Use of risk assessments and performance requirements for selection of offshore subsea leak detection systems

Petroleumstilsynet

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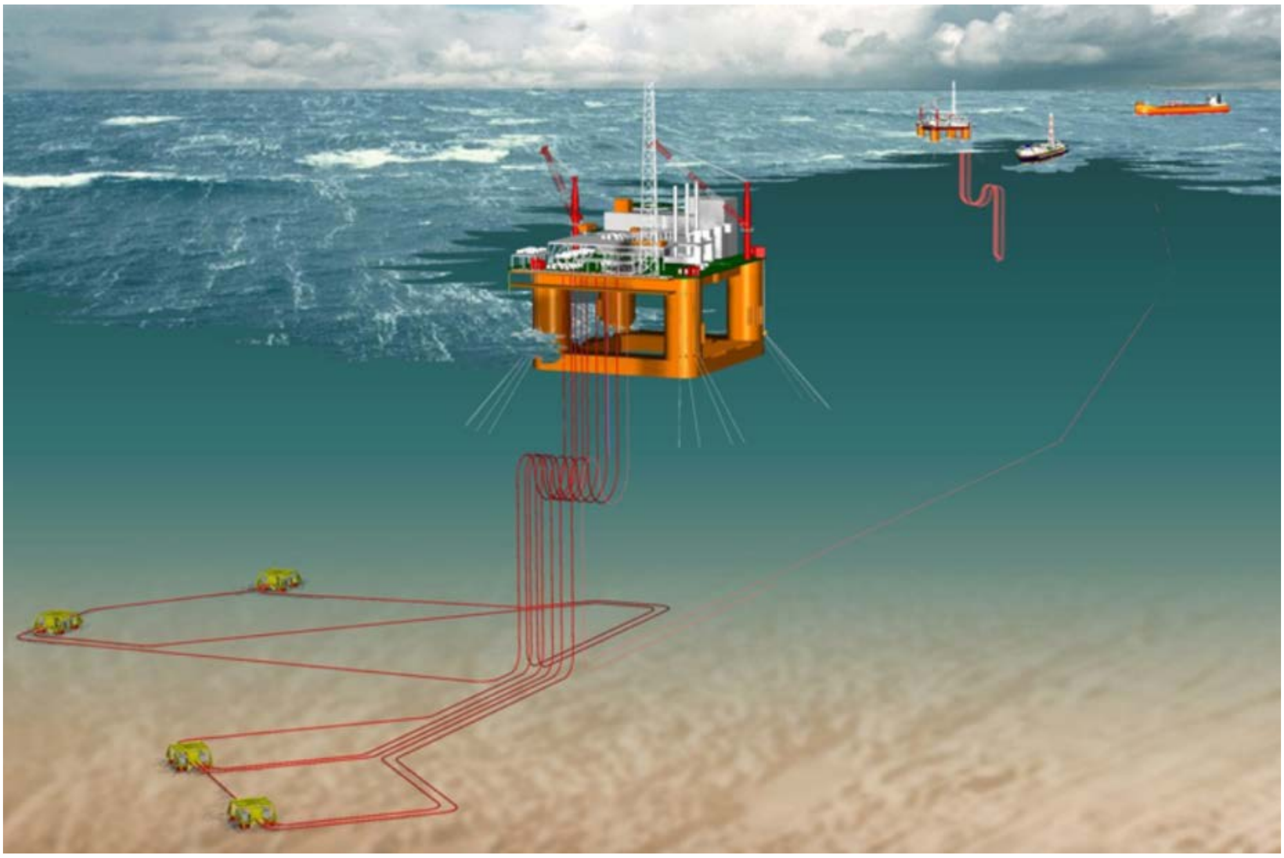

Project name:	PTIL – Saksnr. 17/1225	DNV GL AS Oil & Gas
Report title:	Use of risk assessments and performance requirements for selection of offshore subsea leak detection systems	Subsea Technology Veritasveien 1 1363 Høvik Norway Tel: +47 67 57 99 00
Customer:	Petroleumstilsynet, Postboks 599 4003 STAVANGER Norway	
Customer contact:	Roger L. Leonhardsen	
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Objective: The study aims to get an overview of the use of risk assessments and performance requirements when selecting leak detection technologies, and the focus is for subsea installations. The study will also get a status on the use of mass balance as a leak detection technology.

Prepared by:	Verified by:	Approved by:
Digitally signed by Rajesh Mistry Date: 2018.11.30 15:15:12 +01'00'		Berg, Kristin Nergaard Digitally signed by Berg, Kristin Nergaard Date: 2018.12.03 08:49:59 +01'00'
Rajesh Mistry Principal Engineer	Svein Gundersen Project Manager	Kristin Neergaard Berg Head of Section
Østbøll, Helene Digitally signed by Østbøll, Helene Date: 2018.11.30 22:23:14 +01'00'		
Helene Østbøll Principal Consultant		

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Keywords:
Leak detection, Risk assessment, Performance requirements, technology, subsea, mass balance

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DEFINITIONS AND ABBREVIATIONS

Abbreviations

Abbreviation	Description
ALD	Acoustic Leak Detection
ALVD	Acoustic Leak and Vibration Detection
AUVR	Autonomous under water robot/drone
ERA	Environmental Risk Assessment
FEED	Front end engineering and design
FMECA	Failure Mode, Effect and Criticality Analysis
HC	Hydrocarbons
HIPPS	High Integrity Pressure Protection System
HISC	Hydrogen Induced Stredd Corrosion
HMS	health, safety and environment
IR	Infra Red
JIP	Joint Industry Project
LDS	Leak Detection System
LSS	Leak Sonar System
MEG	Monoethylene glycol
NCS	Norwegian Continental Shelf
NOK	Norwegian currency
OSD	Oil Spill Radar
PSA	Petroleum Safety Authority Norway (Petroleumstilsynet, Ptil)
QRA	Quality Risk Assessment
ROV	Remotely Operated Vehicle
RP	Recommended Practice
R&D	Research & Development
SSC	Sulphide Stress Corrosion

Definitions

Term	Description
Autonomous leak detection system	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)
BAT (Best available techniques)	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: a) "techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; b) "available techniques" 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; c) "best" means most effective in achieving a high general level of protection of the environment as a whole

Term	Description
Detection	action or process of identifying the presence of something concealed; the act or process of discovering, finding, or noticing something
Detector	device that detects the presence of a fluid. It only indicates if the fluid is present or not
Fluid	subset of the phases of matter and includes liquids and gases
global leak detection system	system that remotely covers the whole field, e.g. satellite system
Integrator	party delivering the main assemblies and equipment including documentation in accordance with the scope of supply agreed with the operator
Leak/ leakage	accidentally loss or admittance of contents, (especially liquid or gas), through a hole or crack in a hydrocarbon production system content In this report 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.
Monitoring	process of systematically obtaining information over a period of time
Operator	party responsible for operating an asset or field
Sensor	device that measures a physical or chemical property, such as temperature, salinity humidity, wave height etc.
Point sensor	sensor that detects a leakage within its vicinity, but cannot determine the location of the leak
Sensor coverage	area that the sensor covers In this context: a) regional coverage: covers the entire field development or more b) area coverage: covers an extended area larger than local, but not full field coverage c) local coverage: covers a radius less than 10 m
Supplier	party that supplies goods

Verbal forms

Term	Description
shall	verbal form used to indicate requirements strictly to be followed in order to conform to this document
should	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required
may	verbal form used to indicate course of action permissible within the limits of the document

EXECUTIVE SUMMARY

DNV GL have performed a study on behalf of PSA Norway on the use of risk assessments and performance requirements when selecting offshore leak detection technologies. The focus has been on subsea installations. The study has also looked at the use of mass balance as a leak detection technology for subsea installations.

Operators of subsea installations on the Norwegian Continental Shelf (NCS) and suppliers of leak detection equipment were asked to answer a questionnaire related to the selection process of leak detection system. In addition, Aker BP ASA and Equinor Energy AS were contacted for a more detailed interview because of their large number of operating fields on the NCS. Two different sets of questions were prepared for the operators and suppliers. The questions were reviewed by PSA before they were sent out to the relevant companies. 7 out of 18 operators, and 7 out of 12 suppliers responded on the questionnaire.

Risk assessments – The main feedback is that risk assessments are performed in the development phase of a field, or when considerable changes and updates are made. The use of risk assessments in the leak detection process varies from operator to operator depending on experience and the maturity of the company. Operators with a long track record of activity on the NCS tend to have a good system with internal procedures and organizational structure regarding leak detection.

The feedback also shows that these assessments in many cases are performed late in the development process. A result of performing this late in the process is that the FEED already is in place, and this limits the possibilities for design requirements for many of the different leak detection technologies to make up a suitable and resilient system for the field.

Performance requirements – Setting the functional and performance requirements is the operators responsibility and shall take into consideration the environmental risk, hydrocarbons/chemicals properties, volumes, leak rate and detection time. The main feedback is that all operators that responded have developed functional and performance requirement for the leak detection. The operators and the suppliers confirm that the selected detection system fulfilled the requirements in the best way possible. The functional requirement was also expected to be the same throughout the field life time unless regulatory or technology improvements change specifications.

Mass balance as leak detection system – The main feedback is that most of the operators that responded have considered utilizing mass balance technology as leak detection. Process monitoring is part of the production monitoring, and the mass balance technology is often incorporated in to this.

