PETROLEUMSTILSYNET

Investigation report

Report	
Report title Report from the investigation of the hydrocarbon leak from the S1 template on Åsgard A – 10 March 2017	Activity number 001094029

Security grading		
☑ Public	☐ Restricted	☐ Strictly confidential
☐ Not publicly available	☐ Confidential	

Summary

A leak occurred on 10 March 2017 in connection with a planned activity with well S-4 on the S template, which is tied back to Åsgard A. At the time of the incident, the well was disconnected and a high pressure cap (HPC/blind) had been installed at the connection point on the manifold. The leak occurred when the HPC was pulled. The branch (isolation) valve from the flowline on the manifold to well S-4 had not been closed, and gas and condensate flowed to the sea. Wells producing to the flowline were shut in and the leak continued until pressure in the flowline had equalised with ambient pressure, which took about 20 minutes. Statoil estimates that about 31 tonnes of gas and 1.6 tonnes of condensate escaped. Gas described as “drizzle or light rain” was observed on the surface of the sea. No people were injured in the incident. The PSA decided to investigate it on 14 March 2017.

The investigation has identified five nonconformities related to barriers, risk assessments, interfaces, documentation on requirements and knowledge of governing documents. An improvement point related to follow-up has also been identified.

Involved	
Main group T-1	Approved by/date Kjell M Auflem/1 September 2017
Members of the investigation team Eirik Duesten, Siv A Eeg, Jorun Bjørvik and Johnny Gundersen	Investigation leader Johnny Gundersen

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1 Summary

An activity was initiated during October 2016 to drill a new sidetrack in well S-4 on the S subsea template tied back to Åsgard A. The well was disconnected and the Xmas tree pulled. A high pressure cap (HPC) was installed on the manifold. After a problem arose in connection with completing the well, it was temporarily abandoned and handed back to Åsgard operations and maintenance (D&V). Work on S-4 was due to be completed in March 2017 with *Deepsea Bergen* (DSB), when a leak occurred on 10 March 2017 in connection with pulling the HPC.

Figure 1 - Photograph of the gas leak (Source: Statoil)

No leakage was observed during initial activity with pulling the HPC. The latter was therefore fully unscrewed with a remotely operated vehicle (ROV) to pull it off. At 20.07, the HPC was blown off the manifold hub so that gas and condensate flowed freely to the sea.

DSB contacted the Åsgard A control room, and the two wells producing on the template were shut in at 20.14. The muster alarm on DSB was activated and personnel mustered. Gas was observed on the sea beneath the moonpool, but none of the gas detectors in the area were activated. DSB was withdrawn 75m from the template. The ROV continued to observe the flow from the template, and the leak was reported to have ceased at 20.27. Mustering was terminated at 20.50.

Each well on the S template can be isolated from the subsea manifold with a single branch (isolation) valve. The investigation has established that the direct cause of the gas leak from the S template was that the isolation valve stood in the open position when the HPC was pulled.

It emerged during the investigation that no activities were implemented to secure the isolation valve as a barrier against the sea. Several underlying causes contributed to the failure to detect that the valve was open before pulling the HPC, and to test and secure this valve as a barrier. Through the work on the investigation, five nonconformities were identified.

1. Barriers – no barriers were established to prevent discharges to the sea during work on the template.
2. Risk assessments – in connection with planning and executing the operations on well S-4, important contributors to risk and changes in risk were not identified and assessed.
3. Responsibility – responsibility for testing isolation valves was not unambiguously defined and coordinated in connection with the operations being conducted.
4. Knowledge of governing documents – personnel involved had little knowledge of barrier requirements in governing documentation for work on the template.
5. Documentation on requirements – relevant requirements in governing documents concerning isolation valves were not clarified in the operational procedures.

One improvement point has also been identified.

1. Follow-up – follow-up by management has not contributed to identifying technical, operational or organisational weaknesses, errors and deficiencies.

According to calculations by Statoil, some 31 tonnes of gas and 1.6 tonnes of condensate were released. Under different conditions, the incident could have led to ignitable gas on board DSB.

2 Introduction

A leak occurred on 10 March 2017 in connection with a planned activity with well S-4 on the S template, which is tied back to Åsgard A. At the time of the incident, the well was disconnected and a high pressure cap (HPC/blind) had been installed at the connection point on the manifold. The leak occurred when the HPC was pulled. The branch (isolation) valve from the flowline on the manifold to well S-4 had not been closed, and gas and condensate flowed to the sea. Wells producing to the flowline were shut in and the leak continued until pressure in the flowline had equalised with ambient pressure, which took about 20 minutes. Statoil estimates that about 31 tonnes of gas and 1.6 tonnes of condensate escaped. Gas described as “drizzle or light rain” was observed on the surface of the sea. No people were injured in the incident. The PSA decided to investigate it on 14 March 2017.

The investigation has identified five nonconformities related to barriers, risk assessments, interfaces, documentation on requirements and knowledge of governing documents. An improvement point related to follow-up has also been identified.

2.1 Composition of the investigation team

Johnny Gundersen	- drilling and well, investigation leader
Siv Adelheid Eeg	- drilling and well
Eirik Duesten	- construction integrity
Jorun Bjørvik	- process integrity

The investigation has taken the form of a kick-off meeting and interviews on land with key personnel involved in planning and executing the operations leading up to the incident. In its work, the investigation team has been given access to documents from Statoil. These are listed in appendix A. Analyses carried out by Statoil have been used in evaluating the potential consequences.

2.2 Mandate for the investigation

a. *Clarify the incident’s scope and course of events with an emphasis on safety, working environment and emergency preparedness aspects.*
b. *Assess the actual and potential consequences*
   1. *Harm caused to people, material assets and the environment.*
   2. *The potential of the incident to harm people, material assets and the environment.*
c. *Assess direct and underlying causes, with an emphasis on human, technology and organisation (HTO) and operational aspects, from a barrier perspective.*
d. *Discuss and describe possible uncertainties/unclear aspects.*
e. *Identify nonconformities and improvement points related to the regulations (and internal requirements).*
f. *Discuss barriers which have functioned (in other words, those which have helped to prevent a hazard from developing into an accident, or which have reduced the consequences of an accident).*
g. *Assess the player’s own investigation report (the PSA’s assessment is to be communicated in a meeting or by letter).*
h. *Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.*
i. *Recommend – and contribute to – further follow-up*

2.3 Clarification of terms

2.3.1 Abbreviations

B&B	Drilling and well, operations north, Statoil
BOP	Blowout preventer
D&V	Operations and maintenance unit, Statoil
DOP	Detailed operational procedure (for well operations)
DSB	*Deepsea Bergen*
FCM	Flow control module
HPC	High pressure cap (blind)
HTO	Human, technical and organisational aspects
ROV	Remotely operated vehicle
SENC	*Songa Encourage*
PMV	Production master valve
PWV	Production wing valve
WOCS	Workover control system (used when a well is controlled from somewhere other than the usual facility)

2.3.2 Definitions

Flowline	Production pipeline for hydrocarbons
Handover document	Used when handing over from D&V to B&B or vice versa
Xmas tree	Valve assembly on the wellhead
Manifold	Gathering system for production
Manifold hub	End flange on the manifold
Methanol line	Used to inject methanol in the wellstream
Moonpool	Opening to the sea in the deck of DSB and SENC for access to wells
Template	Framework installed on the seabed for wells, etc
Umbilical	Control cables/feed lines for chemicals, hydraulics, electricity and communication

3 Background

3.1 Description of the interface and interaction

The starting point for the operation concerned was to shut in subsea well S-4 so that a new well (sidetrack) could be drilled out from the original borehole. Many players were involved in connection with this activity. The figure below presents interaction and interfaces between them. *Songa Encourage* (SENC) began the operation by drilling the sidetrack in October 2016 while completing work on S-3. Technical problems with S-4 meant that drilling was halted and the well shut in. SENC left S-4 in December 2016. *Deepsea Bergen* (DSB) completed its work on another well earlier than planned, and it was decided that this rig would move to Åsgard and complete the sidetrack in March 2017.

