FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.

© DNV GL AS April 2016

Any comments may be sent by e-mail to rules@dnvgl.com

This service document has been prepared based on available knowledge, technology and/or information at the time of issuance of this document. The use of this document by others than DNV GL is at the user's sole risk. DNV GL does not accept any liability or responsibility for loss or damages resulting from any use of this document.
CHANGES – CURRENT

General
This document supersedes DNV-RP-F302, April 2010.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

On 12 September 2013, DNV and GL merged to form DNV GL Group. On 25 November 2013 Det Norske Veritas AS became the 100% shareholder of Germanischer Lloyd SE, the parent company of the GL Group, and on 27 November 2013 Det Norske Veritas AS, company registration number 945 748 931, changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS”, “Det Norske Veritas”, “DNV”, “GL”, “Germanischer Lloyd SE”, “GL Group” or any other legal entity name or trading name presently owned by the DNV GL Group shall therefore also be considered a reference to “DNV GL AS”.

Main changes April 2016
— new structure and naming of all sections
— additional scope covering:
  — surface based leak detection techniques
  — structured approach for defining requirements and selecting technology
  — design and documentation requirements
  — operation of leak detection
— updated technologies and regulations.

Editorial corrections
In addition to the above stated main changes, editorial corrections may have been made.

Acknowledgements
This recommended practice was developed by the joint industry project (JIP) Offshore Leak Detection, and is based on the joint shared experiences and JIP report. The work was performed by DNV GL and discussed in regular project meetings and workshops with individuals from the participating companies. They are hereby acknowledged for their valuable and constructive input. In case consensus has not been achievable, DNV GL has sought to provide acceptable compromise. Sponsors of the JIP included the following organisations: Biota Guard, BP, Contros, Eni Norge, Engie, FMC Technologies, ICD Industries, Kongsberg Maritime, KSAT, Lundin, Metas, Mirox, Naxys, Norbit Subsea, Petrobras, Phaze Technologies, Sonardyne, Stinger and Vissim. Further organisations have participated in the review process. DNV GL is grateful for the valuable cooperation and discussions with individuals in these organisations.
CONTENTS

CHANGES – CURRENT ................................................................................................. 3

Sec. 1 Introduction..................................................................................................... 6
  1.1 General.............................................................................................................6
  1.2 Objective........................................................................................................6
  1.3 Scope ..............................................................................................................6
  1.4 Application .....................................................................................................6
    1.4.1 Use and users of this document ..............................................................6
    1.4.2 Alternative methods, the principle of equivalence .......................7
    1.4.3 Regulatory requirements........................................................................7
  1.5 References ....................................................................................................7
  1.6 Definitions and abbreviations .....................................................................8
    1.6.1 Definitions...............................................................................................8
    1.6.2 Abbreviations .......................................................................................9
    1.6.3 Verbal forms ......................................................................................11

Sec. 2 Process and basic principles .........................................................................12
  2.1 Process...........................................................................................................12
  2.2 Roles and basic principles .........................................................................12

Sec. 3 Functional requirements .............................................................................15
  3.1 General...........................................................................................................15
  3.2 Regulations and standards ..........................................................................15
  3.3 Risk assessment............................................................................................16
  3.4 Environmental conditions...........................................................................16
  3.5 Establishing functional requirements .........................................................17

Sec. 4 Design requirements ...................................................................................18
  4.1 General...........................................................................................................18
  4.2 Design life ......................................................................................................18
  4.3 Mechanical design and interfaces ...............................................................18
    4.3.1 Surface based equipment ......................................................................18
    4.3.2 Subsea equipment ...............................................................................18
  4.4 Communication and control requirements .................................................19
    4.4.1 Surface based equipment ......................................................................19
    4.4.2 Subsea equipment ...............................................................................19
  4.5 Power requirements.......................................................................................19
    4.5.1 Surface based equipment ......................................................................19
    4.5.2 Subsea equipment ...............................................................................19
  4.6 Material selection...........................................................................................19
  4.7 Inspection, maintenance and repair.............................................................20
  4.8 Spare parts and obsolescence strategy .........................................................20

Sec. 5 Technology selection ...................................................................................21
  5.1 Best available techniques process for leak detection ................................21
  5.2 Combining technologies .............................................................................22
  5.3 Technology qualification .............................................................................22
    5.3.1 General .................................................................................................22
    5.3.2 Qualification of sensor technology ......................................................22
    5.3.3 Environmental testing .........................................................................22
5.3.4 Testing of electrical equipment ......................................................23
5.3.5 Software verification testing ..........................................................23
5.3.6 Sensor and control system simulations ...........................................23
5.3.7 Qualification of combined leak detection technologies ...............23

Sec.6 Detailed design ........................................................................................... 24
6.1 General .................................................................................................24
6.2 Design specifications ............................................................................24
6.3 System performance ............................................................................25
6.4 System interface engineering ...............................................................26
6.5 Data handling and interpretation .........................................................26
6.6 Test procedures ....................................................................................28
   6.6.1 Factory acceptance test ................................................................28
   6.6.2 Control system integration test ......................................................28
   6.6.3 System integration test .................................................................28
6.7 Training ................................................................................................29

Sec.7 Function testing .......................................................................................... 30
7.1 General .................................................................................................30
7.2 Acceptance criteria ...............................................................................30
7.3 Function test methods ..........................................................................30
   7.3.1 Instrument test ...........................................................................30
   7.3.2 Function test ..............................................................................30

Sec.8 Operation .................................................................................................... 31
8.1 Principles .............................................................................................32
8.2 Framework ...........................................................................................32
   8.2.1 The main elements .......................................................................33
   8.2.2 Interfaces ...................................................................................34
8.3 Work process .......................................................................................35
   8.3.1 Monitor and control .................................................................35
   8.3.2 System upset ............................................................................35
   8.3.3 Detect .......................................................................................36
   8.3.4 Diagnose ..................................................................................36
   8.3.5 Respond ...................................................................................36
8.4 Training and competence .....................................................................36

App. A Regulations and requirements .................................................................... 37
A.1 Country specific regulation and requirements ..................................... 37
A.1.1 Australia ....................................................................................37
A.1.2 Brazil ........................................................................................38
A.1.3 European Union ..........................................................................38
A.1.4 Norway .....................................................................................39
A.1.5 United Kingdom ..........................................................................40
A.1.6 United States .............................................................................40

App. B Leak detection techniques and their characteristics .................................... 41
B.1 Subsea techniques ...............................................................................42
B.2 Surface techniques .............................................................................44
SECTION 1 INTRODUCTION

1.1 General
Concerns for the environment and experiences from industry incidents have increased the focus and expectations of the public and authorities towards operators of oil and gas fields with regards to detection of hydrocarbon leaks. Early detection of hydrocarbon leaks can prevent an occurrence from escalating into a major incident.

The challenge for operators is to successfully implement a leak detection system that is reliable and capable of detecting leaks with an acceptable level of certainty and at the same time meets regulatory requirements. This may require integrating sensors from various suppliers into one system and operating and maintaining the leak detection system over the lifetime of the field.

To assist the industry, DNV GL has developed this recommended practice (RP) for planning, designing, integration and operation of systems for offshore leak detection.

The RP is based on the joint shared experiences and report of the joint industry project (JIP) Offshore Leak Detection /1/. The JIP parties included operators, integrators, suppliers and DNV GL. This document replaces the DNV-RP-F302 Selection and Use of Subsea Leak Detection Systems from 2010.

1.2 Objective
This RP provides recommendations for successful planning, design, integration and operation of leak detection technology in offshore fields for hydrocarbon production.

The referencing of this RP will not substitute the development of a field specific leak detection strategy, but is rather an element in one.

It is emphasised that the application of offshore leak detection systems shall not be used to justify a reduction in the safety level for other offshore systems in terms of design, manufacture, quality assurance etc.

It is also emphasised that the performance of an offshore leak detection system is not determined by the technical specification of the detector technology alone, but by an overall assessment of technical data, system layout and system operation.

1.3 Scope
The scope of this document is to define the process through the phases of a field development project for planning, design, integration and operation of an offshore leak detection system.

The RP covers detection of hydrocarbon leakages. Leaks from topside processing systems are not covered in this report, as these are considered safety critical to personnel and shall follow requirements related to topside safety. The document is intended to supplement, not replace, the national and company requirements.

This document covers surface and subsea based leak detection technologies, ranging from point and area detectors to field-wide sensors. The leak detection technologies can be positioned at different locations, including offshore platforms, subsea structures and mobile installations such as vessels or satellites.

1.4 Application

1.4.1 Use and users of this document
This RP applies to all existing and future offshore units, meaning any fixed or floating offshore installation or structure engaged in oil and gas exploration or production activities, loading or unloading of oil including drilling rigs, oil platforms, floating production, storage and offloading units (FPSOs), floating storage and offloading units (FSOs), subsea equipment, wells and associated pipelines.

The methodology presented within this RP can be used to help meet the requirements of national and international laws and directives. This RP has been developed to be applicable in all offshore areas, and can
be applied as good practice to early leak detection on offshore installations of hydrocarbon production. Anticipated users of this document include:

— offshore oil and gas exploration and production operators and their contractors
— integrators
— suppliers
— regulators
— independent verification bodies/persons.

1.4.2 Alternative methods, the principle of equivalence
This document describes a practice recommended by DNV GL. This should not inhibit use of other alternative approaches meeting the overall objectives of the RP. This also applies to requirements formulated in the verbal form “shall”.

1.4.3 Regulatory requirements
Regulatory requirements are, in the context of this RP, defined as requirements from legislative instruments relevant to offshore oil and gas activities, such as:

— internationally binding conventions/directives
— federal/national acts
— federal/national/state/province/local regulations
— terms and conditions of licenses and permits.

Regulatory requirements represent the minimum requirements to be complied with. Recommendations from this RP may be stricter or additional to regulatory requirements. In the case of contradiction or conflict between regulatory requirements and recommendations in this RP, regulatory requirements shall prevail.

