Integrity management of subsea production systems
FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.
CHANGES – CURRENT

General
This is a new document.
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SECTION 1 GENERAL

1.1 Introduction
The aim of this document is to provide recommendations for managing the integrity of a subsea production system (SPS) during its entire life from conceptual design to abandonment.

1.2 Objective
The objectives are to:

— provide guidelines to ensure that the operation is safe and conducted with due regard to public safety, environment and property
— provide guidance for operators and suppliers for the establishment and maintenance of an integrity management system (IMS)
— promote the establishment of a uniform IMS within and across operator organisations.

The main focus is on the integrity management process (IMP), see Figure 2-1, which includes:

— threat identification
— risk assessment
— inspection, testing and maintenance planning
— inspection, monitoring and testing (IMT) activities
— integrity assessment
— mitigation, intervention and repair.

The recommendations given are applicable to those parts of the subsea production system as defined by the relevant parts of the ISO 13628-series Petroleum and Natural Gas Industries — Design and Operation of Subsea Production Systems and within the battery limits defined in [1.2.1]. It covers structural failures, containment failures and function failures, and threats that may lead to such failures.

The term “should” is generally applied throughout the document, since this is a recommended practice and not a standard.

1.2.1 Battery limits
This document covers sub-systems and components comprising the hydrocarbon flow path between the subsea wellhead and the PLEM, PLET or riser base, in addition to umbilical, subsea control systems and injection systems (chemical, water and gas). Recommendations specific to subsea processing equipment is not given. Reference is made to ISO 13628-1, Annex A, for more detailed description of the subsea production system.

Figure 1-1 shows the battery limits. The battery limits are:

— umbilical termination topside (HPU included in scope)
— outboard hub on riser base (the whole connector included in scope)
— outboard hub on PLEM (the whole connector included in scope)
— outboard hub on PLET (the whole connector included in scope)
— Xmas tree connector
— top of Xmas tree (re-entry hub and tree cap)
— connection between tubing hanger and production tubing for horizontal Xmas tree.

Figure 1-1 is based on ISO 13628-1, Figure A.1.

Repair and recovery tools are not included within the scope of the document but should indeed also be part of an IMP.

The battery limits of the subsea production system to be covered by an IMS should be clearly defined.
Figure 1-1  The battery limits for this recommended practice are illustrated by the red line (figure reproduced from Figure A.1 in ISO 13628-1)

The main sub-systems and components within the battery limits are:

- Xmas tree (tubing hanger included for horizontal tree)
- template, manifold and PGB
- PLEM, PLET and SSIV
- riser base
- protection structure
- umbilical
- subsea control system.

The external interfaces to the above specified battery limits are:

- wellhead
- tubing hanger for vertical Xmas tree
- well intervention equipment
- pipeline (in-field and export)
- riser
- topside control system.
1.2.2 Barriers versus threats

Barriers are used to ensure a safe operation of the system (refer to ISO/TR 12489 for details regarding reliability modelling and calculation of safety systems). This can be illustrated in a Bow-tie diagram as shown in Figure 1-2. Barriers are any kind of measure put in place to prevent a hazardous event (preventive barriers) and any measure that breaks the chain of events to prevent or minimize consequence escalation should the hazardous event take place (reactive barriers). Such measures can be physical or non-physical (human / operational / organisational). Preventive barriers are illustrated on the left side of the bow-tie, whereas the reactive barriers are illustrated on the right side of the bow-tie. A hazardous event can be loss of containment or loss of function of a valve.

Figure 1-2 Bow-tie diagram showing barriers

A threat is an indication of an impending danger or harm to the system, which may have an adverse influence on the integrity of the system. Each threat may lead to a failure, undesirable situation or an abnormal condition. The possible consequences of such an occurrence can be described in terms of failure modes. Some failure modes may be due to a specific degradation mechanism, while others are event based. App.A gives an overview and description of typical threats and failure modes for a subsea production system.

Barriers are measures put in place to control threats. Barriers are not dealt with specifically in this document but is indirectly included as part of the integrity management process.

1.3 Structure of this recommended practice

This recommended practice has been developed to provide guidance for operators and suppliers for the establishment and maintenance of an integrity management system (IMS) for subsea production systems. The objective and battery limits are described in [1.2].

A description of the overall IMS with the core integrity management process (IMP) is given in Sec.2 and Sec.3, respectively considering the IMP in a lifecycle perspective.

Sec.4 to Sec.7 describes the four main activities that form the IMP and gives recommendations for how to establish and maintain integrity by carrying out these activities.

The following appendixes give more details and examples to support the activities described in Sec.4 to Sec.7:

— App.A: Threats and failure modes
— App.B: Risk assessment and IM planning working process
— App.C: Recommendations with regards to corrosion and erosion
— App.D: Integrity reporting template.
1.4 Relation to other codes
This report is based on the requirements and recommendations given in the ISO 13628-series Petroleum and Natural Gas Industries – Design and Operation of Subsea Production Systems and should reflect the industry best practice for how to manage the integrity of a subsea production system. It aims to be a supplement to relevant national rules and regulations.

The integrity management system described is as described in DNV-OS-F101 Submarine Pipeline Systems and DNV-RP-F116 Integrity Management of Submarine Pipeline Systems.

The following standards and recommended practice can be used if more details are required related to reliability management, hazard identification and risk management: ISO 14224, ISO 17776, ISO 20815, ISO 31000, IEC/ISO 31010, DNV-RP-H101, API RP 17N, ISO/TR 12489 and NORSOK Z-008 (see Section 1.5).

1.5 Codes

1.5.1 Legacy DNV Offshore Standards

<table>
<thead>
<tr>
<th>Reference</th>
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<tbody>
<tr>
<td>DNV-OS-F101</td>
<td>Submarine Pipeline Systems</td>
</tr>
</tbody>
</table>

1.5.2 Legacy DNV Recommended Practices

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>DNV-RP-B401</td>
<td>Cathodic Protection Design</td>
</tr>
<tr>
<td>DNV-RP-C203</td>
<td>Fatigue Design of Offshore Steel Structures</td>
</tr>
<tr>
<td>DNV-RP-C204</td>
<td>Design against Accidental Loads</td>
</tr>
<tr>
<td>DNV-RP-C205</td>
<td>Environmental Conditions and Environmental Loads</td>
</tr>
<tr>
<td>DNV-RP-D101</td>
<td>Structural Analysis of Piping Systems</td>
</tr>
<tr>
<td>DNV-RP-F101</td>
<td>Corroded Pipelines</td>
</tr>
<tr>
<td>DNV-RP-F112</td>
<td>Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection</td>
</tr>
<tr>
<td>DNV-RP-F302</td>
<td>Selection and Use of Subsea Leak Detection Systems</td>
</tr>
<tr>
<td>DNV-RP-H101</td>
<td>Risk Management in Marine and Subsea Operations</td>
</tr>
<tr>
<td>DNV-RP-O501</td>
<td>Erosive Wear in Piping Systems</td>
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1.5.3 International standards

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<thead>
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<tr>
<td>IEC 61508</td>
<td>Functional Safety of Electrical/Electronic/ Programmable Electronic Safety-related Systems</td>
</tr>
<tr>
<td>IEC 61511</td>
<td>Functional Safety – Safety Instrumented Systems for the Process Industry Sector</td>
</tr>
<tr>
<td>IEC 82045-1</td>
<td>Document management – Part 1: Principles and methods</td>
</tr>
<tr>
<td>IEC/ISO 31010</td>
<td>Risk Management – Risk Assessment Techniques</td>
</tr>
<tr>
<td>ISO/TR 12489</td>
<td>Petroleum, petrochemical and natural gas industries – Reliability modelling and calculation of safety systems</td>
</tr>
<tr>
<td>ISO/TR 12747</td>
<td>Petroleum and Natural Gas Industries – Pipeline Transportation Systems – Recommended Practice for Pipeline Life Extension</td>
</tr>
<tr>
<td>ISO 13628-series</td>
<td>Petroleum and Natural Gas Industries – Design and Operation of Subsea Production Systems (17 parts of which some are under preparation)</td>
</tr>
<tr>
<td>ISO 14224</td>
<td>Petroleum, Petrochemical and Natural Gas Industries – Collection and Exchange of Reliability and Maintenance Data for Equipment</td>
</tr>
<tr>
<td>ISO 15489-series</td>
<td>Information and documentation – Records management</td>
</tr>
<tr>
<td>ISO 15926-series</td>
<td>Industrial Automation Systems and Integration – Integration of Life-cycle Data for Process Plants Including Oil and Gas Production Facilities</td>
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1.5.4 Other standards (regional, national and industry)

<table>
<thead>
<tr>
<th>Reference</th>
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<tbody>
<tr>
<td>ISO 17776</td>
<td>Petroleum and Natural Gas Industries - Offshore Production Installations - Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment</td>
</tr>
<tr>
<td>ISO 20815</td>
<td>Petroleum and Natural Gas Industries – Production Assurance and Reliability Management</td>
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<td>ISO 31000</td>
<td>Risk Management – Principles and Guidelines</td>
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<tr>
<td>API RP 17A</td>
<td>Design and Operation of Subsea Production Systems</td>
</tr>
<tr>
<td>API RP 17N</td>
<td>Subsea Production System Reliability and Technical Risk Management</td>
</tr>
<tr>
<td>API 579-1/ASME FFS-1</td>
<td>Fitness for Service</td>
</tr>
<tr>
<td>ASME 31.3</td>
<td>Process Piping</td>
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<tr>
<td>ASME 31.8</td>
<td>Gas Transmission Distribution Piping Systems</td>
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<tr>
<td>ASME VIII D2</td>
<td>Boiler and Pressure Vessel Code</td>
</tr>
<tr>
<td>BS 7910</td>
<td>Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures</td>
</tr>
<tr>
<td>EN 1993/ Eurocode 3</td>
<td>Design of steel structures</td>
</tr>
<tr>
<td>EN 13509</td>
<td>Cathodic Protection Measurement Techniques</td>
</tr>
<tr>
<td>NACE Standard TM 0497</td>
<td>Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems</td>
</tr>
<tr>
<td>NORSOK U-001</td>
<td>Subsea Production Systems</td>
</tr>
<tr>
<td>NORSOK U-009</td>
<td>Life Extension for Subsea Systems</td>
</tr>
<tr>
<td>NORSOK Y-002</td>
<td>Life Extension for Transportation Systems</td>
</tr>
<tr>
<td>NORSOK Z-001</td>
<td>Documentation for Operation (DFO)</td>
</tr>
<tr>
<td>NORSOK Z-008</td>
<td>Risk Based Maintenance and Consequence Classification</td>
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1.5.5 Other references