Some of the advantages of mass balance as a leak detection method, is that it can use the already existing process instrumentation, it is not dependent on the weather and that the technology is mature. The method ideally requires steady state production, and is therefore inaccurate when the production is unstable, i.e. varying flow, density, composition, during start-up, shutdown etc. In general, the performance is better for detection of oil than for gas leaks, and multiphase flow tends to deteriorate the effectiveness. The detection time when utilizing mass balance as leak detection technology ranges from minutes to hours, as the performance of the system depends on the size of the leaks, hydrocarbon composition (i.e. oil, gas or multiphase), the stability of the production etc.

1 INTRODUCTION

DNV GL have performed a study for PSA Norway regarding offshore leak detection. The purpose of the study is to provide an updated status of the use of risk assessments and performance requirements when selecting leak detection technologies. The focus has been on subsea installations. The study has also looked at the use of mass balance as a leak detection technology for subsea installations.

There is a high number of subsea systems installed on the Norwegian Continental Shelf today, and with on-going projects and new discoveries, an increase in such systems is expected in the future. Per April 2016 around 450 subsea installations and around 750 subsea wells where in operation on the Norwegian Continental Shelf (Figure 1-1) (PSA Norway /Safetec, 2017). The subsea installations are often advanced concepts with complex structures, hence there is possibilities for failure in different equipment and parts of the system. The failure can lead to environmental and economic treats like unintended leaks or spill of hydrocarbons or chemicals and stop in the production.

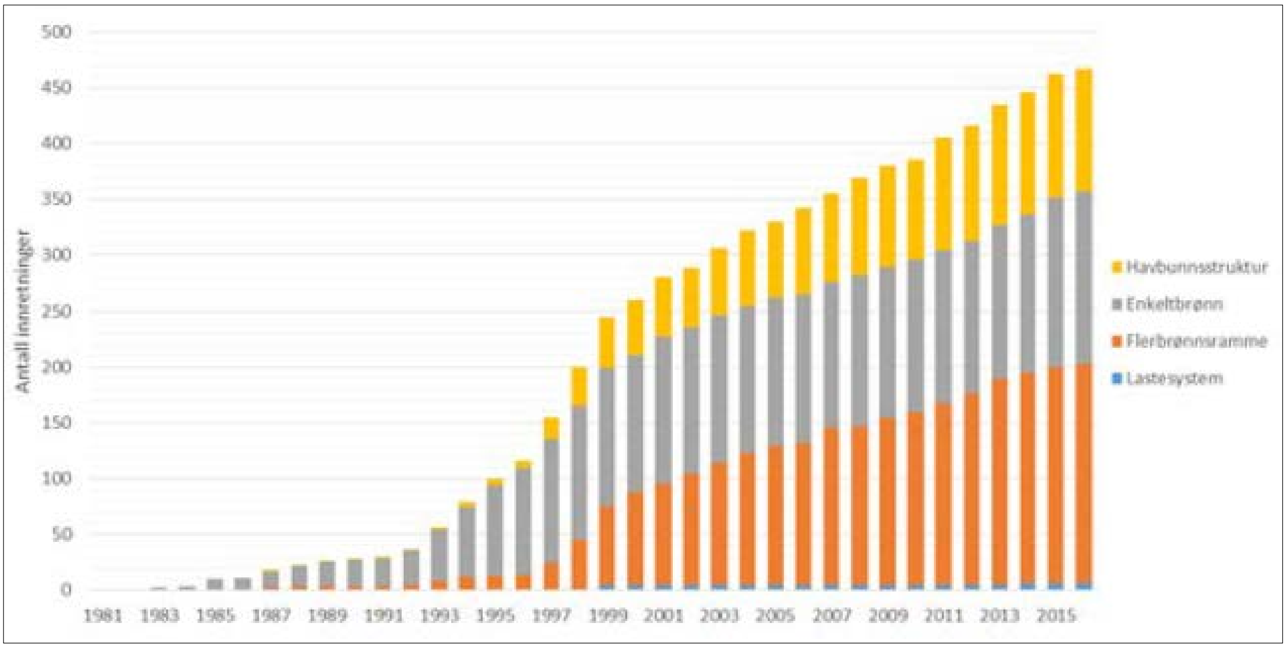

Figure 1-1 *Number of subsea installations on the Norwegian Continental Shelf (NCS) from 1981 to 2016. Yellow = subsea structure, grey = single wells, orange = template with multiple wells, blue = loading system (PSA Norway/Safetec, 2017).*

The RNNP AU report (PSA Norway /Safetec, 2017) shows that the number of incidents with spill of crude oil have declined in the period 2001-2016. The same trend applies to incidents that could have resulted in releases. However, looking at the period 2014 to 2016 in isolation, the report shows an increase regarding incidents in total (PSA Norway /Safetec, 2017). Based on this PSA will have a special attention on incidents related to well control, subsea installations and chemical spill in the coming years.

Regulations give requirements for resilient design of the systems to avoid failure and discharges, but experience shows that leaks of different volumes still happen. 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 a recommended practice (RP) for planning, designing, integrating and operating systems for offshore leak detection (DNV GL, 2016). For an operating field both technology and company requirements and procedures need to work well to get the best utilization and use of the leak detection systems. Figure 1-2 shows a recommended process flow for successful selection and implementation of leak detection technology (DNV GL, 2016).

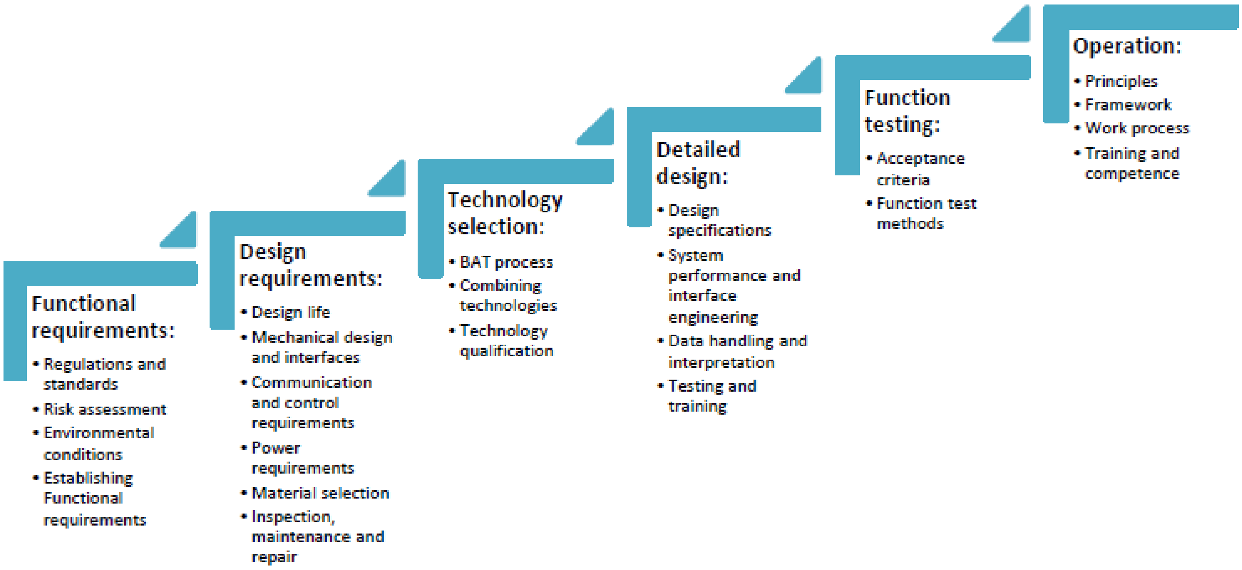

Figure 1-2 *Recommended process flow for successful selection and implementation of leak detection technology (DNV GL, 2016).*

Knowledge and experience is key factors for selection and implementation of leak detection systems for installations on fields. Many of the fields on the NCS today have been operating for a long time, and rules and regulations in their start-up phase may have been very different for what they are today. People with the knowledge of the process of selecting and implementing leak detection systems in the early phase for these fields may have retired or re-located. For these long operating fields, information regarding the original leak detection philosophy may be difficult to access.

In the process of finding the most suited system for a field or installation, a risk assessment shall be performed, and functional requirements shall be established. The operator shall have relevant equipment, routines and systems for detecting leakages on all subsea installations. Several different technologies for leak detection exists today, and it is important to work together with the suppliers to find the best solution.

2 DATA COLLECTION

The data that provide basis for the study were collected through submitting a questionnaire to operators of subsea installations on the Norwegian Continental Shelf (NCS) and suppliers of leak detection equipment. In addition, Aker BP ASA and Equinor Energy AS were contacted for a more detailed interview because of their large number of operating fields on the NCS.

2.1 Preparation

The questionnaire was prepared based on the objectives the PSA Norway had formulated for the leak detection study:

- To give an updated status of expectations to risk assessment and functional requirement for offshore leak detection - with a special emphasis on subsea production systems
- To provide a status on use of mass balance technology as a method for leak detection.

Two different sets of questions were prepared: one for operators and one for suppliers. The questions were reviewed by PSA before submission to the relevant companies.

The complete sets of questions can be found in section 2.1.1 and 2.1.2

2.1.1 Questions for operators

The full questionnaire for the operators can be found in Appendix B, and the questions are listed below.

