of same CRA as for completion equipment shall be evaluated for liners.
3 Cold worked grades of duplex stainless steel shall be limited to 862 MPa (125 ksi) SMYS and maximum 966 MPa (140 ksi) actual yield strength in longitudinal and tangential direction.
4 Detailed material selection for completion equipment to be based upon design requirements and supplier experience.
5 For GRP lining, qualification is required unless field experience can be provided. If GRP solid pipe is evaluated as an alternative for downhole tubing, see 6.3.3.
6 CO_2 corrosion rate estimates shall be based on the model referred to in 4.2.2. Corrosion inhibitors can be used in oxygen free systems provided acceptable from reservoir considerations.
7 Low alloy steel can be used in components located in lower sections of the well if strict dimensional tolerances in service are not required.
8 For short design lives and low temperatures, stainless steels or Ni-based alloys may be considered for completion equipment.
9 Raw seawater contains oxygen and may or may not contain chlorine.

5.4 Structural materials

5.4.1 Steel

Bolting materials shall comply with 5.5.5.

Recommendation:
Benefits of saving weight by using high strength steel (i.e. SMYS of 420 MPa or higher) shall be considered.

5.4.2 Concrete

Concrete materials properties shall comply with NS 3420, Exposure Class Ma - Highly Aggressive Environment and NS 3473. Maximum water to binder ratio shall be 0.45.

5.4.3 Aluminium

Aluminium alloys shall be selected among those given in NORSOK standard M-121.

5.4.4 Passive fireproofing materials

Passive fireproofing materials for protection of structural steel or for area segregation should be of spray applied types. A corrosion protection coating system shall be applied to the steel. Further requirements are given in NORSOK standard M-501.

For outdoor applications, or where the passive fireproofing is subjected to wear, impact or other mechanical damages, an epoxy based coating system shall be used. For other applications, cement type materials with a diffusion open top-coat can be used for steel structures.

5.5 Topside facilities

5.5.1 General

Carbon steel can be used in topside systems where the calculated annual corrosion rate is less than corrosion allowance divided by design life. For inhibitors in topside systems reference is made to 4.2.2

The piping materials shall be standardised on the following material types as far as practical:

- Carbon steel Type 235, Type 235LT, Type 360LT
- Stainless steel Type 316
- Stainless steel Type 22Cr and 25Cr duplex
- Stainless steel Type 6Mo
- Titanium
- GRP.

Other materials shall only be introduced after their performance and availability have been considered.

Cast stainless steel Type 6Mo shall not be used for components to be welded.

Material selections for topside facilities are given in table 2 with amendments as given below. A premise for the selections in the table has been limitation of number of grades and types for each application.

5.5.2 Oil and gas processing

For evaluation of corrosivity in a vessel (i.e. separator or scrubber) and in the liquid carrying piping downstream the vessel, the CO_2 and H_2S partial pressure in the gas carrying piping downstream the vessel can be used. To compensate for the fact that these gases are not at equilibrium with the liquid in each vessel, the corrosion rate found by the prediction model in clause 4.2.2. shall be increased by 25% for separators and liquid carrying piping downstream the separators. No compensation is required for gas scrubbers and liquid carrying piping downstream scrubbers.

Pressure rating, maximum/minimum design temperature and size shall be taken into account when selecting materials.

All components which may contact oil well streams shall be resistant against well treating, well stimulating chemicals and other additives.

5.5.3 Seawater systems

Hot dip galvanised carbon steel can be used in seawater systems provided it is documented to be cost efficient and replacement is planned for in design if necessary. The galvanising shall be performed on completed spools to avoid welds without galvanising. If this material is evaluated for use in firewater systems, special measures shall be made to avoid plugging of sprinkler/deluge nozzles.

Important factors for design and operation of stainless steel sea water systems are:

- Threaded connections are not acceptable
- Commissioning and start-up of the systems should avoid chlorination the first two weeks

Based on an evaluation in each case, internal cathodic protection of stainless steel and other passive materials may be used for piping and components. Internal cathodic protection should be avoided in stainless steel type 316 piping, and shall only be used when the operational conditions do not include full or partial draining of the systems.

Graphite gaskets shall not be used in sea water piping systems.

For piping downstream heat exchangers it shall be taken into account that relatively high operating temperatures may occur when marine fouling is not present inside the heat exchanger, i.e. initially and after cleaning operations.