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<tbody>
<tr>
<td>OSPAR Convention</td>
<td>The Convention for the Protection of the Marine Environment of the North-East Atlantic</td>
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1.6 Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandonment</td>
<td>Activities associated with taking the subsea production system permanently out of service.</td>
</tr>
<tr>
<td>Abnormality</td>
<td>Feature or parameter that is outside the acceptable range, e.g. deviation, damage, failure.</td>
</tr>
<tr>
<td>Barrier</td>
<td>Measure which reduces the probability of realizing a hazard’s potential for harm and which reduces its consequence. Note: Barriers may be physical (materials, protective devices, shields, segregation, etc.) or non-physical (procedures, inspection, training, drills, etc.). (ISO 17776)</td>
</tr>
<tr>
<td>Barrier, Preventive</td>
<td>Physical or non-physical (human/operational/organisational) measure put in place to prevent a hazardous event.</td>
</tr>
<tr>
<td>Barrier, Reactive</td>
<td>Physical or non-physical (human/operational/organisational) measure that breaks the chain of events to prevent or minimize consequence escalation should a hazardous event take place.</td>
</tr>
<tr>
<td>Commissioning</td>
<td>Activities associated with the initial start-up of the subsea production system, ref. ISO628-1, Section 8.5.6. This is part of the operations phase.</td>
</tr>
<tr>
<td>Damage</td>
<td>The result of action (e.g. impact, vibration, erosion) on a structure or component reducing its reliability or the ability to perform the intended function.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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</tr>
<tr>
<td>De-Commissioning</td>
<td>Activities associated with taking the subsea production system temporarily out of service.</td>
</tr>
<tr>
<td>Design</td>
<td>All related engineering to design a system or component including but not limited to structural, material and corrosion control. (Based on DNV-OS-F101)</td>
</tr>
<tr>
<td>Design life</td>
<td>Planned usage time for the total system. (ISO 20815)</td>
</tr>
<tr>
<td>Failure</td>
<td>Loss of ability to perform as required. Note: A failure of an item is an event, as distinct from a fault of an item, which is a state. (ISO/TR 12489)</td>
</tr>
<tr>
<td>Failure mechanism</td>
<td>Physical, chemical or other process that leads to a failure. (ISO 14224)</td>
</tr>
<tr>
<td>Failure mode</td>
<td>Effect by which a failure is observed on the failed item. (ISO 14224)</td>
</tr>
<tr>
<td>Fault</td>
<td>Inability to perform as required. Note: A fault of an item is a state, as distinct from a failure of an item, which is an event. (ISO/TR 12489)</td>
</tr>
<tr>
<td>Inspection (or survey)</td>
<td>Measurement or observation to confirm current condition of a component or equipment.</td>
</tr>
<tr>
<td>Integrity</td>
<td>The ability of the system to operate safely and withstand the loads imposed during the system lifecycle. (Based on DNV-OS-F101)</td>
</tr>
<tr>
<td>Intervention activities</td>
<td>Actions taken to maintain the current condition of the subsea equipment including replacing failed components.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Combination of all technical and administrative actions, including supervisory actions, intended to retain and item in, or restore it to, a state in which it can perform a required function. (ISO 14224)</td>
</tr>
<tr>
<td>Maintenance, Corrective</td>
<td>Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function. (ISO 14224)</td>
</tr>
<tr>
<td>Maintenance, Preventive</td>
<td>Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce probability of failure or the degradation of the functioning of an item. (ISO 14224)</td>
</tr>
<tr>
<td>Mitigating activities</td>
<td>Measures to reduce the likelihood or the consequence of failure.</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Regular recording of operational data and other relevant data in order to establish the current condition of a piece of equipment and analyse its rate of degradation.</td>
</tr>
<tr>
<td>Operating state</td>
<td>A state when an item is performing a required function. (ISO 20815)</td>
</tr>
<tr>
<td>Operation</td>
<td>The action of ensuring that an item is in an operating state.</td>
</tr>
<tr>
<td>Operations phase</td>
<td>All phases from and including commissioning and up to and not including abandonment.</td>
</tr>
<tr>
<td>Operator</td>
<td>The company ultimately responsible for the integrity and operation of the subsea production system.</td>
</tr>
<tr>
<td>Project phase</td>
<td>All phases up to and including pre-commissioning.</td>
</tr>
<tr>
<td>Re-Commissioning</td>
<td>Activities associated with returning a de-commissioned subsea production system into service.</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Existence of more than one means for performing a required function. (ISO 20815)</td>
</tr>
<tr>
<td>Repair activities</td>
<td>Activities with the objective to restore compliance with requirements related to functionality, structural integrity or pressure containment of the subsea production system.</td>
</tr>
<tr>
<td>Re-qualification</td>
<td>Re-assessment and if necessary validation of design due to modified design premises and/or sustained damage. E.g. life extension is a design premise modification.</td>
</tr>
<tr>
<td>Safe operation</td>
<td>Operating the subsea production system in accordance with a set of acceptance criteria established in design and revised throughout the project phase and asset design life.</td>
</tr>
<tr>
<td>Subsea production system</td>
<td>The complete subsea production system comprises several subsystems necessary to produce hydrocarbons from one or more subsea wells and transfer them to a given processing facility located offshore (fixed, floating or subsea) or onshore, or to inject water/gas through subsea wells. (ISO 13628-1)</td>
</tr>
<tr>
<td>Supplier</td>
<td>An organization that delivers materials, components, goods, or services to the operator.</td>
</tr>
<tr>
<td>Take-over</td>
<td>Is defined as the process of transferring operating responsibility from the project phase to the operations phase.</td>
</tr>
<tr>
<td>Testing</td>
<td>Applying a load to confirm a measurable property or function of a component or a system for the purpose of integrity management.</td>
</tr>
<tr>
<td>Threat</td>
<td>An indication of an impending danger or harm to the system, which may have an adverse influence on the integrity of the system. (DNV-RP-F116).</td>
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</table>
### 1.7 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>APB</td>
<td>acid producing bacteria</td>
</tr>
<tr>
<td>BOP</td>
<td>blow-out preventer</td>
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<tr>
<td>CFD</td>
<td>computational fluid dynamic</td>
</tr>
<tr>
<td>CoF</td>
<td>consequence of failure</td>
</tr>
<tr>
<td>CP</td>
<td>cathodic protection</td>
</tr>
<tr>
<td>CRA</td>
<td>corrosion resistant alloy</td>
</tr>
<tr>
<td>CVI</td>
<td>close visual inspection</td>
</tr>
<tr>
<td>DCV</td>
<td>directional control valve</td>
</tr>
<tr>
<td>DFI</td>
<td>design fabrication installation</td>
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<tr>
<td>DFO</td>
<td>documentation for operation</td>
</tr>
<tr>
<td>DTM</td>
<td>digital terrain models</td>
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<tr>
<td>EDP</td>
<td>emergency disconnect package</td>
</tr>
<tr>
<td>ER</td>
<td>electrical resistance</td>
</tr>
<tr>
<td>ESD</td>
<td>emergency shutdown</td>
</tr>
<tr>
<td>FAC</td>
<td>flow accelerated corrosion</td>
</tr>
<tr>
<td>FEM</td>
<td>finite element model</td>
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<tr>
<td>FMEA</td>
<td>failure mode and effects analysis</td>
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<tr>
<td>FSM</td>
<td>field signature method</td>
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<tr>
<td>GAB</td>
<td>general aerobic bacteria</td>
</tr>
<tr>
<td>GRP</td>
<td>glass fibre reinforced plastic</td>
</tr>
<tr>
<td>GVI</td>
<td>general visual inspection</td>
</tr>
<tr>
<td>HAZOP</td>
<td>hazard and operability analysis</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbon</td>
</tr>
<tr>
<td>HIC</td>
<td>hydrogen induced cracking</td>
</tr>
<tr>
<td>HIRA</td>
<td>hazard identification and risk assessment</td>
</tr>
<tr>
<td>HISC</td>
<td>hydrogen induced stress cracking</td>
</tr>
<tr>
<td>HPU</td>
<td>hydraulic power unit</td>
</tr>
<tr>
<td>IM</td>
<td>integrity management</td>
</tr>
<tr>
<td>IMP</td>
<td>integrity management process</td>
</tr>
<tr>
<td>IMS</td>
<td>integrity management system</td>
</tr>
<tr>
<td>IMT</td>
<td>inspection, monitoring and testing</td>
</tr>
<tr>
<td>IR</td>
<td>insulation resistance</td>
</tr>
<tr>
<td>KP</td>
<td>kilometre point</td>
</tr>
<tr>
<td>KPI</td>
<td>key performance indicator</td>
</tr>
<tr>
<td>LCI</td>
<td>life cycle information</td>
</tr>
<tr>
<td>LPR</td>
<td>linear polarisation resistance</td>
</tr>
<tr>
<td>LRP</td>
<td>lower riser pack</td>
</tr>
<tr>
<td>MAOP</td>
<td>maximum allowable operating pressure</td>
</tr>
<tr>
<td>MEG</td>
<td>monoethylene glycol</td>
</tr>
<tr>
<td>MIC</td>
<td>microbially influenced corrosion</td>
</tr>
<tr>
<td>NA</td>
<td>not applicable</td>
</tr>
<tr>
<td>NDT</td>
<td>non destructive testing</td>
</tr>
<tr>
<td>OGP</td>
<td>the international association of oil and gas producers</td>
</tr>
<tr>
<td>PCB</td>
<td>printed circuit board</td>
</tr>
<tr>
<td>PFD</td>
<td>process flow diagram</td>
</tr>
<tr>
<td>PGB</td>
<td>permanent guide base</td>
</tr>
<tr>
<td>PLEM</td>
<td>pipeline end manifold</td>
</tr>
<tr>
<td>PLET</td>
<td>pipeline end termination</td>
</tr>
<tr>
<td>PMV</td>
<td>production master valve</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>PoF</td>
<td>probability of failure</td>
</tr>
<tr>
<td>PW</td>
<td>produced water</td>
</tr>
<tr>
<td>QA</td>
<td>quality assurance</td>
</tr>
<tr>
<td>OIM</td>
<td>operation, installation and maintenance</td>
</tr>
<tr>
<td>ROT</td>
<td>remote operated tool</td>
</tr>
<tr>
<td>ROV</td>
<td>remote operated vehicle</td>
</tr>
<tr>
<td>RP</td>
<td>recommended practice</td>
</tr>
<tr>
<td>SCADA</td>
<td>supervisory control and data acquisition</td>
</tr>
<tr>
<td>SCC</td>
<td>stress corrosion cracking</td>
</tr>
<tr>
<td>SCM</td>
<td>subsea control module</td>
</tr>
<tr>
<td>SEM</td>
<td>subsea electronic module</td>
</tr>
<tr>
<td>SJA</td>
<td>safe job analysis</td>
</tr>
<tr>
<td>SPCU</td>
<td>subsea power and communication unit</td>
</tr>
<tr>
<td>SPS</td>
<td>subsea production system</td>
</tr>
<tr>
<td>SRB</td>
<td>sulphate reducing bacteria</td>
</tr>
<tr>
<td>SSC</td>
<td>sulphide stress cracking</td>
</tr>
<tr>
<td>SSIV</td>
<td>subsea isolation valve</td>
</tr>
<tr>
<td>SW</td>
<td>sea water</td>
</tr>
<tr>
<td>UT</td>
<td>ultrasonic testing</td>
</tr>
<tr>
<td>UTH</td>
<td>umbilical termination head</td>
</tr>
<tr>
<td>UTM</td>
<td>universal transverse mercator</td>
</tr>
<tr>
<td>VIV</td>
<td>vortex induced vibration</td>
</tr>
<tr>
<td>W.O.</td>
<td>work-over</td>
</tr>
<tr>
<td>Xmas Tree</td>
<td>christmas tree</td>
</tr>
</tbody>
</table>
SECTION 2 INTEGRITY MANAGEMENT SYSTEM

2.1 Integrity management
The function of a subsea production system is to control the production and transportation of fluids. The operator should establish, implement and maintain an integrity management system in such a manner that:

— the safety margin during operation is within the acceptable range
— the functionality of the system is ensured
— the resistance against loads meets the specified acceptance criteria.

Subsea production system integrity is thus defined as both the containment of fluids and the reliable operation of safety and production equipment (valves, etc.) with the objective of ensuring both the safety and function of the installation.

Subsea production system integrity is:

— established during the project phase (concept, design, fabrication, installation and pre-commissioning) and
— maintained in the operation phase (commissioning, operation, de-commissioning, re-commissioning, re-qualification and life extension) and the abandonment phase.

The subsea integrity management system shall comply with relevant national requirements.

The scope of work covered by the IMS and system battery limits should be clearly defined.

2.2 Safety philosophy
As a basic principle, the safety philosophy adopted in design should apply.

However, the original safety philosophy may be modified as a result of operator, industry and society developments, technological improvements and improved knowledge of the subsea production system. Moreover, the safety philosophy for most subsea units is different than for above water manned units, in that fire and explosion is unlikely to occur.

Safe operation means operating the subsea production system in accordance with a set of acceptance criteria established in design and revised throughout the project phase and its design life.

Revision of the acceptance criteria can take place:

— as a result of improved knowledge with regards to known threats to the system
— based on identification of new threats
— if a re-qualification is performed
— due to changes in authority or company requirements.

The safety philosophy should address the use of barriers (see [1.2.2]).

Acceptance criteria as defined in design should be identified prior to start of operation and complied with during operation and revised during the design life if necessary.

A change in the basis for design will require a re-qualification as described in [3.3.5] to ensure compliance with acceptance criteria.

It must be verified during the operations phase that the design premises are fulfilled. If this is not the case, appropriate actions should be taken to bring the subsea production system back to safe operation.

2.3 Elements of the integrity management system
The IMS should as a minimum include the following elements, as illustrated in Figure 2-1:

— authority requirements
— company policy
— organisation and personnel
— reporting and communication
— operation controls and procedures
— management of change
— contingency plans
— audits and review
— information management
— the integrity management process covering:
  — risk assessment and IM planning
  — inspection, monitoring and testing
  — integrity assessment
  — mitigation, intervention and repair.

These elements should be reviewed and revised to ensure that they support the IMP. A brief description of each element is given in the following sub-sections.

**Figure 2-1  Integrity management system (ref. DNV-RP-F116)**

### 2.3.1 Company policy

The company policy for subsea integrity management should utilize the safety philosophy that the company holds, and guide people in how this is to be realized.

The company policy is commonly reflected in a set of high level project specific philosophies and strategy documents for the project phase and the operations phase.
2.3.2 Organisation and personnel
The roles and responsibilities of personnel involved with integrity management of the subsea production system should be clearly defined.

Roles and responsibilities that should be addressed are typically related to:

- hand-over of the subsea production system from the project phase to the operations phase (see also [3.2])
- establishing the subsea integrity management system
- executing the integrity activities
- executing and documenting integrity assessment activities
- ensuring integrity management system improvement.

Any needs for training of personnel should be identified and implemented.

2.3.3 Management of change
Modifications of the subsea production system should be carried out according to an established management of change procedure, addressing the continuing safe operation of the subsea production system.

All changes should be documented and communicated to relevant persons within the organisation.

If the operating conditions are changed from what was specified in the design premises, a re-qualification of the subsea production system should be carried out.

2.3.4 Operational controls and procedures
Relevant operational controls and procedures should be prepared. The personnel responsible for the daily operation should be included in this process. They typically cover:

- start-up after shutdown, operation and shutdown
- treatment of non-conformances
- maintenance activities
- monitoring activities
- testing activities.

Procedures for control of critical parameters during operation should be established to ensure that they are kept within the specified design limits. Typical parameters that should be controlled or monitored:

- pressure and temperature
- injection rate of chemicals
- fluid composition, water content, flow rate, density and viscosity
- sand content
- valve function.

Procedures for periodical testing and inspection of all safety equipment, including pressure control and over-pressure protection devices, emergency shutdown systems and automatic shutdown valves, should be established.

2.3.5 Contingency plans
Plans and procedures for emergency situations should be established and maintained based on a systematic evaluation of possible scenarios. Dependent upon the commercial importance of the subsea production system, plans and procedures for contingency repair should also be established.

Contingency (emergency) preparedness procedures - An emergency situation is any situation that endangers the safety of people or the environment. Possible consequences due to an emergency situation should therefore be established. To reduce the consequences of a potential emergency scenario, contingency preparedness plans and procedures should be developed and implemented. An emergency
procedure should at least include the following:

— organisation, roles and responsibilities of parties involved in the event of an emergency situation
— communication lines; who should be informed through different stages of the emergency situation
— identification of potential emergency scenarios
— procedures for initial response to an emergency alarm or situation, e.g.: Isolation of damaged part of the subsea production system, controlled shut-down procedures, emergency shut-down procedures and procedures for depressurisation of the system
— plans and procedures for mitigation to limit potential environmental damage.

Contingency repair procedures - When evaluating the extent of required contingency plans and procedures, and the corresponding need for pre-investments in contingency repair equipment and spares, the following should be considered:

— economic consequences when the subsea production system is out of service
— existence of recognised repair methods
— access to and delivery time of required equipment and spares
— estimated time for repair.

2.3.6 Reporting and communication

A communication structure covering reporting and communication to personnel, management, authorities, customers, public and other stakeholders should be established. Reporting of integrity needs to be fitted into the communication structure (see Appendix 4 for an example of a periodic integrity management reporting template).

This covers both regular and emergency situation reporting and communication.

2.3.7 Audit and review

Audits and reviews of the subsea integrity management system should be conducted regularly. The frequency should be defined by those responsible for the operation of the subsea production system.