1.5 References

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
1.6 Definitions and abbreviations

1.6.1 Definitions

Table 1-1 Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>autonomous leak detection system</td>
<td>system that is present locally at the field, subsea or surface. The system is normally not integrated in the control system, but can send data to the facility (CCR)</td>
<td></td>
</tr>
<tr>
<td>best available techniques (BAT)</td>
<td>most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) &quot;techniques&quot; includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;</td>
<td>Refer to Directive 2010/75/EU of the European Parliament and of the Council of 24th November 2010, see /2/.</td>
</tr>
<tr>
<td></td>
<td>b) &quot;available techniques&quot; means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) &quot;best&quot; means most effective in achieving a high general level of protection of the environment as a whole</td>
<td></td>
</tr>
<tr>
<td>detection</td>
<td>action or process of identifying the presence of something concealed; the act or process of discovering, finding, or noticing something</td>
<td></td>
</tr>
<tr>
<td>detector</td>
<td>device that detects the presence of a fluid. It only indicates if the fluid is present or not</td>
<td></td>
</tr>
<tr>
<td>fluid</td>
<td>subset of the phases of matter and includes liquids and gases</td>
<td></td>
</tr>
<tr>
<td>global leak detection system</td>
<td>system that remotely covers the whole field, e.g. satellite system</td>
<td></td>
</tr>
<tr>
<td>integrator</td>
<td>party delivering the main assemblies and equipment including documentation in accordance with the scope of supply agreed with the operator</td>
<td></td>
</tr>
<tr>
<td>leak/leakage</td>
<td>accidentally loss or admittance of contents, (especially liquid or gas), through a hole or crack in a hydrocarbon production system content In this RP context: the leak relevant for detection may be a small leak for monitoring or repair or a large leak that necessitates immediate action to stop the discharge.</td>
<td></td>
</tr>
</tbody>
</table>
1.6.2 Abbreviations

### Table 1-2 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARP</td>
<td>as low as reasonably practicable</td>
</tr>
<tr>
<td>ANP</td>
<td>Agência Nacional de Petróleo, Gás Natural e Biocombustíveis (National Petroleum Agency - Brazil)</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>ATEX</td>
<td>atmosphère explosible</td>
</tr>
<tr>
<td>BAT</td>
<td>best available techniques</td>
</tr>
<tr>
<td>BSEE</td>
<td>Bureau of Safety and Environmental Enforcement (US)</td>
</tr>
<tr>
<td>CCR</td>
<td>central control room</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>CMMS</td>
<td>computerized maintenance management system</td>
</tr>
<tr>
<td>CODAM</td>
<td>corrosion and damage</td>
</tr>
<tr>
<td>CPM</td>
<td>computational pipeline monitoring</td>
</tr>
<tr>
<td>DCS</td>
<td>distributed control system</td>
</tr>
<tr>
<td>DEC</td>
<td>Alaska Department of Environment Conservation</td>
</tr>
<tr>
<td>DECC</td>
<td>Department for Energy and Climate Change (UK)</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department of Environment, Food and Rural Affairs (UK)</td>
</tr>
<tr>
<td>DOI</td>
<td>Department of the Interior (US)</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation (US)</td>
</tr>
<tr>
<td>DP</td>
<td>differential pressure</td>
</tr>
<tr>
<td>DPC</td>
<td>Ports and Costs Directorate – Marine Authority (Brazil)</td>
</tr>
<tr>
<td>DWPA</td>
<td>Deepwater Port Act (US)</td>
</tr>
<tr>
<td>ECEs</td>
<td>environmental critical elements</td>
</tr>
<tr>
<td>EFAT</td>
<td>extended FAT</td>
</tr>
<tr>
<td>EMC</td>
<td>electromagnetic compatibility</td>
</tr>
<tr>
<td>EPC</td>
<td>engineering procurement and construction</td>
</tr>
<tr>
<td>ERA</td>
<td>environmental risk assessment</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
</tbody>
</table>
Table 1-2 Abbreviations (Continued)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAT</td>
<td>factory acceptance test</td>
</tr>
<tr>
<td>FEED</td>
<td>front end engineering and design</td>
</tr>
<tr>
<td>FMECA</td>
<td>failure mode, effect and criticality analysis</td>
</tr>
<tr>
<td>GPR</td>
<td>ground-penetrating radar</td>
</tr>
<tr>
<td>HAZID</td>
<td>hazard identification</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbon</td>
</tr>
<tr>
<td>HLIF</td>
<td>hyper-spectral laser-induced fluorescence</td>
</tr>
<tr>
<td>HMI</td>
<td>human machine interface</td>
</tr>
<tr>
<td>HSE</td>
<td>health, safety and environment</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IED</td>
<td>Industrial Emissions Directive (EU)</td>
</tr>
<tr>
<td>IMS</td>
<td>information management system</td>
</tr>
<tr>
<td>IPPC</td>
<td>Integrated Pollution Prevention and Control Directive (EU)</td>
</tr>
<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standardisation Organisation</td>
</tr>
<tr>
<td>ITP</td>
<td>inspection and test plan</td>
</tr>
<tr>
<td>JIP</td>
<td>joint industry project</td>
</tr>
<tr>
<td>LD</td>
<td>leak detection</td>
</tr>
<tr>
<td>LDS</td>
<td>leak detection system</td>
</tr>
<tr>
<td>LIDAR</td>
<td>light detection and ranging</td>
</tr>
<tr>
<td>MDIS</td>
<td>Master Control System and Distributed Control System Standardisation</td>
</tr>
<tr>
<td>MRB</td>
<td>manufacturing record book</td>
</tr>
<tr>
<td>MTE</td>
<td>Ministério do Trabalho e Emprego (Ministry of Labour and Employment - Brazil)</td>
</tr>
<tr>
<td>MWR</td>
<td>microwave radiometer</td>
</tr>
<tr>
<td>NCS</td>
<td>Norwegian continental shelf</td>
</tr>
<tr>
<td>NDIR</td>
<td>non-dispersive infrared spectrometry</td>
</tr>
<tr>
<td>NOPSEMA</td>
<td>National Offshore Petroleum Safety and Environmental Management Authority (Australia)</td>
</tr>
<tr>
<td>OMM</td>
<td>operation and maintenance manual</td>
</tr>
<tr>
<td>OPGGS Act</td>
<td>Offshore Petroleum and Greenhouse Gas Storage Act 2006 (Australia)</td>
</tr>
<tr>
<td>OPGGS(S) Regulations</td>
<td>Offshore Petroleum and Greenhouse Gas Storage (Safety) Regulations 2009 (Australia)</td>
</tr>
<tr>
<td>OSD</td>
<td>Offshore Safety Directive (EU)</td>
</tr>
<tr>
<td>PSA</td>
<td>Petroleum Safety Authority Norway</td>
</tr>
<tr>
<td>RADAR</td>
<td>radio detection and ranging</td>
</tr>
<tr>
<td>ROV</td>
<td>remotely operated vehicle</td>
</tr>
<tr>
<td>RP</td>
<td>recommended practice</td>
</tr>
<tr>
<td>SAR</td>
<td>synthetic aperture radar</td>
</tr>
<tr>
<td>SAS</td>
<td>safety and automation system</td>
</tr>
<tr>
<td>SCM</td>
<td>subsea control module</td>
</tr>
<tr>
<td>SCS</td>
<td>subsea control system</td>
</tr>
<tr>
<td>SECEs</td>
<td>safety and environmental critical elements</td>
</tr>
<tr>
<td>SEM</td>
<td>subsea electronic module</td>
</tr>
<tr>
<td>SIIS</td>
<td>Subsea Instrumentation and Interface Standardisation</td>
</tr>
</tbody>
</table>
1.6.3 Verbal forms

For verification of compliance with this RP, the following definitions of the verbal forms, shall, should and may are applied:

Table 1-3 Verbal forms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>shall</td>
<td>verbal form used to indicate requirements strictly to be followed in order to conform to this document</td>
</tr>
<tr>
<td>should</td>
<td>verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required</td>
</tr>
<tr>
<td>may</td>
<td>verbal form used to indicate course of action permissible within the limits of the document</td>
</tr>
</tbody>
</table>
SECTION 2 PROCESS AND BASIC PRINCIPLES

2.1 Process
The process recommended for successful selection and implementation of leak detection technology in offshore fields for hydrocarbon production is shown in a diagram process in Figure 2-1. Operator shall prepare as early as possible a leak detection philosophy to describe their high level ideas and intentions for leak detection.

Figure 2-1 Recommended process flow for successful selection and implementation of leak detection technology

The recommended process consists of the following key stages that are separately discussed in the following sections (see Table 2-1).

Table 2-1 Key stages of the recommended process with their corresponding project phases and the sections where they are discussed

<table>
<thead>
<tr>
<th>Key Stages</th>
<th>Project phases</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional requirements</td>
<td>Front end engineering and design (FEED)</td>
<td>3</td>
</tr>
<tr>
<td>Design requirements</td>
<td>FEED</td>
<td>4</td>
</tr>
<tr>
<td>Technology selection</td>
<td>FEED</td>
<td>5</td>
</tr>
<tr>
<td>Detailed design</td>
<td>Detailed Design</td>
<td>6</td>
</tr>
<tr>
<td>Function testing</td>
<td>Installation and Commissioning</td>
<td>7</td>
</tr>
<tr>
<td>Operation</td>
<td>Operation</td>
<td>8</td>
</tr>
</tbody>
</table>

2.2 Roles and basic principles
When an operator plans to develop an offshore oil and gas field or modify an existing field a FEED is initiated. The operator must comply with the regulations set forth by the authority of the country where the field is located. The regulations may imply that the operator shall include a leak detection system at the field.

A leak detection system delivery will normally be split between several integrators. It is important that the FEED is done to a level where the scope of work from the different integrators is sufficiently detailed. The operator shall prepare an overall leak detection philosophy with functional design specifications for each...
contract. Typical contracts relevant for leak detection are:

— topside production system including overall integration of leak detection system
— subsea productions system (SPS)
— subsea umbilicals, risers and flow lines (SURF)
— autonomous leak detection system
— global leak detection system.

See Figure 2-2.

Figure 2-2  Example of break down of requirements and scope for offshore leak detection

To ensure that the total leak detection system meets the overall functional requirements, it is recommended to define a system responsible.

The leak detection system shall as far as possible be one integrated system for the whole field. In order to obtain the best available leak detection system for the specific field application, a structured selection process shall be performed in the FEED phase before the details are specified for each of the main contracts.