Table 2 - Materials for topside facilities, sheet 1 of 3

	Materials	Note
Oil and gas production and processing	Corrosivity evaluations shall be based on 4.2.2. and 5.5.2.	
Wellhead equipment/ X-mas trees	13Cr4Ni, Low alloy steel with alloy 625 weld overlay.	1
Piping and vessels	22Cr duplex, 25Cr duplex, 6Mo, 316, Superaustenite.	
Thick wall vessels	Carbon steel with 316, Alloy 625, Alloy 825 or 904 clad or weld overlay.	
Piping and vessels in low corrosivity systems	Carbon steel.	
Inlet side of compressors	Carbon steel. Carbon steel with CRA weld overlay or solid CRA if required, based upon corrosivity evaluations.	
Piping, vessels for produced water	316, 22Cr duplex, 25Cr duplex, 6Mo, Titanium or GRP.	
Seawater systems and raw seawater injection	See also 5.5.3.	4
Wellhead equipment/ X-mas trees	Carbon steel with weld overlay according to 4.3	
Vessels	Titanium, GRP, carbon steel with internal rubber lining or organic coating in combination with cathodic protection.	
Piping materials	6Mo, 25 Cr duplex, Titanium, GRP.	
Piping components	6Mo, 25Cr duplex, Titanium, Alloy 625, Alloy C276, Alloy C22.	2,3
Valves in GRP systems	GRP, Carbon steel with polymeric lining, NiAl bronze.	
Normally drained systems	Copper base alloys, 6Mo, Titanium. Carbon steel for short lifetimes, e.g. 5-10 years.	4
Pumps	25Cr duplex, 6Mo, Titanium,	5,6

Table 2 - Materials for topside facilities, sheet 2 of 3

	Materials	Note
Deaerated seawater injection	See also 5.5.4.	
Wellhead equipment/ X-mas trees	Low alloy steel with Alloy 625 weld overlay in sealing surfaces.	
Piping	Carbon steel, GRP.	
Deaeration tower	Carbon steel with internal organic coating, plus cathodic protection in bottom section .	
Pump and valve internals	Provided carbon steel housing: 13Cr4Ni, 316, 22Cr duplex, 25Cr duplex.	6
Produced water and aquifer water injection	Carbon steel, 316, 22Cr duplex, 6Mo, Titanium, GRP. Wellhead and X-mas trees as for deaerated seawater injection.	13
Fresh and potable water	Hot dip galvanised carbon steel, GRP, Polypropylene, 316, Copper base alloys.	7
Drains and sewage		
Open drain	GRP, carbon steel.	
Closed drain without oxygen	316, carbon steel.	
Closed drain with oxygen	22Cr duplex, 25Cr duplex, 6Mo, Titanium, GRP.	
Sewage	GRP, polyethylene.	
Flare systems		
Relief system	316, 6Mo, low temperature carbon steel.	
Burner components	Alloy 800H, Alloy 800HT, Alloy 625; For temperatures below 650°C: 310.	
Flare boom	Structural steel with thermally sprayed aluminium.	
Dry fuel gas and diesel	Carbon steel.	
Piping	Carbon steel.	
Tanks	Carbon steel, GRP.	8
Lubrication and seal oil	316, 22Cr duplex, 6Mo.	9
Hydraulic fluid	316, carbon steel upstream filters.	
Instrument air	316, carbon steel upstream filters.	

Table 2 - Materials for topside facilities, sheet 3 of 3

	Materials	Note
Inert gas/plant air piping	Carbon steel, 316.	
Instrumentation		
Tubing	316, Hastelloy C. 6Mo, 25 Cr duplex, Titanium.	5,10
Junction boxes/cabinets	GRP, 316.	
Cable trays	316; Hot dip galvanised carbon steel in fully HVAC controlled areas.	
HVAC ducts and units		
Ventilation/air intake ducts	316, Hot dip galvanised steel.	11
Air handling units	316.	
Seawater coils	Titanium.	
Active fire fighting systems		
Dry CO_2 systems	Carbon steel.	
Freshwater/plant air/nitrogen	316.	5
Glycol	Carbon steel, 316.	
Methanol	Carbon steel, 316.	
AFFF	316, GRP.	
Heating/cooling media	Carbon steel. CRA in heat exchanger tubes.	
Miscellaneous chemical systems	GRP, 316, 6Mo, Titanium.	12
Bolting materials	See 5.5.5	

NOTES

1 Sealing surfaces of components in Type 13Cr4Ni shall be overlay welded with Alloy 625. For wells with low corrosivity and/or short lifetime, low alloy steel with alloy 625 weld overlay in sealing surfaces only can be used. For weld overlay, ref. 4.3.
2 Shall also be used for process wetted parts of instrument systems
3 See 6.3 for design limitations. Weld overlay can be applied to prevent crevice corrosion, ref. 4.3.
4 Copper alloys shall not be used in combination with CRAs and Titanium. Exception can be components in fire water systems, provided galvanic corrosion can be avoided by proper isolation. If electrical isolation (15.000 ohm in dry system) is ensured and verified after installation, mechanical connections between bronze/brass and noble alloys such as Type 6Mo and titanium alloys are acceptable.
5 See clause 6 for design limitations.
6 Ceramic filled epoxy coatings can be used for shorter lifetimes, e.g. 5-10 years.
7 Large diameter piping and tanks can be made in internally coated carbon steel.
Tanks not intended for potable water, shall in addition be cathodically protected. GRP, polypropylene and coating used for potable water shall be accepted by the national health authorities.
8 Tanks in carbon steel shall have 3 mm corrosion allowance at the bottom section. In addition the bottom and roof shall be coated. Cathodic protection shall only be used if corrosion products from the sacrificial anodes do not cause damage to the turbines. No corrosion allowance is required for cathodically protected surfaces.
9 Type 316 is acceptable up to operating temperature 70°C provided located indoor or in sheltered areas and not insulated.
10 For uninsulated stainless Type 316 instrument piping downstream a shut-off valve, normally no extra precautions are required, provided process medium temperature is below 85°C and there is no flow in the instrument piping.
11 Hot dip galvanised steel can be used in living quarter and domestic areas.
12 The combination of chemical and material has to be considered in each case. Titanium or GRP shall be used for hypochlorite systems.
13 Materials selection to be based on a corrosivity evaluation as described in par. 4.2.3.