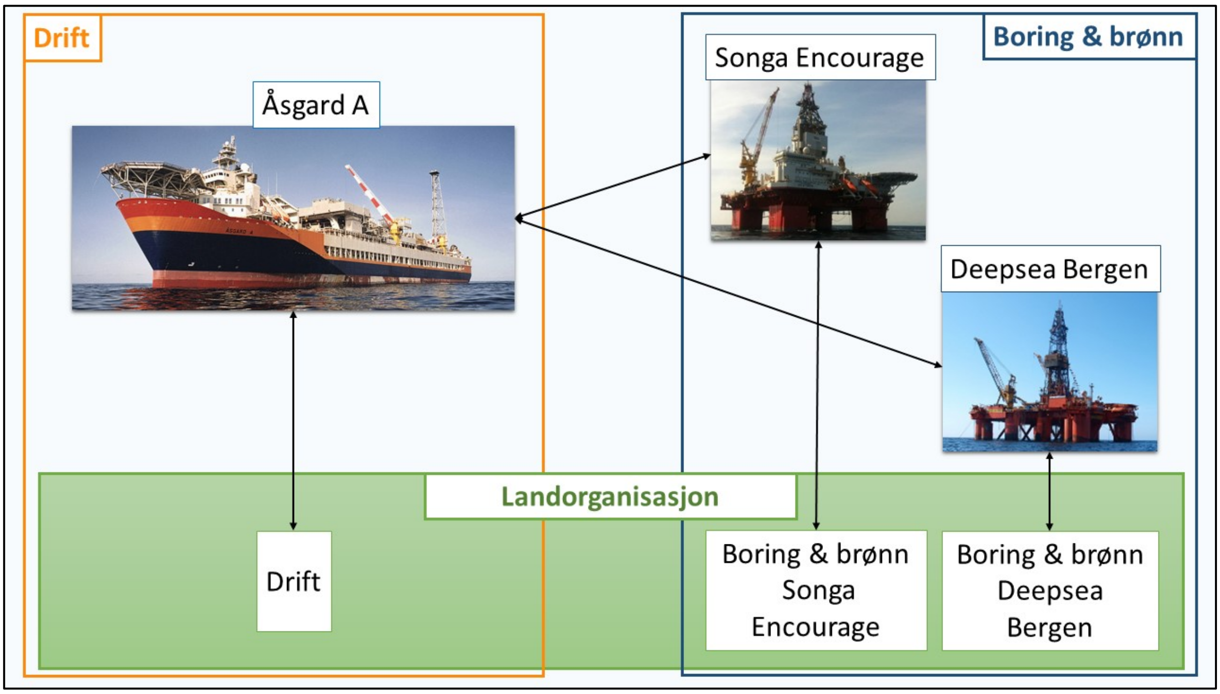

Figure 2 - Interface and interaction.

Key: Drift = D&V; Landorganisasjon = land organisation; Boring & brønn = B&B.

3.1.1 Handover of well responsibility

Åsgard A shut in S-4 and prepared documentation, including documented well status, for handover of well responsibility to SENC. The status of the two branch (isolation) valves on the manifold could be seen on the screen dump attached to the document. A handover meeting was held and the handover document was signed by both parties. SENC worked on the well and contacted the operations and maintenance (D&V) organisation as and when required.

SENC faced problems installing equipment in the well and had to suspend work temporarily. It secured the well and handed responsibility back to Åsgard A. In that connection, SENC prepared handover documentation, including documented well status, for Åsgard A. A handover meeting was held and the handover document was signed by both parties.

DSB was to complete work on the well. Åsgard A had done no work on the well in the intervening time (only had it handed back for monitoring) and handed over well responsibility to DSB. Åsgard A made some amendments to the handover documentation it had received from SENC and delivered the document to DSB. Reference to SENC’s handover documentation was made in the handover document. The status of the isolation valves on the manifold was covered in a separate table in the document. SENC's handover documentation was not available on board DSB. A handover meeting was held and the handover document was signed by both parties.

3.1.2 Planning work for the well

Work to be done on the well was planned on land by the drilling and well (B&B) unit in operations north. It developed an activity programme as well as a detailed operational procedure (DOP) for each operation to be conducted on the drilling facility. The planning group comprised personnel who work with a specific drilling facility. They included representatives from Statoil, the rig contractor and service companies.

Plans called for the whole well to be drilled by SENC, and DOPs were prepared for all operations before the activity started in October 2016. After SENC had to break off the operation and DSB took over, the same DOPs were used. A supplement to the original SENC work programme was also prepared for the operations with DSB.

3.1.3 Fixed meetings and other interaction

D&V: fixed morning meetings between Åsgard A D&V and the operations organisation on land.

B&B: fixed morning meetings by Statoil's drilling supervisor with the drilling contractor on the facility and with the drilling operations manager on land.

No fixed meetings were held between the operations organisation land and B&B, but they communicated via e-mail and phone as and when required.

No experience transfer took place between the two drilling facilities which worked on the well, nor was any document produced for such transfer between the planning groups.

3.2 Description of the subsea system

This section provides a brief description of components in the subsea system which are relevant to the incident.

The template is the interface between the flowline(s) and well(s).

The S template comprises four production wells with associated manifold, and stands in 300m of water 11km from Åsgard A. Production from the template is transferred to Åsgard A via two 10-inch flowlines tied together in a U configuration, each with a volume of 590m^3. All four wells can be connected to each of the flowlines and are isolated from the template by a single valve.

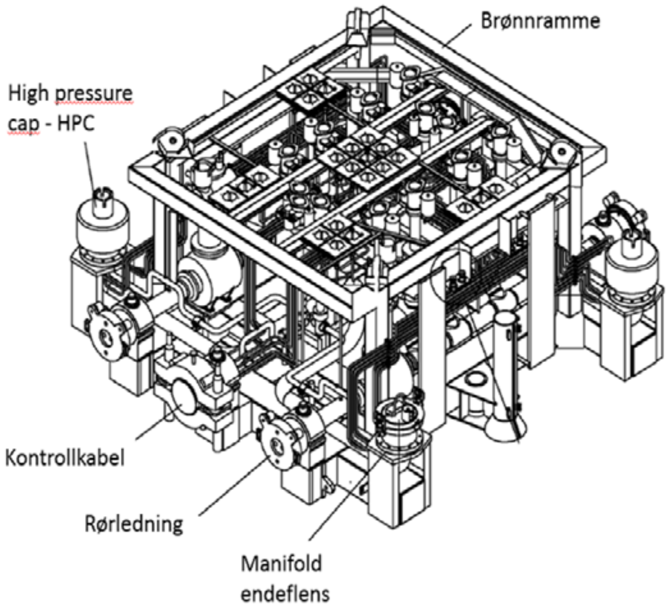

Figure 3 - The subsea template. (Source: Statoil)

Key: Brønnramme = template; Kontrollkabel = umbilical; Rørledning = flowline; Manifold endeflens = manifold hub.

During normal operation, the isolation valves on the template are used to control which flowline each well will produce to. When work operations call for disconnection of the flow control module (FMC)/Xmas tree, these valves function as barriers against discharges to the natural environment. As shown in figure 4, valves 41 and 42 are the isolation valves for S-4. The diagram also shows the isolation valves for the other wells. These valves are hydraulically operated and can be locked in position using an ROV. This is described in more detail in section 3.2.1

Hydraulics, scale inhibitor and methanol[1] are supplied to the template by umbilical. The methanol injection point is placed between the production main valve (PMV) and the production wing valve (PWV). When work operations require FMC disconnection, the isolation valve (49) on the methanol line is closed. This valve can only be operated by ROV.

Normal operating pressure in the flowline is about 80 bar, and production from this template primarily comprises gas with some condensate. Figure 4 presents a simplified diagram of the system.