A best available techniques (BAT) process should be used to select the leak detection system. The BAT concept is further explained in Sect. 5 and a two-step BAT process is suggested. The BAT I process should be performed during the FEED, see Figure 2-3. The process requires knowledge about each single leak detector and has interaction with the leak detector qualification process. The BAT II process should be performed during detailed design. BAT II is the final input to the leak detection system selection and requires interaction with the leak detection system qualification process. It is essential that both BAT processes are controlled either by operator or the party defined as system responsible, with assistance from integrators and suppliers.

The final system selection and system qualifications should be the responsibility of the integrator in order to have a qualified integration and interface definition. The leak detection equipment is delivered from supplier to integrator; however, there are also cases where supplier delivers directly to operator.

The typical process for specification, system selection, design, qualification, manufacturing, testing and
operation of a leak detection system is shown in Figure 2-3. The recommended responsible party for each process step, operator, integrator or supplier, is shown in different colours.

Figure 2-3  Offshore leak detection: Project execution and best available techniques process - the recommended responsible party for each process step, operator, integrator or supplier, is shown in different colours
SECTION 3 FUNCTIONAL REQUIREMENTS

3.1 General
The following sub-sections contain the main aspects to consider when establishing the high level requirements for a leak detection system.

3.2 Regulations and standards
The primary requirement is compliance with authority regulations local to the field where the leak detection system will be applied. Regulatory compliance is the responsibility of the operator and is imposed on integrators and suppliers through established contracts. The authority regulations may refer further to industry standards for specific requirements. The main aspects applicable to operators in Australia, Brazil, EU, Norway, UK and US related to leak detection are included in App.A.

The leak detection equipment and components shall follow requirements as specified by the operator. The operator may refer to industry standards and/or internal company requirements and/or project specific requirements.

Summarized, the general requirement hierarchy is built on (priority order):

1) authority regulations
2) industry standards
3) company requirements.

Where requirements are overlapping under a contract, the strictest requirement of these three applies.

For reference, some applicable industry standards are listed in Table 3-1.

Table 3-1 Standards of relevance for leak detection systems

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>API 1130</td>
<td>Computational Pipeline Monitoring for Liquids</td>
<td>Leak detection methods for pipelines</td>
</tr>
<tr>
<td>ATEX</td>
<td>Collection of standards within ICS 922</td>
<td>Applicable for equipment located in areas with risk of explosion</td>
</tr>
<tr>
<td>DNVGL-OS-D203</td>
<td>Integrated Software Dependent Systems (ISDS)</td>
<td>Sets standards for SW development, qualification and maintenance</td>
</tr>
<tr>
<td>DNV-RP-A203</td>
<td>Technology Qualification</td>
<td>Describes the qualification process</td>
</tr>
<tr>
<td>DNV-RP-F116</td>
<td>Integrity management of submarine pipeline systems</td>
<td>Systematics for integrity management</td>
</tr>
<tr>
<td>IEC 61000-2</td>
<td>Electromagnetic compatibility (EMC)</td>
<td>EMC guidance for subsea equipment</td>
</tr>
<tr>
<td>IEC 61508</td>
<td>Functional safety of electrical/electronic/programmable electronic safety-related systems</td>
<td>Requirement to safety critical systems</td>
</tr>
<tr>
<td>IEC 62402</td>
<td>Obsolescence management</td>
<td>Guidelines for obsolescence management</td>
</tr>
<tr>
<td>ISO 12207</td>
<td>Systems and software engineering — Software life cycle processes</td>
<td>Sets standards for SW development, qualification and maintenance</td>
</tr>
<tr>
<td>ISO 13628-1</td>
<td>Design and operation of subsea production systems – General requirements and recommendations</td>
<td>Applicable for definition of the overall requirements for the subsea production system</td>
</tr>
<tr>
<td>ISO 13628-4</td>
<td>Design and operation of subsea production systems Part 4: Subsea wellhead and tree equipment</td>
<td>Applicable for subsea wellhead and tree equipment</td>
</tr>
<tr>
<td>ISO 13628-6</td>
<td>Design and operation of subsea production systems – Subsea control systems (SCM)</td>
<td>Applicable for subsea control equipment including electronic equipment and sensors</td>
</tr>
<tr>
<td>ISO 15156</td>
<td>Materials for use in H2S-containing environments in oil and gas production</td>
<td>Applicable for basic material selection, sour environment</td>
</tr>
<tr>
<td>ISO 21457</td>
<td>Materials selection and corrosion control for oil and gas production systems</td>
<td>Applicable for basic material selection</td>
</tr>
<tr>
<td>IEC 61892</td>
<td>Mobile and fixed offshore units – Electrical installations –</td>
<td>Requirements to topside electrical systems</td>
</tr>
</tbody>
</table>
3.3 Risk assessment

The following risk assessments shall be performed to support the establishing of high level requirements for the leak detection system:

- Environmental risk assessment (ERA) calculating probable discharge scenarios and impact on affected environmental resources. The ERA will determine the required risk mitigation.
- Leak scenario identification to define likely leakage scenarios for small, medium and large leakages. Identified leak scenarios will determine functional requirements for the leak detection system.
- Leak hotspot identification through a failure mode, effect and criticality analysis (FMECA) or similar. Identified leak hotspots will determine where leak detectors should be placed.

In an especially sensitive area where a leakage of hydrocarbons may have significant impact, the leak detection system shall have stricter requirements, e.g. with regards to detection time. In areas where the environmental risk is lower, a simpler solution may be acceptable. The risk assessment should also include considerations regarding changes in the risks levels over the field’s life time.

3.4 Environmental conditions

Required tolerance for the leak detection system integrity and performance to environmental conditions shall be defined.

Environmental conditions should include:

- wave spectra and significant wave height
- visibility and precipitation statistics
- wind speed and direction statistics
- current data on surface and subsea
- data on thermoelines and inter-layers in the water column
- expected temperatures (sea surface, water column)
- condition of the water surface (e.g. ice or open water)
- water depth
- vulnerable resources in the area
- distance to shore.

In addition, technologies may require specific environmental conditions that they will be sensitive to, like:

- natural seepage
- acoustic noise
- other, as relevant for technology.
3.5 Establishing functional requirements

High level functional requirements for leak detection shall be defined by the operator and shall be a description of the system functions and their performance. Functional requirements shall consider operation, maintenance and function-testing.

The functional requirements shall be in accordance with:

1) relevant authority regulations and standards, see [3.2]
2) performed risk assessments, see [3.3]
3) environmental conditions, see [3.4].

Key parameters for defining high level functional requirements shall include:

— minimum leakage rate and/or volume to be detected
— ability to locate leakage source
— ability to measure position and extent of leaked fluid
— specified detection range
— detection time for the minimum leakage within the specified range
— type of fluids and fluid concentration to be detected
— classification of leaking fluid
— availability of the leak detector.

It is not the purpose of this document to dictate requirements. Requirements should be set on a field specific basis. Table 3-2 below is an example of functional requirements, listing commonly needed parameters.

Table 3-2 Example of typical values used, as relevant, for functional requirements for leak detection system

<table>
<thead>
<tr>
<th>Functional requirements</th>
<th>Typical values or units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum leakage rate to be detected</td>
<td>[m^3/hr] or [% of production flow] or [bar DP]</td>
</tr>
<tr>
<td>Location of leakage source</td>
<td>‘Yes’ or ‘No’, accuracy +/− [m]</td>
</tr>
<tr>
<td>Position and extent of leaked fluid</td>
<td>Position, [m]</td>
</tr>
<tr>
<td>Detection range</td>
<td>[m], [m^2]</td>
</tr>
<tr>
<td>Detection time for the minimum leakage within the specified range</td>
<td>[s]</td>
</tr>
<tr>
<td>Type of fluids and fluid concentration to be detected</td>
<td>‘Condensate’, ‘Light oil’, ‘Heavy oil’, ‘gas’</td>
</tr>
<tr>
<td>Classification of leaking fluid</td>
<td>‘Yes’ or ‘No’</td>
</tr>
<tr>
<td>Availability</td>
<td>[% uptime], [other reliability measure]</td>
</tr>
</tbody>
</table>
SECTION 4 DESIGN REQUIREMENTS

4.1 General
The operator shall prepare a field and installation layout and basis of design that describes the field development and required main facilities. Operator shall prepare as early as possible a leak detection philosophy to describe their high level ideas and intentions for leak detection.

4.2 Design life
The design life requirement shall be specified for the leak detection system and for the individual components.

For components with shorter design life than what is specified for the system, a maintenance philosophy shall be provided for the design life of the system and captured in the systems operation and maintenance manual (OMM). Components shall be designed for easy replacement when required. Spare parts and special replacement tools shall be tested and provided. The minimum design life for an offshore facility is normally 25 years (maintainable life).

4.3 Mechanical design and interfaces
Layout and space restrictions of an offshore installation pose requirements to the mechanical fit of leak detectors.

4.3.1 Surface based equipment
The following design and interface parameters shall be defined:

— required location of the different sensors
— maximum size and weight
— mechanical interface
— special assembly and mounting requirements
— sensor’s view to areas critical for leakage
— maintenance and access requirements.

4.3.2 Subsea equipment
Subsea has particular challenges related to access, space and retrofit and the requirements to mechanical design shall therefore be defined early in the engineering phase.

The following design and interface parameters shall be defined:

— required location of the different sensors
— integrated into subsea template or autonomous unit
— maximum size and weight
— mechanical interface
— special assembly and mounting requirements
— sensor’s view to areas critical for leakage
— requirements for replacement of sensors and cables with electrical connectors
— special design requirements for subsea system i.e. enclosed covers, free height above instrument etc.
— intervention and access requirements.

Due consideration shall be made with respect to maintenance and/or replacement of the assembly and/or its critical parts subsea.
4.4 Communication and control requirements

Proprietary interface technologies should not be used.

4.4.1 Surface based equipment

The following shall be specified:

— physical interface
— type of signal
— communication via Central Control Room (CCR) or independent control (layout)
— software requirements (Integrated in instrument or part of control system), as applicable
— degree of automation and operator involvement
— data transfer rate
— time interval between measurements
— any other requirements relevant for the technology.