5.5.4 Water injection

Water injection covers systems for injection of deaerated seawater, raw untreated seawater, produced water and combinations and mixing of different waters.

Corrosivity evaluations for deaerated injection seawater shall be based on a maximum operating temperature of 30°C and the following Oxygen Equivalent levels (see clause 3.1 for definition of Oxygen Equivalent):

- 50 ppb for 90% of operation time.
- 200 ppb for 10% of operation time, non continuous.

Even if the specification for the deaeration equipment gives more strict requirements, the above shall be basis for the material selection. If the specified Oxygen Equivalent or temperature is above 50 ppb or 30°C respectively for normal operation, the basis for material selection shall be subject to special evaluation.

Recommendation:
For carbon steel submarine injection flowlines the corrosion allowance should be minimum 3 mm.

In injection water systems where alternating deaerated seawater, produced water, aquifer water and/or gas could flow through the systems, the material selection shall take this into account. All components which may contact injection water or back-flowing fluids, shall be resistant against well treating chemicals or well stimulating chemicals in case of back-flow situations. For carbon steel piping maximum flow velocity shall be 6 m/s.

5.5.5 Bolting materials for piping, equipment, structural and subsea applications

The general bolting material for bolt diameters above 10 mm in piping systems and equipment shall be carbon or low alloy steel selected in accordance with the ASTM Standards listed in table 3 below. Bolts with a diameter ≤ 10 mm shall be stainless steel Type 316 for metal temperatures below 60°C for topside applications based upon maximum operating temperature.

Table 3 - Temperature range for bolting materials

Temperature range, (°C)	BOLT[4)]	NUT	Size range, (mm)
-100/+400	A 320 Grade L7	A 194 Grade 4/S3 or grade 7/S3	≤65
	A 320 Grade L43	A 194 Grade 7/S3 or A194 grade 4/S3	<100
-46/+400	A 193 Grade B7	A 194 Grade 2H	All
-29/+540	A 193 Grade B16[1)]	A 194 Grade 7	All
-196/+540	A 193 Grade B8M[2)]	A 194 Grade 8M/8MA[3)]	All

NOTES

1 This grade should not be used for permanent subsea equipment. Grade B16 is intended for high temperature service, outside the temperature range for Grade B7.
2 Type 316 bolts and nuts shall not be used at maximum operating temperature above 60°C if exposed to wet marine atmosphere.
3 Use 8MA with class 1 bolts.
4 Use of bolting for pressure equipment under PED shall be verified by a PMA.

Bolting materials for **structural applications** shall generally be carbon or low alloy steels.

The following limitations shall apply:

- For topside applications, the strength class shall not exceed ISO 898 class 10.9.
- For submerged bolts, the strength class shall not exceed ISO 898 class 8.8, ASTM A 320 Grade L7 or A 193 Grade B7.
- Bolts with a diameter above 25 mm shall be impact tested to the same requirements as for the steels to be bolted.

If other bolting materials are required due to corrosion resistance or other reasons, the material shall be selected in accordance with the general requirements of this document. For subsea applications, Alloy 625 shall be used when corrosion resistant bolts are required at ambient temperature, i.e. for conditions where the bolts are exposed to aerated seawater and cathodic protection cannot be ensured. It shall be verified that the materials have acceptable mechanical properties at the actual design temperatures.

Bolts screwed into component bodies shall be of a material that is compatible with the body with respect to galling and ability to disassemble the component for maintenance, if relevant. Possibility for galvanic corrosion, thermal coefficient if relevant, and for subsea applications the effect of cathodic protection, shall be considered.

Carbon steel and/or low alloy bolting material shall be hot dip galvanised or have similar corrosion protection. For submerged applications, where dissolution of a thick zinc layer may cause loss of bolt pretension, electrolytic galvanising or phosphating shall be used. Electrolytic galvanising shall be followed by post baking. For subsea installations the use of poly tetra fluor ethylene (PTFE) based coatings can be used provided electrical continuity is verified by measurements. Cadmium plating shall not be used.

5.6 Subsea production and flowline systems

5.6.1 General

Material selections for subsea production and flowline systems are given in table 4. For carbon steel flowlines the requirements given in 5.7 apply.

Recommendation:
Metal to metal seals that may be exposed to seawater without cathodic protection should be made in corrosion resistant alloys such as UNS R30035, R30003, Alloy 625 and Alloy C276. Generally, metal to metal sealing materials shall be more noble than surrounding surfaces.