- What type of leak detection equipment/systems are/will be installed on the different subsea installations that your company operates? Please list as follows: Subsea installation name + type of leak detection technology (e.g. Field X: Capacitance and Sniffer)
- Did you consider mass balance technology as leak detection system for any of the fields where this is not installed?
  - Yes, No, Other
- Do you have a functional specification or performance requirement for the subsea leak detection system/equipment?
  - Yes, No, Partly
- Are the requirements fulfilled?
  - Yes, No, Partly
- Who participated in the final selection of leak detection system in your company?
  - Colleagues (subject matter experts), Supplier, Other- please specify
- To what extent will the requirements vary during the field lifetime?
- Did you perform an environmental risk assessment identifying probable discharge scenarios including impact assessment on environmental resources for your field(s)? Please list the fields where a risk assessment was performed:
- Did the risk assessment define likely scenarios for small, medium and large leakages?
  - Yes, No, Other

- Did the risk assessment identify leak hotspots through failure mode, effect and criticality analysis (FMECA) or similar?
    - Yes, No, Other
    - Comments to the above
- What kind of leakages can be expected on the different locations?
- Where on the subsea installations are leakages most likely to occur? (e.g. Pipeline, template, connection point, etc.)
- Where on the installation are the sensors located?
- How small volumes can be detected and how soon can these be detected?
- Is there more than one sensor/unit installed on the subsea installations?
    - Only 1, 2-4 sensors/units, 5-7 sensors/units, More than 7
- Has any of the equipment detected any leakages?
    - Yes, No
- What is expected detection time for each technology on the field?
- What is your general experience with leak detection equipment?
- Are there any limitations that could be improved?

2.1.2 Questions for suppliers

The full questionnaire for the suppliers can be found in Appendix C, and the questions are listed below.

- What type of leak detection technology have you delivered to subsea installations?
- On which fields/installations are the leak detection system installed?
- How many units have you supplied for each field? Please list field, + type and number of sensor + year they were supplied/taken into use.
- How was your involvement in the selection process for leak detection equipment?
- Did your client have a functional requirement for the leak detection system?
    - Yes, No, Partly
- Does your leak detection system fulfill the client's functional requirements?
    - Yes, No, Not applicable, Partly
- Were you involved in any risk assessment process related to the selection of leak detection technology for your supply?
    - Yes, No, Partly
    - Please specify your involvement in the risk assessment
- What type of hydrocarbons can be detected by your sensors/systems? Please check all that apply.
    - Oil, condensate, gas

- What is the minimum volume/mass of hydrocarbons that can be detected by the different leak detection system your company supply? Please list the sensor type + minimum volume/mass of hydrocarbons that can be detected.
- What is the expected detection time for each of your leak detection system?
- Can you give an overview of where the leak detection sensors are located on the installation?
- What was the basis for the actual location of the sensors?
- If there are supplied several sensors for one subsea installation, what determined the number of sensors and their locations?
- In case a sensor fails, will this be detected and reported?
    - Yes, No, Other
- Do you know if there are other complimentary leak detection systems installed on the same field? If yes, please list them.
- Has mass balance technology been part of the evaluation for leak detection in any of your deliveries?
    - Yes, No, Other
- Can you give us technical specifications, dimensions, weight, sensitivity, need for power, tolerances etc. for the different leak detection sensor/systems you supply?
- Are there requirements for calibration and maintenance after the equipment have been taken into use?
    - Yes, No, Other
- What technology is currently being developed and will be available through your company within the next 2 years?
- What type of feedback have you got from your clients?

2.2 Submission and responses

An e-mail with an introductory text and a link to the questionnaire was submitted to 18 operators, and 12 suppliers. In total 38 e-mails were sent to one or several persons in the organizations. 14 of the persons responded to the questionnaire.

2.2.1 Operators

The following 18 operators were contacted:

Operator:	Operator:
A/S Norske Shell	Neptune Energy Norge AS
Aker BP ASA	OKEA AS
ConocoPhillips Norge	Point Resources AS
DEA Norge AS	Repsol Norge AS
Eni Norge AS	Spirit Energy Norge AS
Equinor Energy AS	Teekay Norway AS

Operator:	Operator:
Faroe Petroleum Norge AS	Total E&P Norge AS
Gassco AS	VNG Norge AS
Lundin Norway AS	Wintershall Norge AS

Some of the operators listed above may have changed name or merged with other operators. DNV GL has chosen to list the company names based on the e-mail address of the recipients.

Figure 2-1 gives an overview of the number of operators that responded versus the number of operators that did not respond to the questionnaire.

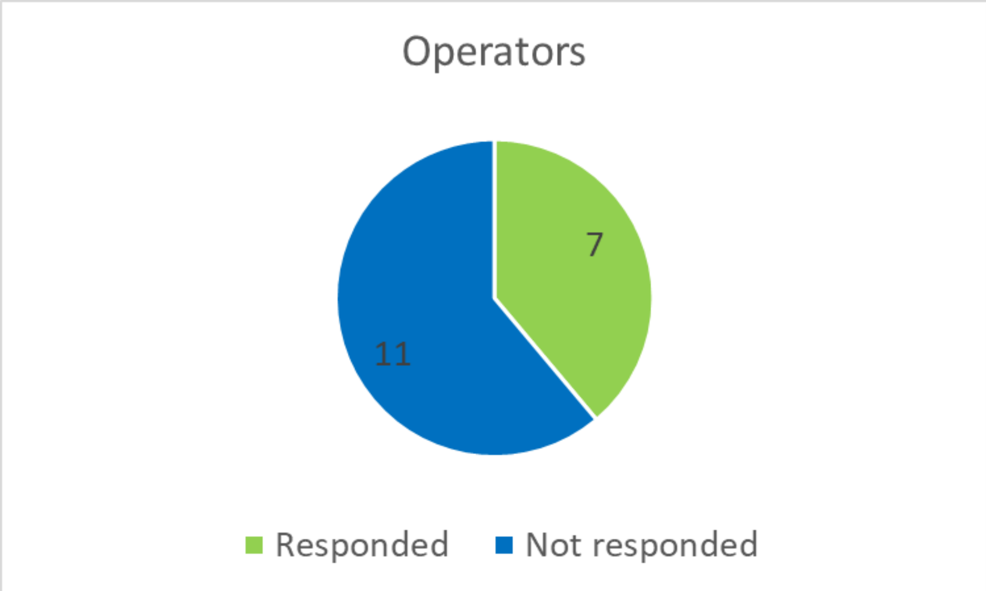

Figure 2-1 *Submission and response of operators*

2.2.2 Suppliers

The following 12 suppliers were contacted:

Supplier:	Supplier:
ABB AS	NAXYS AS (GE)
Aker Solutions AS	Norbit Subsea AS
Franatech AS	OneSubsea
IKM AS	PSO AS
Kongsberg Oil & Gas Technologies AS	STINGER AS
METAS AS	TechnipFMC

Some of the suppliers listed above may have changed name or merged with other suppliers. DNV GL has chosen to list the company names based on the e-mail address of the recipients.

Figure 2-2 gives an overview of the number of suppliers that responded versus the number of suppliers that did not respond to the questionnaire.

Figure 2-2 *Submission and response of suppliers.*

2.3 Follow up – Interviews

Aker BP and Equinor were interviewed in more detail, based on a selection of the questions from the questionnaires. 1-hr interviews were conducted to get a better insight of the leak detection system selected and the selection process for the various fields.

The following questions were focused on during the interviews:

- What type of leak detection equipment/systems are/will be installed on the different subsea installations?
- Is mass balance technology used as leak detection system for this field?
- Did you consider mass balance technology as leak detection system for this field?
- Did you perform an environmental risk assessment identifying probable discharge scenarios including impact assessment on environmental resources for the field?
- Did the risk assessment define likely scenarios for small, medium and large leakages?
- What kind of leakages can be expected (oil, gas, condensate)?
- Where on the subsea installations are leakages most likely to occur? (e.g. Pipeline, template, connection point etc.)
- Where on the installation are the sensors located?
- Is there more than one sensor/unit installed on the subsea installations?
- Have any of the equipment detected any leakages?

3 LEAK DETECTION TECHNOLOGIES

3.1 Background

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. The Activities regulations section 57 states that “the operator shall establish a remote sensing system that provides sufficient information to ensure that acute pollution is as quickly as possible discovered and mapped so that the position, area, quantity and properties can be determined".

According to DNVGL-RP-F302, the sensor coverage is classified as:

- **Regional coverage**, i.e. covering the entire field development or more.
- **Area coverage**, i.e. covering a large area of the field, but does not cover the entire field.
- **Local coverage**, i.e. covering the area close to the sensor.

Different technologies for leak detection are available today, as illustrated in Figure 3-1. The leak detection techniques are categorized in subsea- and surface-based leak detection techniques, and Table 3-1 includes both techniques and devices. Appendix A gives a high-level comparison of the different technologies for both surface and subsea detection.