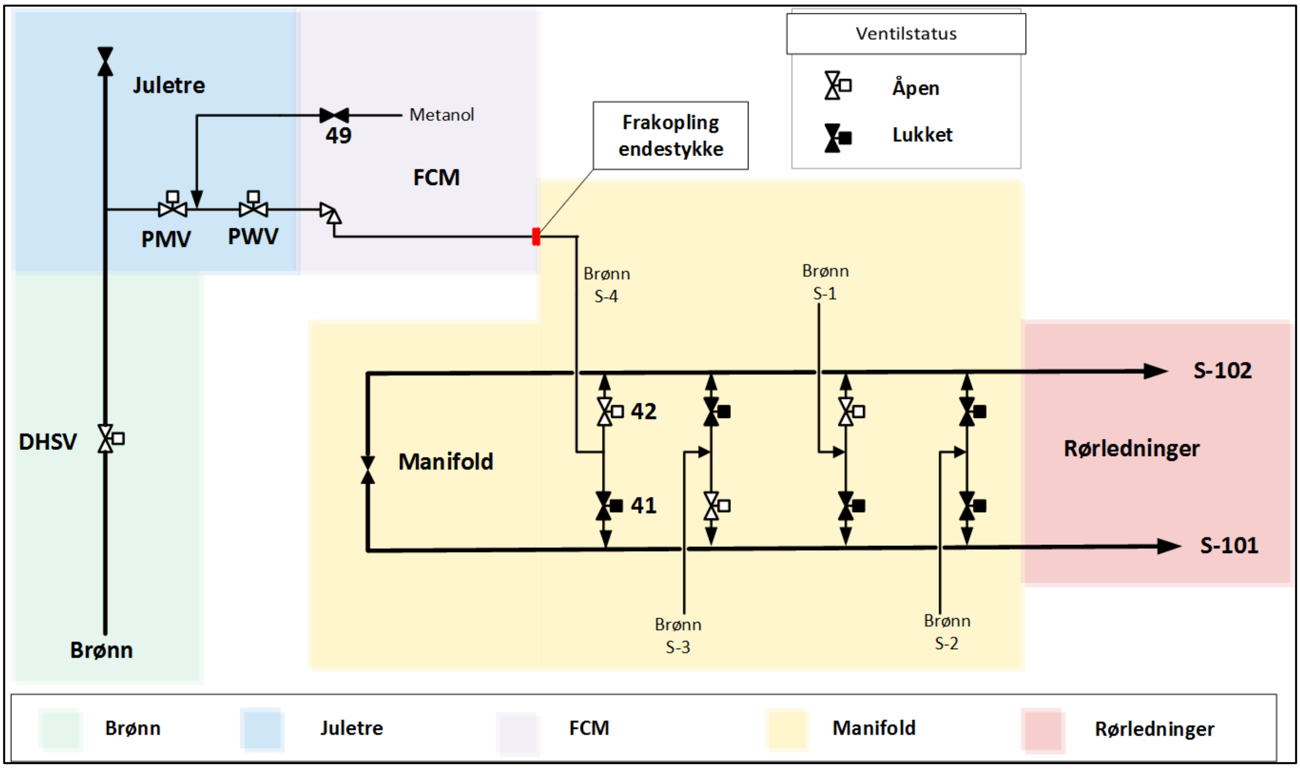

Figure 4 - Simplified diagram covering relevant parts of the subsea system.

Key: Juletree = Xmas tree; Frakopling endestykke = Disconnection point for manifold hub; Ventilstatus Åpen Lukket = Valve status Open Closed; Brønn = Well; Rørledninger = Flowlines.

3.2.1 Manifold isolation valve (branch valves 41/42)

The isolation valve is a gate type with a diameter of 5 1/8 inches (about 13cm), designed to withstand potential pressures and temperatures. Special requirements for testing and securing the isolation valve apply when it is used as a barrier. These are described in section 3.3.

[1] Ethanol rather than methanol is now used in the relevant line.

The isolation valve has an actuator which can be operated either hydraulically or by an ROV. When disconnecting the FCM, the hydraulic line to the actuator will be disconnected and isolated. That means hydraulic fluid will be blocked on both open and closed sides of the actuator and it will not be possible to change the valve position either hydraulically or by ROV. This type of hydraulic actuator is little used on the Norwegian continental shelf.

The actuator is constructed in such a way that the valve (gate) can accidentally move if the hydraulic pressure has been bled off on both open and closed sides. If pressure in the flowline is above the hydrostatic pressure, the valve can move towards closed. Similarly, if flowline pressure is below the hydrostatic pressure, the valve can move towards open.

Two indicators are installed on top of the actuator. One shows whether the valve position is open or closed, and the other whether the valve has been locked into position by an ROV. This indicator will read open, neutral or closed, as shown in figure 6. If the ROV indicator shows open or closed, it is not possible to change the valve's position hydraulically from the Åsgard A control room. During work on the well, the umbilical for communication with Åsgard was disconnected and the workover control system (WOCS) umbilical was connected to the drilling facility (SENC/DSB). According to Statoil, a block was inserted in the control system to prevent the isolation valves being operated via the WOCS. Possible combinations of valve and ROV lock are shown in figure 7.

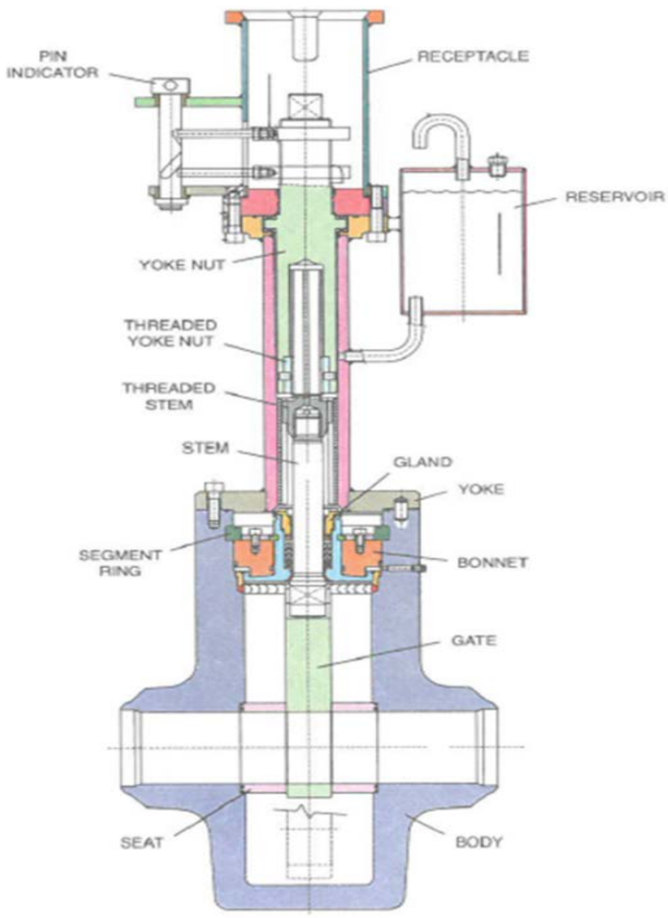

Figure 5 - Isolation valve (Source: Statoil)

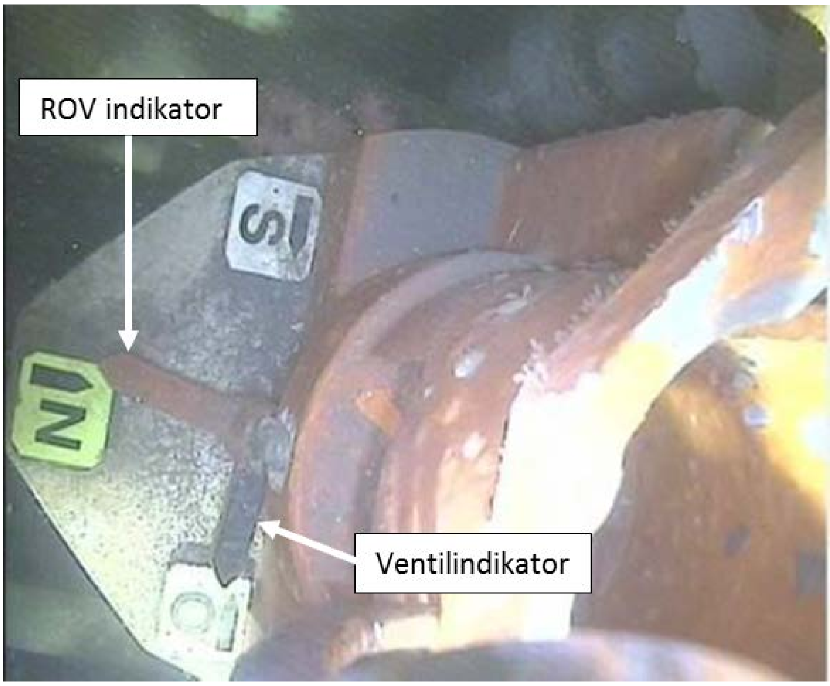

Figure 6 - Indicators on isolation valve 42 (Source: Statoil)