All polymeric/elastomeric materials shall be qualified and the performance documented in all relevant exposure conditions in accordance with 6.4.

For levelling systems and other systems mainly used for installation, carbon steel shall be considered.

All bolting materials shall comply with 5.5.5.

Restrictions for maximum SMYS and actual yield strength shall apply for all components exposed to ambient seawater with cathodic protection, according to 6.1.

Table 4 - Material selection for subsea production and flowline systems, sheet 1 of 2

Application	Materials	Notes
Wellheads and X-mas trees		
Wellhead equipment/X-mas trees for production	13Cr4Ni, Low alloy steel with Alloy 625 overlay. Relevant API/ISO standards	1
Wellhead equipment/X-mas trees for deaerated seawater	Low alloy steel with Alloy 625 weld overlay in sealing surfaces. Design must allow for corrosion on not- overlayed parts. Relevant API/ISO standards	1
Wellhead equipment/X-mas trees for aerated seawater	Carbon steel with weld overlay according to 4.3.	
Wellhead equipment/X-mas trees for produced water and aquifer water	As for production.	
Retrievable equipment internals	13Cr or CRA's with higher PRE	
Non-retrievable equipment internals, incl. X-mas trees	Alloy 718 or CRA's with higher PRE	
Subsea Manifold Piping		
Piping systems for well fluids	6Mo, 22Cr duplex, 25Cr duplex.	
Piping for deaerated seawater	6Mo, 25Cr duplex. Carbon steel can be used for shorter design life, i.e. less than 15 years.	
Piping for gas	Carbon steel, 22Cr duplex, 6Mo. Material selection shall follow guidelines in 4.2.2.	
Piping for produced water and aquifer water	22Cr duplex, 25Cr duplex, 6Mo. Carbon steel can be used for shorter design life (i.e. less than 6-8 years) and if low corrosivity.	
Piping for raw seawater	Titanium.	
Hydraulic fluids/glycol/methanol	316.	2
Chemical injection and annulus bleed systems	316.	
Retrievable valve internals	13Cr, 17 - 4 PH, Alloy 718.	
Non-retrievable valve internals	Alloy 718.	

Table 4 - Material selection for subsea production and flowline systems, sheet 2 of 2

Application	Materials	Notes
Subsea Rigid Flowlines		3
Oil and gas	Carbon steel, 13Cr, SM13Cr , 22Cr duplex or CRA clad carbon steel. Material selection shall follow guidelines in 4.2.2.	4,5,6
Deaerated seawater injection	Carbon steel.	4
Produced water and aquifer water injection	Carbon steel, 22Cr and 25Cr duplex, 6Mo.	5
Raw seawater injection	Titanium, 6Mo, 25Cr duplex, internally polyethylene lined carbon steel.	
Hydrate Inhibitor Lines	Carbon steel, 316, 22Cr duplex.	7
Subsea Production Control Systems		
Umbilicals, metallic	25Cr duplex, encapsulated. Titanium.	8,9,10
Umbilicals, polymer hoses	Polyamide 11, Thermoplastic elastomer (TPE), High strength carbon or high strength polymer fibres.	11

NOTES

1 For weld overlay, ref. 4.3. Sealing surfaces of components Type 13Cr4Ni shall be overlay welded with Alloy 625.
2 Carbon steel and stainless steel with lower PRE than Type 316 can be used provided documented by field experience and/or tests.
3 Flexible pipe should be considered as alternative to rigid pipe. Carbon steel clad with CRA can be used as alternative to solid CRA. Guidance on selection of CRAs for injection is given in table 1.
4 Carbon steel and weld metal can be alloyed with approx. 0.5% chromium for oil production and deaerated seawater injection flowlines to improve corrosion resistance.
5 Type 25Cr and Type 13Cr to be documented with respect to feasibility/weldability.
6 Cost effectiveness of using duplex stainless steels with a lower alloying content than for Type 22Cr should be considered.
7 Carbon steel can be used if acceptable from cleanliness point of view.
8 See Table 5 for limitation for titanium in methanol service.
9 Type 22Cr duplex can be used if cathodic protection can be ensured. For 25 Cr duplex without cathodic protection, external polymeric sheathing is required.
10 Carbon steel with external protection (cathodic protection in combination with coatings - organic or thermally sprayed aluminium) can be used if acceptable from cleanliness requirements point of view.
11 Documented functionality in relevant fluids with extrapolation of service life is required. Ref. 5.6.3. Not to be used for methanol service.

5.6.2 Flexible flowlines and risers

Generally the requirements of ISO 13628-2, API RP 17J and Det Norske Veritas "Guidelines for Flexible Pipes" shall be satisfied. Due consideration shall be made to evaluate the possibility of failure due to corrosion and/or corrosion-fatigue of the steel reinforcement caused by the internal and/or the external environment. If "sour" conditions apply, the effect of H_2S on steel reinforcement and inner liner shall be considered. The gas diffusing through the polymeric sheets shall be considered wet. If welding is performed on reinforcement wires, the resulting reduction in strength shall be taken into consideration in the design.