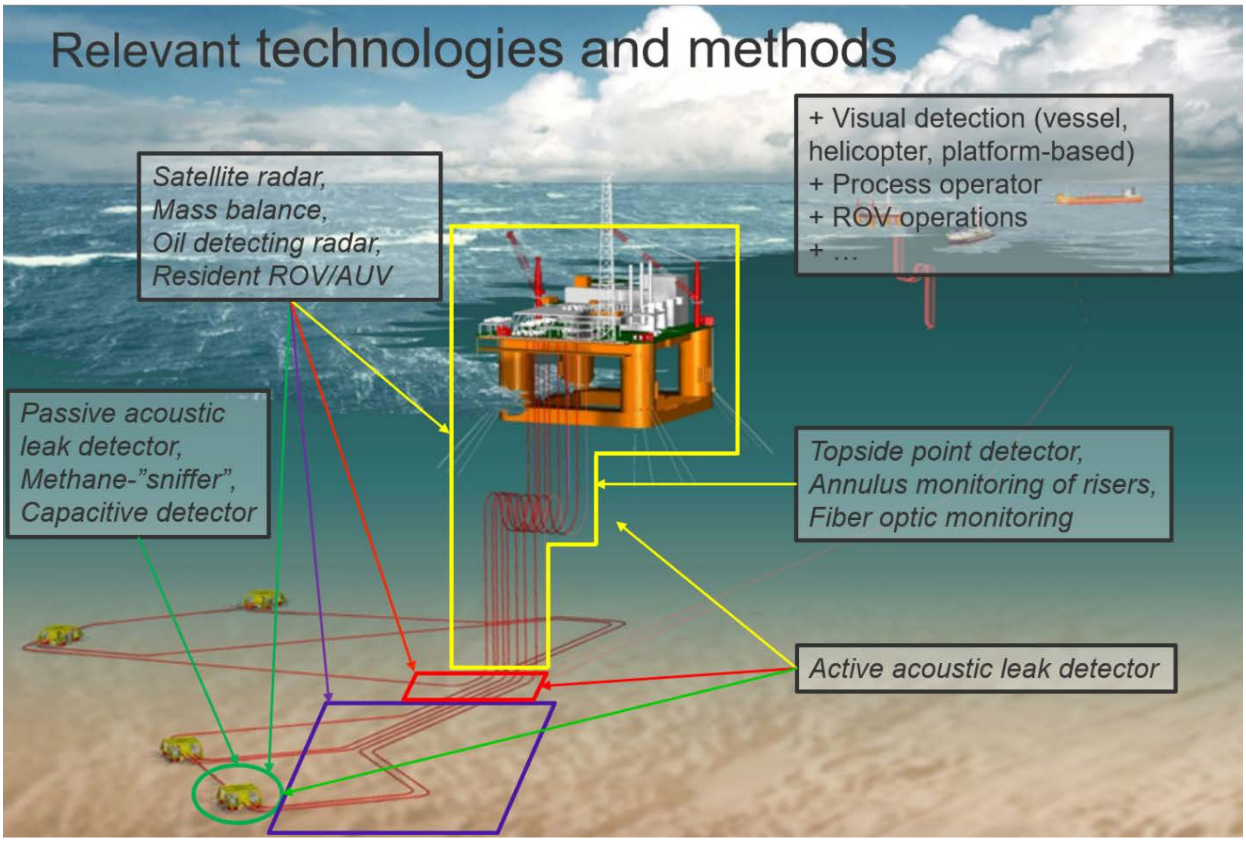

Figure 3-1 *Examples of some relevant technologies and methods (This and front-page illustration by courtesy of Equinor).*

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.

Table 3-1 *A list of available subsea and surface leak detection techniques.*

Leak detection techniques	
Subsea	**Surface**
Active acoustic	Radar
Capacitive sensor	Ground-penetrating radar
Fibre optic	Navigation radar with oil spill detection
Fluorescent	Side-looking airborne radar
Internal leak detection system/ mass balance	Synthetic aperture radar
Volumetric collection	Fluorescence
Methane sniffer	Hyper-spectral laser-induced fluorescence LIDAR
Semi-conductor	Electromagnetic reflection
Optical NDIR	Infrared imaging
Laser absorptiometry	Microwave radiometer
Optical camera	Spectral scanners
Passive acoustic	Ultraviolet sensor
	Visual surveillance camera

Based on the survey done by DNV GL in 2015 in connection with the leak detection JIP, the dominating leak detection technologies on NCS were passive acoustic and capacitive sensors.

3.2 Questions and response

3.2.1 Technologies in use today

For operators the questions regarding technologies in use today where:

Question operator: What type of leak detection equipment/systems are/will be installed on the different subsea installations that your company operates? Please list as follows: Subsea installation name + type of leak detection technology (e.g. Field X: Capacitance and Sniffer)

- The feedback supports the knowledge collected in 2015 that the main leak detection technologies on the NCS are passive acoustic and capacitance.

Question operator: What is your general experience with leak detection equipment?

- Leak detection systems needs to be followed-up with regards to alarm handling procedures, competence, training and tuning of system.
- Reliability is generally far too poor given the low expected frequency of leaks.
- Some gaps in robustness (availability of components).
- Accuracy (estimate of leak rate and location) is often poor or missing.
- Additional parameters, e.g. spatial coverage and cost, are generally in need of improvement.
- Thorough follow-up of systems including alarm handling procedures, as well as cross-referencing of methods, in order to avoid actual leak events being missed due to low trust in the system. Competence, training and tuning are all necessary elements in a fully functional system.
- The system needs regular calibration to avoid false alarms.

Question operator: Are there any limitations that could be improved?

- There is a wish for a system that could be able to detect any leaks (both hydrocarbons and chemicals, and both small and larger volumes). In a cost-benefit perspective, this is not applicable today.
- Certain new methods may represent a step change in performance for leak detection, but for existing methods there is limited room for improvement. The largest potential for improvement lies in improved cross-referencing among already installed methods, including operator-based evaluations.
- Focus on human interface and operational evaluations.
- Some of the newer operators have limited experience to answer the question.

For suppliers the questions regarding technologies in use today where:

Question supplier: What type of feedback have you got from your clients?

- Overall the feedback from the clients to the suppliers are positive and that the systems are working as intended. On some installations there are false alarms, and this is in most cases due to wrong tuning of the system and to background noises. One supplier points out that there in some cases are a lack of operational procedures for alarm handling, and that the operational engagement to leak detection seems to be based on personal initiatives.

Question supplier: In case a sensor fails, will this be detected and reported?

- All suppliers answer yes.

Question supplier: Do you know if there are other complimentary leak detection systems installed on the same field?

- The replies indicate that for most fields on the NCS, the requirements and complexity of the field make it impossible to only have one system. For each field a leak detection philosophy should be made, and technologies complimentary to each other are installed to make a resilient system.

Question supplier: Can you give us technical specifications, dimensions, weight, sensitivity, need for power, tolerances etc. for the different leak detection sensor/system you supply?

- The leak detection sensors/systems available today varies a lot in functionality and size. The replies are diverse, from details not available to detailed information on systems with weight from 30-900 kg (in air), integrated systems, systems with different technical specifications and variation in need for power and tolerance.

Question supplier: What type of leak detection technology have you delivered to subsea installations?

- The suppliers that replied delivers different technologies like ROV and other mobile equipment, hydrocarbon sniffers, active- and passive acoustic sensors, integrated LDS, Leak sonar systems (LSS), fluorescent laser and analysis software (to remove background noise and inform when leakage are above pre-set limits).

Question supplier: On which fields/installations are the leak detection system installed?

- The suppliers of acoustic systems deliver to a long list of fields on the NCS. Sniffers are delivered and installed on Valhall. Leak detection sonar systems (LSS) will be installed on Troll next year.
- Suppliers of ROV and other equipment that is not stationary delivers the equipment to the operator and do not know on what installation or field they are used.

3.2.2 New technologies

A lot of different leak detection technologies exist today as listed in chapter 3.1 and Appendix A, but new and approved technology is being developed all the time. To get an indication on what will be seen in the near future, one of the questions for the suppliers where:

Question supplier: What technology is currently being developed and will be available through your company within the next 2 years?

- A few of the suppliers answered with no answer/confidential.
- Digitalization - use of a wider range of measurements and combining information from various systems could result in improved LDS (leak detection system) solutions.
- Further enhancement of subsea condition monitoring capacity by use of machine learning/digitalization, e.g. choke cavitation, slug detection, structural integrity monitoring (vibrations). These are all related to software updates and will use existing hardware platform; thus, enhanced functionality can be achieved by software upgrades.
- One supplier is currently developing next generation LSS with project name L-BAS (NCR supported Project # 259190). This is a joint R&D project in cooperation with Petrobras and UFRJ (University Federal Rio de Janeiro) in Brazil. In Norway; Kongsberg Maritime, Aker Solution and CMR are partners. The L-BAS Project is focusing on CO_2 and Methane leakage at depths down to 3000 meters, in addition to oil and gas. Improved acoustic technology and analysis software application customized CO_2/Methane detection. This system will be the next generation LSS with improved specifications and operational depths down to 3000 meters for oil, CO_2 and Methane. L-BAS will also be customized and available for P&A, Plug and Abandonment (-shut down wells)

- Active, passive acoustics, laser.

During interviews with selected operators, some additional information of on-going tests and studies for new/approved technology was received:

- Active acoustic sensors using echo sounder will be tested in 2019.
- On-going development for radar on platform.
- Methane sniffers have since 2013 been integral and permanent part of the Operation Safety System at Valhall. More testing of methane sniffers is currently being performed.
- Autonomous under water robot/drone (AUVR). Testing is on-going. Diffuse leaks are usually being discovered by routine inspections or by operations being done close by. By using an AUVR the frequency for inspections can be higher, and the AUVR can move around and continuously look for leaks from subsea field installations and pipelines. The system is so far not integrated in the control system but can send data to the facility (CCR). The AUVR will be permanently stationed under water. They can work if needed, or otherwise charge at a charging stations. The charging stations are using electromagnetism, and the AUVR can also send information and pictures to control rooms onshore via the charging stations.