The main objective of the reviews should be to:

— assess the effectiveness and suitability of the integrity management system
— establish the improvement needs.

The main objective of the audits should be to:

— assess the compliance with authority and company requirements
— establish rectification needs.

2.3.8 Information management

A system for collection of life cycle information should be established and maintained in order to ensure access to the relevant documentation throughout the systems service life. Life cycle information typically includes (see also [3.3.8]):

— documents from the project phase
— operational procedures/manuals
— operational data
— documents covering any modifications or events
— inspection, monitoring and testing records and reports
— reports covering any assessments or analyses.

Standards relevant for information and document management:

— ISO 15489-series Information and documentation – Records management
Standards relevant for data collection and integration:

- ISO 14224 *Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment*
- ISO 15926-series *Industrial automation systems and integration – Integration of life-cycle data for process plants including oil and gas production facilities.*

### 2.3.9 Integrity management process

The integrity management process (IMP) is the core of the integrity management system (IMS) and is described in more detail in Sec.3.
SECTION 3 INTEGRITY MANAGEMENT PROCESS

The integrity management process (IMP) is the core of the integrity management system (IMS) and should ensure safe, cost effective and reliable operation of the subsea production system. It is a continuous and iterative process that should be part of the whole lifecycle of the system, starting in the project phase and continuing through the operations phase and abandonment phase.

Focusing on the IMP already during the design phase (establish integrity), enables implementation of risk reducing measures early. This may improve the life cycle costs of the installation by reducing potential high costs for offshore work during the operational phase.

The IMP should comply with relevant national requirements.

It consists of four main activities as illustrated in Figure 3-1:

— Risk Assessment and Integrity Management Planning, which includes threat identification, risk assessment, long term and short term (annual) planning for inspection, monitoring and testing
— Planning and execution of Inspection, Monitoring and Testing activities
— Integrity Assessment based on inspection, monitoring and testing results and other relevant life cycle information
— Planning and execution of required Mitigation, Intervention and Repair activities.

Each of the four main activities is covered in more detail in Sec.4 to Sec.7.

Figure 3-1 The integrity management process constitutes the core of Figure 2-1

When looking at the subsea production system in a lifecycle perspective there are three important stages related to the integrity management process:

1) Establish integrity during the project phase (concept, design, fabrication, installation and pre-commissioning) ([3.1])
2) Transfer integrity from the project phase to the operations phase ([3.2])

3) Maintain integrity during the operations phase (commissioning, operation, de-commissioning, re-commissioning, re-qualification and life extension) and abandonment phase ([3.3]).

For all these phases there are a need for establishing an organisation and preparing strategies and procedures that can ensure that the integrity management process is carried out. The organisational structure will vary over time across the different phases due to different focus, and this will mean different requirements to competence for the personnel.

### 3.1 Establish integrity

The integrity management process should be established during the project phase, and should include a systematic and iterative review of risks (see ISO 20815 for work processes that this should interact with, with respect to production assurance and reliability management). This implies identification of the main threats to the system and their associated risks, and subsequently developing strategies to manage these risks. This also includes identifying the need for inspection, monitoring and testing (IMT) and adjusting the system to accommodate this.

There should be no remaining high or very high risks from design even when mitigating actions have been considered, as this indicate an inadequate design (see [7.2.1] and Table B-1).

The choices made in the early design, like selection of the type of equipment, materials, condition monitoring systems, new or proven technology, robustness of design, redundancy, and fabrication and installation methods, will be decisive for the IMT programs during the operations phase. The operator should establish an organisation responsible for handling the operational aspects during the project phase. The purpose is to ensure that the operational aspects are taken into consideration and planned for at an early stage.

Direct involvement of personnel planning for operation during the project phase has the following advantages:

— an opportunity to maximize value over the asset life by ensuring relevant input from operation to design and fabrication of the subsea production system
— a comprehensive knowledge of the system which will facilitate safe operation and integrity management when the operations personnel bring this back to the operational organisation.

Documentation relevant for the operations phase (DFO) should be identified and prepared during this stage (see [3.3.8]).

### 3.2 Transfer integrity

Transfer of integrity from the project phase to operation should be planned and as a minimum the following plans should be established:

— philosophy and strategy for transfer of integrity (should be developed early as part of the concept development)
— detailed plans for hand-over from the project to the operation
— plan for development of DFO.

The plans should ensure that the operational organisation, operational procedures and relevant technical documentation are in place for hand-over and start-up of operation.

The main activities include:

— transfer of DFO (see [3.3.8])
— project and operations organisation cooperating to identify and resolve any remaining design or documentation issues that are important for operation
— training of personnel responsible for the operation of the system
— carry out an initial risk assessment and develop initial high level, long term plans for IMT.
The majority of the integrity transfer activities will occur during pre-commissioning and commissioning but some of the activities need to be initiated earlier. This includes identification, specification, and verification of documentation for operation (DFO) and identifying needs for training of personnel.

A plan for take-over of the subsea production system and a checklist for project deliverables that are considered essential for take-over should be prepared.

Check lists should be prepared, including responsible people, to verify and document that the above requested information is received prior to take-over.

### 3.3 Maintain integrity

Maintaining integrity (which includes the commissioning, operation, de-commissioning, re-commissioning, re-qualification, life extension and the abandonment phase), concern all activities related to the operational phase. Typical documentation that should be collected and updated during these phases is listed in [3.3.8.3].

#### 3.3.1 Commissioning

Commissioning comprises activities associated with the initial start-up of the subsea production system. Reference is given to ISO 13628-1:2005(E) Section 8 for requirements to commissioning.

During commissioning it should be verified that the operational limits are within the requirements defined in the project phase.

Other important design conditions that may need verification are: flow parameters (pressure, temperature, dew point condition, hydrate formation sensitivity, sand production, etc.), valve function, containment, external corrosion protection system, vibration, etc.

The strategy for inspection, monitoring and testing established prior to commissioning and as a part of the initial Risk Assessment and IM Planning activity should be revised and take into account any relevant events that have occurred during commissioning. This may include the identification of new threats and a need for revised plans with additional IMT activities.

#### 3.3.2 Operation

Operation covers the day to day operation and should include updates of operational procedures and activities for maintaining integrity such as:

- operational control procedures and activities
- start-up and shutdown procedures
- planned maintenance activities
- inspection, monitoring and testing
- mitigation, intervention and repair
- storage and preservation of spares and contingency equipment.

#### 3.3.3 De-commissioning

De-commissioning is the set of activities associated with taking the subsea production system temporarily out of service. De-commissioning should be planned for and prepared. The following should be considered:

- environmental aspects
- obstruction for ship traffic and fishing activities
- preservation to reduce effect from degradation mechanisms
- corrosion impact on other structures.

De-commissioning should be conducted and documented in such a way that the subsea production system can be re-commissioned and put into service again.

A de-commissioned subsea production system should continue to be managed by the integrity management process, i.e. the system should still be covered by IMT plans, etc.
3.3.4 Re-commissioning
Re-commissioning is to restore the originally intended operating performance. As for commissioning, preservation should be appropriately terminated, fluid correctly filled and the integrity should be verified. The main difference between commissioning and re-commissioning is that the system to be re-commissioned may have been out of service for a very long time and the verification of its integrity may be more challenging. The same requirements will apply as for commissioning.

3.3.5 Re-qualification
Re-qualification is a re-assessment of the design under changed design conditions.
A re-qualification may be triggered by a change in the original design basis, by not fulfilling the design basis or by mistakes or shortcomings discovered during normal or abnormal operation. Possible causes may be:

— preference to use a more recent standard e.g. due to requirements for higher utilisation for the existing system
— changes of premises such as environmental loads, deformations, scouring, etc.
— changes of operational parameters such as pressure, temperature, fluid composition, etc.
— change of flow direction or change of fluid
— degradation mechanisms having exceeded the original assumption, such as corrosion rate, dynamic responses causing fatigue (e.g. VIV or start/stop periods), etc.
— extended design life (see [3.3.6])
— damages such as corrosion defects, cracks, damaged or consumed anodes, etc.

3.3.6 Life extension
Several operators are now experiencing a need for operating some of their subsea production systems longer than the original design life.

The purpose of the life extension process is to document acceptable system integrity to the end of the extended design life.

The following standards can be used when considering life extension:

— NORSOK U-009 gives guidelines related to life extension of subsea systems.
— NORSOK Y-002 gives guidelines related to life extension of transportation systems (umbilicals and pipelines).
— ISO/TS 12747 gives guidelines to assess the feasibility of extending the life of a pipeline system beyond its specified design life.

3.3.7 Abandonment
Abandonment comprises the activities associated with taking the system or parts of the system permanently out of operation. An abandoned system cannot be returned to operation. Depending on the legislation this may require physical cover or removal of the system.

Subsea production system abandonment should be planned and prepared.

An abandonment evaluation should include the following aspects:

— relevant national regulations
— health and safety of personnel, if the system or parts of the system is to be removed
— environmental considerations, especially pollution
— obstruction for ship traffic and fishing activities
— corrosion impact on other structures.

ISO 13628-1:2005(E) Section 8 gives guidelines related to the abandonment of subsea production systems.
Abandoned parts of a subsea production system may continue being managed by the integrity management process, i.e. the system may still be covered by IMT plans, etc.
Authorisation for disposal of subsea equipment at sea shall be in agreement with authorities in the country it concerns and their main focus is to prevent pollution, damage and interference with legitimate activities at sea (fishing, etc.).

3.3.8 Documentation

A searchable electronic system for collection of life cycle information should be established and maintained for the entire service life of the system as recommended in [2.3.8] (Information Management). It is important that information relevant for normal operation, integrity control activities and emergency situations is readily available during the operations phase. This may include design documents, test reports, procedures, IMT plans, drawings, etc. Documentation that may be of importance for a life extension of the subsea production system should also be considered.

References to relevant standards for information and document management, as well as data collection and integration, is given in [2.3.8].

3.3.8.1 Documentation in the establish integrity stage

The integrity should be established and documented during the project phase. This includes essential information and documentation relevant for the operations phase (DFO) that needs to be available throughout the life of the system.

Typical DFOs are:

— documentation that should be available from design, fabrication and installation as listed in ISO 13628-1, Section 9 and Annex E
— any non-conformances and damage during the project phase that needs to be followed up during the operations phase or can have impact on the operation of the system
— relevant documentation from the Integrity management system support processes ([2.3.1] to [2.3.7])
— relevant documentation developed as part of the integrity management process:
  — risk assessment
  — high level, long term plans for IMT.

3.3.8.2 Documentation in the transfer integrity stage

During the transfer of integrity it should be ensured that all DFOs have been completed and verified before hand-over. This may include updating some of the documentation.

Representatives from the project organisation should take active part in the hand-over process including training of personnel (software, hardware, operating procedures, equipment design).

3.3.8.3 Documentation in the maintain integrity stage

To be able to maintain the integrity of the subsea production system relevant documentation should be collected and updated. This is typically:

— organisational chart showing the functions responsible for the operation and integrity management of the subsea production system
— personnel training and qualification records
— physical and chemical characteristics of transported media including sand data
— equipment function characteristics (valve function, hydraulic fluid consumption, etc.)
— risk assessment and plans for inspection, monitoring and testing
— inspection, monitoring and testing results
— condition assessment reports and any other relevant analyses
— operational procedures
— description of any damage or failure including full particulars of repairs, modifications and replacements

In case of a re-qualification or life extension of the system (see [3.3.5] and [3.3.6]) all the relevant documentation related to the re-assessment process of the original design should be kept for the extended service life.
SECTION 4  RISK ASSESSMENT AND INTEGRITY MANAGEMENT PLANNING

4.1 General
This section presents the risk assessment approach, the requirements relevant for risk assessment activities and the development of an integrity management plan.

Threats which could directly or indirectly jeopardise the integrity of the system should be identified and evaluated using a risk based approach. The risk assessment should cover the entire subsea production system. The risk identification and assessment should be documented. Integrity management plans should be established based on:

— the risk assessment carried out as part of the integrity management process
— relevant input from production assurance and reliability processes carried out (see ISO 20815)
— relevant input from any other HSE processes and risk assessment activities carried out for the system or parts of the system.

A step-by-step guideline for carrying out risk assessment and IM planning is shown in App.B.

4.2 Basis for risk assessment
The risk assessment should include the following:

— identification of all equipment and functions where a failure may jeopardise the system integrity
— for all equipment and functions, identify the potential threats and failure modes, and estimate the risk associated with these
— identify risk reduction measures or mitigating activities based on the outcome of the risk assessment
— prepare a basis for planning of the main activities of the core Integrity management process as described in Sec.5 to Sec.7.

4.2.1 Prevailing documents
4.2.1.1 Risk philosophy document
In order to ensure that the risk assessment is carried out consistently, the risk approach should be documented. A high level risk philosophy document should be established and preferably applied across different assets, e.g. subsea production systems, pipeline systems, offshore structures and plants. This is very important when it comes to communication of risk.

The risk matrix to be applied should be defined (see [4.2.3]).

4.2.1.2 Asset risk management guideline
Asset specific risk management documents aligned with the risk philosophy document and authority requirements should be established. These documents may include:

— reference to authority requirements
— reference to operator specific requirements and prevailing procedures
— list of threats to be considered for the most common equipment types
— list of inspection, monitoring and testing methods to be included in the IMT plan
— guidance on selection among comparable IMT methods
— relevant failure statistics (operator and industry).

4.2.1.3 Risk assessment practice
A common practice for evaluation of the individual threats for typical components should be established. These documents should at least contain the following:

— description of the threats and the operators experience associated with these threats
— information required to describe the threats
— detailed description of the assessment model. It is recommended to establish a levelled approach; where the conservatism decreases with increasing level. The first level should be a screening level which typically requires generic type of input to reach a conclusion.
— any limitations of the assessment model with guidance on exceptions
— calculation example for each defined level.

4.2.2 Risk assessment approaches

Different risk assessment approaches can be used. Common for all the approaches is an evaluation of the probability of an event and the consequences of this event. The risk assessment approach used should meet the risk assessment objectives and be suitable for the risk faced.