Measures to avoid internal galvanic corrosion by proper material selection and/or electrical isolation shall be ensured at all interfaces to neighbouring systems such as at subsea production manifold piping and flowlines.

The material for the inner metallic layer of non bonded pipe can be stainless steel Type 316 provided pitting corrosion and local erosion penetrating the liner do not deteriorate the functional performance and reliability of the flexible pipes. The choice of inner material shall take into account the possibility of being exposed to seawater during installation and commissioning.

The following shall be documented.

- Material properties verifying consistency between the design requirements and the fabricated quality.
- Documentation demonstrating that polymeric materials will be resistant to the internal and external environment and maintain adequate mechanical and physical properties throughout the design life of the system shall be in accordance with 6.4.

5.6.3 Subsea production control systems

For polymeric based hoses, material selection shall be based upon a detailed evaluation of all fluids to be handled. The annulus bleed system will be exposed to a mixture of fluids, such as production fluid, methanol, completion fluid and pressure compensating fluid. A hose qualification programme shall be carried out including testing of candidate materials in stressed condition, representative for actual working pressure, unless relevant documentation exists. The results from qualification testing shall provide basis for service life extrapolation according to methods such as Arrhenius plots.

For umbilicals, the electric cable insulation material shall also be qualified for all relevant fluids. The materials selected for the electrical termination should be of similar type in order to ensure good bonding between different layers. The material selection for metals and polymers in electrical cables in the outer protection (distribution harness) and in connectors in distribution systems shall have qualified compatibility with respect to dielectric fluid/pressure compensation fluid and sea water. The functionality in sea water of the individual barriers relative to the service life, shall be documented.

The different parts of the components in hydraulic and chemical distribution systems shall have documented compatibility with relevant process fluids, dielectric fluid and sea water.

5.6.4 Drilling and workover risers

The required accumulated exposed design life shall be defined at an early stage.

All welded parts shall be post weld heat treated.

Resistance to "sour" conditions shall be taken into account for parts of the drilling and workover risers which may be exposed to reservoir fluids during drilling and testing. Compliance with "sour" service requirements as given in 4.2.2. shall be met, unless less stringent requirements are justified.

For drilling risers a total erosion/corrosion allowance of minimum 6 mm shall be included for accumulated design lives exceeding 10 years.

For workover risers manufactured from C-steel, reduction in wall thickness due to corrosion shall be evaluated. Effects of corrosion shall be accounted for by a minimum of 1 mm unless it can be demonstrated through routine maintenance that a corrosion allowance can be eliminated.

5.7 Pipeline systems

Pipeline systems shall be in accordance with DNV OS-F101.

The material selection for pipeline systems for processed oil and gas shall be C-Mn steel. For unprocessed or partially processed oil and gas a corrosivity evaluation according to par. 4.2.2 shall be done and materials and corrosion control selected accordingly.

Pipeline systems containing gas shall be designed for a minimum design temperature that takes into account possible blow down situations.

The following is excluded from the scope of PED: Pipelines comprising piping or a system of piping designed for the conveyance of any fluid or substance to or from an installation (onshore or offshore) starting from and including the last isolation device located within the confines of the installation, including all the annexed equipment designed specifically for pipelines. This exclusion does not apply to standard pressure equipment such as may be found in pressure reduction stations or compression stations.

5.8 Chains and mooring lines for floating units

In mooring line systems a corrosion rate of 0.4 mm/year for splash zone and 0.1 mm/year for fully submerged conditions shall be used as basis for corrosion allowance and lifetime estimates. An evaluation of possible corrosion due to bacterial activity on the seabed shall be carried out.

Wire rope segments shall have a protection system consisting of an outer jacketing (typically polyethylene or polyurethane), galvanised wires and a filler material to prevent ingress of water. In addition, zinc sacrificial wires may be incorporated.

6 Design limitations for candidate materials

6.1 General

Design limitations for the application of different material types, e.g. maximum/minimum temperature, maximum SMYS and actual yield strength, weldability, etc. are defined in the following.

The following general requirements apply for all steel types (including bolts):

For carbon and low alloy steels, the yield to tensile strength ratio (actual values) shall not exceed 0.9.

- For materials intended for welding, SMYS shall not exceed 560 MPa.
  Note: If this requirement can not be met, higher SMYS is acceptable provided documentation showing acceptable properties with respect to weldability and the in service properties of the base material, heat affected zone and weld metal on both sides is presented.
- For submerged parts that may be exposed to cathodic protection, the following shall apply:
  For carbon and low alloy steels, SMYS shall not exceed 700 MPa (725 MPa for bolts). The actual yield strength shall not exceed 950 MPa. Alternatively, it may be verified that the actual hardness in base materials does not exceed 295 HB. For carbon steel welds a max. limit of 350 HV10 applies. For stainless steels and non-ferrous materials, resistance against hydrogen embrittlement shall be controlled by specifying that the actual hardness of the material shall be in accordance with NACE MR0175, unless otherwise documented.
  Note: For materials where NACE MR0175 specifies different hardness levels for different environmental conditions, the hardness levels corresponding to “Test Level II” in Table 1 of MR0175, or the most similar environmental condition, shall apply.
- For the ISO and ASTM bolt materials listed in 5.5.5 additional requirements to yield strength/hardness beyond that specified in the respective standards do not apply.
- Metallic materials for pressure retaining components which are not covered by NORSOK Standards and Material Data Sheets or applicable codes, shall as a minimum be according to DNV RP B 201.