4.4.2 Subsea equipment

The following data shall be specified:

— physical interface
— type of signal
— communication and data processing via subsea electronic module (SEM), CCR or independent control (layout)
— SIIS level
— MDIS
— Software requirements (Integrated in instrument or part of control system), as applicable
— degree of automation and operator involvement
— data transfer rate
— time interval between measurements
— any other requirements relevant for the technology.

4.5 Power requirements

Minimum and maximum power requirements shall be defined based on the overall functional requirements. The leak detection system should be designed for minimum power consumption.

4.5.1 Surface based equipment

IEC 61892 sets requirements to topside electrical systems and components for electrical installations on mobile and fixed offshore units. Equipment located in hazardous areas shall comply with ATEX requirements.

4.5.2 Subsea equipment

The electrical requirements for a subsea control system are described in ISO 13628-6.

Electrical cables with connectors should be installed between the leak detection sensor and the subsea control module (SCM) or an independent control unit. The leak detection sensor can be retrievable with or without the electrical cables.

4.6 Material selection

All equipment mounted as part of the production system or offshore environment shall have material selection in accordance with ISO 21457. It is also recommended to use NORSOK M-001 as a reference standard for material selection.
For equipment mounted in a production system for sour service, the material selection shall also comply with ISO 15156.

Water migration in polymeric materials is a potential failure mode and shall be assessed during qualification and design of the equipment.

### 4.7 Inspection, maintenance and repair

The design of the leak detection system shall include a maintenance philosophy for the maintainable lifetime, see [4.2]. The equipment shall be designed for accessibility for maintenance. The maintenance philosophy shall be included in the systems OMM.

### 4.8 Spare parts and obsolescence strategy

The spare parts strategy should include:

- parts to be changed during planned maintenance
- parts to be controlled for obsolescence
- complete equipment units for replacement in case of failure
- spare parts used for redundancy.

It is recommended that the spare part strategy is developed after selection of the overall leak detection system. Each technology should have a predefined list of recommended spare parts that will form the input to the spare parts strategy.

A separate obsolescence strategy should be developed for the leak detection system. The following should be included:

- plan for obsolescence
- design criteria for obsolescence
- control routines for obsolescence during field life (may be part of the maintenance plans)
- spare parts for obsolescence
- program for replacement of obsolete parts.

The obsolescence strategy should be used for all type of equipment, but is particularly important for components with rapid development i.e. electronics and software.

The obsolescence of components may be solved in different ways such as:

- alternative component
- alternative equipment assembly
- replace the component by similar parts
- develop new equipment with the same functional requirements.
SECTION 5 TECHNOLOGY SELECTION

5.1 Best available techniques process for leak detection

A standardized, structured and objective assessment process should be followed for selection of leak detection technology. A BAT process built on an already known concept in technology selection is recommended for offshore leak detection. The assessment of techniques and configurations should take into account environmental, technical and economical considerations as well as project and site specific conditions. The BAT process may include the relationship between the associated costs and the estimated risk reduction attained.

A two-step BAT process is outlined in Figure 5-1 where BAT I is the step where single techniques are assessed, while BAT II is the step where configurations of techniques are compared.

![Diagram of the BAT process]

Figure 5-1 Best available techniques process for leak detection

The BAT process requires technical knowledge of the properties and capabilities of each leak detector. An overview of proven and emerging leak detection techniques are given in App.B.

The BAT process should initially be performed early in a project and be re-iterated for more comprehensive evaluations when more information is available.

The BAT process shall also be applied for existing installations or brown fields when there is a need for retrofitting leak detection techniques. The technology selection may be limited by existing infrastructure and autonomous leak detection systems may, in such cases, be given special consideration.

The BAT process shall be documented.
5.2 Combining technologies

The design of the leak detection system should include considerations of combining complementary technologies. Combining technologies can improve the reliability and range of the leak detection system and reduce false alarms. Combination of technologies can be done local on one equipment module or installed on different modules.

The following parameters should be considered:

- reliability and performance of the sensors
- area coverage and using a combination of point sensors and area sensors
- qualification records of the different sensor techniques
- data collection capacity and software to compare the output data from the different sensors
- combination of dedicated leak detection sensors and process sensors such as flow, pressure and temperature transmitters
- integration possibilities (i.e. alarm decision, algorithms and visualization)
- use of a secondary sensor to verify the function of the primary sensor
- possible interference between the technologies, sensors and system components.

5.3 Technology qualification

5.3.1 General

The leak detection equipment and system shall be qualified according to the specified function, operating environment and design life. The method for technology qualification of equipment and systems shall follow a process as described in DNV-RP-A203 or equivalent. FMECA or equivalent methods shall be used to identify the failure modes to be mitigated by qualification of equipment. A qualification gap list shall be prepared during the FEED phase to identify any qualification tests that are required to be performed during detailed engineering.

It is anticipated that at least the following aspects need to be considered to qualify the leak detection system:

- environmental testing
- testing of electrical equipment
- software verification and testing
- sensor and control system simulations
- leak detection simulations
- qualification of combined leak detection technologies.

The qualification testing shall include the applicable tests as described in ISO 13628-6 Ch.11 Sec.2 [11.2]. The evidence of the qualification shall be documented in a design qualification report.

5.3.2 Qualification of sensor technology

The sensor technology shall be qualified considering e.g. fluid, area, size and time, as close to the conditions for intended application as possible and located in structures giving similar boundary conditions.

Qualification of sensor technology should include simulation of leaks with different quantities and durations.

5.3.3 Environmental testing

The sensors shall be qualified for operation in the applicable environment. Examples of environmental tests include:

- Hyperbaric testing of subsea sensors and other pressure containing equipment to 1,1 x design water depth according to ISO 13628-6 Ch.11 Sec.2 [11.2]. Cyclic hyperbaric testing should be performed if the sensor shall be retrieved and reinstalled during lifetime.
- Testing of surface based sensors with variable wind, wave, precipitation and visibility conditions shall
be considered. This will be applicable for infrared cameras and radar systems. Satellite system limitations with respect to clouds and visibility shall be defined.

— Other type of environmental testing may include seabed current and reduced visibility.

5.3.4 Testing of electrical equipment
Electromagnetic compatibility (EMC) shall be considered as part of the qualification. This is valid for both surface and subsea based equipment. Reference is made to IEC 61000-2 and IEC 61892, see Table 3-1. Special requirements apply to topside equipment located in hazardous areas.
For surface based electrical systems, the minimum testing requirements are found in the IEC 61892 series of standards.
For subsea applications, testing of electrical and optical equipment shall as a minimum be in accordance with ISO 13628-6.

5.3.5 Software verification testing
All software shall go through verification testing as part of the qualification.
Software test design should be performed in accordance with a dedicated process, e.g. based on ISO 12207 or DNV-OS-D203, see Table 3-1. The process described in DNV-RP-A203 App.D should be used as a guideline.

5.3.6 Sensor and control system simulations
Sensor simulators shall be available for system integration testing, as applicable, see [6.6.2]. Sensor simulators should be electrically equal to the actual sensor. The simulation tests should be repeated if the control system is changed.

5.3.7 Qualification of combined leak detection technologies
The combined technologies shall be qualified individually.
The qualification of combined technologies should include additional activities not covered by the individual qualification such as:
— testing of interference
— sensitivity testing
— single and dual detection for different fluids and in different areas
— evaluation of the combined detection range.
SECTION 6  DETAILED DESIGN

6.1  General
This chapter describes the detailed design of the offshore leak detection system. Detailed design builds on the design requirements and develops with further details until the specifications and drawings are ready to be released for manufacture.

6.2  Design specifications
Based on the requirements developed by the operator, the integrator shall develop design specifications to meet the requirements. For an offshore leak detection system, where both surface and subsea based technologies are involved, more than one integrator and supplier will be involved, see an example in Figure 6-1. In some cases, the operator may also have a direct interface to the supplier.

Figure 6-1  Example of contract and scope of work split for an offshore leak detection system

The design specifications should be provided in the same units as the requirements.

The specifications shall contain detailed information on e.g.:

- functional design specification
- environment data
- design life
- specification of size, weight and mechanical interfaces
- specification of communication and control
- specification of power required
- material specifications
- HMI or specification of user interfaces and how data should be presented to the end user.

Supplier and integrator shall supply documentation of any data and procedures that are necessary for the operator.
The following documentation shall be delivered for use in the operation phase, as applicable:

- OMM including obsolescence plan
- general arrangement drawing
- product data sheet (for instruments and valves)
- safety data sheets (for chemicals)
- spare parts interchangeability register (SPIR)
- manufacturing record book (MRB)
- project software documentation
- storage of measurement data and access to stored data.

Detailed design documents that are developed as a part of the project are listed below:

- design report
- initial alarm classification
- interface drawings
- block diagram (system drawing)
- equipment assembly drawing (normally retained by supplier)
- mounting / assembly procedure (normally retained by supplier)
- electrical diagram / schematic
- data allocation / signal list / instrument index / tag list (normally part of operational data base)
- 3D model (normally retained by supplier)
- factory acceptance test (FAT) procedure
- input to control system integration test (EFAT)
- input to system integration test (SIT)
- inspection and test plans (ITP)
- dispatch dossier (used for release of equipment)
- MC Dossier
- transport and handling instructions (also included in OMM)
- preservation and storage instructions (also included in OMM)
- function test specification (including description of downloading of software).

1) Design report can be equal to the Design Report made from Technology Qualification if supplied equipment is identical to qualified equipment. Any changes shall be documented and qualified as relevant.

In addition, the qualification procedures and reports containing the qualification evidence for the leak detector shall be available for the buyer (integrator or operator).

### 6.3 System performance

Referring to Figure 6-1, a leak detection system may consist of deliveries under more than one contract. The performance of the total leak detection system shall be assessed towards the defined functional requirements, to verify that the requirements are met.

It is recommended to define a system responsible that will evaluate the performance of the total leak detection system.

In the example in Figure 6-1 the delivery of leak detection equipment and accompanying specifications are:

- leak detection and specifications from surface based (topside) integrator
- leak detection and specifications from SPS Integrator
- leak detection and specifications from Leak Detection Supplier 1.