ISO 31000, IEC/ISO 31010, ISO 17776, ISO 20815, ISO 14224, ISO/TR 12489 and NORSOK Z-008 can be used to set the risk assessment requirements and to choose the risk assessment approach.

4.2.3 Risk matrix

The risk matrix to be applied should be defined and be relevant for the system in question, and include:
— risk categories and interpretation of these
— acceptable risk level
— probability of failure (PoF) categories and interpretation of these
— consequence of failure (CoF) categories and interpretation of these.

The matrix should preferably be defined by the operator and used across different assets (see [4.3.1]). An example of a risk matrix and risk categories is given in Table 4-1 and Table 4-2, respectively.

Work selection matrices should also be defined, e.g. recommended IMT intervals dependent on location in the risk matrix. This is described in [4.4.5].

Table 4-1 Example of a risk matrix

<table>
<thead>
<tr>
<th>Severity</th>
<th>Safety</th>
<th>Environment</th>
<th>Cost (million EUR)</th>
<th>Increasing probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Multiple fatalities</td>
<td>Massive effect</td>
<td>&lt; 10^3</td>
<td>Failure is not expected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large damage area, &gt; 100 BBL</td>
<td>1 - 10</td>
<td>Never heard of in the industry</td>
</tr>
<tr>
<td>D</td>
<td>Single fatality or permanent disability</td>
<td>Major effect</td>
<td>0.1 - 1</td>
<td>An accident has occurred in the industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Significant spill response, &lt; 100 BBL</td>
<td>1 - 10</td>
<td>Has been experienced by most operators</td>
</tr>
<tr>
<td>C</td>
<td>Major injury, long term absence</td>
<td>Localized effect</td>
<td>0.01 - 0.1</td>
<td>Occurs several times per year</td>
</tr>
<tr>
<td>B</td>
<td>Slightly injury, a few lost work days</td>
<td>Minor effect</td>
<td>0.001 - 0.1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>No or superficial injuries</td>
<td>Slightly effect on the environment, &lt; 1BBL</td>
<td>&lt; 0.01</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>M</td>
<td>H</td>
<td>VH</td>
<td>VH</td>
<td>VH</td>
</tr>
<tr>
<td>D</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>VH</td>
<td>VH</td>
</tr>
<tr>
<td>C</td>
<td>VL</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td>B</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>A</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
</tbody>
</table>
4.2.4 Probability of failure

The outcome of an evaluation of the probability of failure is either a numerical value or a probability of failure category.

Table 4-3 presents an example where five PoF categories are applied and which shows how quantitative and qualitative terms can be linked to these.

### Table 4-3 Example of a PoF description

<table>
<thead>
<tr>
<th>Category</th>
<th>Failure probability</th>
<th>Quantitative</th>
<th>Qualitative term</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&gt; 10^{-2}</td>
<td>Very high</td>
<td>Failure is expected</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Failure has been experienced several times a year by the operator</td>
</tr>
<tr>
<td>4</td>
<td>10^{-3} to 10^{-2}</td>
<td>High</td>
<td>Failure is likely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Failure has been experienced by most operators</td>
</tr>
<tr>
<td>3</td>
<td>10^{-4} to 10^{-3}</td>
<td>Medium</td>
<td>Failure is rare</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Failure has occurred in industry</td>
</tr>
<tr>
<td>2</td>
<td>10^{-5} to 10^{-4}</td>
<td>Low</td>
<td>Failure is unlikely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Failure has never been heard of in the industry</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 10^{-5}</td>
<td>Very low</td>
<td>Failure is unrealistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Failure has not been expected in industry</td>
</tr>
</tbody>
</table>

4.2.5 Consequence of failure

The consequences of a failure are dependent on the failure mode (leak, burst, loss of function, etc.), the physical location and which hierarchical level the failed item belongs to, e.g. system, equipment unit or component (see ISO 14224). The physical location is determined by factors like offshore location, water depth, environmentally sensitive area, etc.

If the consequences are modelled without taking into consideration a specific failure mode, the most severe mode should be assumed.

An assessment of consequence of failure is to take the following into consideration as a minimum:

- safety (personnel)
- environment
- economy.
Other types of consequences, like operator reputation, can also be considered.

Examples of qualitative ranking categories which can be used to evaluate the consequence of failure are shown in Table 4-4 (based on ISO 17776) where reputation is also considered. See also example of risk matrix in Table 4-1.

### Table 4-4 CoF qualitative ranking scales

<table>
<thead>
<tr>
<th>Category</th>
<th>Safety</th>
<th>Assets</th>
<th>Environment</th>
<th>Reputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Insignificant</td>
<td>Insignificant</td>
<td>Insignificant</td>
<td>Insignificant</td>
</tr>
<tr>
<td>B</td>
<td>Slight/Minor injury</td>
<td>Slight/Minor damage</td>
<td>Slight/Minor effect</td>
<td>Slight/Minor impact</td>
</tr>
<tr>
<td>C</td>
<td>Major injury</td>
<td>Local damage</td>
<td>Local effect</td>
<td>Considerable effect</td>
</tr>
<tr>
<td>D</td>
<td>Single fatality</td>
<td>Major damage</td>
<td>Major effect</td>
<td>Major national impact</td>
</tr>
<tr>
<td>E</td>
<td>Multiple fatalities</td>
<td>Extensive damage</td>
<td>Massive effect</td>
<td>Major international impact</td>
</tr>
</tbody>
</table>

### 4.3 Risk assessment activities

#### 4.3.1 Initial risk assessment

An initial risk assessment should be carried out as part of the transfer from the project phase to the operations phase (see Figure 4-1). The threats to the system and potential failure modes should be identified, and the preventing or mitigating measures implemented in the project phase should be documented. The main threat groups are shown in Table 4-5, and typical threats are given in App.A and App.B. App.C details the threats due to corrosion and erosion. A description of the typical failure modes are given in App.A.

### Table 4-5 Main threat groups

<table>
<thead>
<tr>
<th>Threat Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design fabrication installation (DFI) threats</td>
</tr>
<tr>
<td>Material degradation threats</td>
</tr>
<tr>
<td>Internal medium threats</td>
</tr>
<tr>
<td>Third party threats</td>
</tr>
<tr>
<td>Structural threats</td>
</tr>
<tr>
<td>Control system threats</td>
</tr>
<tr>
<td>Natural hazard threats</td>
</tr>
<tr>
<td>Operational threats</td>
</tr>
</tbody>
</table>

The outcome from the risk assessment should be documented and include:

- list of relevant threats to the system
- protective means and integrity control activities
- acceptance criteria (i.e. design criteria)
- associated risks.

An example on how to document the risk assessment and IM planning is given in App.B (Table B-1).

In order to document the relevance of the various threats, it is recommended that the initial risk assessment includes a qualitative analysis of all potential failure mechanisms. A full risk assessment should then be carried out for the threats that are identified as relevant.

#### 4.3.2 Detailed risk assessment

The detailed risk assessment or an update of the initial risk assessment should be performed by the operator when the subsea production system is handed over and ready for operation. The detailed risk assessment should include risk assessment on a sub-systems or component level, and ensure that no new threats have been introduced during the pre-commissioning or commissioning phase.

#### 4.3.3 Periodic update of risk assessment and re-assessment

The level of risk associated with any given threat may change with time, for example in the form of change...
in trawling activity, in the design of trawling and fishing equipment, new methods for inspection and monitoring, etc. Updates may be initiated based on:

- the results from inspection, monitoring and testing activities
- the results from any integrity assessment
- changes in operating parameters or any other changes that may affect the total threat picture
- changes to the authority requirements or other premises and assumptions for the period in question.

A detailed re-assessment of risk should therefore be performed typically every 5-7 years including the entire IMT program.

4.4 Developing inspection, monitoring and testing plans

Inspection, monitoring and testing (IMT) plans should describe the minimum required IMT activities (incl. max. intervals) for different sub-systems or components based on the risk assessment.

The initial IMT plans are normally based on the following assumptions:

- no outstanding non-conformances from design, fabrication and installation
- as installed surveys have been successfully completed and the non-conformities addressed (if any)
- post installation testing and commissioning have been undertaken in accordance with the relevant design and installation codes and the non-conformities have been addressed (if any).

The above assumptions should be confirmed prior to the finalization of the IMT plan. The components to be included in the IMT plan should be determined based on the following:

- risk assessment; components that have a medium risk level should be part of a periodic IMT plan. Components with a low risk level should also be part of a periodic IMT plan if the risk level is likely to change over time or the design standards require periodic inspection or testing.
- issues with certain systems or components that have arisen during fabrication or installation which may require more frequent IMT activities or closer follow-up
- integrity monitoring data from various sensors and monitoring devices (sand detectors, corrosion coupons, etc.) and measurements carried out (dew-point, fluid composition, etc.) to monitor the performance or integrity of the system.
- the detectability of any prospective inspection method or monitoring devices to capture degradation, process deviations and other symptoms, and their capability of trending (prognostic) the data
- operation data; information recorded by the control system, telemetry, supervisory control and data acquisition (SCADA), etc.

For each component included in an IMT plan, the visual indication or parameter that should be monitored needs to be identified and a criterion for taking further corrective action or carrying out IMT activities needs to be defined.

Planning and scheduling should also involve the necessary logistical activities such as e.g. sourcing and allocation of spares, access to inspection equipment, manning and relevant procedures.

The iterative working process for risk assessment and IM planning initiated in the project phase and updated throughout the entire life of the system is illustrated in Figure 4-1.
4.4.1 Initial inspection, monitoring and testing plan

The initial inspection, monitoring and testing (IMT) plan, relevant for new or modified systems, should give the minimum required IMT activities (incl. max. intervals) for different sub-systems or components. The risk assessment should be used as basis for the initial IMT plan. The plan should be developed and available prior to the start-up of the system.

The objective of the initial IMT plan is to verify that the system performs in accordance with design premises. The initial IMT plan should typically be based on design documentation, DFI resumés, HAZOP studies, previous experience and industry best practice.

![Figure 4-1 Risk assessment and IM planning working process](image)

4.4.2 Long term inspection, monitoring and testing plan

When the system is taken over for operation by the operator, an update of the initial risk assessment or a detailed risk assessment should be carried out (see [4.3.1] or [4.3.2] respectively).

The updated risk assessment and the initial IMT plans will constitute the basis for the long term IMT plans. The long term IMT plan should document and justify what, why, how and when an IMT activity should be
performed. This program should typically cover at least 8 years.

### 4.4.3 Periodic update of inspection, monitoring and testing plan

Inspection, condition monitoring and testing should be carried out regularly according to the prepared IMT plans.

If certain threats show excessive degradation a more rigorous IMT regime should be implemented in addition to investigating the cause of degradation. Equivalently, if no degradation is recorded over time, the possibility of extending the IMT intervals from the initial plan should be considered.

The plans should be periodically updated based on information gained, knowledge about the application of new analysis techniques / methods within condition monitoring, inspection and testing and the change of risk over time.

The confidence in the inspection, monitoring and testing results should be taken into consideration.

A detailed re-assessment of the entire IMT plan including risk analyses should therefore typically be performed every 5-7 years.

### 4.4.4 Event based inspection, monitoring and testing

If an event occurs such as a dropped object or a monitoring parameter exceeding its acceptance criteria, an assessment should be carried out to determine the condition of the system and whether additional actions need to be carried out, such as a re-qualification of the system or more frequent IMT activities. The periodic IMT plan should be updated accordingly.

### 4.4.5 Frequency

The frequency of IMT activities should be determined typically based on:

- risk level (work selection matrices - normally related to the threat or threat group)
- confidence in the input data for the risk assessment
- confidence in integrity status
- evaluation of possible development of risks.

A typical work selection matrix gives IMT intervals (frequency) dependent on either location in the risk matrix or risk level. An example is shown in **Table 4-6**.

**Table 4-6** Example of work selection matrix – external inspection, monitoring and testing frequency (years)
4.4.6 Workflow diagrams

It is recommended to establish workflow diagrams to ensure that consistent actions are taken dependent on the results from the risk assessment.

A workflow diagram can be useful for following up high risk elements and is a graphic presentation of all the major steps of a process. It can help to:

— understand the complete process
— identify the critical stages of a process
— locate problem areas
— show relationships between different steps in a process
— define tools/procedures to be applied
— assign responsibilities
— threat group level, in this case the worst consequence related to the grouped threats apply
— individual threat level, in this case the worst consequence related to possible failure modes apply.

A workflow diagram and a description of the different main tasks that the working process consists of are given in App.B (Table B-1).
SECTION 5 INSPECTION, MONITORING AND TESTING

5.1 General

The objective of IMT activities is to gather information in order to establish the current condition of a component and to analyse its rate of degradation.

Plans developed as part of the Risk Assessment and IM Planning activity should form the basis for the detailed planning for the IMT activities. Any deviations from the original plans should be reported and the reason for the deviation established.

Unexpected events may initiate the need for unplanned IMT activities. To what extent, how and when to carry out an unplanned IMT activity should be established as part of the risk assessment and IM planning activity. This is to ensure coordination with other prospective IMT activities and to evaluate the need for modification of the original plan.

The detailed IMT plans should be updated on a regular basis and be based on preceding plans and the results achieved from the integrity control activities (inspection, monitoring, testing and integrity assessment).

In the following the definitions given below for inspection, monitoring and testing are used:

**Inspection** (or survey): Measurement or observation to confirm current condition of a component or equipment.

Examples of inspection activities are: Measurement of the protective steel potential, visual observation of depletion of anodes, visual detection of leaks, thickness measurements, sea bottom subsidence measurements, visual observation for permanent deformation or damage, etc.

**Monitoring**: Regular recordings of operational data and other relevant data needed in order to establish the current condition of a component and/or to analyse its rate of degradation.

Examples of monitoring activities are: Recording of temperature, pressure, fluid composition, valve position, choke position, maritime activity, etc. Any abnormal or extreme values should be recorded even if the duration is short.

**Testing**: Applying a load to confirm a measurable property or function of a component or a system

Examples of testing activities are: The load can be in the form of e.g. force, pressure, electrical load, etc. depending on the function of the equipment. Typical tests are insulation resistance test, valve barrier test, etc.