In cases where the minimum design temperature is a limiting factor for a material, also temperature exposures during intermediate stages (such as manufacturing, storage, testing, commissioning, transport, installation) shall be considered when specifying the minimum design temperature and handling procedures.

6.2 Materials for structural purposes

6.2.1 Steel

Material requirements to the applicable grades are defined in NORSOK Material Data Sheets, M-120 and Standard M-101.

The impact toughness test requirements given to, and the application of, the specified structural materials are based on a minimum design temperature of -10°C. If lower design temperatures are applicable, sufficient fracture toughness properties have to be verified. For the most critical design class, this shall include CTOD testing of base material, weld metal and HAZ at the minimum design temperature.

6.2.2 Concrete

Design limitations for application of structural concrete shall be according to NS 3473 including Exhibit B and NS 3420.

6.2.3 Aluminium

Aluminium may be used within limitations given in NORSOK Standard M-121, for all relevant ambient temperatures. Aluminium alloys shall not be used for elevated temperatures. In particular, AlMg-alloys with Mg-content above 3.0% shall not be used when the design temperature is above 60°C. Special consideration shall be given to loss of strength above approximately +100°C.

Hardened aluminium alloys suffer from a reduction in strength in the heat affected zone after welding. The actual reduction factors to be used shall comply with applicable design code but shall be evaluated and verified by welding and appropriate mechanical testing. The weld metal strength shall be included in this evaluation and minimum yield and tensile strength requirements shall also be defined. Necessary precautions shall be taken to ensure homogeneous material properties in extruded sections and in particular across extrusion welds.

6.2.4 GRP

For GRP used in applications such as panels, gratings and other secondary applications, special emphasis must be put on risk assessment and evaluation of fire performance.

6.3 Materials for pressure retaining purposes

6.3.1 General

Materials shall be used within the limits given in table 5. Materials for piping systems shall comply with NORSOK Standards L-001 (M-630), M-601 and M-CR-621.

Materials shall resist general corrosion, localised corrosion in the form of pitting and crevice corrosion and environmental cracking in the form of CSCC and SSC. NACE MR0175 considers only SSC. Limitations for CRA's in "sour" service beyond NACE MR0175 are given in table 6. It is emphasised that H_2S limits for CRA material categories are difficult to state on a general basis. Specific limits for the material type and grades to be used should be established accordingly by testing according to EFC Publication no. 16 for carbon and low alloy steel and EFC Publication no. 17 for CRAs. For requirements to manufacturing, heat treatment and material properties, reference is made to NACE MR0175.

In carbon steel vessels that are clad or overlay welded with austenitic stainless steels or nickel alloys (minimum 3 mm thickness), the backing steel hardness shall be limited to 325 HV10.

Note: This only applies for moderately sour conditions normally found in North Sea offshore operations and at moderate temperatures (<200°C).

The lower temperature limits for carbon steel imposed by the design code and NORSOK Standards requirements shall be adhered to. In special circumstances impact tested steel may be used below these limits. Such cases require individual attention. The maximum design temperature shall be according to the applicable design codes for all types of materials. Free machining grades are not acceptable for pressure retaining purposes.

Table 5 - Metallic materials for pressure retaining purposes, sheet 1 of 2

Material	Min. design temp. (°C)	Impact testing required	Other requirements	Note
Carbon and low alloy steel				1
235 235 LT 360 LT 3.5% Nickel steel	- 15 - 46 - 46 -101	 Yes Yes Yes		
Martensitic stainless steels				2,3
SM13Cr 13Cr 13Cr valve trim parts 13Cr4Ni 13Cr4Ni double tempered	- 35 - 10 - 29 - 46 -100	Yes Yes Yes		
Austenitic stainless steels				4
316 6Mo Superaustenite	-101 -196 -101 -196 -101	 Yes Yes 	Max. operating temp. 60°C. Higher temperatures acceptable if full HVAC control, oxygen free environment or used subsea with cathodic protection. 6 Mo seawater systems with crevices: Max. operating temp. 20°C, max. residual chlorine 1.5 ppm. Max. operating temperature 120°C in saliferous environment, ref. par. 6.3.4. Max. operating temperature 120°C in saliferous environment.	
Duplex stainless steels				5
22Cr 25Cr	- 46 - 46	Yes Yes	Maximum operating temperature 100°C for 22Cr and 110°C for 25Cr if exposed to saliferous atmosphere. Probability for cracking should be assessed in systems affected by acidising if sulphide containing scales can be formed. Limitations for 25Cr in seawater systems as for 6Mo.	
Nickel base alloys	-196		Crevice corrosion limitation for Alloy 625 in sea water systems as for 6Mo.	