Key: ROV indikator = ROV indicator; Ventilindikator = Valve

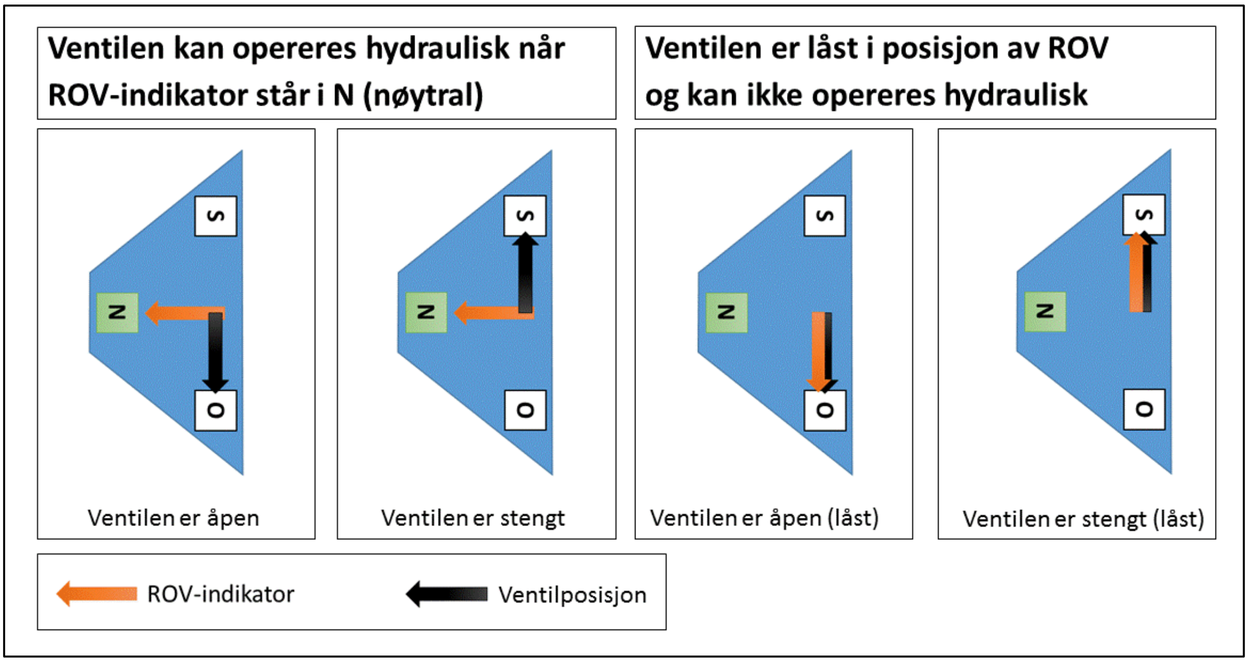

Figure 7 - Possible positions for indicators.

Key: (left) Valve can be operated hydraulically when the ROV indicator is in N (neutral); Valve is open; Valve is closed. (right) Valve is locked in position by ROV and cannot be operated hydraulically; Valve is open (locked); Valve is closed (locked). (bottom) ROV indicator; Valve position

3.2.2 Manifold hub

In connection with pulling the Xmas tree and/or FCM, the production flowline from the isolation valve to the manifold hub will be exposed to seawater.

A five-inch main flowline for production, a two-inch methanol line and 11 small lines for hydraulics and other chemicals are connected to the manifold. The FCM has a connection to each of these lines, assembled in the manifold hub.

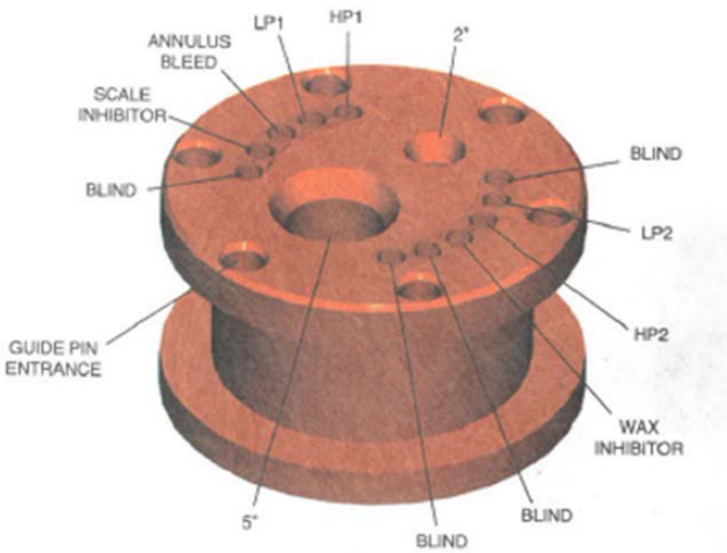

Figure 8 - Manifold hub (Source: Statoil)

3.2.3 High pressure cap

An HPC is installed on the manifold hub to serve as a physical barrier against discharges from the flowline during work on the well while the FCM is disconnected.

The HPC is specially designed for use with the relevant manifold hub. Its function is to seal the supply lines for the utility systems and the actual production flowline against water intrusion, and to prevent leaks to the natural environment should the isolation valve fail to remain closed.

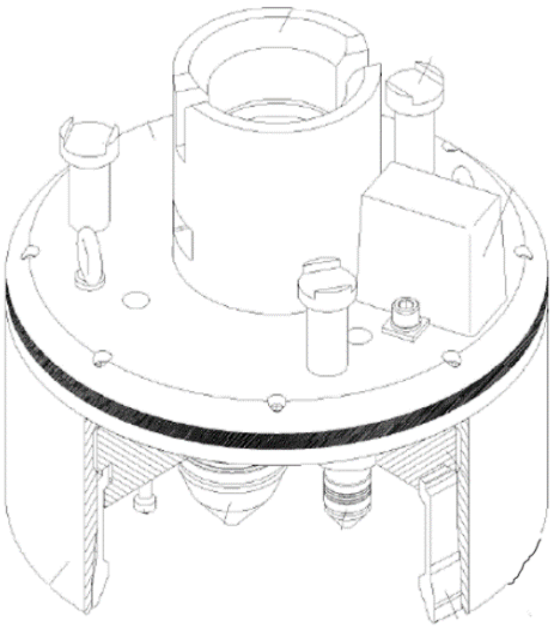

Figure 9 - HPC (Source: Statoil)

A dedicated tool mounted on an ROV is used to install and remove the HPC.

On the S template, the pressure between the isolation valve and the manifold hub cannot be established. Nor is a pressure gauge provided on the HPC itself, which means it is not possible to determine the pressure behind the HPC before it is unscrewed. A special procedure has been established for pulling the HPC in order to check whether a possible leak has arisen in the isolation valve before completely removing the HPC. In addition, a separate line is provided on the HPC for bleeding off possible hydrocarbons behind it. This line is narrow, which means it could be blocked by small impurities.

3.3 Documents

3.3.1 Governing documents

TR 3526 describes Statoil's requirements for parallel drilling, well operations and production, and applied to the operation under way when the incident occurred. Appendix B specifies that the DOP must set requirements for leak testing of relevant isolation valves on the manifold when disconnecting wells from the latter. It also specifies that well handovers must comply with OM01.07.02 from D&V to B&B and OM01.07.01 from B&B to D&V.

OM101.07.04 describes Statoil's requirements for handing over well responsibility from B&B to D&V. It specifies which processes are to be followed and what information must be given in the document prepared and signed when handing over a well from B&B to D&V.

OM101.07.13 describes Statoil's requirements for handing over well responsibility from D&V to B&B. It specifies which processes are to be followed and what information must be given in the handover document. Requirements include testing well barriers before handover and including the results in the handover document, but similar stipulations are not made for valves on the manifold. The document states that information must be obtained on the correct position for manual valves on the Xmas tree/manifold/template at the handover point. This information must be obtained by the technical system manager.