Other technology development and testing may currently be performed, so please note that the summary of new technologies in this report is purely based on the feedback from the questionnaires and interviews.

3.3 Conclusions

A lot of different leak detection technologies are available today from no-stationary equipment like ROV to large and heavy sensors stationed on or close to the templates or other subsea installations.

During the leak detection JIP in 2015, an overview of installed LD technologies was collected, and it showed that capacitance and passive acoustic sensors dominated in number of fields and number of sensors. Methane sniffers are currently tested out on selected fields and will according to the feedback be installed on several fields in the coming years.

Technology are constantly in development and the suppliers are improving existing technologies as well as developing new technologies. Automatization and unmanned equipment is in focus, and the AUVR is one technology that shows promising possibilities as part of the leak detection systems in the future.

4 MASS BALANCE USED AS LEAK DETECTION METHOD

4.1 Background

Mass balance as a leak detection method is based on monitoring the pressure/flow drop between pressure sensors and flow meters installed in the subsea production system or pipeline. Comparing flow in and out of the system will reveal significant loss of flow (leaks). If the imbalance exceeds a pre-set threshold, it will generate an alarm. The system provides continuous monitoring and will alert within minutes to one/several hours depending on leak size and location. Large leaks may for example be detected within minutes with correct system configuration, while smaller leaks may take longer time to detect, or may not be detected until scheduled ROV inspection detects it visually. The interviews have indicated that so far, this method has mostly been used for pipelines and not for subsea production systems; and it has only been able to detect medium and large leaks – typically leaks greater than 5 % of the total flow.

The interviewees have also indicated that the method requires steady state production, and is therefore inaccurate when the production is unstable, i.e. varying flow, density, composition, during start-up, shutdown etc. In general, the performance is better for detection of oil than for gas leaks, and multiphase flow tends to deteriorate the effectiveness.

Furthermore, the method requires a software for collecting data, and for flow/pressure drop modelling. Proper configuration/modelling is crucial in order to achieve required/optimal leak detection.

Some of the advantages of mass balance as a leak detection method, is that:

- it can use the already existing process instrumentation (e.g. pressure and flow transmitters)
- it is not dependent on the weather
- the technology is mature.

The operators have communicated that the system has generally good uptime when its configurated properly, and its considered to be a good method when the production rates are high and stable.

The disadvantages of the method, as communicated by the operators, are the following:

- low sensitivity of the system,
- system is inaccurate during multiphase flow, and in these situations,
- it is challenging to configurate/tune the system accurately to avoid false alarms.

4.2 Questions and response

For operators the questions regarding mass balance where:

Question operator: Did you consider mass balance technology as leak detection system for any of the fields where this is not installed?

- Yes, most of the operators have considered and utilizing mass balance technology as leak detection. Process monitoring is already part of the production monitoring, and the mass balance technology is often incorporated in to this.

Question operator: Where on the installation are the sensors located?

- Mass balance is generally located at end points of the production systems, i.e. in the pipelines.

Question operator: What is expected detection time for each technology on the field?

- The detection time when utilizing mass balance as leak detection technology ranges from minutes to hours, as the performance of the system depends on the size of the leaks, hydrocarbon composition (i.e. oil, gas or multiphase), the stability of the production etc.

For suppliers the questions regarding mass balance where:

Question supplier: Has mass balance technology been part of the evaluation for leak detection in any of your deliveries?

- Mass balance is generally *not* part of the supplier evaluation but is part of the operators' evaluation process.

Question supplier: Do you know if there are other complimentary leak detection systems installed on the same field?

- Integrated mass balance system, CCTV, radar and satellite as a total leak detection system is planned for some fields.

4.3 Conclusion

With the information stated in section 4.1 in mind and based on the information gathered from the operators and suppliers of leak detection systems, it can be concluded that the mass balance technology is in general deemed as a system with low failure rates. With its advantages, it is a method that is and has been considered as leak detection system for the different fields.

The use of mass balance requires a good understanding of the process system, and therefore training of personnel to increase their understanding and competence of the systems will, among others, enable correct tuning of the system, and thus get a more functional and reliable system.

The interviews have indicated that the operators have had good experience in utilising mass balance as leak detection method on Troll/Fram and Ivar Aasen field, where the production rates are high and stable.

The technology requires "tuning in" as the production rate and composition changes over time, and a lower limit for leak needs to be re-calibrated.

5 RISK ASSESSMENTS RELATED TO LEAK DETECTION

5.1 Background

The operators are required to have an overview over all potential risk their activity might represent to human safety and on the environment. Norwegian authorities require use of leak detection techniques to detect a potential oil spill at an early stage, which in turn could minimize the consequences of an acute oil pollution. The purpose of remote sensing systems for leak detection, is to ensure that acute oil pollution of significance is detected within a satisfactory period of time, mapped, assessed and notified so that necessary measures can be taken.

The process recommended for successful selection and implementation of leak detection technology in offshore fields for hydrocarbon production, recommends the operator to prepare a leak detection philosophy as early as possible in the process to describe their high-level ideas and intentions for leak detection. The first step in the process is setting functional requirements, and risk assessments are a part of these requirements (see Figure 1-2).

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

- **Environmental risk assessment** calculating probable discharge scenarios and impact on affected environmental resources. The environmental risk assessment 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. The proximity to sensitive resources on the seabed, such as corals or sponges, will also have an impact on the decision of number of sensors on the subsea installations.

Required tolerance for the leak detection system integrity and performance to environmental conditions shall be also defined, and in addition technologies may require specific environmental conditions that they will be sensitive to, like natural seepage and acoustic noise.

5.2 Questions and response

5.2.1 Environmental risk assessment

For operators the questions regarding risk assessment where:

Question operator: Did you perform an environmental risk assessment identifying probable discharge scenarios including impact assessment on environmental resources for your field(s)?

- The feedback shows that the operators perform environmental risk assessments for their activity both because it is a regulatory requirement but also because it gives the operator an indication on what risk their activity may possess to the environment. The replies indicate that the risk assessments are performed in different phases of the project, and in some cases too late to be a part of the design phase. To get the best use of an ERA to support the leak detection philosophy, it should be performed in an early phase of the development project (see Figure 1-2).

For suppliers the questions regarding risk assessment where:

Question supplier: Were you involved in any risk assessment process related to the selection of leak detection technology for your supply?

- The answers show that about 50 % of the suppliers have been fully or partly involved together with the operator in the risk assessment process.

Question supplier: Please specify your involvement in the risk assessment.

- The involvement varies from meetings with operator and government, to participation in risk assessments and TRL (Technology Readiness Level) and evaluations of model robustness. The answers also depend on how mature the suppliers' technology are, and how long the equipment have been available in the market.

5.2.2 Leak scenario identification and leak hotspot identification

For operators the questions regarding leak scenarios where:

Question operator: Where on the subsea installations are leakages most likely to occur? (e.g. Pipeline, template, connection point, etc.)

- Leakages are most likely to occur on different locations on the fields from templates to import and export pipelines. The replies listed; templates, pipelines, riser base (near host), connections, connection points, X-mas tree, flanges, spools, valves, choke valves and control modules.

Question operator: Did the risk assessment define likely scenarios for small, medium and large leakages?

- All operators performed risk assessments, and the risk assessments defines the likely scenarios for small, medium and large leakages.

Question operator: What kind of leakages can be expected on the different locations?

- The operators reply that it is difficult to generalize and that it varies from small leakages through flange connections to full blown ruptures of pipeline and risers, and blowout scenarios (leak from well stream).
- The leaks would be of hydrocarbons (oil, gas, condensate), chemicals, hydraulic oils, water based hydraulic fluids, MEG, drilling and completion fluids, and leaks of chemicals during pre-commissioning of flowlines/pipelines.

Question operator: Did the risk assessment identify leak hotspots through failure mode, effect and criticality analysis (FMECA) or similar?

– The replies from the operators states that FMECA was performed. One operator did not know but assumed this was performed by contractor. Classical ERA's do not cover FMECA, but leak detection risk analysis performed indirectly account for failure mode and hotspots.

For suppliers the questions regarding leak scenarios where:

Question supplier: What type of hydrocarbons can be detected by your sensors/systems (oil, condensate, gas)?

– Oil, condensate and gas, depending on the equipment.

Question supplier: Can you give an overview of where the leak detection sensors are located on the installation?

– The leak detection sensors are located on different places on the field, depending on the type of equipment. Not stationary equipment is stored on installations or vessels. The sniffers at Valhall are located on nodes around the risers. Acoustic equipment (and laser) can be located on the manifold or on x-mas tree, surrounding the conductor cluster or on subsea installations, near installations and on ROV or AUV. Leak detection sonar systems stand alone for scanning a certain area or is integrated on existing installations. Mass balance is typically installed by inlet (FT upstream choke + PT/TT/DT downstream choke) or outlet (PT/TT/DT upstream choke + FT downstream choke).

Question supplier: What is the minimum volume/mass of hydrocarbons that can be detected by the different leak detection system your company supply? Please list the sensor type + minimum volume/mass of hydrocarbons that can be detected.