Table 5 - Metallic materials for pressure retaining purposes, sheet 2 of 2

Material	Min. design temp. (°C)	Impact testing required	Other requirements	Note
Titanium base alloys				6
Grade 2	-196		Seawater operating temperature limits if crevices are present: Unchlorinated 95°C, Chlorinated 85°C, Brine 80°C.	
Other grades				7
Copper base alloys			Max. Velocity cfr. BS MA 18. For intermittent service max. 10 m/s. Not for stagnant conditions.	8, 10
90-10, 70-30, NiAl bronze, gun metal			Fresh seawater and normally drained systems.	8
Admiralty brass, gun metal, tin bronze			Fresh water normally drained systems.	
Aluminium base alloys	-196			9

NOTES

1 Carbon steel Type 235 can be used in piping systems with minimum design temperature down to -15ºC for thickness less than 16 mm
2 A corrosivity evaluation shall be carried out if temperature > 90ºC, or chloride concentration >5%.
3 Impact testing for well completion shall be carried out at -10°C or the min. design temperature if this is lower. Use of 13Cr at temperatures below -10°C requires special evaluation.
4 Impact testing of austenitic stainless steel Type 316 and 6Mo weldments has not been considered necessary above -101°C. Type 6Mo stainless steel can be used in seawater systems with crevices above 20°C if crevices are weld overlayed, ref. 4.3. No threaded connections acceptable in seawater systems.
5 Type 25 Cr stainless steel can be used in seawater systems with crevices above 20°C if crevices are weld overlayed, ref. 4.3. No threaded connections acceptable in seawater systems.
6 Shall not be used for hydrofluoric acid or pure methanol (> 95%) or exposure to mercury or mercury based chemicals. Titanium shall not be used for submerged applications involving exposure to seawater with cathodic protection unless suitable performance in this service is documented for the relevant operating temperature range.
7 Service restrictions shall be documented for other Titanium grades.
8 Shall not be exposed to mercury or mercury based chemicals, ammonia and amine compounds.
9 Shall not be exposed to mercury or mercury containing chemicals
10 Chlorination may not be needed with a sea water system based on 90-10 Cu-Ni.

6.3.2 Bending and cold forming of pipes

Bending of pipes shall be in accordance with NORSOK Standard L-001 data sheet NBE1. Additional materials limitations to cold forming are given below.

It shall be documented that the material after bending complies with the requirements to mechanical properties and corrosion resistance as per the relevant MDS.

The hardness of cold formed duplex stainless steels to be used subsea with cathodic protection shall be limited to the NACE MR0175 requirements for sour service for these materials. Ref. is also made to the NOTE under 2nd bullet in 6.1.

6.3.3 Glass fibre reinforced plastic (GRP)

Design of piping systems in GRP materials shall in general be according to ISO 14692 parts 1 - 4 and according to ASME B 31.3. The need for fire and impact protection shall be evaluated whenever GRP is used.

The use of GRP for piping systems on platforms is limited as follows:

- No use in hydrocarbon and methanol systems.
- Max. internal design pressure 40 bar g.
- Design temperature range from -40 up to 95°C for epoxy and up to 80°C for vinylester.
- The possible hazard for static electricity build-up shall be accounted for.

For GRP tanks and vessels the following limitations apply:

- Design pressure in bar times internal volume in litres shall not exceed 75000 and a design temperature of maximum 75°C.
- The potential hazard for static electricity build-up shall be accounted for.
- The use for systems containing hydrocarbons shall be based on risk assessment.

For systems where GRP can be applied, epoxy and vinylester resins shall be evaluated as alternatives for piping components and tanks. Polyester resin can be used in tanks for seawater and open drain services.

For systems handling hypochlorite, GRP with vinylester resin and PVC lining or titanium shall be used. For sulphuric acid, only GRP with vinylester resin and PVC lining shall be used. For other strong acids, GRP with C glass or ECR glass combined with resin rich internal barrier, or CRA of applicable grade, shall be used.

If GRP is considered used as rigid pipe for downhole produced water and seawater injection tubing, material properties shall be documented in accordance with relevant API standards and ASTM D 2992.

For other than seawater and freshwater, the fluid compatibility shall be documented in accordance with 6.4.

6.3.4 Chloride induced stress corrosion cracking (CSCC)

Chloride induced stress corrosion cracking depends on stress level and environmental conditions such as pH and salt concentration. Maximum operating temperatures for different unprotected stainless steels are given in Table 5.

The 22Cr, 25Cr and 6Mo materials may be used above these temperatures provided corrosion protection according to NORSOK M-501. The temperature limits may be exceeded in dry, fully HVAC controlled environments.