For testing of safety equipment, appropriate standards and codes (used as basis for design) should be utilized. Many designs are based on the functional safety standards IEC 61508 and IEC 61511. ISO/TR 12489 can be referred to regarding testing in relation to probability estimation needed for safety.

Test interval requirements given by the respective authorities shall be adhered to.

An unacceptable situation, mechanical damage or other abnormalities detected during the planned IMT activities should immediately be reported and subjected for review and the appropriate actions taken. This should be done in order to evaluate if this incident will have impact on the overall strategies and to establish if a re-qualification (see [3.3.5]) should be carried out.

A summary of relevant inspection, monitoring and testing parameters is given in Table 5-1 and discussed in [5.2] to [5.4].
5.2 Recommendations for inspection activities

The purpose of the inspection should be clearly defined prior to the inspection (see [4.4]) and all acceptance criteria elucidated. The necessary inspection activities should be described in detail.

Inspection activities may include, but not be limited to:

- crack detection and sizing
- corrosion/erosion – internal: Wall thickness measurements
- corrosion – external: Visual inspection for evidence of corrosion, wall thickness measurements
- coating damage: Visual inspection

### Table 5-1 Typical inspection, monitoring and testing parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Umbilicals</th>
<th>Foundation/Soil</th>
<th>Structures</th>
<th>Rigid piping</th>
<th>Connectors/Flanges</th>
<th>Valves</th>
<th>Control systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion - external</td>
<td>X 1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coating damage</td>
<td>X 1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine growth</td>
<td>X 1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaks</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsidence</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scouring</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP-system condition (incl. anode fastening cables)</td>
<td>X 1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign body detection</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion/Erosion - internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>X 2)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>X 3)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid composition</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Current</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vibration</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic fluid level</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Current</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship traffic</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishing activity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure testing</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Valve barrier testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation resistance</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical system tests</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument testing and calibration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function (e.g. valves, actuators, hatches, etc.)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuity (cables, tubing, fibres)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP-system condition (steel protective potential)</td>
<td>X 1)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) End terminations
2) From topside
- marine growth: Visual inspection, thickness measurements
- leaks: Visual inspection for detection of leaks to the environment
- deformation: Visual inspection
- damage: Visual inspection for permanent deformations
- subsidence: Visual inspection or relative height measurements
- scouring: Visual inspection
- CP-system condition: Visual inspection for assessment of anode depletion and check for damage to anode fastening cables (see App.C for details), measurement of steel protective potential
- foreign body detection.

The main process steps associated with the inspection are:

- detailed planning
- execution
- reporting and documentation
- assessment of the data collected during inspection.

The detailed planning for an inspection typically includes the following:

- detailed description of the scope of work
- specification of reporting format
- development of work packages
- preparation of work instructions and procedures
- establishment of responsibilities and communication lines between inspection supplier and operator
- procurement of equipment
- establishment of plans for the mobilisation of equipment and personnel
- carrying out risk management activities for the inspection activity.

The execution of the inspection typically includes the following:

- mobilisation of personnel and equipment and transportation to the site
- carrying out safety activities
- completing the inspection activities
- de-mobilisation
- preliminary reporting towards the specified reporting criteria.

Documentation of the inspection, assessment of the inspection data and final reporting typically includes:

- quality control of the inspection results
- assessment of inspection results with respect to integrity
- recommendation of further assessments if necessary
- issuing of final inspection report.

Reporting of inspection results should aim at being in a standardised format to ease the assessment work, fulfil reliability and maintenance reporting requirements for Computerized Maintenance-Management Information System purposes (see ISO 14224) and to better allow for trending of inspection data such as corrosion rates, valve function, etc.

All work instructions, procedures, communication lines and responsibilities, which are mandatory for a safe and cost-effective inspection process, and which constitutes the operation manual, should be implemented as part of the subsea integrity management system as described in Sec.2.

Recommendations with regard to risk management in marine and subsea operations can be found in DNV-RP-H101.

Guidelines concerning hazard identification and risk assessment for marine and subsea operations can be found in ISO 17776.
5.2.1 Inspection capabilities
Inspection can be carried out with a wide range of inspection tools having different capabilities and areas of application. As a basis for the detailed inspection plan, the available technology, relevant for the specific threat to be inspected for, should be identified.

External inspections are normally carried out using a remotely operated carrier equipped with different inspection tools. This can for instance be tools for visual inspection (e.g. video recording) and physical measurements (e.g. steel electrochemical potential measurements). External inspections can also be performed by divers.

5.2.2 Preparation for inspection
The detailed work description, including all relevant acceptance criteria, should be prepared prior to inspection and should include the following as a minimum:

— description of the system, including any special information important for the inspection
— purpose of the inspection
— specification of required equipment
— the accuracy of the equipment
— detailed description of the equipment and inspection tools
— requirements for calibration of the equipment
— qualification of personnel
— detailed instructions for the inspection including operational procedures
— requirements for documentation of inspection results and findings
— preparation of the inspection report outline.

Deviations from the annual inspection plan should be explained and documented.

5.2.3 Listings and digital reporting
The amounts of collected data from one single survey either externally or internally can be significant. Most data are reported in so called "listings".

Listings for umbilicals may contain information like (measured as a function of KP or easting/northing):

— time and date
— KP (distance)
— easting and northing positions
— seabed configuration, average seabed profile, trenches, rock dumping
— scouring
— location and condition of mattresses, sleepers, protection structures
— location of umbilical termination
— free span length, gap, shoulders
— debris, mines, ship wrecks, fishing equipment, etc.
— abnormalities like visible damage to umbilical, leakage, unintended exposure, upheaval buckling and signs of corrosion on termination head
— CP recordings on termination head.

Listings for templates and manifolds may contain information like:

— time and date
— seabed configuration, rock dumping
— scouring, subsidence, settlement, well expansion
— location and condition of mattresses, sleepers, protection structures
— debris, mines, ship wrecks, fishing equipment, etc.
— coating damage
— damage or abnormalities like dents, leakage, unintended exposure, broken hatches, torn jumper cables, displacement and signs of corrosion
— valve position and results of any ROV valve tests
— anode condition and activity
— CP recordings
— condition of ROV panels.

Listings should be in a digital format. To obtain good quality in survey reporting, it is important that listings are in a consistent format. The format should be selected based upon the amount of data recorded, specification for data formatting and available software.

5.2.4 Inspection report

Inspection reports are normally issued as first-hand reports shortly after the inspection and as final inspection reports later on. In most cases, these reports contain the same type of information (and conclusions) but are issued at different times. However, some adjustments of the inspection results may appear after a more detailed assessment of the results has been performed.

5.2.4.1 External inspection reports

After an inspection, a report including a printout of the listings (first hand report, final report) should always be issued. This report should typically contain information on the following:

— scope of the inspection
— survey vessel
— description of inspection tools and equipment and calibration certificates
— acceptance criteria
— accuracy and confidence level for the selected inspection methods
— reference to relevant procedures for the inspection
— KP definitions
— coverage of survey
— UTM coordinates and conversion algorithm applied
— date and time, KP
— seabed configuration
— explanation of expressions, terms and symbols used in reports and listings
— sea state (current, waves, etc.) during survey
— Digital Terrain Models (DTM), KP database or alignment sheets used to plan the survey and used during the survey
— data recorded on-line and off-line, post processing, manipulation and smoothening of data
— threshold or cut-off levels for reporting (like limiting free span length, gap)
— listings of findings
— findings that exceed acceptance criteria
— listing of deviations from plan.

Instead of printing all listings in the survey report, the report should summarise the information similar to what is listed in the bullet points above.

The report should also include:

— definitions and an explanation on how the data should be read and interpreted
— cross reference to digital reports (file name), charts, drawings, pictures and videos delivered.

5.2.5 Review of inspection results

In addition to the report from the inspection suppliers, which might include an assessment of the results, the operator should carry out a high level evaluation of the inspection and the results. This evaluation should address:
— if the inspection has been carried out according to the inspection plan
— the quality of the inspection (i.e. confidence in results)
— a high level evaluation of the inspection results with respect to the integrity (e.g. classified as insignificant, moderate, significant, severe findings)
— recommendation for further assessment of the findings.

5.3 Recommendations for monitoring activities

Monitoring activities may typically be:

— flow rate
— pressure
— temperature
— fluid composition (content of CO₂, H₂S, water, etc.)
— electrical current
— voltage
— power
— leak detection
— sand detection
— vibration
— hydraulic fluid level
— sea current
— ship traffic
— fishing activity.

The main activities associated with monitoring are:

— description of the purpose of the monitoring
— data acquisition and storage
— retrieval and analysis of data
— documentation and reporting, including comparison to acceptance criteria.

Any abnormal or extreme values should also be recorded even if the duration is short.

5.3.1 Monitoring capabilities

Monitoring may be by an on-line computer controlled system carrying out sampling at regular intervals or it may be based on manual sampling for further laboratory testing or investigation.

Monitoring may be intrusive or non-intrusive. An intrusive method will for example require access through a pipe wall for measurements to be made (e.g. fitting of pressure gauges, sand detectors, etc.) whilst a non-intrusive technique is performed externally.

5.3.2 Review of monitoring data

The results from monitoring activities should be evaluated at pre-determined intervals that have been based on the risk assessment and the time frame of the monitored parameters. A more frequent evaluation may be appropriate early in the operations phase. The review should at least consider:

— that all planned monitoring activities have been done and carried out in accordance with specifications
— that the monitoring data are within the design envelope, and if not, ensure that deviations have been handled according to relevant procedures
— a high level evaluation of the monitoring results with possible impact on the integrity assessment
— recommendations for further assessment as required.
5.4  Recommendations for testing activities

Testing activities may typically include:

- pressure testing – internal
- pressure testing – external
- valve barrier testing
- leak detection
- insulation resistance
- electrical system test
- instrument testing and calibration
- general communication testing
- function (e.g. valves, actuators, etc.)
- continuity/communication (cables, tubing, fibres).

Barrier testing of a valve is defined as testing the integrity of the valve to perform as a barrier, i.e. ability to isolate upstream and downstream.

5.4.1  System internal pressure testing

System pressure testing can be used to both demonstrate the strength of a system and test for leaks. System pressure testing may be required when:

- the original mill pressure test or system pressure test does not satisfy requirements according to the design standard in the case of e.g. a new design pressure (i.e. re-qualification)
- as an alternative to documenting the current condition of the subsea production system if general inspection techniques cannot be utilised to inspect the internal or external condition.

There are limitations associated with pressure testing when applied after the system has been operated for a number of years. These are typically:

- the method does not provide any information regarding the depth or location of sub-critical flaws
- the method does not verify that the acceptance criteria are fulfilled (e.g. wall thickness)
- it normally requires the system to be taken out of service for the testing
- it may be a challenge to remove water from the system following a hydrostatic pressure test. Such residual water has the potential for initiating internal corrosion.
SECTION 6 INTEGRITY ASSESSMENT

Long term IMT plans developed as part of the Risk Assessment and IM Planning should form the basis for any integrity assessment (see [4.4]).

When an abnormality is detected for a component or there is a change in functional performance, an integrity assessment should be performed. The assessment should include an evaluation of the current condition based on the inspection, monitoring and testing data and the possible impact of the abnormality on further operation.

An overview of some relevant standards and recommended practices for assessing the abnormality of components and changes in functional performance is given in Table 6-1.

Details concerning the abnormality should be established and as far as possible be quantified taking accuracy and uncertainty of measurements into consideration. The root cause(s) should be identified. Additional inspection, monitoring and testing may be necessary. If the integrity level of the component is not satisfactory to allow for further operation immediate actions needs to be put in place. Relevant information should be gathered and reported and used as input for an update of the risk assessment and plans for mitigation, intervention or repair.

A component having an abnormality may be operated temporarily until the abnormality has been removed or repaired, provided that it is demonstrated that the safety margin is within the acceptable range. Immediate actions in form of mitigating measures or temporary precautions may need to be activated.

For some abnormalities integrity assessment may be carried out using suitable analysis methods such as FEM, etc.

The integrity assessment process should be based on documentation and data from:
- design, fabrication and installation
- operation
- inspection, monitoring and testing.

The integrity assessment may be split into:
- corrosion assessment covering analysis of internal and external corrosion data
- mechanical assessment covering evaluation of the mechanical properties of components with damage or failures
- functional assessment covering analysis of the impact of an abnormality on the functional performance of the system.

The data acquired from such activities should be properly documented to ensure traceability and enable trending.

Reporting of the integrity management activities and results can be done according to the reporting template example shown in App.D.
### Table 6-1 Examples of failure modes and relevant assessment codes

<table>
<thead>
<tr>
<th>Failure Mode (Damage / Abnormality)</th>
<th>Code / Guideline</th>
<th>Comment</th>
<th>Piping</th>
<th>Structure</th>
<th>Valve Body &amp; Welds</th>
<th>Connectors / Flanges</th>
<th>Umbilical</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>IEC 60812</td>
<td>Procedure for failure mode and effects analysis (FMEA)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Metal loss</td>
<td>ASME VIII D2</td>
<td>Boiler and pressure vessel code</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DNV-RP-O501</td>
<td>Erosion for simple geometry</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>ASME B31.3</td>
<td>Including the “modified edition”</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>API 579-1 / ASME FFS-1</td>
<td>Assessment of general, local metal loss and pitting corrosion (for pressurized components)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>BS-7910</td>
<td>Guide on methods for assessing the acceptability of flaws in metallic structures</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dent</td>
<td>ASME VIII D2</td>
<td>Boiler and pressure vessel code</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>API 579-1 / ASME FFS-1</td>
<td>Assessment of dents, gouges, and dent-gouge combinations</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>BS-7910</td>
<td>Guide on methods for assessing the acceptability of flaws in metallic structures</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Crack</td>
<td>BS-7910</td>
<td>Guide on methods for assessing the acceptability of flaws in metallic structures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DNV-RP-C203</td>
<td>Fatigue</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>API 579-1 / ASME FFS-1</td>
<td>Assessment of crack-like flaws</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Relative displacement (from e.g. settlement, subsidence, scouring, well growth)</td>
<td>DNV-OS-F101</td>
<td>Submarine pipeline systems</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASME 31.3</td>
<td>Process piping</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASME 31.8</td>
<td>Gas transmission distribution piping systems</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EN 1993/Eurocode 3</td>
<td>Design of steel structures</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Weld issues (Undercut, lack of fusion or penetration, concavity and overlap)</td>
<td>BS-7910</td>
<td>Guide on methods for assessing the acceptability of flaws in metallic structures</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SECTION 7 MITIGATION, INTERVENTION AND REPAIR

7.1 General
Long term IMT plans or event based IMT plans developed as part of Risk Assessment and IM Planning and Integrity Assessment should form the basis for mitigation, intervention and repair activities.