OM105.07.01 describes processes for planning, readying and resetting when isolating energy and hazardous media in order to work safely on systems and equipment.

R-18601 has been drawn up by Statoil D&V and describes requirements for approved physical barriers when working on subsea installations. The document specifies requirements for work on a template with both dual and single tested barriers. When working with only one tested barrier, this must be tested and secured and a risk analysis prepared for the operation. In addition, possible leaks must be evaluated in terms of the consequences for the plant/facility and the natural environment. This document defines a secured valve as a barrier if it has been tested for internal leakage and simultaneously locked in the closed position without opportunities for being operated. Examples are given which indicate that the valve can have a locking function which is activated by ROV.

3.3.2 Operational documents

FMC procedure OMM-0012419 describes how an HPC should be pulled in order to verify that the isolation valve is not leaking. This procedure provides a step-by-step description of how the HPC should be unscrewed as well as how, and for how long, it should be pressure-checked. Section 1.1.1 in the procedure, Safety Notes, states that important precautions include seeing to it that the isolation valve on the manifold is in the closed position.

FMC manual OMM-0010580 for operation and maintenance of a 5 1/8-inch gate valve provides technical data and describes the structure of the valve, which was used for isolation on the manifold for the S template. The possibility that the valve could change position accidentally is not described.

Amendment to activity programme for completion of well 6506/12S-4
This supplement to the SENC work programme was drawn up to tailor the operation to DSB. It includes a description of risk assessments carried out to document risk in connection with the use of a new drilling facility.

A **DOP** is Statoil's detailed procedure which describes sub-operations and specifies who is responsible for executing them. It also describes the risk which could be present. DOPs are drawn up by the planning group and reviewed by operational personnel out on the facility. A brief description of the relevant DOPs related to the incident is provided below.

<u>DOP 01 (SENC)</u>
The purpose of the DOP is described at the beginning of the procedure. This states that the template will be inspected, the status of the manifold valves established, and the BOP moved to well S-4. The programme specifies that the drilling supervisor on SENC will see to it that Åsgard A has set the Xmas tree, well and manifold to the correct valve status <u>before</u> the handover of S-4. In addition, section 2 of this DOP states that an ROV will put the manifold valves (41, 42 and 49) in the right position for operation – in other words, locked by ROV against accidental operation.

<u>DOP 10 (SENC)</u>
The purpose of this DOP is to describes how the Xmas tree will be pulled. This includes the preparations to be made prior to this operation. It specifies that the pressure between the PWV and isolation valves must be bled off towards the well. The procedure also states that final confirmation that the manifold valves are closed must be obtained. DOP 10 specifies that manifold valves 31, 32 and 39 (belonging to well S-3) are the ones to be checked, rather than 41, 42 and 49.

<u>DOP 02 (DSB)</u>
This DOP describes how the HPC is to be pulled, the Xmas tree run and the connection with the tree tested. The procedure includes a specification that the template must be inspected and that the closure of valves 41, 42 and 49 on the manifold must be verified. Where valve 42 is concerned, the DOP states that the indicator shows the well to be in open/neutral position, but that it is assumed to be closed.

4 Course of events

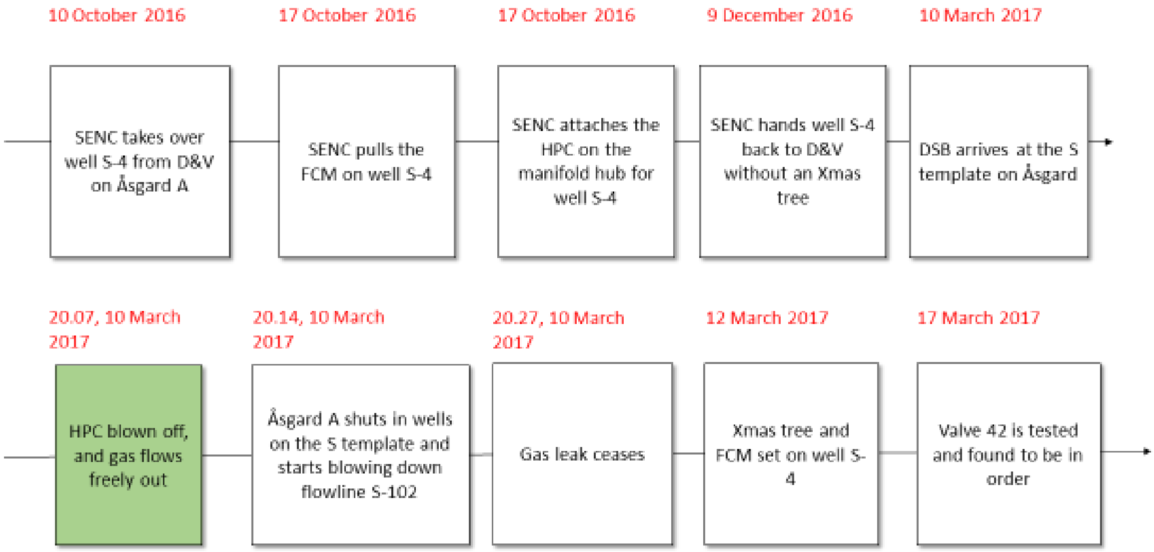

Figure 10 - Course of events.

Before the operation in 2016
Isolation valve 42 was leak-tested in 2014. The result was just outside the test criterion. An internal exemption application was written in Statoil, and the FCM on well S-4 was replaced. No notifications were made for equipment belonging to S-4.

9 October 2016
DOP 01 for pulling the BOP from S-3 to S-4 was approved and signed. This procedure specifies that the drilling supervisor on SENC must see to it that Åsgard A has set the Xmas tree, well and manifold to the correct valve status before the handover of S-4. Section 2 also states that the ROV will place the manifold valves (41, 42 and 49) in the right position for operation – in other words, locked against accidental operation.

9 October 2016
DOP 10 for pulling the Xmas tree was approved and signed. As part of this activity, the position of the valves on the manifold must be finally confirmed before the Xmas tree is pulled. DOP 10 specifies that manifold valves 31, 32 and 39 are to be checked. These are for S-3 and not S-4, which was being worked on at the time. In connection with execution, the ROV log shows that valves on S-3 were the ones checked. Activity under way on S-3 was completed during the start-up of work on S-4. Statoil has reported that the valve designations in DOP 10 are wrong and should have been 41, 42 and 49, and that these were the valves checked by ROV. The ROV log shows that valves 31, 32 and 39 were the ones verified.

10 October 2016
S-4 was shut in to drill a new track from the original well (slot recovery). B&B for operations north took over the well from Åsgard D&V and re-enters from SENC in order to drill and complete a new well track. A detailed programme was drawn up for the planned work, and risk assessments of the relevant operations were carried out in advance.
A handover document was drawn up before B&B took over responsibility for the well. Dated 10 October 2016, the handover document from D&V stated that barriers were established and

ready for work on the well. However, no overview of valves tested nor pressure chart which show the test were attached. An attached screen dump from the Åsgard A control room showed that valves 41 and 42 were closed. The investigation has been unable to establish why valve 42 changed position between 10 and 17 October 2016.[2]

17 October 2016
The FCM and Xmas tree were disconnected and pulled. Before disconnection, the pressure between the PWV and the Xmas tree was bled down pursuant to DOP 10. No pressure was observed after the bleed-off. A leak to the sea from the methanol injection line was detected after the disconnection. A check by ROV revealed that the methanol injection valve (49) was open. It was closed by ROV. The indicator on valve 42 was also found to show that the valve was open and had not been locked against accidental operation. Efforts were made to operate valve 42, but ceased following information that this could damage the valve.

A HPC was installed on the manifold hub later the same day to secure the production flowline after the FCM and Xmas tree were disconnected. Statoil reports that the production flowline had been open for six-eight hours after disconnection without leakage being observed.

SENC connected to the wellhead and began plugging back and securing the lower part of the original well path. After completing this work, a new track was drilled to a measured depth of 6 006m.

7 December 2016
Problems arose with completing the new well track. The decision was taken to abandon the well temporarily, and it was handed back to Åsgard D&V.