6.4 Polymeric materials

The selection of polymeric materials, included elastomeric materials, shall be based on a thorough evaluation of the functional requirements for the specific application. Dependent upon application, properties to be documented and included in the evaluation are:

- Thermal stability and ageing resistance at specified service temperature and environment.
- Physical and mechanical properties.
- Thermal expansion.
- Swelling and shrinking by gas and by liquid absorption.
- Gas and liquid diffusion.
- Decompression resistance in high pressure oil/gas systems.
- Chemical resistance.
- Control of manufacturing process.

Necessary documentation for all important properties relevant for the design, area/type of application and design life shall be provided. The documentation shall include results from relevant and independently verified tests, and/or confirmed successful experience in similar design, operational and environmental situations.

Polymeric sealing materials used in well completion components, X-mas trees, valves in manifolds and permanent subsea parts of the production control system shall be thoroughly documented. For these components documentation for relevant materials from all suppliers used shall be provided. Reference is made to NORSOK standard M-710.

Table 6 - H_2S limits for generic CRA classes

Material	Chloride concentration, max. (%)	Min. allowed in-situ pH	Temperature, max. (°C)	Partial pressure H_2S, max. (bar)	
Martensitic stainless steels					
13 Cr	5	3.5	90	0.1	
Austenitic stainless steels					
316	1 5 5	3.5 3.5 5	120 120 120	0.1 0.01 0.1	
6Mo	5 5	3.5 5	150 150	1.0 2.0	
Duplex stainless steels					
22Cr	3 1	3.5 3.5	150 150	0.02 0.1	
25Cr	5 5	3.5 4.5	150 150	0.1 0.4	
Nickel alloys					
625		3.5		5	
C276				>> 5	
Titanium		3.5		>> 5	

NOTES

The limits given assumes complete oxygen free environments.

1 If one of the listed parameters exceeds the given limit, it is recommended to test the material according to EFC Publication no. 17.

2 The temperature limit may be increased based upon evaluation of specific field data and previous experience. Testing may be required.

7 Qualification of materials and manufacturers

7.1 Material qualification

7.1.1 General

The selection of materials for applications which may affect the operational safety and reliability level shall be made among the listed qualified materials.

The materials listed in clause 4 and 5 shall be regarded as qualified when used within the design limitations given in clause 6. Other materials can be added to those listed if adequate documentation is available and the objective of limiting number of material types and grades is maintained.

Qualified materials shall fulfil the following requirements:

1. The material is listed by the relevant design code for use within the stated design requirements.
2. The material is standardised by recognised national and international standardisation bodies.
3. The material is readily available in the market and stocked by relevant dealers.
4. The material is readily weldable, if welding is relevant, and known by potential fabricators.
5. The material has a past experience record for the applicable use, e.g. same type of component and dimensional range.

7.1.2 Qualification by past experience

Where the same type of material is regularly supplied for the same application, the qualification shall be based on experience. This applies to most materials supplied and used within the limitation of the design codes. The exception to this can be manufacturing of special components outside the normal dimensional range.

7.1.3 Qualification by general test data

Where well known materials are used in "new" applications or "new" materials are to be used, the qualification may be by reference to results from relevant laboratory or production tests.

7.1.4 Qualification by specific test programme

When a material is proposed for a new application and the selection cannot be based on the criteria in 7.1.1 to 7.1.3, a qualification programme shall be initiated. The objective of the programme shall be clearly defined before starting any testing. Such objectives may be qualitative or quantitative and aim at defining if the product is acceptable or not for the design life of the system.

The qualification programme shall consider both the effect of the manufacturing route as well as fabrication on the properties obtained. Where possible, reference materials with known performance (good, borderline or unacceptable) shall be included for comparison.

7.2 Manufacturer qualification

Under certain conditions it may be necessary to apply additional requirements to the potential or selected manufacturers to ensure their capabilities to supply the required material. Such qualification shall be evaluated when one of the following conditions are present:

1. The materials to be supplied include stainless steel Type 6Mo, Type 22Cr, Type 25Cr and titanium.
2. The requested material dimensions and/or quality require special demands by being outside the range of standardised products or outside the normal production range of the potential manufacturer.
3. For non-metallic sealing materials for topside gas systems subjected to rapid depressurisation, well completion and critical permanent subsea equipment.

Reference is made to NORSOK standard M-650 and M-710.

7.3 Familiarisation programmes for fabrication contractors

Fabrication contractors having limited experience with the specified material or with the intended fabrication procedures and equipment, shall perform familiarisation and qualification programmes prior to initiating critical or major work during procurement, manufacturing, fabrication and construction. The purpose shall be to prequalify and verify the achievement of specified requirements on a consistent basis.

Areas identified which may require such familiarisation and qualification programmes are listed below:

- Joining and installation of GRP components
- Welding and fabrication of aluminium structures
- Aluminium thermal spraying.
- Internal vessel coating.
- Wax coating of valves and other components.
- Welding of steels with SMYS > 460 MPa
- Welding of stainless steel Type 6Mo and Type 25Cr duplex.
- Welding of titanium
- Welding/joining of bimetallic (clad) pipes.
- Cold forming.