In this example it rests with operator to assess whether the total leak detection system meets the defined functional requirements.
6.4 System interface engineering

The engineering required to integrate each chosen leak detector will be specific to each technology and must be assessed based on the layout of the offshore facility. This is equal to regular instrumentation engineering and is not covered in further detail by this document.

6.5 Data handling and interpretation

The operator shall define procedures for handling and interpretation of data. The data delivered by the leak detection system is of value to the operator only when data can be interpreted and used for operational decision making. Operating procedures for handling leak detection alarms; including verification, responsibilities, tasks, criteria for taking action, actions to be taken etc. shall be established as defined in [8.2.1.1].

As exemplified in Figure 6-2, data from a group of different sensors surface and/or subsea is sent to the CCR, either via the subsea control system or directly to the CCR. In the CCR, the operator interprets the data. In addition, data may be sent onshore for interpretation by experts. For satellite systems, data interpretation is done by experts onshore, before the results are communicated back to the operator offshore.

Operator shall ensure that the leak indicating alarm is configured with the right priority in the control system.
It may be considered to analyse the commingled leak detection system data by use of e.g. multivariate analysis or similar. The performance of such analysis shall be verified through technology qualification, see [5.3].
6.6 Test procedures

6.6.1 Factory acceptance test
Each individual leak detector shall be verified by FAT prior to delivery. The procedure for FAT shall include simulation of loads, pressures, environmental and operating conditions, as relevant. The FAT shall as a minimum verify:

— function, as defined by functional specification
— interfaces (mechanical, power and communication)
— mechanical size and weight.

The leak detector supplier shall propose a procedure for FAT which shall be approved by the buyer (integrator and/or operator). The FAT procedure shall be in accordance with referenced standards, as applicable.

6.6.2 Control system integration test
A control system integration test shall be performed to verify the function and interfaces of the control system with all instrumentation and infrastructure installed. It will also verify parts of the performance of the leak detector. A procedure for the EFAT shall be defined prior to the testing and shall be approved by the buyer (integrator and/or operator).

A simulator, replicating the leak detector as an instrument will be required for the control system integration test. The simulator may give dummy readings, but shall be equal to the full leak detector in interface, software, communication (sending and receiving) and power consumption during inrush and steady state. Limited functions of the simulator shall be clearly specified by the supplier.

Items to verify during an EFAT include:

— communication - sending and receiving of signals from instrument to destination (typically CCR)
— power consumption
— check for interference between instruments / systems.

The leak detector supplier shall propose methods of verifying their equipment in the EFAT and deliver test equipment as required.

6.6.3 System integration test
SIT refers to testing the leak detector integrated into the rest of the facility system. The integration test shall demonstrate that interface requirements are met and that the complete system functions as required. The SIT is the final test before commissioning of the equipment and the leak detector itself is used for this test (not a simulator).

A procedure for SIT shall be defined prior to the test.

In addition to the items listed under [6.6.2], the system integration test will also verify:

— fit, function and performance according to specification
— retrievability and maintainability is as required.

Actual maintenance and operation procedures shall be used as a basis for the test.

The leak detector supplier shall propose methods of verifying their equipment in the SIT and deliver test equipment as required.
6.7 Training
Training of personnel shall be included in the control system integration testing and SIT. Training shall include:

— familiarisation with equipment and equipment function, failure modes and limitations
— understanding of operating procedures
— understanding of maintenance procedures.
SECTION 7 FUNCTION TESTING

7.1 General
After installation of the leak detection system, it shall be verified that the system works as intended on a regular basis. The extent of testing, the method and the time between each test shall be defined during design, see [6.2] and described in the OMM.

For leak detectors or leak detection systems where the instrument itself is not placed on or near the facility (e.g. satellite), the necessary function testing over lifetime is the responsibility of the leak detection supplier.

7.2 Acceptance criteria
The acceptance criteria for the functional testing shall link back to the defined functional specification, see [3.5].

Acceptance criteria shall be formulated against at least:

- minimum leakage rate detected
- ability to locate leakage
- detection range
- detection time
- type of fluids and fluid concentration detected
- ability to classify fluid type.

The acceptance criteria should be quantitatively specified.

7.3 Function test methods

7.3.1 Instrument test
The power consumption and communication of each leak detector in the system shall be tested on a regular basis. This may be done through the control system. Such tests will verify that the instrument is alive, but does not verify that it functions as a leak detector.

7.3.2 Function test
Function testing shall verify that the instrument functions as a leak detector. Function tests may be based on a real leak or simulation of a leak. Principles for simulation of a leak for a given detection technology must be deduced from the physics of the measurement principles for each technology.

Simulations may consist of:

- discharge of environmentally friendly fluids
- exposing sensor to material(s) that reproduce the properties that the sensor reacts to
- generation of acoustic sound
- playback using underwater transducer
- release of pressurised air.

The function test method shall be described in a procedure and any required tools shall be developed during detailed design of the leak detection system.
SECTION 8  OPERATION

Effective detection of potential leakages is dependent on the design integrity of the leak detection system ensured in the design phase, see Sec.6. The technical integrity and operational integrity shall be ensured during the operation phase.

These three elements are presented in Figure 8-1 as follows:

— design integrity: the design of the leak detection system
— technical integrity: the technical condition of the leak detection system at any time, which is determined by proper maintenance, testing and inspections
— operational integrity: the operation of the leak detection system, which is determined by developing and implementing proper operating procedures, including communication, reporting and training.

Figure 8-1 Three elements ensuring that a leak detection system functions as intended

Operation of the leak detection system covers the operational and the technical integrity. The overall approach is illustrated in Figure 8-2 and further detailed in sub-sections following.
8.1 Principles

The operation of the leak detection system shall be based on the following principles:

— Maintenance, testing and inspection are an integral part of the facility’s maintenance system, and follow the operator’s maintenance philosophy.
— Operating procedures for leak detection are a fundamental part of the operator’s management system, and interfaces with relevant other main work processes are defined and managed.
— The alarm and event handling for leak detection complies with the operator’s alarm philosophy.
— The operating procedures for operation and maintenance of leak detection system are based on information provided by the suppliers, requirements in the operator’s management system and the operator’s alarm philosophy and alarm specifications.
— The leak detection system is manned by trained operators who know what the detection measures and system limitations are.
— Responsibilities and reporting lines are well defined and communicated.

8.2 Framework

The intention of the framework is to assist the operator to integrate the leak detection management system into the operator’s overall management system. In addition, continual improvement shall be a driver in the management of the leak detection system. Continual improvement refers to the process of planning, executing, measuring results and acting on any opportunity for improvement, and should be referred to as the “Plan- Do- Check- Act” circle as shown in Figure 8-2.

The leak detection management system shall be based on overall operator policies and the interfaces with other main processes such as maintenance, general alarm and event handling, emergency response and spill monitoring shall be taken into consideration.
8.2.1 The main elements

8.2.1.1 Establish system and procedures

Before the leak detection management system with operating procedures is established, it is important to evaluate and understand the context of the leak detection system for the facility as this can significantly influence how the operating procedures are designed. The contextual evaluation shall include, but is not limited to:

— the regulatory environment for leak detection and oil spill response
— the purpose of the leak detection system; detect hydrocarbon leakage, monitor oil spill etc.
— the different types of leak detection system installed
— permanent versus autonomous systems (e.g. ROV)
— independent and/or SAS integrated alarm system
— locations for monitoring of alarms; in the CCR, on the stand-by vessel, onshore etc.
— the link between the alarm system and the information management system (IMS)
— involved parties; may include CCR and other parts of the offshore organisation, stand-by vessel, onshore support organisation, emergency response organisation and system suppliers
— whether the leak detection systems are considered as barriers and hence have to follow the operator’s barrier strategy
— capabilities; understood in terms of resources and knowledge
— operator’s alarm culture, e.g. how personnel respond to alarms.

Once the context of the leak detection system has been established, the management system with operating procedures shall be set up, including:

— Accountability and appropriate competence of the leak detection system; including implementing and maintaining all relevant operating procedures.
— Interfaces with other main processes; defining how these interfaces shall be handled including communication and information flow. Typical interfaces are described in [8.2.2].
— Allocation of resources. Consideration shall be given to:
  — people, skills, experience and competence
  — resources needed to handle all alarms and meet the response criteria defined, and to maintain the leak detection system
  — capture and follow up of data and information in the IMS
  — training programmes.
— Developing an alarm philosophy (defining what to do if a sensor is activated) for handling the leak detection system as a governing document in the management system. The alarm philosophy shall be a part of the operator alarm philosophy and standards. A preliminary alarm philosophy should be developed at an early stage to ensure that this is taken into account during the design phase.
— Defining the operating procedures for handling leak detection alarms; including responsibilities, tasks, criteria for taking action, actions to be taken etc.
— Reporting lines; including immediate notification of an alarm, report/notify needs for maintenance or repair, report performance data, monitor and report spill etc.
— Communicating and consulting with relevant stakeholders such as suppliers and the operator’s emergency preparedness organisation, maintenance personnel and health, safety and environment (HSE) organisation to ensure that the management system and operating procedures for leak detection are appropriate.
8.2.1.2 Implement system and procedures
When implementing the management system and operating procedures for the leak detection system the operator shall:

— communicate and involve relevant stakeholders
— define the appropriate timing and strategy for implementation
— ensure compliance with statutory and regulatory requirements
— ensure sufficient awareness and knowledge among the organization, e.g. through information and training sessions.

8.2.1.3 Audit and review
In order to ensure that the management system for leak detection system is effective and continues to function as intended, the operator shall:

— periodically review and analyse alarm data, including false alarms, and evaluate trends
— periodically review maintenance, inspection and testing data
— include audits of the management system for the leak detection system in the operator’s audit programmes.

8.2.1.4 Improve system and procedures
Based on the results from the audits and reviews, decisions shall be made on how the leak detection system, the leak detection management system and the operating procedures shall be improved.

Industry experience shows that a large number of false alarms constitutes a major problem in terms of ineffective alarm and event handling. Procedures shall be defined for communication with, and involvement of, the suppliers. Investigations should be made to discover the root causes of false alarms in order to avoid these in the future. Results from reviews and analyses of alarm data and maintenance and testing should be shared with the suppliers. The operator should establish formal feedback (e.g. related to functionality, HMI, other user experiences) to the system suppliers in order to improve the alarm system.