A new ROV survey was carried out on the template, including valve 42. Personnel on SENC asked the planning team on land about the valve's position and whether it was really closed. In a series of e-mails, the planning team asked whether the valve might be open. The response from D&V was that the issue had been discussed earlier, that flowline S-102 was pressurised now and that it was in any event impossible to operate the valve by ROV or to test it again because the Xmas tree was disconnected.

The planning team stated in an e-mail dated 8 December that the uncertainty over the status of valve 42 would be clearly described in the handover document from B&B when the well was handed back to D&V. It also asked again about the pressure in flowline S-102 when the Xmas tree was disconnected. The response from D&V on 12 December states in part that an overview (Lotus Notes) had been received from the control room which showed it had closed the valve on 11 October 2016. It later transpired that this overview was not updated with all the operations conducted on the valve. In its 12 December e-mail, D&V asked the planning team how this issue should be taken forward. The team responded that the well was now handed back to D&V and that the valve was inoperable hydraulically, but not locked against accidental opening. Based on the e-mail correspondence, it was assumed that valve 42 had to be locked.

[2] It is uncertain whether valve 42 changed position between 10-17 October 2016. This is discussed in greater detail in chapter 8 on uncertainties.

9 December 2016
The handover document from B&B to D&V was signed later the same day. This specified that the well was temporarily secured and that the barriers in the well were tested. The pressure chart which showed this was included in the document. It was also specified that valve 42 on the template was assumed to be closed, but that the indicator was in the open position. Furthermore, the document stated that the ROV log said nothing about the valve being closed and that no attempts had been made to close the valve since it could not be operated after the Xmas tree was pulled. In addition, it was recommended that the valve should be assumed to be open when pulling the HPC at a later date. The handover document also included a table showing the status of the manifold valves on handover. This presented the status of valves 49, 41 and 42. Valve 42 was described as closed, with a comment that the indicator showed open/neutral but that the valve was assumed to be closed.

After the well was handed back to D&V, it remained shut in until March 2017. DSB had an opening in its work programme, and it was decided to complete well S-4 with this facility. A supplement to the original planning document for SENC was drawn up to adapt the plan to DSB. In addition, some of the key personnel involved in planning the operation with SENC were transferred across. They included the lead drilling engineering, the completion engineer and Petec personnel. It emerged from the interviews that they had relatively little time to prepare.

9 March 2017
DSB arrived on the Åsgard field and moored over the S template.

10 March 2017
Well S-4 was handed over from D&V to B&B. According to Statoil, the well had been “parked” with D&V, which handed it back “as is”. The handover document specified that no changes had occurred in the well since it was handed over from B&B to D&V in December 2016. Reference was specifically made, both initially in section 1.1 and in section 1.3 on well design and special conditions, to the earlier handover document dated 9 December 2016. The paragraph in section 1.3 concerning uncertainty about the status of valve 42 specified in the handover document dated 9 December 2016 was not included. The table which showed the status of the manifold valves specified that valve 42 was closed, with a comment that the indicator showed open/neutral but that the valve was assumed to be closed. A printout from the Lotus Notes valve database was also included in the handover document in order to show the operating history of the valves, including 41 and 42. It subsequently transpired that this was neither updated nor accurate.

DSB began the job of pulling the HPC later the same day, in line with DOP 02, which covered this work by DSB. An ROV latched onto the HPC and made eight turns of the cap to check whether there was gas underneath. Some gas emerged and dissipated rapidly. The ROV operator observed for 30 minutes as specified in the procedure. The gas quantity and duration were as expected. The HPC was turned a further four times, and some more gas flowed out. Observation continued for 15 minutes, followed by eight more turns until the flange was unscrewed. No bubbles were observed. The ROV was withdrawn and a jack installed on it to pull out the HPC. As the jack was establishing a grip, the HPC shot off and an uncontrolled flow of gas and condensate began from the manifold hub at 20.07. The control room on Åsgard A was immediately notified by DSB. At 20.14, the producing wells on the S template were shut in. The general alarm was sounded and personnel on DSB mustered.

Gas (said to resemble “light rain/drizzle”) was observed on the sea in the moonpool, but no gas detectors on the facility were activated. DSB was withdrawn 75m from the template. The gas flow ceased at 20.27. Mustering was terminated at 20.50. Debriefings were held with the crew at 23.00 and 07.00 the following day.

The estimated ambient pressure at the S template is 34.6 bar. When the pressure is higher than this in the flowline, gas will blow out of it if one end is open to the sea. At lower pressure, water will intrude into the flowline, and it would not be possible to identify this leak with an ROV-mounted camera.

Date	Explanation	Pressure	Consequence
07.00, 17 October 2016	Pressure in flowline S-102 before the FCM/ Xmas tree were pulled	25 bar	Seawater leaked into the flowline
15.00, 17 October 2016	Pressure in flowline S-102 after the FCM/ Xmas tree were pulled	30 bar	Seawater leaked into the flowline
20.08, 10 March 2017	Pressure in flowline S-102 before the HPC was pulled	82.8 bar	
20.12-20.27, 10 March 2017	Pressure blowdown of flowline S-102	Pressure fell to 34.6 bar	Gas leak (the flowline eventually filled with seawater)

Table 1- Overview of pressure in the flowlines related to the course of events.

5 Causes and discussion

5.1 Direct cause

The direct cause of the gas leak from the S template was that the HPC was pulled with the isolation valve open.

5.2 Underlying causes

Pursuant to its mandate, the investigation concentrated primarily on planning activities and interfaces between D&V and B&B related to the use of the isolation valve as a barrier. This chapter describes possible underlying causes for the failure to identify that valve 42 was not closed before the HPC was pulled, and why isolation valves were not tested as barrier valves. It emerged during the investigation that defined activities in the DOP related to the isolation valve as a barrier were not carried out. The investigation has not looked more closely at the reasons why defined activities were not performed.

5.2.1 Barriers

The design of the subsea installation only allows a single barrier to be established against production flowlines S-101 and S-102 when pulling and installing a HPC on the manifold.

Statoil's governing documentation permits parallel subsea operations (well activity at the same time as production) with a single barrier, providing the defined conditions described in R-18601 are met (see section 3.3). Such a solution makes extra demands on the preparation of and compliance with procedures for ensuring that the barriers are intact. The solution used for the manifold hub provided limited opportunities for detecting possible leaks.

Nothing was said in the handover document about testing the isolation valve, whether a pressure test, duration or the person responsible for implementation. The documentation shows that the valve was not tested as a barrier ahead of pulling the Xmas tree. Information from the interviews suggest that the conclusion was drawn, based on observations before and after bleed-off, that the isolation valve was closed and that this information was regarded as a barrier test. This was said to be established practice for similar operations in B&B. The isolation valve was later assumed to be closed when installing and pulling the HPC. As a result, the requirements in R-18601 and TR-3526 on testing and locking the isolation valve were not complied with for these operations, and necessary barriers pursuant to the requirement documents were not established.

B&B failed to comply with the requirement in DOP 01 to assure itself that Åsgard A had put the manifold valves in the correct position before it took over well responsibility. Nor were isolation valves 41 and 42 locked in the right position before pulling the Xmas tree in accordance with the same procedure. Although uncertainty in the organisation over the quality of the isolation valve as a barrier was identified, this was not checked in more detail.

According to the interviews, B&B personnel involved in planning and executing the operations for pulling the HPC were not familiar with the testing general requirements in R-18601, which applied to operations on subsea facilities with a single barrier. This document was characterised by B&B as applying only to D&V. Personnel were unfamiliar with the testing requirements for isolation valves on the template which applied for pulling the Xmas tree in connection with parallel operations. Nor were interviewees from B&B or D&V aware that the isolation valves on the template could accidentally change position as described in section 3.2.1.

5.2.2 Risk assessments and handling of uncertainty

As described in section 3.3.1, requirements when working on subsea systems with a single barrier are to secure the valve in position and to carry out a risk analysis for the operation – including an assessment of the leak potential. The supplement to the activity programme for well completion with DSB includes a register of identified risks with assessments and measures taken. Measures identified in relation to the risk of pulling the HPC are a test of the valve pair on the manifold during the preceding month and the procedure for controlled bleed-off through the HPC during removal. The identified risk with the proposed risk-reducing measures gives the impression of being predefined. The measures are not assessed or signed out in the risk register. Changes to the operation and status of equipment which could involve other consequences, with associated uncertainty, are hardly covered at all.