Mitigating activities are measures taken to reduce the likelihood for or the consequence of failure.

Intervention activities are actions taken to maintain the current condition of the components including replacing failed components.

Repair activities are activities with the objective to restore compliance with requirements related to functionality, structural integrity or pressure containment

In some cases there may be a need for technology qualification of the above activities prior to execution. This can for instance be qualification of intervention tools, a contingency seal or a new chemical.

Mitigation, intervention and repair typically include the following main activities:

— detailed planning
— technology qualification if necessary
— mobilization
— execution
— documentation.

All mitigations, interventions and repairs should be carried out by experienced and qualified personnel in accordance with approved procedures.

Mitigation, intervention and repair activities may introduce new constraints to the system which must be assessed and approved by relevant skilled personnel before initiation.

Mitigation, intervention and repair activities should not impair with the integrity of the overall system.

All interventions and repairs should be verified, tested and inspected by qualified personnel in accordance with approved procedures. NDT personnel, equipment, methods, and acceptance criteria should be approved in accordance with appropriate standards and codes.

All the equipment that is removed due to failure or planned regular replacement should be inspected to establish the level of degradation and reason for failure.

Recommendations with regard to risk management in marine- and subsea operations can be found in DNV-RP-H101.

Guidelines concerning hazard identification and risk assessment for marine and subsea operations can be found in ISO 17776.

7.2 Methods

7.2.1 Mitigation methods
Examples of mitigation means are:

— restriction in operational parameters such as MAOP, inlet temperature, flow rate and number of operations (open/close)
— use of chemicals in order to mitigate corrosion, improve flow, reduce scaling or avoid hydrate formation
— shortening of the IMT interval
— planned replacement intervals of components with high likelihood of failure.
7.2.2 Intervention means
Examples of intervention means are:
— launch of a scraper pig
— replacement of SCM pod
— cleaning to remove marine growth or calcareous deposits
— replacement of metal seal with a spare seal in case of seal failure, or change to a contingency seal in case of seal seat damage.

7.2.3 Repair methods
There are cases where repair of subsea equipment has been performed but most of them have been based on a case by case solution.

A repair may be temporary or permanent depending upon the extent of the damage. A temporary repair may be acceptable until the permanent repair can be carried out or the component/sub-system can be replaced, provided the integrity of the system is maintained at an acceptable level.

A repair that results in change of form, fit or function should be recorded in all documents describing the repaired object. This to avoid problems in future campaigns. Examples are a new frame or an object restricting future interventions.

7.3 Detailed planning
Detailed planning for mitigation, intervention and repair should take into consideration authority regulations. The purpose and acceptance criteria of the activities should be established prior to the detailed planning. This is normally carried out as part of the development of mitigation, intervention and repair strategies. Detailed planning should include:
— a detailed definition of the scope of work
— if necessary, detailed specification of selected activities or relevant methodology
— preparation of detailed procedures for execution
— establishment of responsibilities and communication lines between involved parties
— establishment of plans for mobilisation, logistics and coordination of the intervention and repair activity
— establishment of plans for carrying out the repair or intervention
— defining the documentation requirement.

7.3.1 Detailed procedures
Execution of mitigation, intervention and repair activities can be complex and consist of many different sub-activities.

Example of those sub-activities can be:
— emptying the equipment (removal of fluid)
— disconnecting the electrical power
— seabed intervention (e.g. excavation, gravel filling) for access and to provide stable support conditions for tools and equipment needed for the operation
— launching of intervention/repair tooling
— restraining and supporting the remaining equipment prior to un-bolting or cutting of failed equipment
— un-bolting or cutting and removal of failed equipment or interfacing equipment as required
— cleaning, close visual inspection and NDT of remaining equipment, as required
— installation of new equipment or repair of failed equipment
— retrieval of installation tools and if applicable failed equipment
— onshore detailed inspection of the damaged equipment
— commissioning of repair operation (e.g. function or pressure test).
For all these sub-activities detailed procedures should be prepared and these should typically include:

- procedures defining project organisation, the roles, responsibilities and communication lines between all parties involved
- procedure for emptying or isolation of fluid or electrical power
- emergency preparedness plans for the operation
- procedures for seabed interventions
- procedure for required marine operation, including restrictions related to weather window
- intervention or repair procedures
- function and pressure test procedures.

### 7.3.2 Safety management – Mitigation, intervention and repair

Typical aspects to be considered with regards to safety management:

- operating envelope
- risk for 3rd party damage from the operation itself
- HAZOP, HIRA or SJA for the different actions
- potential consequences of the actions to the overall subsea production system.

### 7.4 Mobilisation and execution

Mobilisation implies that relevant equipment and personnel needed to perform the operation are available.

Execution includes preservation of equipment, transportation to site, safety activities, coordination and communication activities, drills, completion, testing and close-out activities, etc.

The approved operational procedures for the sub-activities need to be adhered to and signed off for compliance during operation and the quality of the work needs to be verified.

### 7.5 Documentation

The mitigation, intervention and repair activities should be documented and given as input for the further Risk Assessment and IM planning. See [3.3.8].

The results of the implemented work and the control activities should be documented. All the documents describing the objects exposed to the campaign should be identified and updated. This is to ensure correct procedures being developed for future campaigns.

In the events of any findings during the execution, those should be reported in a timely manner.

An example of an integrity management reporting template is shown in App.D.
APPENDIX A  THREATS AND FAILURE MODES

Table A-1 gives an overview of typical threats and failure modes for the main subsea components, and Table A-2 gives a description of the typical failure modes. The failure modes given can be on different levels: System level, equipment level or component level. In addition the failure modes can be primary or secondary, where a primary failure mode can develop into a secondary. Table A-1 and Table A-2 are based on DNV-RP-F116 and experience from the participants of the joint industry project. They are not aligned with ISO 14224.

Table A-1  Summary of typical threats and failure modes

<table>
<thead>
<tr>
<th>Threat group</th>
<th>Threat</th>
<th>Threat description</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFI threats</td>
<td>Design</td>
<td>Insufficient knowledge</td>
<td>Burst</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insufficient experience</td>
<td>Metal loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insufficient qualification of new technology</td>
<td>External or internal leak</td>
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<tr>
<td></td>
<td></td>
<td>Incorrect design (does not meet with functional requirements)</td>
<td>Cracking</td>
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<tr>
<td></td>
<td></td>
<td>Incomplete design basis</td>
<td>Yielding</td>
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<tr>
<td></td>
<td></td>
<td>Incorrect materials selection</td>
<td>Collapse</td>
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<tr>
<td></td>
<td></td>
<td>Equipment or system interface issues</td>
<td>Loss of function</td>
</tr>
<tr>
<td></td>
<td>Manufacturing</td>
<td>Insufficient knowledge</td>
<td>Material ageing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insufficient experience</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Insufficient manufacturing follow-up</td>
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<tr>
<td></td>
<td></td>
<td>Design specification not adhered to</td>
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<tr>
<td></td>
<td></td>
<td>Insufficient qualification of manufacturer</td>
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<tr>
<td></td>
<td></td>
<td>Insufficient traceability of raw materials</td>
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<td></td>
<td></td>
<td>Shortcomings and damages introduced during manufacturing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fabrication</td>
<td>Insufficient knowledge</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Insufficient experience</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insufficient fabrication follow-up</td>
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<td></td>
<td></td>
<td>Welding shortcomings</td>
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<tr>
<td></td>
<td></td>
<td>Assembly errors (e.g. wrong bolt torque etc.)</td>
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<tr>
<td></td>
<td></td>
<td>Incomplete FAT</td>
<td></td>
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<tr>
<td></td>
<td>Coating application</td>
<td>Insufficient knowledge</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Insufficient experience</td>
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<tr>
<td></td>
<td></td>
<td>Insufficient follow-up during coating application</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Coating shortcomings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Testing</td>
<td>Overload due to incorrect test pressure (on- and offshore pressure testing)</td>
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<tr>
<td></td>
<td></td>
<td>Incomplete system integration test</td>
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<tr>
<td></td>
<td>Temporary storage</td>
<td>UV radiation</td>
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<tr>
<td></td>
<td></td>
<td>Inadequate preservation (e.g. internal corrosion)</td>
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</tr>
<tr>
<td></td>
<td>Installation</td>
<td>Damage or overload during transportation</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Mechanical damage, overload, fatigue, deformation, HISC due to installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assembly errors (e.g. wrong bolt torque etc.)</td>
<td></td>
</tr>
<tr>
<td>Threat group</td>
<td>Threat</td>
<td>Threat description</td>
<td>Failure mode</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td><strong>Material degradation threats</strong></td>
<td>Corrosion</td>
<td>Internal uniform corrosion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental cracking</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>External corrosion due to</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— CP system failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— lack of CP (loss of electrical continuity)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— excessive anode consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— coating damage</td>
<td></td>
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<tr>
<td></td>
<td>Galvanic corrosion</td>
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<tr>
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<td>Crevice corrosion due to seawater</td>
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<tr>
<td></td>
<td>Coating degradation</td>
<td>Formation of cold spots causing internal corrosion</td>
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</tr>
<tr>
<td></td>
<td>HISC</td>
<td>Cracking due to a combination of excessive load, hydrogen and susceptible material</td>
<td>Cracking</td>
</tr>
<tr>
<td></td>
<td>Ageing</td>
<td>Elastomeric seal ageing</td>
<td>Loss of function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incorrect materials selection</td>
<td>Material ageing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Embrittlement due to insufficient UV resistance, heat resistance or resistance to low temperature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Erosion</td>
<td>Due to a combination of sand content and fluid velocity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wear</td>
<td>Change of friction on hard faced seal surfaces</td>
<td>Galling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Material loss due to movement/abrasion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cavitation</td>
<td>Implosion of gas bubbles in liquid phase</td>
<td></td>
</tr>
<tr>
<td><strong>Internal medium threats</strong></td>
<td>Fluid impurity</td>
<td>Clogging or corrosion due to impurities or contamination in hydraulic or chemical injection fluid</td>
<td></td>
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<tr>
<td></td>
<td>Change in reservoir</td>
<td>Change in well fluid composition (e.g. oil/gas/water composition change, well souring, etc.)</td>
<td>Metal loss Clogging</td>
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<tr>
<td></td>
<td>conditions</td>
<td>Sand production</td>
<td>External or internal leak</td>
</tr>
<tr>
<td></td>
<td>Fluid incompatibility</td>
<td>Clogging or corrosion due to mixing of incompatible fluids (hydraulic and injection chemicals)</td>
<td>Cracking Loss of function Material ageing Clogging</td>
</tr>
<tr>
<td></td>
<td>Fluid backflow in</td>
<td>Incompatibility of fluid and material (hydraulic, injection or well stimulation chemicals)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>umbilical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Third party threats</td>
<td>Change in well fluid composition (e.g. oil/gas/water composition change, well souring, etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trawling</td>
<td>Trawl board impact</td>
<td>Burst</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trawl line snag</td>
<td>External or internal leak</td>
</tr>
<tr>
<td></td>
<td>Anchoring</td>
<td>Ship traffic</td>
<td>Cracking</td>
</tr>
<tr>
<td></td>
<td>Dropped objects</td>
<td>Intervention equipment, ship traffic</td>
<td>Yielding</td>
</tr>
<tr>
<td></td>
<td>Vandalism / terrorism</td>
<td>International and political situations</td>
<td>Collapse</td>
</tr>
<tr>
<td></td>
<td>Traffic – landfall area</td>
<td>Umbilical: Vehicle impact</td>
<td>Loss of function</td>
</tr>
<tr>
<td></td>
<td>Other mechanical impact</td>
<td>ROV, ship sinking, marine operations etc.</td>
<td></td>
</tr>
</tbody>
</table>
### Table A-1 Summary of typical threats and failure modes (Continued)