8.2.2 Interfaces
The leak detection system is one of many systems on the facility, and the leak detection management system shall be incorporated in the operator’s management system. The leak detection system has interfaces to the other systems and processes of the operator, and it is essential that reporting lines and procedures are in place to handle those interfaces correctly.

The interfaces between the leak detection system and the following main processes are briefly described below:

— maintenance
— alarm and event handling
— spill monitoring
— emergency response.

Oil spill response is considered to be a part of the operator’s emergency response system.

8.2.2.1 Maintenance
Maintenance, including inspection, testing and calibration, of the leak detection system shall be an integral part of the facility’s general maintenance system, and follow the operator’s maintenance philosophy.

The maintenance activities for the leak detection system should be established and followed up in the facility’s computerized maintenance management system (CMMS) according to the facility’s maintenance strategy and procedures for maintenance management. The maintenance activities shall be based on both maintenance manuals from supplier’s and the operator’s requirements to maintenance.

Equipment failures shall be reported in the CMMS and corrective maintenance work shall be initiated and handled in the CMMS according to facility’s maintenance management procedures.
Maintenance of the leak detection system shall be analysed and improved according to facility’s maintenance management procedures.

8.2.2.2 Alarm and event handling
Alarms coming from the leak detection system shall be handled according to operator’s alarm philosophy defined in the operator’s management system. Alarm and event handling is discussed in more detail in [8.3].

8.2.2.3 Spill tracking and monitoring
In case of a detected leak, the operator’s system for spill tracking should be activated to provide information about the spill.

Some parts of the leak detection system are part of the spill monitoring system and will automatically track the oil spill. For those leak detection systems that do not automatically monitor the oil spill it is important to have clear reporting and communication lines in place to ensure sufficient tracking of the spill. This should be included in the operator’s oil spill response plan.

8.2.2.4 Emergency response
In case of strong indications of leaks, the operator’s emergency response plan might need to be initiated. To ensure efficient emergency response clear reporting lines have to be defined and communicated.

8.3 Work process
The main work process for management of the leak detection system, “alarm and event handling”, starts with detecting an alarm and ends with a response.

Figure 8-2 shows a generic model of this work process and builds on the rationale that an alarm requires a response from a human operator. The human operator is located anywhere (e.g. offshore, onshore or third party organisation). However, the CCR will usually play an important role.

Operating procedures shall be developed to support the work process. The operating procedures are dependent on the different technologies used and on how the alarm system is configured.

The operating procedures shall clearly define:

— Roles and responsibilities. The person responsible for detecting a system upset, the alarm responsible, shall also be responsible for initiating further actions in order to avoid unclear responsibilities. This is particularly important when different people at different locations are involved, e.g. when using onshore specialists and/or third parties in the alarm and event handling process.

— Communication lines. Several sources of information may be required to investigate an alarm and initiate a response. Several activities and actions may be necessary to acquire this information. The person responsible for acting upon an alarm shall know who to contact and when.

8.3.1 Monitor and control
Monitoring and control of the leak detection system are part of the daily routines and activities of the alarm responsible. These activities consist of several manual and automatic tasks, which are usually performed by a control room operator.

8.3.2 System upset
A system upset occurs when the leak detection system indicates an abnormal situation. This information may come from different sources. For example sensors may detect abnormalities and send information via the alarm system logic, onshore specialists may discover abnormalities when processing information data and third party specialists may discover abnormalities when analysing radar/satellite images.

Prior to operation, each potential system upset should be assessed and given a priority according to predefined criteria. These criteria should take into account field specific requirements. To ensure focus on critical system upsets, all critical system upsets shall be routed to the alarm responsible, while all non-critical system upsets should be routed to supplier or discipline responsible person.
8.3.3 Detect
An abnormal condition is detected when an alarm responsible is made aware of a system upset. This is often presented to a control room operator visually and/or audibly, but the alarm responsible may also be located elsewhere (e.g. onshore, third party). Alarms shall be handled by the control room operator.

8.3.4 Diagnose
Diagnosis of the situation begins after the system upset has been detected. In this stage the alarm responsible seeks an understanding of the situation and investigates if the alarm is not a false positive. The alarm responsible shall begin investigating the authenticity of the alarm and initiate support activities if needed. Such activities could include, but are not limited to:

- cross-checking with other subsea sensor readings and other activities in the area such as drilling and well operations, intervention, maintenance and repair, seismic, trawl and fisheries activities.
- using different leakage detection methods to verify information
- initiating inspections and assessments from platform, vessel or helicopter
- initiating remote sensing assets such as dedicated oil spill surveillance aircraft or satellite
- initiating ROV inspection
- lessons learned.

The alarm responsible should take into account field specific requirements on response time, leak rates and released volume when deciding actions to be carried out in the diagnose phase.

During the diagnosis the alarm responsible may suppress certain system upsets based up the operator’s alarm suppression philosophy, pre-defined criteria for alarm suppression and the alarm responsible’s expert judgement.

8.3.5 Respond
The result on the diagnosis is either a confirmed leak or a false alarm. The alarm responsible shall communicate the result and relevant information according to defined reporting lines and operating procedures. Response is initiated according to accountability and responsibility.

Appropriate responses to a confirmed leak shall include, but are not limited to:

- initiate corrective maintenance
- initiate emergency response.

Appropriate responses to a false alarm should include, but are not limited to:

- initiate root cause analysis
- initiate calibration of sensors
- initiate feedback to supplier.

The response depends on the criticality of the confirmed leak.

8.4 Training and competence
Personnel responsible for alarm and event handling shall be trained and competent in the leak detection system implemented on board. The training shall cover the operating procedures for the leak detection system.

Training in various realistic usage of the alarm system shall be provided, both as basic training and refresher training. Use of a simulator is a good way to train users of the leak detection system, and should be a part of the basic training regime.

Handling of leak detection alarms shall be included in the facility’s drills and exercises for oil spill response.

Training and competence related to the leak detection system shall be implemented in the operator’s competence and training matrices.
APPENDIX A REGULATIONS AND REQUIREMENTS

This appendix summarizes regulatory requirements for offshore leak detection applicable to operators in Australia, Brazil, EU, Norway, UK and US

This overview is provided as information only. The regulations and requirements may have been updated since the time of this writing. It is recommended to check the most updated official sources.

The relevant acts, regulations and recommended standards have been analysed for each country and the main aspects related to leak detection have been described to better understand their applicability to offshore leak detection requirements. In the case of contradiction or conflict between regulatory requirements and/or text or recommendations in this report, regulatory requirements shall prevail. Note also that the regulatory requirements, acts, regulations and recommended standards from the relevant countries are subject to change and projects should always refer to the latest revision of these documents.

The analysis is based on a thorough review of the following:

— national acts and regulations related to leak detection
— international standards recommended in the regulations
— applicable international legislation.

Regulatory requirements for leak detection are often broad and high level and difficult to specifically identify in acts and regulations. However, leak detection can often be considered covered in certain requirements related to release and discharge control, pollution control and monitoring, and control and mitigating measures.

It should be noted that only regulations applicable to offshore waters have been considered. Individual company requirements and internal policies that should be taken into account when selecting a leak detection system are not included.

A.1 Country specific regulation and requirements

A.1.1 Australia

In Australia, there are two authorities whose legislation is relevant for leak detection. The Department of Environment designs and implements the Australian Government’s policies and programmes to protect and conserve the environment, while the National Offshore Petroleum Safety and Environment Management Authority (NOPSEMA) regulates the health and safety, structural integrity, and environmental management of all offshore facilities in coastal waters where State powers have been conferred.

The Offshore Petroleum and Greenhouse Gas Storage (Safety) Regulations 2009 (OPGGS(S)) /3/, sets requirements to the operator to conduct and document assessments that identify technical and other control measures necessary to reduce that risk to a level that is as low as reasonably practicable.

The Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (The Principal Regulations) /4/ and the Petroleum and Greenhouse Gas Storage Legislation Amendment (Environment measures) Regulation 2014 (The Regulation) /5/ require that, anyone who wants to conduct petroleum activities in Australian waters prepare and implement an environment plan for the period of the activity. The environment plan should include, among other things, a summary of arrangements for monitoring and oil pollution emergency response; and monitoring arrangements for both normal operations and emergency conditions, including monitoring to inform response and remediation activities.

There is no specific requirement in the Australian regulatory regime to the type of leak detection system, its performance in time or quantity of accidental release to the environment. However the concept of leak detection is covered by the regulations in establishing necessary control measures (The OPGGS(S) regulations) and in implementing an environment plan (The Principal Regulations and the Regulation), where arrangements for monitoring oil pollution for both normal operations and emergency conditions are required. Multiple possible options for mitigation and control are also required.
A.1.2 Brazil

In Brazil, the National Petroleum Agency (ANP) regulates activities within the petroleum and natural gas and biofuels sectors. ANP has two resolutions that are applicable for this analysis:

- The ANP Resolution 43 /6/ establishes requirements and guidelines to offshore units for implementation and operation of a Management System for Operational Safety, aiming to protect human life and the environment. It is required to ensure that accidents are prevented and incidents are correctly managed.

- The ANP Resolution 44 /7/ covers reporting of incidents related to offshore oil and gas activities.

In Brazil, the Ministry of Labour and Employment (MTE) introduces prescriptive elements for health and safety at work. According to the MTE Annex II from Norm No. 30 – Platforms and Facilities Support /8/, all platforms should have automatic systems that paralyze the process, isolate systems and equipment and, when required, depressurize equipment, in order to limit the escalation of abnormal situations such as oil spills. Section 16.6 of the annex presents details about prevention and control of leaks, spills, fires and explosions.

Neither the ANP Resolutions nor the MTE Annex II Norm have specific requirements to the type of detection or time for detection of accidental release to the environment. However in 2013, MTE issued a draft version of a new rule for offshore platforms /9/. The text is currently under public consultation and not officially approved however, in order to have an overview of main aspects related to oil leak detection for the future, a brief description is included.

Section 27 of the new regulation presents details about prevention and control of leaks, spills, fires and explosions. The operator of a facility is required to develop and implement a specific plan to prevent and control leaks, spills, fires and explosions. The plan shall be developed giving consideration to the means and actions to minimize occurrence and mitigate consequences in case of failure in prevention and control systems, and for fugitive emissions.