Several indications received during the operation before handing the well back to D&V in December 2016 created uncertainty about the actual status of the manifold valves, particularly valve 42, and that the requirements for using a single barrier were not followed up.

- ROV inspection showed that valves 41 and 42 were not secured in the locked position.
- ROV inspection showed that the position indicator for valve 42 showed it was open. There was no known history of the isolation valve indicators having faults or deficiencies.
- Failure to secure valves 41 and 42 in the closed position and leaks via valve 49 suggested that sub-tasks in the DOP had not been carried out.

Questions were raised before the well was handed back over operating pressure in the flowline when installing the HPC in an attempt to resolve uncertainty about the valve position. Operating pressure was not finally clarified, and the handover document therefore contained a recommendation to assume that the valve might be open.

Uncertainties related to the actual position of valve 42 and awareness of the failure to lock valves 41 and 42 in position were not included in risk assessments in the appendix to the activity programme. Nor was the risk of impurities or hydrates blocking the bleed line on the HPC discussed/included in the assessments. Compensatory measures over and above normal practice for pulling the HPC were therefore not evaluated. (Blowdown of the flowline was mentioned in interviews as a possible compensatory measure, but was not assessed ahead of the operation in March 2017.)

Lack of observed gas leaks when installing the HPC meant that the valves were assumed to be closed. It has subsequently been clarified that the operating pressure in flowline S-102 during HPC installation was sufficiently low to prevent any leakage from this source.

5.2.3 Responsibility

The isolation valve on the manifold was a barrier (the only one) when preparing to pull the FCM and Xmas tree in October 2016 and the HPC in March 2017, and should accordingly have been tested and thereafter secured in the locked position before work started. It cannot be tested or operated after the FCM and Xmas tree have been disconnected.

It emerged from the interviews that responsibility for barrier testing was not clearly assigned or coordinated, and that it was unclear who should test the manifold valve before pulling the HPC. D&V maintained that B&B should inform it when testing was needed, while B&B thought such tests were D&V's responsibility. According to requirements in the handover document, both B&B and D&V were responsible for the valve status and for necessary barriers being established, tested and documented before handing over well responsibility.

The investigation team's impression is that little collaboration and communication prevailed between D&V and B&B in such operations, and that high partitions can exist between the organisations which hinder quality improvements in operational planning and execution. Better communication and closer involvement of D&V in this phase could have clarified the uncertainty about the need for barriers and over the status of the isolation valve. It is questionable whether the quality of handover meetings and their timing are optimum. Information discussed at the meetings seems to be limited and very general, and the time available is often limited because the drilling facility is waiting to start work.

5.2.4 Follow-up of the operation

Some of Statoil's managers for planning and implementing operations related to the incident have been interviewed. These are the planning manager, the drilling operations manager and the drilling supervisors on both facilities. The impression gained from these interviews is that management had little hands-on involvement and limited knowledge of or participation in key conditions related to the incident. These include the uncertainty over barrier status, risk assessments for operations and barriers, and execution of detailed operations. Nor is it documented that they have been asked for their view on various conditions or that they have posed questions about decisions or plans for operations. The interviews have revealed that management had little involvement in the risk process or comments about identifying and managing risk. This could be because ongoing operations related to the incident were regarded as standard activities, and management did not give priority to becoming involved. It was pointed out in the interviews that managers have much to do and that responsibility for ensuring jobs are carried out as planned rests with those doing the work. In the investigation team's view, this operation was not standard. Two drilling facilities were involved in the work, the personnel involved had varying levels of experience, and the technical challenges posed by the operation indicated a need for close follow-up by management.

It was maintained in the interviews that management relied on the preparations made before the Xmas tree was disconnected on 17 October 2016. The managers said that they had not been sufficiently involved to be able to foresee the challenges posed by this operation. The investigation team was told that the management were copied in the e-mail correspondence concerning the uncertainty over valve position and pressure in the flowlines.

5.2.5 Documentation on requirements

The governing documents used for planning and executing operations ahead of the incident concentrate to a great extent on wells and well barriers. Little is said about valves on the template in key documents which are much used in B&B. That applies to documents specifying requirements for handover of well responsibility (OM101.07.04 and OM101.07.13) and to well integrity document TR3507/GL3507. These documents, for example, contain only requirements for testing and verifying specific well barriers and not barriers for other types of operations such as an isolation valve when pulling an HPC. Requirements are described for testing well barriers at handover of wells from B&B to D&V, and the description of the expected content in the handover document specifies only information related to the well. This applies to handover of well responsibility both from D&V to B&B and vice versa.

The documents which set requirements for the isolation valves, such as R-18601 and TR3526, were unfamiliar in B&B, which thereby failed to comply with them. Testing isolation valves (as barriers) was not described in the DOP for the individual operations, as required by TR3526. The DOP for pulling the HPC, for example, failed to identify applicable barriers or specified requirements for testing these. A separate procedure had not been established for pulling the HPC, as was the case for corresponding operations on such fields as Oseberg.

Appendix B to TR3526 refers to handover documents with the wrong document references. OM01.07.02 (handover of wells from D&V to B&B) and OM01.07.01 (handover of wells from B&B to D&V), which are referenced in TR3526, have been replaced by OM101.07.13 and OM01.07.04 respectively.

5.2.6 Design of the HPC

The HPC used in this incident was an older model, unable to indicate whether there was pressure behind it before pulling. The procedure for pulling an HPC (reference OMM-0012419) specifies that it should be turned six times, followed by a check for signs of leakage through the bleed-off line. Finding a leak which does not dissipate quickly suggests that the isolation valve is not closed and the HPC can be screwed back on. Furthermore, the HPC was unscrewed completely through a total of 20 turns. Newer solutions have been developed with opportunities for verifying pressure without unscrewing the HPC. People involved were not familiar with incidents reported earlier where the bleed-off function on the HPC had become blocked.

6 Potential of the incident

Actual consequence
The consequence of the incident was that gas and condensate escaped to the sea and the atmosphere. Currents and wind direction were favourable, so that little gas flowed to DSB.

Based on figures from Statoil, about 31 tonnes of gas and 1.6 tonnes of condensate are estimated to have been discharged. In addition, production from the S template was halted for 28 days.

Potential consequence
Gas hazard analyses by Statoil show that the discharge could have led, under different weather conditions, to ignitable gas entering DSB's moonpool. These analyses show that ignition of the gas would not have threatened the integrity of the facility, but could have led to fatalities had there been personnel in the area.

7 Observations

The PSA's observations fall generally into three categories.

- Nonconformities: observations where the PSA believes a breach of the regulations has occurred.
- Improvement points: observations where the PSA sees deficiencies, but lacks sufficient information to establish a breach of the regulations.
- Barriers which have functioned.

7.1 Nonconformities

7.1.1 Barriers

Nonconformity
No barriers were established to prevent discharges to the sea during work on the template.

Grounds

- Isolation valves 41 and 42 were not tested and secured in the closed position pursuant to the requirements in governing documents (R-18601 and TR3526).
- Failure to comply with the applicable DOP 01 from October 2016 related to verification of the isolation valves and locking these in the right position.
- SENC looked for pressure on the manifold side of the Xmas tree, and used this as a test of the isolation valve. That does not accord with internal requirements for a barrier test.
- B&B paid insufficient attention to the need for barriers from the manifold to the natural environment when planning and executing operations.

Requirements
Section 5, litera b of the management regulations on barriers
Section 5, litera c of the facilities regulations on the design of facilities

7.1.2 Risk assessments

Nonconformity
In connection with planning and executing the operations on well S-4, important contributors to risk and changes in risk were not identified and assessed.

Grounds

- Uncertainty over the status of the isolation valve was not given sufficient weight or subject to adequate assessment on several occasions in the planning phase.
- The consequence of the valve possibly being open was not assessed and compensatory measures were not discussed.
- Relevant governing documentation (R-18601) containing requirements for risk assessment of work with a single barrier was unfamiliar to people involved in B&B.
- Earlier experience with incidents involving HPCs were not known to those involved, and could therefore not be assessed in the risk review.
- No account was taken of the failure to lock the isolation valve in the closed position.
- Adequate compensatory measures, such as bleeding off pressure in the flowline, were not assessed with an eye to the uncertainty about the status of the isolation valves.