<table>
<thead>
<tr>
<th>Threat group</th>
<th>Threat</th>
<th>Threat description</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural threats</strong></td>
<td>Excessive mechanical loads</td>
<td>Due to pipeline/riser expansion, drilling, intervention, subsidence, well growth, scouring, settlement, vibrations, over-torquing, new-tie-ins, XT retrieval, BOP loads, etc.</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
</tr>
<tr>
<td></td>
<td>Excessive pressure loads</td>
<td>Pressure variations, fluid hammer, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Excessive thermal loads</td>
<td>Temperature variations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fatigue</td>
<td>VIV due to waves, current or wind, scouring</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
</tr>
<tr>
<td></td>
<td>VIV due to the process, fluid hammer, slugging, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyclic loading due to pressure and temperature variations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mud/Sand movement</td>
<td>Unable to move equipment, open hatches, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine growth</td>
<td>Unable to install or retrieve equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unable to carry out inspection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Umbilical: Increased tension and dynamic behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcareous layer</td>
<td>Unable to install or retrieve equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local buckling</td>
<td>Umbilical over-bending or thermal expansion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-bottom stability</td>
<td>Damage to outer sheath of umbilical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twist</td>
<td>Damage to outer sheath or bending of umbilical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freespan</td>
<td>Umbilical freespan due to sea currents, fatigue/VIV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of bolt tension</td>
<td>Umbilical hang-off</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Control system threats</strong></td>
<td>Loss of power (electrical, hydraulic)</td>
<td>Due to material degradation, low insulation resistance, water ingress, calcarceous formation on mating surfaces, contamination on contact surfaces, cooling system failure, etc.</td>
<td>External or internal leak Loss of function</td>
</tr>
<tr>
<td>Sensor drift or failure</td>
<td>Incorrect measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication error</td>
<td>Loss of monitoring data or signals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software failure</td>
<td>Loss of communication and data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obsolescence / lack of spare parts</td>
<td>Loss of monitoring data or signals</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Natural hazard threats</strong></td>
<td>Extreme weather</td>
<td>Umbilical: Excessive mechanical loads</td>
<td>Burst External or internal leak Cracking Yielding Collapse Loss of function</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>Excessive mechanical loads, unable to move equipment, open hatches, etc.</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
<td></td>
</tr>
<tr>
<td>Landslides</td>
<td>Excessive mechanical loads, unable to move equipment, open hatches, etc.</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
<td></td>
</tr>
<tr>
<td>Ice loads</td>
<td>Excessive mechanical loads, unable to move equipment, open hatches, etc.</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
<td></td>
</tr>
<tr>
<td>Volcanic activity</td>
<td>Excessive mechanical loads, excessive thermal loads, unable to move equipment, open hatches, etc.</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
<td></td>
</tr>
<tr>
<td><strong>Operational threats</strong></td>
<td>Incorrect operation</td>
<td>Operation outside of the specified operational envelope (pressure, temperature, sand, oxygen content, etc.)</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
</tr>
<tr>
<td>Incorrect procedures</td>
<td>Procedures not updated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human errors</td>
<td>Overfamiliarity (e.g. ignored alarms, etc.)</td>
<td>Burst Metal loss External or internal leak Cracking Yielding Collapse Loss of function Material ageing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient training</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient experience</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table A-2  Typical failure modes

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Description</th>
<th>Cause (Damage/Abnormality)</th>
<th>Consequence</th>
<th>Degradation Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burst</td>
<td>Failure due to loss of pressure containment</td>
<td>Wall thinning, crack propagation, overload, metal loss, sand</td>
<td>Large spill</td>
<td>Corrosion, erosion, fatigue</td>
</tr>
<tr>
<td>External leak</td>
<td>Failure jeopardizing system pressure containment</td>
<td>Localized corrosion attack, small crack, damaged seal, loss of external corrosion protection</td>
<td>Small spill</td>
<td>Material ageing, corrosion, erosion, fatigue</td>
</tr>
<tr>
<td>Metal loss</td>
<td>Reduction of system pressure containing capacity</td>
<td>Coating damage, wall thinning</td>
<td>Wall thinning, reduced load bearing capacity</td>
<td>Corrosion, erosion</td>
</tr>
<tr>
<td>Cracking</td>
<td>Fracture capacity exceeded</td>
<td>Overload, vibrations</td>
<td>Large spill</td>
<td>HISC, environmental cracking, fatigue</td>
</tr>
<tr>
<td>Yielding</td>
<td>Too high utilisation of the material due to overload</td>
<td>Dent, overload, displacement</td>
<td>Loss of function, loss of functionality</td>
<td>Corrosion, erosion</td>
</tr>
<tr>
<td>Collapse (buckling)</td>
<td>Deformation of the cross section or full collapse</td>
<td>External overload, deformation</td>
<td>Loss of or reduced function</td>
<td>Corrosion, erosion</td>
</tr>
<tr>
<td>Loss of function</td>
<td>Loss of or reduced function; Control system failure or component failure preventing equipment to operate as intended</td>
<td>Ovalisation, deformation, control system failure due to internal or external leak, diffusion</td>
<td>Loss of functionality, loss of power (electrical/hydraulic), loss of function, overheating</td>
<td>Material ageing, corrosion, HISC, environmental, cracking</td>
</tr>
<tr>
<td>Material ageing</td>
<td>Delamination of polymeric materials reducing e.g. strength or protective capability. Ageing of elastomeric material due to chemical and thermal exposure</td>
<td>Material degradation due to exposure to conditions outside of qualified range e.g. UV, temperature, chemicals</td>
<td>Loss of function, internal and external leak</td>
<td>Ageing</td>
</tr>
<tr>
<td>Internal leak</td>
<td>Isolated components not able to fulfil its function</td>
<td>Material ageing, ovalisation, deformation</td>
<td>Loss of function, loss of sealing capability, contamination, hydrate formation</td>
<td>Corrosion, material ageing, wear</td>
</tr>
<tr>
<td>Clogging</td>
<td>Clogging of piping or equipment preventing fluid flow</td>
<td>Wax or hydrate formation due to incorrect operation</td>
<td>Loss of function, loss of functionality</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B  RISK ASSESSMENT AND INTEGRITY MANAGEMENT PLANNING WORKING PROCESS

B.1 Risk assessment - a working process description
The risk assessment comprises the following main tasks; see also Figure B-1 below:

a) Establish equipment scope
b) Identify threats
c) Data gathering
d) Data quality review
e) Estimate probability of failure (PoF)
f) Estimate consequences of failure (CoF)
g) Determine risk
h) Identify risk mitigating measures
i) Ensure all interfaces have been considered
j) Determine aggregated risk
k) IMT Planning (see [4.4]).

The results of the risk assessment should be documented in a "Risk assessment and IM planning worksheet". A typical worksheet is shown in Table B-1 below.

a) Establish equipment scope
The subsea components as well as all components where a failure jeopardises the structural integrity of the subsea components should be included.

b) Identify threats
A general overview of subsea component threats is presented in App.A.
Identification of threats should be done in workshops with participation from all relevant disciplines. It is also important to involve resources with background from both design and operation; resources with in-depth knowledge of the system in question. These working sessions should be structured and planned, and the outcome should be properly documented.

Typical sources for identification of threats are:

— previous risk assessments (carried out in the project phase and in the operations phase)
— design documentation, hereunder but not limited to DFI documents
— results and documentation from Integrity management process activities, e.g. subsea components IMT reports
— operators’ and industry experience, e.g. failure statistics.

The output of the threat identification activities is a list of relevant threats and notes with regard to e.g. failures, failure mechanisms, failure modes, location, as well as related issues of uncertainty.
It is recommended to develop an appropriate template for carrying out and recording results and notes from the reviews and risk assessments.

c) Data gathering
The data needed to perform the risk assessment varies from threat to threat and is also dependent on the adopted risk approach. The data sources should be documented (see ISO 20815, Annex E.2 on reliability data source matters).

d) Data quality review
The quality of data should be reviewed and in case of missing or large uncertainties in the data, conservative assumptions should be made. Alternatively, more accurate data need to be gathered, e.g. through additional inspections, monitoring and testing.
The uncertainties in the data should be documented as this is important input for selecting the correct and most cost effective mitigating actions.

e) Estimate probability of failure (PoF)

The estimation of probability of failure should follow a documented procedure (ref. ISO/TR 12489, ISO 14224 or ISO 20185). Deviation from the procedure should be documented and justified.

All threats should be considered either as individual threats or on a group level. Components of equal type can be evaluated together.

If the consequence modelling is done on a failure mode level, e.g. leak, burst; the estimation of PoF needs to be done for all the relevant failure modes.

f) Estimate consequence of failure (CoF)

The consequence of failure can be modelled at:

— threat group level, in this case the worst consequence related to the grouped threats apply
— individual threat level, in this case the worst consequence related to possible failure modes apply
— failure mode, in this case the consequence profile can be used for all threats which may lead to this failure mode.

g) Determine risk

The risk is the product of PoF x CoF. If the risk is not acceptable, mitigating measures need to be evaluated.

h) Identify risk mitigating measures

To be able to select cost effective mitigation, it is important to identify the risk driving factors. In this context, the results from step d) may provide valuable information.

Further, selection of the most cost effective measure may only be done after all threats have been considered. Risk reduction can either be achieved by reducing the probability or the consequence (or both) of an event.

Typical measures to reduce the probability are:

— analytical, i.e. more refined calculations
— additional inspection, monitoring and testing
— intervention or repair
— de-rating e.g. load reduction
— load control measures
— replacement.

Among the measures to reduce the consequence are:

— analytical, i.e. more refined calculations
— enhance emergency response procedures and associated equipment (especially related to safety and environmental consequences)
— enhance subsea components repair strategies and equipment to reduce down time (economic consequences)
— establish redundancy solutions to take over the functionality of the failed equipment.

i) Ensure all interfaces have been considered

Make sure that the risk assessment also includes the interfaces between the various types of equipment have been covered.

j) Determine aggregated risk

If a quantitative risk assessment has been carried out, a total risk profile can be generated for the whole subsea production system summing up the contribution from all threats. To get an overall correct risk level, all relevant failure modes need to be addressed.
The above is less feasible if a qualitative risk assessment has been undertaken where the risk is expressed in qualitative terms, e.g. Low, Medium and High (unless these terms are associated with a value or if a scoring/index system has been applied).

The risk profile should be benchmarked towards risk profiles for similar/comparable subsea production systems. This is done to ensure consistency in the risk assessment and to detect gross errors.

An overall evaluation of the subsea production system should be made. All identified mitigations should be highlighted and documented.

**k) IMT planning (see [4.4])**

The IMT plan should be based on the results from the risk assessment.

The IMT planning for the subsea components may be grouped dependent on the IMT types. This grouping may reflect:

— the IMT type capabilities
— historical practice
— risk level (to focus the IMT activities on high risk sections). Note that locations with unacceptably high risk may need ad-hoc inspection, monitoring or testing which is not part of the long term plan.

![Figure B-1 Risk assessment – working process](image-url)

**Figure B-1 Risk assessment – working process**
Table B-1  Risk assessment and integrity management planning worksheet

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection, Monitoring, Testing, Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Failure Mode</th>
<th>Failure Mechanism</th>
<th>Threat</th>
<th>Threat Group</th>
<th>Mitigation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C RECOMMENDATIONS WITH REGARDS TO CORROSION AND EROSION

C.1 Objectives
The objectives of this appendix are to:

— give an overview of different corrosion threats commonly associated with oil and gas production, and applicable techniques for inspection of corrosion control systems and recommendations regarding corrosion monitoring
— give guidance to sand management and control in order for a field operated in a sand production regime to control erosion.

C.2 Introduction
Corrosion and erosion threats to a subsea production system should be managed by the integrity management process.

The integrity management process (see Sec.3) comprises the following main activities:

— Risk Assessment and IM Planning (Sec.4)
— Inspection, Monitoring and Testing (Sec.5)
— Integrity Assessment (Sec.6)
— Mitigation, Intervention and Repair (Sec.7).

Relevant corrosion threats will depend on the components materials, fluid corrosivity and efficiency of options for corrosion mitigation. Materials in corrosion resistant alloys and carbon steel internally lined or clad with a corrosion resistant alloy (CRA) are considered fully resistant to CO$_2$-corrosion in an oil and gas production system.

Guidance note:
Alloys resistant to CO$_2$-corrosion: Type 13Cr martensitic materials, 22Cr and 25Cr duplex stainless steel and austenitic Ni-based alloy.

For subsea production system flow accelerated corrosion (FAC) should be considered in vulnerable areas, such as in e.g. pipe bends. FAC may occur on materials forming poorly soluble corrosion films (e.g. carbon steel) and in combination with water chemistry and mass-transfer phenomena due to e.g. enhanced flow. CRA is not expected to suffer from FAC.

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

Sand particles and other solids may be present in the fluid, and may result in erosive wear of components such as manifold pipes, pipe bends, blinded tees, connections, control valves, etc. The erosion potential is mainly dependent on the type of particle, impact angle and flow rate (production rate).

Duplex and martensitic stainless steel components require special consideration in terms of the susceptibility to environmentally assisted cracking, primarily related to (HISC).

Table C-1 below gives an overview of the most common corrosion threats.

<table>
<thead>
<tr>
<th>Corrosion Threat</th>
<th>Initiator</th>
<th>External 1</th>
<th>Internal 2</th>
<th>Time dependency</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>O$_2$-corrosion</td>
<td>O$_2$ + water</td>
<td>o</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>CO$_2$-corrosion</td>
<td>CO$_2$ + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3, 7</td>
</tr>
<tr>
<td>Top of line corrosion</td>
<td>CO$_2$ + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3, 7</td>
</tr>
<tr>
<td>Preferential weld corrosion</td>
<td>CO$_2$ + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3, 7</td>
</tr>
<tr>
<td>General H$_2$S-corrosion</td>
<td>H$_2$S + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 2, 3, 7</td>
</tr>
<tr>
<td>Sulphides stress cracking (SSC)</td>
<td>H$_2$S + water</td>
<td>(x)</td>
<td>(x)</td>
<td>Abrupt</td>
<td>1, 2, 3, 7</td>
</tr>
<tr>
<td>Stress corrosion cracking (SSC)</td>
<td>H$_2$S + chloride/oxidant + water</td>
<td>(x)</td>
<td>(x)</td>
<td>Abrupt</td>
<td>1, 2, 3</td>
</tr>
</tbody>
</table>
V.3 Risk assessment and integrity management planning

V.3.1 Establishing and transferring integrity

System risk reviews should be carried out throughout the concept, design and fabrication phases. Personnel responsible for the system risk review and strategy development activity should attend these reviews.

Identification of relevant corrosion and erosion threats should already take place during the concept phase as part of the preliminary materials selection. The need for internal corrosion and erosion control and provisions for inspection and monitoring will in that respect also be assessed. The system risk review and strategy development should therefore be initiated during the concept phase and followed up in the subsequent design phase.

The system risk review and strategy development should provide input to the documentation summarizing the basis for the design (e.g. the Design Résumé) with regards to corrosion and erosion threats and provisions for corrosion and erosion mitigation and monitoring. A sand management strategy should also be developed during the establish integrity phase.