– Suppliers replies reflect a claim that the different sensors were able to detect very small leakages within a very short time (seconds) provided the sensors are located close to the leak. Typically, the hydrocarbon sniffer can detect 0,05 l/min gas leak at 300 m water depth and oil down to 0,005 l/min at the same water depth. Methane sensor detects 20nMol/l- 1 microMol/l with a standard range 50 nMol/l – 10 microMol/l. Detection time is almost immediate under ideal conditions.

Question supplier: What is the expected detection time for each of your leak detection system?

– Detection time is almost immediate (in seconds) under ideal conditions. The detection time can vary depending on whether the system is set to monitor a specific area or to scan a sector, and if it will monitor the complete water column from seabed to surface.

5.3 Conclusions

The answers from the operators that replied indicate that risk assessments are performed in the projects. The replies also show that the design and material selection of subsea installations is robust and there are very few leakages during normal operating conditions. The risk assessments are either project specific or based on industry recommendations like Scandpower's LCR data dossier and the Recommended failure rates for pipelines – DNVGL-2017-0547.

Leaks are difficult to generalize, and it varies from small leakages through flange connections to full blown ruptures of pipeline and risers, and blowout scenarios (leak from well stream). The leaks could be of hydrocarbons (oil, gas, condensate), chemicals, hydraulic oils, water based hydraulic fluids, MEG, drilling and completion fluids, and leaks of chemicals during pre-commissioning of flowlines/pipelines.

Leakage will typically occur in connections such as flanges and connectors, seals, valves and welds. The operators reported back possible leakage scenarios and possible causes for these leaks. The possible scenarios are listed in Table 5-1. The general impression is that leakages will/can occur if the equipment and system is operating outside the design limitations, and often in relation with intervention or other work being carried out on the installation. Other leakages that is registered are leakages from flexible risers. Leakage caused by material failure, corrosion, cracking or loads exceeding design load can in principle occur anywhere and is therefore harder to identify.

Table 5-1 *Common leak scenarios and cause of leakage on subsea systems.*

Leak scenario	Cause of leak
Small leaks from flanges	Seal or bolt failure, Incorrect torque, Damage seal faces etc., Incorrect operations, Incorrect valve status during intervention, overpressure and overload
Material related leakages	Fatigue, corrosion, erosion, HISC, SSC
Mal-operation leaks	Incorrect valve status during intervention
Over pressurization leaks	Failure of HIPPS
Out of design external loads leaks	Trawl, anchor impact, dropped objects

Recent development projects on the NCS are focusing on cost savings and reports back with savings of billions of NOK. It will be speculative to say that this savings makes the subsea production units less resilient, but the annual reporting for fields in operation in the coming years will show if there is an increase in leak incidents.

6 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

6.1 Background

Functional requirements shall be defined by the operator and shall be a description of the system functions and their performances. The functional requirements shall consider operation, maintenance and function testing. Requirements should be set on a field specific basis.

The functional requirements shall be in accordance with; relevant authority regulations and standards, performed risk assessments and environmental conditions. Key parameters for defining high level functional requirements are:

- 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.

An example of typical values used in specifying functional requirement for a leak detection system is shown in Table 6-1. This is just to show what functional requirements may be, but the operator have to set specific functional requirements for each of their fields in operation.

Table 6-1 *Example of typical values used in specifying functional requirement for a leak detection system (DNV GL, 2016).*

Functional requirements	Typical values or units
Minimum leakage rate to be detected	[m^3/hr] or [% of production flow] or [bar DP]
Location of leakage source	'Yes' or 'No', accuracy +- [m]
Position and extent of leaked fluid	Position, [m^2]
Detection range	[m], [m^2]
Detection time for the minimum leakage within the specified range	[s]
Type of fluid and fluid concentrations to be detected	'Condensate', 'Light oil', 'Heavy oil', 'gas'
Classification or leaking fluid	'Yes' or 'No'
Availability	[% uptime], [other reliability measure]

Subsea equipment has particular challenges related to access, space and retrofit and the requirements to mechanical design shall therefore be defined early in the engineering phase. Particular consideration regarding maintenance and/or replacement of critical parts subsea shall be made.

6.2 Questions and response

For operators the questions regarding functional and performance requirements where:

Question operator: Do you have a functional specification of performance requirement for the subsea leak detection system / equipment?

- All replies were yes on this question. One operator with a high number of subsea wells added the following information; functional specifications and performance requirements have always been issued, covering some, but not all, desired performance parameters.

Question operator: Are the requirements fulfilled?

- All replies from operators said yes to this question, except for one where the system is not yet installed on their field. One operator added that in some cases, early versions of passive acoustic leak detectors and of capacitance HC leak detectors did not perform according to requirements, due to either faulty sensors or poor installation.

Question operator: To what extent will the requirements vary during the field life time?

- Most of the replies indicated that the requirements will be constant during the field life time unless regulatory or technology improvements change specifications.

Question operator: How small volumes can be detected and how soon can these be detected?

- The replies indicated that it is difficult to quantify this value, and that this will vary between the different type of technologies, and on the production and pipeline systems.

Question operator: Is there more than one sensor / unit installed on the subsea installations? (Only 1, 2-4 sensors / units, 5-7 sensors / units, More than 7).

- Number of sensors on the units are dependent on the type and size of the field and varies from only 1 to more than 7 sensors.

Question operator: Has any of the equipment detected any leakages?

- One operator answered yes.

For suppliers the questions regarding functional and performance requirements where:

Question supplier: What was the basis for the actual location of the sensors?

- The basis for the sensor location is dependent on the type of sensor and is based on performance analysis prior to installation. In some cases, it is the EPC contractor that decides the best location. This is dependent on the actual installation.

Question supplier: If there are supplied several sensors for one subsea installation, what determined the number of sensors and their locations?

- Performance Analysis Prior to installation.
- Sufficient accuracy for each segment (either fully instrumented or combined with simulation model).
- Test and redundancy.

Question supplier: Did your client have a functional requirement for the leak detection system?

- In most cases the equipment supplier's reply's that they have been given a functional requirement by their client, only one had not been given such requirement.
- One of the suppliers said that "in some cases we have seen functional requirement such as requirement for leak detection system to cover a wide area (entire subsea installation) and capability to indicate leakage location"

Question supplier: Does your leak detection system fulfil the client's functional requirements?

- All suppliers confirmed that their LDS fully or partly fulfilled the requirements. Suppliers of no stationary equipment answered not applicable.

Question supplier: Are there requirements for calibration and maintenance after the equipment has been taken into use?

- The replies indicate that warning and alarm thresholds is set to in-situ conditions for the equipment, and that it is recommended to perform regular system maintenance (system status, sensor status, communication status, history logs, performance and improvement). For the integrated LDS, models based on physical measurements, and statistical models there will be requirement for calibration.

Question supplier: how many units have you supplied for each field? Please list field, + type and number of sensors + year they were supplied / taken into use.

- For no stationary equipment, no permanent LDS are installed. One of the suppliers of acoustic leak detection sensors have delivered between 1 and 7 sensors for 30 different fields on the NCS and are contracted to deliver between 1 and 2 sensors the next years for 6 fields in development. 11 sniffers are installed on Valhall. The replies also indicated that some of the suppliers have been/are involved in many different projects on the NCS, both upgrading for existing fields and in new developments.

6.3 Conclusions

Setting the functional and performance requirements is the operators responsibility and shall take into consideration the environmental risk, hydrocarbons/chemicals properties, volumes and leak rate. Functional requirements shall be defined by the operator and shall be a description of the system functions and their performances. The functional requirements shall consider operation, maintenance and function testing.

The replies from the operators and suppliers indicate that functional and performance requirement for the leak detection systems have been developed, and that the selected LDS fulfilled these requirements in the best way possible. The functional requirement was also expected to be the same throughout the field life time unless regulatory or technology improvements change specifications.

For subsea installations, the feedback states that a reliable leak detection system should consist of a combination of local sensors placed on the installation in combination with an integrated system or a surface system. Feedback from the use of local sensors like capacitance and acoustic is that they often generate false alarms and that tuning and calibration for each installation is important for the system to work optimal.

The Leak Sonar System (LSS) have been tested on the Kristin field to see that the system delivered according to specifications and requirements. The feedback from the test was positive, confirming that the LSS detected even small leakages at both short and long distances. The main difference between LSS and existing hydrophone systems, is that the LSS do not depend on any noise generated by the leakage but receive reflections from powerful pulses transmitted into the monitored water column. These reflections have the same frequencies as transmitted frequencies and making the system much more confident, since noise generated by operations in the area do not affect the frequency used.

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. The proximity to sensitive resources on the seabed, such as corals or sponges, will also have an impact on the decision of number of sensors on the subsea installations.

Small leaks from subsea installations and installations with lower probability for leaks (like pipelines) may be difficult to detect if they are below what process monitoring and mass balance methods can detect. The environmental consequences of a small leak on the surroundings depend on the volume and the vicinity to sensitive environmental resources. Small volumes will probably dilute and disappear in the water masses because of natural weathering of the hydrocarbons. Still there are in the operators' best interest to have full control of their activities regarding equipment, environment and production.

Through the NOFO agreement the operators have access to satellite surveillance pictures every 24-27 hours if needed. But for satellites to detect leaks from subsea systems, the leak must reach the surface. Some small leaks will never reach the surface and hence not be detected by the satellites. It is possible to model a wide range of releases of hydrocarbons and see if and when the hydrocarbon may reach the surface depending on the volume leaked, but a more effective way to detect these leaks will be if the mass balance systems where developed to be able to detect also smaller leaks.