Section 30 requires that the operator of a facility develop and implement an Emergency Response Plan, which includes specific actions to be taken if an event that results in situations of severe and imminent risk to workers’ safety and health occurs.

The new rule has no specific requirements regarding type of detection or time for detection of accidental release to the environment.

A.1.3 European Union

The European Commission is one of the main institutions of the EU. It represents and upholds the interests of the EU as a whole. The Commission drafts proposals and is responsible for managing the day-to-day business of implementing EU policies. Further, the Commission is responsible for issuing directives.

The EU Industrial Emissions directives (IED) /2/ came into force in January 2011 and merged seven directives into one, including the Integrated Pollution Prevention and Control (IPPC) directive. The IED requires that local authorities issue permits to relevant installations. A permit “should also include emission limit values for polluting substances, or equivalent parameters or technical measures, appropriate requirements to protect the soil and groundwater and monitoring requirements.” Permit conditions should be set on the basis of Best Available Techniques.

The Directive 2013/30/EU on the safety of offshore oil and gas operations with the Offshore Installations (Offshore Safety Directive) (OSD) /10/, includes elements that are applicable for leak detection. In annex 1 of the OSD, information to be submitted in a report on major hazards for operation of a production installation is described. This includes “an assessment of the identified potential environmental effects resulting from the loss of containment of pollutants arising from a major accident, and a description of the technical and non-technical measures envisaged to prevent, reduce or offset them, including monitoring.” In Annex III, competent authorities appointed by the member states are required to undertake a thorough assessment of reports on major hazards to ensure that “measures and arrangements for the detection of, and the rapid and effective response to, an emergency are clearly identified and justified”.

Further, there are several requirements in the OSD addressing limitation of pollution and mitigation measures which are relevant for considerations related to leak detection.
It should be noted that the OSD is a directive and hence specifies the goals or results that should be achieved. The local authorities can use their own legislative framework, but need to ensure that the specific requirements and goals of the directive are achieved. It is therefore possible that national regulations and requirements will be more stringent. Further, OSD encourages experience exchange with regards to best practice which could increase the focus on leak detection requirements.

A.1.4 Norway

Leak detection on the Norwegian Continental Shelf (NCS) is well regulated and is often seen as best practice internationally. Detecting abnormal conditions like hydrocarbon leaks is laid down in national legislation and is regulated by the Petroleum Safety Agency Norway (PSA) and enforced by the Norwegian Environment Agency. Operating companies are expected to define satisfactory functional requirements for their systems. The requirements should be related to the risks associated with their own activities.

PSA is the independent government regulator with responsibility for safety, emergency and preparedness and the working environment in the Norwegian petroleum industry. Key requirements relating to HSE in the offshore petroleum industry subject to the supervisory authority of the PSA are found in the Framework Regulations /11/, Management Regulations /12/, Facilities Regulations /13/ and Activities Regulations /14/. Each of these regulations has requirements that can be related to leak detection.

The Framework Regulations Section 11 (Risk Reduction Principles) requires that harm, or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with legislation, including operator requirements and acceptance criteria. In addition, the risk shall be further reduced to the extent possible. When reducing the risk, operators should choose the technical, operational and organizational solutions that offer the best results, provided that the costs are not significantly disproportionate to the risk reduction achieved.

The Framework Regulations Section 48 (Duty to monitor and record data from the external environment) states that operators shall monitor and record data from the external environment. Further, operators shall obtain sufficient information “to ensure that all pollution caused by own activities is detected, mapped, assessed and notified, so that necessary measures can be implemented”. The Management Regulations Section 5 (Barriers) requires that operators establish barriers and performance requirements with regards to technical, operational and organisational elements.

The Facilities Regulations Section 8 (Safety Functions) requires that facilities are equipped with safety functions that at all times are able to detect abnormal conditions, prevent abnormal conditions from developing into situations of hazard and accident, and limit harm in the event of accidents.

The Activities Regulations Section 57 (Detection and mapping of acute pollution (remote sensing system)) requires the operator to "establish remote sensing systems to detect and map the position, area, quantity, and properties of acute pollution.” It also states that “[t]he remote sensing system shall as independent of visibility, light and weather conditions as possible, provide sufficient information to ensure that acute pollution from the activity is detected and mapped as quickly as possible.” The regulations also explain that "[t]he Environment Agency can set more explicit requirements regarding detection and mapping of acute pollution.” It is also stated that there shall be a plan for detecting and mapping based on the environmental risks and that the "remote sensing system shall give sufficient information on amounts of discharge and dispersal, so that decisions on necessary risk reduction measures can be made”. This includes coverage, drifting direction and amount of discharge. The regulations also emphasise that operators shall contribute with further developing the remote sensing systems. The Norwegian Environment Agency is in the supervisory authority in charge of nature management, pollution control and reducing greenhouse gas emissions in Norway. Through the Pollution Control Act /15/, the Norwegian Environment Agency normally requires 3 hours detection time on manned offshore installations and 12 hours on unmanned ones. In addition, operators must inform the authorities immediately after events that may cause significant environmental impacts.

Guideline No. 100 /16/ from the Norwegian Oil and Gas Association assists operators in defining field specific detection systems and complying with requirements. The guideline recommends defining stricter performance requirements to leak detection systems with regards to rates and detection times for installations close to vulnerable resources and activities with higher spill probability.
A.1.5 United Kingdom

Necessary measures to prevent pollution from occurring and to control possible releases are requirements stated in the UK legislation, and cover the concept of leak detection. However there are no specific requirements regarding leak detection systems, type of detection, or time for detection of accidental release to the environment. The UK regulations have a performance-based approach that requires operators to continually minimize hazards and risks to “as low as reasonably practicable” (ALARP), but there is no detailed description or guidelines on how to present or achieve those.

On the UK Continental Shelf, the authorities may give directions to the operator of any offshore installations for the purpose of preventing or reducing pollution, or the risk of pollution. Operators of specified installations are required to obtain a permit to operate. To be granted a permit, the operator must demonstrate that necessary measures are taken to prevent accidents affecting the environment or, where they occur, to limit their consequences in relation to the environment.

In addition to reducing oil spill risks and their consequences, the operator’s main responsibility is to undertake offshore operations in a manner that prevents pollution incidents from occurring in the first place. Environmental Statements submitted to the authorities must include a detailed assessment of potential releases in relation to the measures to prevent and control the release, the results of the modelling and the potential environmental impacts.

The UK has incorporated the additional requirements of the EU Offshore Safety Directive (see chapter 4). Leak detection systems have to be included as Safety and Environmental Critical Elements (SECEs).

A.1.6 United States

In the US, requirements specifying leak detection are clearly related to pipeline leaks whereas for offshore facilities and installations, the regulatory requirements are more subjective. Requirements regarding leak detection (for pipeline), pollution and/or spill prevention, monitoring and discharge detection from the Code of Federal Regulations (CFR) are seen as key.

Title 49 CFR - Transportation and Title 30 – Mineral Resources Regulations /17/ require that a computational pipeline monitoring (CPM) leak detection system installed on a hazardous liquid pipeline transporting liquid in single phase (without gas in the liquid) complies with API 1130.

Title 30 CFR– Mineral Resources Regulations /18/ require that measures to prevent unauthorized discharge of pollutants into the offshore waters are in place both for DOT of DOI pipelines.

Title 40 CFR – Protection of environment Regulations /19/ require that the owner or operator of an offshore oil drilling, production, or work over facility, address discharge prevention measures and describe the discharge detection equipment in place, including procedures and personnel in charge.

Title 33 CFR - Navigation and Navigable Waters Regulations /20/ require that spill prevention or leak detection systems that will be installed on a deep-water port are not only described in the application for a license to operate, but also that the system(s) have been selected through a BAT screening. The applicant must also document that procedures around leak detection are in place and that personnel are trained to be able to operate the systems.

While a metering system to provide a continuous volumetric comparison between the input and the deliveries onshore is required on pipelines, there is no specific requirement in the US regulatory regime on the type of leak detection system, its performance in time and quantity on accidental release to the environment for offshore facilities and deep-water ports. However the concept of leak detection is covered by the regulations in establishing necessary prevention measures and plans.
APPENDIX B LEAK DETECTION TECHNIQUES AND THEIR CHARACTERISTICS

An important target for detection of leakages both subsea and on the surface, is to achieve early warning of small to medium sized leaks for monitoring and corrective actions.

Techniques covered include those that are commercially delivered and field proven in addition to emerging techniques. The focus is permanently installed leak detectors. The detectors may require access to the facility control system for continuous monitoring or be independent of the facility control system (autonomous systems).

Sensor coverage is described as:

- regional coverage, meaning that they can cover the entire field development or more
- area coverage, meaning that they can cover a large area of the field but not full field coverage
- local coverage, meaning that they will cover an area close to the sensor.

The accuracy of the placement, the range covered and positioning parameters vary from technique to technique. Some techniques require contact with the leaking medium, and can detect a leakage in their vicinity but cannot determine the location of the leak. Sensors using these principles are named point sensors. These sensors may be an option for monitoring of high risk leak points. Some of the sensors can also be used for additional purposes, including condition monitoring. This can potentially result in early warnings and allow the operators to take actions before an incident escalates into a leak. In the table below (subsea techniques) "leak positioning" refers to the capability of a single sensor. System configuration and processing software may enable leak positioning.

The leak detection techniques are categorised in subsea- and surface based leak detection techniques, and the list below includes both techniques and devices.

Subsea leak detection techniques:

- active acoustic
- bio sensor
- capacitive sensor
- fibre optic
- fluorescent
- internal leak detection system/ mass balance
- volumetric collection
- methane sniffer
- semi-conductor
- optical NDIR.
- laser absorptiometry
- optical camera
- passive acoustic
- multisensor.

Surface leak detection techniques:

- radar
- ground-penetrating radar
- navigation radar with oil spill detection
- side-looking airborne radar
- synthetic aperture radar.
- fluorescence
— hyper-spectral laser-induced fluorescence LIDAR.
— electromagnetic reflection
— infrared imaging
— microwave radiometer
— spectral scanners
— ultraviolet sensor
— visual surveillance camera.