### Table C-1 Common corrosion threats (Continued)

<table>
<thead>
<tr>
<th>Corrosion Threat</th>
<th>Initiator</th>
<th>External 1)</th>
<th>Internal 3)</th>
<th>Time dependency</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen induced cracking (HIC)</td>
<td>H₂S + water</td>
<td>(x)</td>
<td>(x)</td>
<td>Abrupt</td>
<td>1, 2, 3, 7</td>
</tr>
<tr>
<td>Microbiologically influenced corrosion (MIC)</td>
<td>Bacteria + water + organic matter often in combination with deposit</td>
<td>O</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3, 4</td>
</tr>
<tr>
<td>Corrosion-erosion</td>
<td>Produced sand + O₂ / CO₂ + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>Flow accelerated corrosion</td>
<td>High fluid flow locally + O₂ / CO₂ + water</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1</td>
</tr>
<tr>
<td>Under deposit corrosion</td>
<td>O₂ / CO₂ + water + debris/scaling</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>Galvanic corrosion</td>
<td>O₂ / CO₂ + water</td>
<td>O</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>Elemental sulphur</td>
<td>(H₂S + O₂ + water) / (S + water)</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>Carry-over of glycol</td>
<td>(H₂S + O₂ + water) / (CO₂ + water)</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3</td>
</tr>
<tr>
<td>Hydrogen induced stress cracking (HISC)</td>
<td>Cathodic protection + load/stress + susceptible material</td>
<td>x</td>
<td>NA</td>
<td>Abrupt</td>
<td>1, 3, 5</td>
</tr>
<tr>
<td>Acid corrosion</td>
<td>Acid</td>
<td>NA</td>
<td>x</td>
<td>Time dependent</td>
<td>1, 3, 6</td>
</tr>
</tbody>
</table>

1) External corrosion should be controlled by the application of external corrosion coating in combination with cathodic protection (CP). Galvanic corrosion will be eliminated by cathodic protection.

2) Corrosion control through materials selection and qualification according to ISO-15156. Applicable both for internal and external. (See also Note 7)

3) Aggravating factors with regards to internal corrosion may be:
   - Lack of control with chemical injections for corrosion control
   - Presence of organic acids
   - Scaling and deposits.

4) Of primary concern is sulphate reduced bacteria (SRB). SRBs produces H₂S through their metabolism. See Note 2.

5) Susceptible materials are: 13Cr, 22Cr, 25Cr and high strength steels

6) Chemicals for cleaning internally

7) Corrosion resistant alloys are considered fully resistant to CO₂-corrosion in an oil and gas production system

NA: Not applicable

x: Probable threat

(x) Internal: Very low probability due to the general requirement for materials resistance to sour service under such conditions

(see also Note 2)

(x) External: In seabed sediments there will always be some H₂S production due microbiologically activity. It appears to be no indication that this has caused cracking due to H₂S.

α: Very low probability, due to the application of an external corrosion protection system (coating and CP)
C.3.1.1 Design of corrosion monitoring systems

Techniques and equipment for corrosion monitoring should be selected based on:

— monitoring objectives, including requirements for accuracy and sensitivity
— fluid corrosivity and the corrosion preventive measures to be applied
— potential corrosion mechanisms.

A risk assessment analysis can be used to identify the relevant corrosion mechanisms, their associated corrosion forms (e.g. pitting, uniform attack) and high risk areas. In addition it can form the basis for the design of the corrosion monitoring program.

If it is planned for chemical injection to mitigate corrosion, the criticality in terms of regularity of the injections, any need for backup injection systems or spare equipment, should also be evaluated.

The corrosion monitoring methods and fluid analyses that are most suitable for monitoring the corrosion or fluid corrosivity should be established, considering their accuracy and sensitivity.

The most suitable location of any monitoring device should be established during design (e.g. located in the areas with hold-up and drop-out of water). Installation of monitoring devices on a subsea production system may not be feasible and monitoring of the fluid corrosivity will therefore be restricted to the receiving or departing facility e.g. topside a platform.

Since a subsea production system principally will be inaccessible for in-line inspections, monitoring of the internal condition of the system will mainly be restricted to monitoring of the process parameters, chemical injection rate for corrosion mitigation and by intrusive and non-intrusive methods located in accessible areas, typically at pipeline outlet and inlet topside. However, it is possible to monitor a submerged section by the installation of instrumented spools installed inline the pipeline close to the subsea manifold (see guidance note). The location of the instrumented spool must be carefully determined, such that the area most susceptible to corrosion is selected (e.g. low point areas, areas were water drop-out is expected).

Guidance note:
The field signature method (FSM) is a non-intrusive monitoring method which makes it possible to monitor changes in the pipe wall in real-time at pre-defined locations.

C.3.1.2 Design of erosion monitoring systems

For fields operating in a sand production regime IMT, maintenance and production optimisation are key factors. A sand monitoring system should be established with the capability of continuously monitoring sand production from wells.

The components that will be most exposed to erosion in the subsea production system should be identified early to facilitate the selection of monitoring equipment and systems for predicting and assessing the probability of erosion. The sand monitoring system should have the capacity of continues measurements of sand production either as intrusive probes or acoustic sensors or a combination. Data from the sand monitoring system should further be used as input to an on-line erosion monitoring software collecting and analysing the data.

C.3.1.3 Inspection

Monitoring does not give information about actual loss of wall thickness in a component. Since the subsea production system is inaccessible for in-line inspection retrieval of a component may be the only way of inspecting it unless ROV operated NDT can be used. It should, however, be noted that not all components are retrievable, such as manifold piping.

Guidance note:
Since internal inspection is in principle not possible, CRA materials are commonly used for process wetted parts in order to eliminate the risk for internal corrosion.

C.3.2 Risk assessment and strategy development

Erosion and corrosion may lead to loss of containment by pinhole leak to rupture.

The process leading to the loss of containment due to corrosion will vary depending on the corrosion
mechanism. The various tables provided in this appendix contain information that can be used in connection with risk assessments and strategy development for internal and external corrosion control.

For fields operating in a sand production regime, a sand management strategy needs to be developed to control the erosion (see [C.3.1.2]).

C.4 Inspection, monitoring and testing

C.4.1 Inspection of external corrosion
The objective of monitoring and inspecting the external corrosion protection system is to confirm that the system functions properly and to look for any shortcomings caused by installation or during operation.

External inspection includes to a large extent inspection of the external corrosion protection system. Most often is the inspection limited to look for coating deficiency, discoloration due to formation of rust, the condition of the galvanic anodes and measurements of steel protective potential.

Inspection for any suspected external corrosion may be carried out by wall thickness measurements if feasible by portable NDT equipment.

Inspection of the external corrosion protection system with a galvanic cathodic protection system can include:

<table>
<thead>
<tr>
<th>Monitoring items</th>
</tr>
</thead>
<tbody>
<tr>
<td>— visual inspection of the external coating condition</td>
</tr>
<tr>
<td>— visual inspection of the condition and consumption of the galvanic anodes</td>
</tr>
<tr>
<td>— steel-to-electrolyte potential measurements</td>
</tr>
<tr>
<td>— potential measurements of galvanic anodes</td>
</tr>
<tr>
<td>— evidence of corrosion at areas without coating (exposed bare steel).</td>
</tr>
</tbody>
</table>

Monitoring of the CP-system can be performed by portable equipment or by permanently installed sensors. Portable equipment can be managed by a diver or by a remote operating vehicle (ROV).

Most of the instrumentation used for portable surveys is reference electrodes for potential, field gradient measurements, a metal tip probe for direct metallic contact and camera.

C.4.1.1 Visual inspection
Visual inspection of unburied parts can be performed by a diver or with an ROV equipped with a camera. Visual examination may include inspection of:

<table>
<thead>
<tr>
<th>Inspection items</th>
</tr>
</thead>
<tbody>
<tr>
<td>— damage to anode fastening cables</td>
</tr>
<tr>
<td>— anode consumption (assessment of anode dimensions)</td>
</tr>
<tr>
<td>— measurement of anode dimensions</td>
</tr>
<tr>
<td>— identification of missing or damaged anodes</td>
</tr>
<tr>
<td>— coating damage</td>
</tr>
<tr>
<td>— corrosion damage (rust).</td>
</tr>
</tbody>
</table>

Excessive anode consumption is indicative of coating deficiencies, inappropriate designed CP system or current drain to adjacent structures (e.g. pipeline).

**Guidance note:**
Small anodes with high anode current output to net mass ratio will be more rapidly consumed than large anodes with a higher ratio, which could result in an insufficient total anode current capacity towards the end of the design life.

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Low anode consumption can indicate passivation of the galvanic anode.

Apparent rust or discoloration of the steel is indicative of under-protection.

C.4.1.2 Potential survey
The effectiveness of the CP-system can only be assessed by measuring the actual structure-to-seawater potential. Commonly used survey method to obtain the structure-to-seawater potential for subsea production systems is by “direct contact measurements”, where the structure-to-seawater potential
difference is measured with a voltmeter by direct contact with the steel via a metal tip probe and a reference electrode located adjacent to the steel surface.

**Guidance note:**
Subsea components are sometimes provided with a small area intentionally left uncoated in order to facilitate structure-to-seawater potential measurement of the component (monitoring points).

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**C.4.1.3 Monitoring and inspection of galvanic anodes**
Galvanic anodes can be monitored by direct and indirect techniques. Direct techniques include direct measurement of anode potential and current output. Indirect measurement includes measurement of the electrical field in order to assess the anode current output and potential level in the vicinity of (close to) the anode.

Monitoring techniques for the condition and performance of galvanic anodes may include:
- anode 'stab' measurement for anode potential
- electrical field gradient measurements – can be used for semi-quantitative measurement of the anode current output
- installation of anode current monitoring shunt for quantification of anode current output
- induction coil meters for determination of anode current output.

Accessibility to anodes on a subsea production system may be restricted which means that some of these techniques may not be feasible.

**C.4.1.4 Initial survey**
A visual post-installation survey should preferably be performed to look for any damage to the coating and the CP-system caused by installation.

**C.4.1.5 Requirement for calibration of equipment**
All equipment used for potential measurements should be calibrated. For the calibration of reference electrodes reference is made to NACE Standard TM 0497 or an equivalent standard.

**C.4.2 Inspection of internal corrosion and erosion**
Internal inspection for monitoring a time dependent internal corrosion mechanism or erosion will require wall thickness measurements. Wall thickness measurements can be performed by:
- portable equipment or permanently installed equipment. Measurements are taken from the external surface at a specific location.
- alternatively, retrievable equipment can be brought to shore for inspection.

**C.4.3 Inspection of abrupt corrosion threats**
Abrupt corrosion threats are typically stress corrosion cracking mechanisms and hydrogen induced stress cracking. Due to their abrupt nature, regular inspection for such failures is normally not carried out.

**C.4.4 Monitoring**

**C.4.4.1 General**
The objective of internal corrosion monitoring is to confirm that a fluid remains non-corrosive or to evaluate the efficiency of the corrosion preventative measures.

**Guidance note:**
Corrosion monitoring can also be used to diagnose any prospective corrosion problems in the system (e.g. MIC), for determination of inspection schedules and extended design life assessments.

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Corrosion resistant alloys are considered resistant to CO₂-corrosion. For such systems, monitoring could be restricted to condition monitoring of process parameters and scheduled monitoring of fluid composition. CMn- and low alloy steel material, which are not resistant to corrosion, will in addition, require monitoring of the internal corrosion and the corrosivity of the fluid.
Corrosion monitoring of subsea production systems handling dry gas could be restricted to monitoring of the water dew point.

Corrosion monitoring does not give information about actual loss of wall thickness.

**C.4.4.2 Corrosion surveillance**

Corrosion surveillance includes activities related to condition monitoring and corrosion monitoring and comprises:

- monitoring process parameters (e.g. pressure)
- fluid analysis (e.g. of corrosive species)
- monitoring aimed at controlling the corrosion (e.g. corrosion inhibitor, dew point)
- use of corrosion probes or other more sophisticated monitoring techniques
- chemical analysis of corrosion products (e.g. on corrosion probes, debris collected after cleaning of the connecting pipeline)
- integrity monitoring (wall thickness measurements by permanently installed equipment or used at a specific location).

The objective of the corrosion surveillance is to detect any operational changes, changes in the fluid corrosivity and incipient corrosion that may lead to a potential threat.

**C.4.4.3 Corrosion monitoring techniques**

It is normally not feasible to carry out corrosion monitoring on subsea system directly. Monitoring of fluid corrosivity is normally carried out topside. Relevant techniques for monitoring internal corrosion can be found in DNV-RP-F116 Appendix C.

**C.4.4.4 Erosion monitoring techniques**

Sand monitoring system can either consist of intrusive probes or acoustic sensors or a combination.

**C.4.4.5 Typical monitoring parameters for corrosion**

The extent of fluid analysis will depend on the fluid composition and the use of chemical treatment for limiting the corrosion. DNV-RP-F116 Appendix C gives an overview of typical monitoring parameters to be considered in connection with planning and implementation of a corrosion monitoring program.

Use of chemicals for corrosion control should always include monitoring of the efficiency of the chemical injection. It is worth noting that the lists above can be extended to include other parameters. This will depend on the particular need for a specific system.

**C.5 Integrity assessment**

**C.5.1 Corroded pipes**

For integrity assessment of corroded header pipes, reference can be made to DNV-RP-F101.

**C.5.2 Cathodic protection system**

The cathodic protection potential criteria as given by the design code (or the CP-design code applied) should be maintained throughout the design life.

**C.5.3 Erosion**

Erosion prediction and modelling can be carried out by using DNV-RP-O501 or similar codes. For complex geometries Computational Fluid Dynamic (CFD) can be used for analysis. They can be used to develop operational acceptance criteria for safe operation of the components (e.g. control valves).

**C.6 Mitigation, intervention and repair**

**C.6.1 Mitigation**

Mitigation actions can be production optimization to control erosion. This may include the use of reduced production rates.
C.6.2 Intervention
Intervention may be considered if erosion or corrosion is suspected. This may lead to retrieval of affected equipment.
Other instances where intervention may be considered are:
— removal of debris that may damage the external corrosion protection system
— activities in order to limit or reduce stresses
— removal of debris in order to get access to ROV operated panels
— planned retrieval of equipment for maintenance or replacement.

C.6.3 Repair
Repair usually involves replacement of failed equipment.
APPENDIX D INTEGRITY REPORTING TEMPLATE

D.1 Example of a periodic integrity management reporting template

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Appendices
Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.