7 TECHNOLOGY SELECTION PROCESS

7.1 Background

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 economic considerations as well as project and site-specific conditions. 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.

Effective detection of potential leakages is dependent on the design integrity of the leak detection system ensured in the design phase. The technical integrity and operational integrity shall be ensured during the operation phase, see Figure 7-1 (DNV GL, 2016).

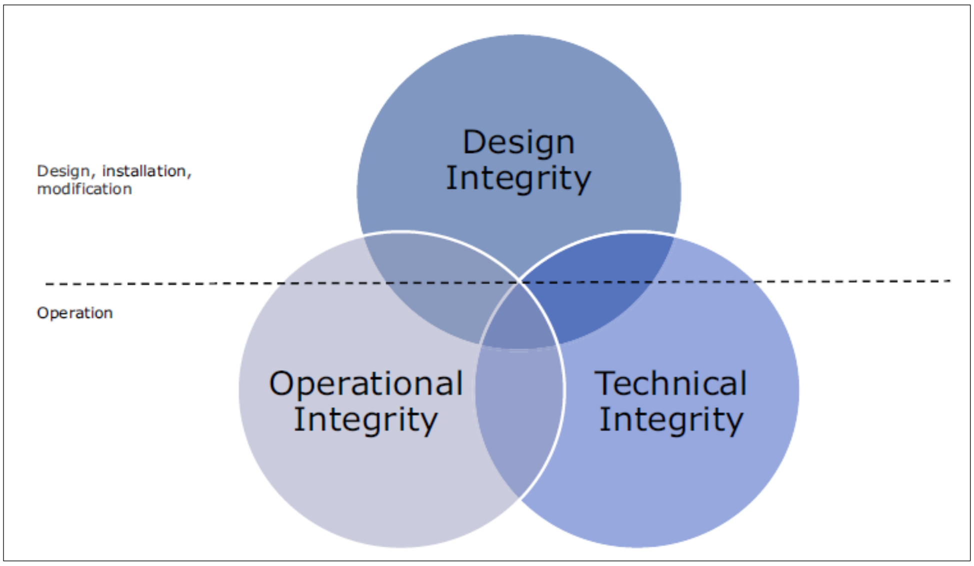

Figure 7-1 *The three elements ensuring that a leak detection system functions as intended (DNV GL, 2016).*

7.2 Questions and response

For operators and suppliers, the questions regarding technology selection process where:

Question operator: Who participated in the final selection of leak detection system in your company?

- The selection was made by colleagues, subject specialists and dedicated project team in the company.

Question supplier: How was your involvement in the selection process for leak detection equipment?

- The suppliers were involved to a varying degree in the selection process, from just being selected as supplier to being involved in the project together with the operator and to be involved in R&D and designing of new technology.

7.3 Conclusions

DNV GL's RP recommends doing risk assessments and set the functional requirements as the first step in the leak detection philosophy for a field. In this way the field can be designed to the meet the functional requirements in the best way possible, and leak detection equipment can be tested and adapted to ensure optimal coverage and detection for the field.

All operators confirm that risk assessments were carried out as part of the process of selecting leak detection equipment, but that the assessments were performed during different phases of the project. The replies also indicate that the final selection of the LDS is done internally by the operators' project team. For operators with a long track record of production on the NCS, internal procedures and guidelines are in place, and the process of selecting leak detection systems are well integrated in the development projects. For smaller or more unexperienced operators the selection process of LDS varies from project to project.

The suppliers were involved to a varying degree in the operators' selection process. Only half of the suppliers that replied had participated in a selection process. They were involved to a varying degree, from giving supportive information of their equipment to being involved with contracting companies for detailed design and integration of leak detection on the subsea installations.

Experience from this study and other projects have shown that in many cases the leak detection philosophy is included late in the development and FEED phase, and this will often limit the number of technologies suitable for the field design. The optimal LDS meeting all requirements for the field in question is easier to select if there is a large number of technologies available when performing a BAT I process (selection of available/acceptable technologies). Then in the configuration assessment (BAT II) the combination of technique(s) should be considered in a holistic approach, with a conservative evaluation of the different evaluation segments; environmental, economic and technical parameters and performance. Examples of including leak detection late is seen on some fields on the NCS, where sensors not compatible with template design are installed and not working properly or not working at all.

To build a resilient system that best meet the requirements, the operators and suppliers would benefit of working together when setting the functional requirements and during the FEED.

8 FUTURE STUDIES

Based on review and evaluation of the feedback from the operators and suppliers in this study, some information gaps have been identified.

DNV GL suggests some future studies regarding leak detection, like:

- What is possible to achieve with a leak detection system?
- Use, procedures and management of leak detection systems.
- Flow assurance requirements.
- Installation and maintenance of leak detection systems.
- Certainties (false positive and negatives) on the leak detection system.
- Thresholds of different technologies (range and rate). Test to verify range and rate under operative conditions, and not only under ideal conditions.
- Look into API RP 1130, Computational Pipeline Monitoring for Liquids, and see how this can be used more actively for the NCS

The authorities should also focus on the benefits for operators to have leak detection system installed (e.g. condition monitoring, detection of irregularities before asset integrity may be jeopardized etc.).

9 REFERENCES

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APPENDIX A
Leak detection technologies

Leak detection systems can be divided into two main categories; non-continuously and continuously systems.

The Activities regulations section 57 states that “the operator shall establish a remote sensing system that provides sufficient information to ensure that acute pollution is as quickly as possible discovered and mapped so that the position, area, quantity and properties can be determined".

According to DNVGL-RP-F302, the sensor coverage is classified as:

- **Regional coverage**, i.e. covering the entire field development or more.
- **Area coverage**, i.e. covering a large area of the field, but does not cover the entire field.
- **Local coverage**, i.e. covering the area close to the sensor.

A high-level comparison between the subsea and surface leak detection techniques is presented in the below tables. It should be noted that a field development specific evaluation and selection of remote sensing systems should be performed to ensure that acute oil pollution of significance is detected, mapped, assessed and notified so that necessary corrective actions can be taken.

Table A-1 Subsea techniques

Principle	Principle method description	Form of HC	Sensor coverage	Leak positioning 1)	Limitations
Active acoustic	Based on the same principle as sonars. Detector emits pulses of sound that are reflected by boundaries between different media.	All	Area coverage	Yes	Sensitive to shadowing and background noise. Some versions generate a lot of data. Not effective on ingress
			Local coverage Point sensor	No	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.
Bio sensor	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.	Oil	Local coverage Point sensor	No	Seawater currents or buoyancy effects may lead leaking medium away from sensor. Supporting sensors are needed.
Capacitive sensor	Measures change in the dielectric constant of the medium surrounding the sensor.	All	Local coverage Point sensor	No	Biological growth. Dependent upon size and shape of collector. If polymerized material is used in sensor, it can absorb water and affect sensitivity.
Fibre-optic	Fibre-optic cable installed along the entire length of the pipeline or structure to be monitored. Can be based on either temperature or acoustics.	All	Area coverage (entire pipeline system)	Yes	Fibre optic cable has limited bend radius. Trade-off between spatial resolution and detection sensitivity.

Principle	Principle method description	Form of HC	Sensor coverage	Leak positioning 1)	Limitations
Fluor-escent	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.	Oil	Local coverage Point sensor	No	Marine growth. Medium to be detected must naturally fluoresce or a fluorescent marker must be added into the fluid.
Internal LD system (mass balance)	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.	All	Area coverage (entire pipeline system)	No	Inaccurate when the production is unstable. Not able to detect small leaks (typical less than 5% of the total flow).
Methane sniffer	Three measurement principles: - Semi-conductor - Optical NDIR - Laser absorptiometry Dissolved methane diffusing over a membrane and into a sensor chamber.	All	Local coverage Point sensor	No	Quantification of leak is difficult. Dependent on diffusion towards the sensor and seawater currents may lead the leaking medium away from the sensor.
Optical camera	Use of video camera for surveillance of the subsea system.	All	Local coverage	Yes	Line of sight sensor, depending on lightning. Sensitive to marine growth, water turbidity and pollution.
Passive acoustic	Hydrophones listening for sounds (pressure waves) resulting from a leakage.	All	Area coverage	Yes	Need differential pressure for detection. Background noise can limit the sensitivity.
Volumetric collection	Leak detection based on volumetric measurements. When a predetermined volume is collected, an action is initiated in the system and will give an alarm.	All	Local coverage Point sensor	Yes	Sensitive to biological growth. Fishing activity (trawls) can be an issue.

Principle	Principle method description	Form of HC	Sensor coverage	Leak positioning 1)	Limitations
Multi-sensor	Combination of two or more complementary sensors types. Complementary leak detection principles should be selected.	Depends on type of sensors used in combination.	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.		
1)"Leak positioning" refers to the capability of a single sensor. System configuration and processing software may enable leak positioning.					

Table A-2 Surface techniques

Principle	Principle method description	Form of HC	Detection range	Ability to classify	Limitations
Radar	An active sensor that emits energy at a certain wavelength and collects the backscattered signals and then analyses them				
	Ground-penetrating radar (GPR) sends microwaves into the material situated below. GPR can detect oil under ice and snow	Oil			Structures within the ice or snow can give rise to false positives.
	Navigation radar with oil spill detection uses conventional navigation radars. Software for automatic oil spill detection is available	Oil	Depends on factors such as radar transceiver power, radar antenna height, wind speed and polarization.	No	Needs wind (approx. between 2-12 m/s) to detect oil.
	Side-looking airborne radar (SLAR) is an active sensor that sends radar signals to the water surface. SLAR is a line scanner only used in aircraft systems	Oil	Maximum swath width is 80 km.	No	Needs wind to detect oil.
	Synthetic aperture radar (SAR) sends radar signals to the water surface. SAR is available for aircraft systems, satellite systems and ship-based systems	Oil	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.	No	Needs wind to detect oil.