At the time of writing, mainly qualitative functional descriptions for operation of the different techniques are available. The descriptions are mainly based on information provided from Suppliers in addition to technology screening and information from the industry during the Offshore Leak Detection JIP.

It should be noted that, although it is the intention, the overview presented in this appendix may not include all available leak detection principles.

### B.1 Subsea techniques

A high level comparison between the subsea leak detection techniques are presented in the following table:

<table>
<thead>
<tr>
<th>Principle</th>
<th>Principle method description</th>
<th>Form of HC</th>
<th>Sensor coverage</th>
<th>Leak positioning¹)</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active acoustic</td>
<td>Based on the same principle as sonars. Detector emits pulses of sound that are reflected by boundaries between different media.</td>
<td>All</td>
<td>Area coverage</td>
<td>Yes</td>
<td>Sensitive to shadowing and background noise. Some versions generate a lot of data. Not effective on ingress leaks. Limited sensitivity for oil.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sensor sensitivity depends on difference in acoustic impedance between leaking medium and seawater. Dependent upon size and shape of collector in combination with seawater currents.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Local coverage Point sensor</td>
<td>No</td>
<td>Seawater currents or buoyancy effects may lead leaking medium away from sensor. Supporting sensors are needed.</td>
</tr>
<tr>
<td>Bio sensor</td>
<td>Uses a living organism to detect the presence of pollution. Biosensor's response is measured by heart activity and degree and frequency of opening/ closing the clam.</td>
<td>Oil</td>
<td>Local coverage Point sensor</td>
<td>No</td>
<td>Biological growth. Dependent upon size and shape of collector. If polymerized material is used in sensor, it can absorb water and affect sensitivity.</td>
</tr>
<tr>
<td>Capacitive sensor</td>
<td>Measures change in the dielectric constant of the medium surrounding the sensor.</td>
<td>All</td>
<td>Local coverage Point sensor</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Fibre-optic</td>
<td>Fibre-optic cable installed along the entire length of the pipeline or structure to be monitored. Can be based on either temperature or acoustics.</td>
<td>All</td>
<td>Area coverage( entire pipeline system)</td>
<td>Yes</td>
<td>Fibre optic cable has limited bend radius. Trade-off between spatial resolution and detection sensitivity.</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>Use a light source of a certain wavelength for exciting molecules in the target material to a higher energy level. The molecules then relax to a lower state and light is emitted at a different wavelength which can be picked up by a detector.</td>
<td>Oil</td>
<td>Local coverage Point sensor</td>
<td>No</td>
<td>Marine growth. Medium to be detected must naturally fluoresce or a fluorescent marker must be added into the fluid.</td>
</tr>
<tr>
<td>Principle</td>
<td>Principle method description</td>
<td>Form of HC</td>
<td>Sensor coverage</td>
<td>Leak positioning&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>Limitations</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Internal LD system (mass balance)</td>
<td>Pressure and flow monitoring by instrumentation installed in the SPS. Measured values compared to simulation model predicting expected pressure and flow given no leaks. Large deviation btw measured and predicted values indicate a leak in the system.</td>
<td>All</td>
<td>Area coverage (entire pipeline system)</td>
<td>No</td>
<td>Inaccurate when the production is unstable. Not able to detect small leaks (typical less than 5% of the total flow).</td>
</tr>
<tr>
<td>Methane sniffer</td>
<td>Three measurement principles: - Semi-conductor - Optical NDIR - Laser absorptiometry Dissolved methane diffusing over a membrane and into a sensor chamber.</td>
<td>All</td>
<td>Local coverage Point sensor</td>
<td>No</td>
<td>Quantification of leak is difficult. Dependent on diffusion towards the sensor and seawater currents may lead the leaking medium away from the sensor.</td>
</tr>
<tr>
<td>Optical camera</td>
<td>Use of video camera for surveillance of the subsea system.</td>
<td>All</td>
<td>Local coverage</td>
<td>Yes</td>
<td>Line of sight sensor, depending on lightning. Sensitive to marine growth, water turbidity and pollution.</td>
</tr>
<tr>
<td>Passive acoustic</td>
<td>Hydrophones listening for sounds (pressure waves) resulting from a leakage.</td>
<td>All</td>
<td>Area coverage</td>
<td>Yes</td>
<td>Need differential pressure for detection. Background noise can limit the sensitivity.</td>
</tr>
<tr>
<td>Volumetric collection</td>
<td>Leak detection based on volumetric measurements. When a predetermined volume is collected an action is initiated in the system and will give an alarm.</td>
<td>All</td>
<td>Local coverage Point sensor</td>
<td>Yes</td>
<td>Sensitive to biological growth. Fishing activity (trawls) can be an issue.</td>
</tr>
<tr>
<td>Multi-sensor</td>
<td>Combination of two or more complementary sensors types. Complementary leak detection principles should be selected.</td>
<td>Depends on type of sensors used in combination.</td>
<td></td>
<td></td>
<td>Higher power consumption and increased data bandwidth compared to use of single sensors. Stand-alone integration might not be, due to the above. Potential additional complexity relating to the subsea control system.</td>
</tr>
</tbody>
</table>

1) "Leak positioning" refers to the capability of a single sensor. System configuration and processing software may enable leak positioning.
## B.2 Surface techniques

A high level comparison between the surface leak detection techniques are presented in the following table. Empty cells are due to lack of information or difficulty of obtaining/finding information:

<table>
<thead>
<tr>
<th>Principle</th>
<th>Principle method description</th>
<th>Form of HC</th>
<th>Detection range</th>
<th>Ability to classify</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>An active sensor that emits energy at a certain wavelength and collects the backscattered signals and then analyses them</td>
<td>Oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Ground-penetrating radar (GPR)</strong> sends microwaves into the material situated below. GPR can detect oil under ice and snow</td>
<td>Oil</td>
<td></td>
<td></td>
<td>Structures within the ice or snow can give rise to false positives.</td>
</tr>
<tr>
<td></td>
<td><strong>Navigation radar with oil spill detection</strong> uses conventional navigation radars. Software for automatic oil spill detection is available</td>
<td>Oil</td>
<td>Depends on factors such as radar transceiver power, radar antenna height, wind speed and polarization.</td>
<td>No</td>
<td>Needs wind (approx. between 2-12 m/s) to detect oil.</td>
</tr>
<tr>
<td></td>
<td><strong>Side-looking airborne radar (SLAR)</strong> is an active sensor that sends radar signals to the water surface. SLAR is a line scanner only used in aircraft systems</td>
<td>Oil</td>
<td>Maximum swath width is 80 km.</td>
<td>No</td>
<td>Needs wind to detect oil.</td>
</tr>
<tr>
<td></td>
<td><strong>Synthetic aperture radar (SAR)</strong> sends radar signals to the water surface. SAR is available for aircraft systems, satellite systems and ship-based systems</td>
<td>Oil</td>
<td>For airborne installations: Maximum swath width is 60 km. For satellite based installations: Each satellite image can cover a track gauge of up to 300 km.</td>
<td>No</td>
<td>Needs wind to detect oil.</td>
</tr>
<tr>
<td>Fluorescence</td>
<td>An active sensor recording the release of fluorescent light</td>
<td>Oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Hyper-spectral laser-induced fluorescence (HLIF) LIDAR</strong> is an active sensor that utilizes a laser in the UV range. The laser excites molecules in certain hydrocarbon compounds to a higher energy state. When the compounds go back to their non-excited state they release fluorescent light that can be recorded by a receiver. It works effectively in icy waters.</td>
<td>Oil</td>
<td>For shipboard installations: 10-50 m; for fixed installations: up to 500 m. Horizontal range for airborne installation (300 m altitude): ± 75 m</td>
<td>Able to classify the oil type, also in the upper part of the water column. Able to measure the thickness of thin oil spills (in the range 0.1-20 µm).</td>
<td>Limited range of detection (at the line of sight).</td>
</tr>
<tr>
<td>Electro-magnetic reflection</td>
<td>Passive sensors that measure emitted energy at different wavelengths</td>
<td>Oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principle</td>
<td>Principle method description</td>
<td>Form of HC</td>
<td>Detection range</td>
<td>Ability to classify</td>
<td>Limitations</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>------------</td>
<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Infrared imaging (IR)</strong></td>
<td>A passive sensor that measures thermal energy emitted from oil and water in the infrared region. Two different types of IR cameras exist: Cooled and un-cooled cameras.</td>
<td>Oil</td>
<td>Up to 5 km depending on type of camera, environmental conditions, oil composition and slick age.</td>
<td>While it is difficult to estimate the thickness of an oil slick, the pictures can give indications of the thickest parts of the slick.</td>
<td>Cannot detect thin oil sheens. Operation is affected by fog and poor weather. Requires trained operator – reliable automatic detection not yet available.</td>
</tr>
<tr>
<td><strong>Microwave radiometer (MWR)</strong></td>
<td>A passive sensor that measures emitted microwave radiation</td>
<td>Oil</td>
<td>Maximum 1000 m.</td>
<td>Able to measure the thickness of the oil spill (50 µm-few mm).</td>
<td>Low spatial resolution. MWR requires a dedicated aircraft to accommodate a special antenna.</td>
</tr>
<tr>
<td><strong>Spectral scanners</strong></td>
<td>Passive sensors that analyse reflected solar light for a material</td>
<td>Oil</td>
<td>Able to give identifications of oil type (light/crude) and thickness of the oil slick.</td>
<td>Spectral scanners generate a large volume of data which limit their ability to provide near real-time data and images.</td>
<td></td>
</tr>
<tr>
<td><strong>Ultraviolet (UV) scanner</strong></td>
<td>A passive sensor that uses reflected sunlight in the UV region to detect oil spills</td>
<td>Oil</td>
<td>No</td>
<td>Needs sunlight to operate. Operation is affected by fog and rain. False positives can occur due to wind sheens, sun glint and sea weeds.</td>
<td></td>
</tr>
<tr>
<td><strong>Visual surveillance cameras</strong></td>
<td>(still pictures or video) Passive sensors that operate in the visible region of the electromagnetic spectrum</td>
<td>Oil</td>
<td>100 m – 2 km</td>
<td>No Light and weather dependent. Requires a trained operator.</td>
<td></td>
</tr>
</tbody>
</table>
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.