Principle	Principle method description	Form of HC	Detection range	Ability to classify	Limitations
Fluorescence	An active sensor recording the release of fluorescent light				
	Hyper-spectral laser-induced fluorescence (HLIF) LIDAR 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.	Oil	For shipboard installations: 10-50 m; for fixed installations: up to 500 m. Horizontal range for airborne installation (300 m altitude): ± 75 m	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).	Limited range of detection (at the line of sight).
Electro-magnetic reflection	Passive sensors that measure emitted energy at different wavelengths				
	Infrared imaging (IR) is 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.	Oil	Up to 5 km depending on type of camera, environmental conditions, oil composition and slick age.	While it is difficult to estimate the thickness of an oil slick, the pictures can give indications of the thickest parts of the slick.	Cannot detect thin oil sheens. Operation is affected by fog and poor weather. Requires trained operator – reliable automatic detection not yet available.
	Microwave radiometer (MWR) is a passive sensor that measures emitted microwave radiation	Oil	Maximum 1000 m.	Able to measure the thickness of the oil spill (50 µm-few mm).	Low spatial resolution. MWR requires a dedicated aircraft to accommodate a special antenna.
	Spectral scanners are passive sensors that analyses reflected solar light for a material	Oil		Able to give identification of oil type (light/crude) and thickness of the oil slick.	Spectral scanners generate a large volume of data which limit their ability to provide near real-time data and images.

Principle	***Principle method description***	***Form of HC***	***Detection range***	***Ability to classify***	***Limitations***
	Ultraviolet (UV) scanner is a passive sensor that uses reflected sunlight in the UV region to detect oil spills	Oil		No	Needs sunlight to operate. Operation is affected by fog and rain. False positives can occur due to wind sheens, sun glint and sea weeds.
	Visual surveillance cameras (still pictures or video) are passive sensors that operate in the visible region of the electromagnetic spectrum	Oil	100 m – 2 km	No	Light and weather dependent. Requires a trained operator.
Please note: The empty cells above are due to lack of information or difficulty of obtaining/finding information.					

APPENDIX B
Questback sent to operating companies

Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as operator

Information about data processing

DNV GL is on behalf of Ptil performing a study regarding offshore leak detection. The study aims to get an overview of the use of risk assessments and performance requirements when selecting leak detection technologies, and the main focus is for subsea installations. The study will also get a status on the use of mass balance as a leak detection technology.

In the following, no personal data is asked for, other than your email address and phone number.
We need to identify you as a respondent in order to follow up with you. However, in the further processing of data, it will not be possible to identify you as a person or as a company.

We therefore kindly ask you to check the acceptance box below and to proceed to the questions.

How to contact us

DNV GL
Rajesh Mistry
Principal Engineer, Drilling & Well
rajesh.mistry@dnvgl.com
Mobile +4793288802

If you would like to obtain more information about the processing of your personal data click here

☐ I agree to the processing of my personal data in accordance with the information provided herein.

I don't want to participate

Next

Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as operator

There is a great number of subsea systems installed on the Norwegian Continental Shelf today, and with on-going projects and new discoveries there is expected an increase in such systems in the future. Regulations give requirements for resilient design of the systems to avoid discharges, but experience shows that leaks of different volumes still happen.

The following questionnaire covers some overall questions regarding leak detection systems installed on your field(s), including the selection process, specifications and requirements of the systems. Ptil and DNV GL will appreciate if you take the time to answer the questionnaire. After the answers are received, we may follow up with a phone call to get more details where this is necessary.

Please enter your e-mail address:

*** Please enter your direct phone number/mobile number so we can get in touch with you.**

What type of leak detection equipment/systems are/will be installed on the different subsea installations that your company operates? Please list as follows: Subsea installation name + type of leak detection technology (e.g. Field X: Capacitance and Sniffer)

0/4000

Did you consider mass balance technology as leak detection system for any of the fields where this is not installed?

- ○ Yes
- ○ No
- ○ Other

Do you have a functional specification or performance requirement for the subsea leak detection system/equipment?

- ◯ Yes
- ◯ No
- ◯ Partly

Are the requirements fulfilled?

- ◯ Yes
- ◯ No
- ◯ Partly

Who participated in the final selection of leak detection system in your company?

- ☐ Colleagues (subject matter experts)
- ☐ Supplier
- ☐ Other, please specify

To what extent will the requirements vary during the field lifetime?

0/4000

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as operator

Did you perform an environmental risk assessment identifying probable discharge scenarios including impact assessment on environmental resources for your field(s)? Please list the fields where a risk assessment was performed:

0/4000

Did the risk assessment define likely scenarios for small, medium and large leakages?

- ○ Yes
- ○ No
- ○ Other

Did the risk assessment identify leak hotspots through failure mode, effect and criticality analysis (FMECA) or similar?

- ○ Yes
- ○ No
- ○ Other

Comments to the above

0/4000

Next >>

Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as operator

What kind of leakages can be expected on the different locations?

0/4000

Where on the subsea installations are leakages most likely to occur? (e.g. Pipeline, template, connection point etc.)

0/4000

Where on the installation are the sensors located?

0/4000

How small volumes can be detected and how soon can these be detected?

0/4000

Is there more than one sensor/unit installed on the subsea installations?

- ○ Only 1
- ○ 2-4 sensors/units
- ○ 5-7 sensors/units
- ○ More than 7

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as operator

Has any of the equipment detected any leakages?

- ○ Yes
- ○ No

What is expected detection time for each technology on the field?

0/4000

What is your general experience with leak detection equipment?

0/4000

Are there any limitations that could be improved?

0/4000

Send

100 % completed

APPENDIX C
Questback sent to suppliers of leak detection equipment

Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as supplier

Information about data processing

DNV GL is on behalf of Ptil performing a study regarding offshore leak detection. The study aims to get an overview of the use of risk assessments and performance requirements when selecting leak detection technologies, and the main focus is for subsea installations. The study will also get a status on the use of mass balance as a leak detection technology.

In the following, no personal data is asked for, other than your email address and phone number. We need to identify you as a respondent in order to follow up with you. However, in the further processing of data, it will not be possible to identify you as a person or as a company.

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I don't want to participate

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as supplier

There is a great number of subsea systems installed on the Norwegian Continental Shelf today, and with on-going projects and new discoveries there is expected an increase in such systems in the future. Regulations give requirements for resilient design of the systems to avoid discharges, but experience shows that leaks of different volumes still happen.

The following questionnaire covers some overall questions regarding leak detection systems installed on field(s) you have been involved in, including the selection process, specifications and requirements of the systems. Ptil and DNV GL will appreciate if you take the time to answer the questionnaire. After the answers are received, we may follow up with a phone call to get more details where this is necessary.

Please enter your e-mail address:

*** Please enter your direct phone number/mobile number so we can get in touch with you.**

What type of leak detection technology have you delivered to subsea installations?

0/4000

On which fields/installations are the leak detection system installed?

0/4000

How many units have you supplied for each field? Please list field, + type and number of sensor + year they were supplied/taken into use.

0/4000

How was your involvement in the selection process for leak detection equipment?

0/4000

Did your client have a functional requirement for the leak detection system?

- ○ Yes
- ○ No
- ○ Partly

Does your leak detection system fulfill the client's functional requirements?

- ○ Yes
- ○ No
- ○ Not applicable
- ○ Partly

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as supplier

Were you involved in any risk assessment process related to the selection of leak detection technology for your supply?

- ○ Yes
- ○ No
- ○ Partly

Please specify your involvement in the risk assessment:

0/4000

What type of hydrocarbons can be detected by your sensors/systems? Please check all that apply.

☐ Oil

☐ Condensate

☐ Gas

What is the minimum volume/mass of hydrocarbons that can be detected by the different leak detection system your company supply? Please list the sensor type + minimum volume/mass of hydrocarbons that can be detected.

0/4000

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as supplier

What is the expected detection time for each of your leak detection system?

0/4000

Can you give an overview of where the leak detection sensors are located on the installation?

0/4000

What was the basis for the actual location of the sensors?

0/4000

If there are supplied several sensors for one subsea installation, what determined the number of sensors and their locations?

0/4000

In case a sensor fails, will this be detected and reported?

- ○ Yes
- ○ No
- ○ Other

Do you know if there are other complimentary leak detection systems installed on the same field? If yes, please list them.

0/4000

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Petroleum Safety Authority Norway

DNV·GL

Offshore leak detection - your input as supplier

Has mass balance technology been part of the evaluation for leak detection in any of your deliveries?

- ○ Yes
- ○ No
- ○ Other

Can you give us technical specifications, dimensions, weight, sensitivity, need for power, tolerances etc. for the different leak detection sensor/systems you supply?

0/4000

Are there requirements for calibration and maintenance after the equipment has been taken into use?

- ○ Yes
- ○ No
- ○ Other

What technology is currently being developed and will be available through your company within the next 2 years?

0/4000

What type of feedback have you got from your clients?

0/4000

Send

100 % completed

About DNV GL

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 & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.