Requirements
Section 29 of the activities regulations on planning

7.1.3 Responsibility

Nonconformity
Responsibility for testing isolation valves was not unambiguously defined and coordinated in connection with the operations being conducted.

Grounds
- It emerged from the interviews that communication was limited between D&V and B&B on operations to be performed after B&B had taken over the well.
- R-18601 does not describe who is responsible for testing isolation valves.
- It emerged from the interviews that B&B expected D&V to have tested all the barrier valves before well handover, while D&V for its part expected B&B to tell it which valves should be tested.

Requirements
Section 6, paragraph 2 of the management regulations on management of health, safety and the environment
Section 13 of the management regulations on work processes

7.1.4 Knowledge of governing documents

Nonconformity
Personnel involved had little knowledge of barrier requirements in governing documentation for work on the template.

Grounds
R-18601 defines approved barriers for work on a subsea installation. Planning of the work operations had not identified how these should be established.

- R-18601 and TR3526, which specified requirements for the isolation valves, were not known to the planning group.
- Documents on requirements for the handover of wells between D&V and B&B only contain requirements related to barriers against wells. Requirements for barriers in other types of operations are not described in the handover documents.
    - No reference is made to R-18601 in the OM101.07.04, OM101.07.13 or TR3526 documents on handover of well responsibility.
- The management has not ensured that the personnel doing the work are sufficiently familiar with relevant governing documents or that internal requirements are observed.

Requirements
Section 20, litera b of the activities regulations on start-up and operation of facilities

7.1.5 Documentation of requirements

Nonconformity
Relevant requirements in governing documents concerning isolation valves were not clarified in the operational procedures.

Grounds
- Leak testing of isolation valves is not described in the DOP as required by appendix B.2.7 to TR3526.

- Documents on requirements for the handover of well responsibility do not describe which barriers should be identified, tested and secured on the manifold.
- Operational documents make little mention of barriers other than those on wells.

Requirements
Section 24, paragraph 2 of the activities regulations on procedures

7.2 Improvement point

7.2.1 Follow-up

Improvement point
Follow-up by management has not contributed to identifying technical, operational or organisational weaknesses, errors and deficiencies.

Grounds
It emerged from interviews with management personnel at several levels that their involvement in planning and executing the operations had been limited.

- Identifying and managing risk.
- Assessing specific challenges, such as the status of barriers.
- Assessing the organisation's expertise and capacity in planning and executing operations.
- Seeing to it that personnel doing the work were sufficiently familiar with relevant governing documents and that internal requirements were complied with.

Requirement
Section 21, paragraph 2 of the management regulations on follow-up.

7.3 Barriers which have functioned

- Åsgard A and DSB had established communication, so that they were ready to shut down should an incident occur.
- When the incident occurred, wells S-1 and S-3 were shut in to limit the discharge.
- The emergency response to the incident accorded with established requirements.

8 Other comments

8.1 Available data for investigation

In two cases, the investigation has been unable to secure documentation from the control system on SENC and DSB.

1. It has not been possible to obtain logs from the control system on SENC for possible operation of isolation valve 42 between 10-17 October 2016 from either Statoil or Songa.
2. It has not been possible to clarify whether gas detectors on DSB registered gas during the incident, since detector history is only stored for 30 days. Confirmation has been obtained that no gas detector reached its activation limit.

In order to establish the causes of incidents, it is important that data are available from the control system. Some time can elapse in a number of cases from the initial incident until the actual incident occurs, and the question of whether 30 days is an adequate length of time for storing control system data therefore needs to be assessed.

8.2 Experience from other facilities.

The investigation secured access to a document used for Oseberg (system and operation document S004718Opr), which was valid from 21 March 2017. Its section 3.4 describes how to pull an HPC from a template with barriers against the reservoir and the production facility respectively. This document refers to R-18601 and specifies that valves against the production facility must be tested and defined by a test in a separate document. In addition, it specifies that the valves must not only be closed but locked by ROV to avoid accidental operation. No corresponding documentation was established for Åsgard.

When well responsibility was handed over from Åsgard A to a multipurpose vessel for replacing the FCM in 2014, a detailed procedure was drawn up which included a description of how risk is to be assessed for all activities and how the isolation valve is to be tested. This document was unknown to the B&B personnel responsible for planning and executing the operations on S-4 in October 2016 and March 2017.

9 Discussion of uncertainties

This chapter covers uncertainties which the investigation team has been unable to verify.

9.1 Change of valve position

A key aspect of the incident is the change in status for valve 42. Uncertainty prevails about the circumstances which caused its position to change from closed to open between 10 October 2016 and 17 October 2016.

Operating the isolation valves on the manifold from Åsgard A is not possible after control has been transferred from the installation to SENC. Statoil states that a block has been inserted in the control system on SENC so that the isolation valves on the manifold cannot be operated. This means that the position of isolation valves 41 and 42 on the manifold could not be changed from the time the FCM was disconnected on 17 October 2016 until it was reconnected on 24 March 2017. Confirmation has been received that valves 41 and 42 were closed on the morning of 10 October 2016, and that valve 42 was open on 9 December 2016. How the change of position for valve 42 occurred is unknown. Logs for all operations and alarms in the SENC control room are automatically deleted after 30 days, making it impossible to verify whether any operations involving forced activation of isolation valve 42 took place between the morning of 10 October 2016 and 17 October 2016, when it was still theoretically possible to operate the relevant valve.

The investigation has identified three possible causes for a change in valve 42's position:

- the valve was erroneously operated from SENC during 10-17 October 2016
- pressure changes in the hydraulic system arising from the operation of other valves could have caused the isolation valve to move
- if hydraulic pressure had been bled off and pressure in the flowline was low, the valve could have moved to the open position.

It has not been possible to confirm or deny any of the possibilities above through interviews or available documentation.

9.2 Testing of valve 42

The view was expressed in the initial stages of the investigation that isolation valve 42 was tested and that the indicator gave an erroneous reading. What is expected with regard to testing of the isolation valves on the manifold is not described in the DOP. What was done by B&B to test the valves in October 2016 has not been described to the investigation team. It is also unclear how far B&B considered its own pressure observation (inflow test) to be a barrier test for the isolation valves on the manifold.

Statoil has subsequently leak-tested the valve, which satisfied an acceptance criterion of two per cent over 10 minutes. The valve was also operated, and the indicator was observed to move to the correct position (neutral/closed).

10 Assessment of Statoil's investigation of the incident

Statoil has conducted an investigation of the incident. Its description of the course of events as well as the direct and underlying causes related to technical factors and governing documents by and large coincides with the PSA's own findings. Recommended improvement proposals to ensure knowledge of and compliance with requirements for establishing barriers with this type of parallel operation appear to be well defined and justified.

Management follow-up related to the execution of operations is only assessed to a limited extent in the report.

11 Gas hazard analysis, subsea gas leak on DSB

Statoil's simulations show that the worst conceivable scenario would be if the subsea gas leak occurred in calm conditions. The analyses concludes that a possible ignition of the leak would probably have resulted in a fire under the facility's lower deck and an explosion in the partially enclosed volume above the moonpool. Estimates indicate that blast pressure in the partially enclosed volume could cause local explosion injuries, but would not threaten the integrity of the derrick or the rest of the facility. Personnel in the parts of the rig adjacent to the sea and in the moonpool area could possibly have been exposed to loads with a potentially fatal outcome.

The investigation team has no comments on the assumptions and hypotheses applied in the analysis or on the results obtained.

12 Sources

Sources of photographs of the facilities
Åsgard A
http://www.skipsmagasinet.no/nc/forsiden/nyhet/artikkel/gass-kondensatfunn-nord-for-aasgard/ (date: 18 April 2017)

Deepsea Bergen
http://www.odfjelldrilling.com/ (date: 18 April 2017)

Songa Encourage
http://www.songaoffshore.com/Pages/Rigs.aspx (date: 18 April 2017)

13 Appendices

Appendix A: Overview of personnel interviewed and participants in meetings
Appendix B: The following documents have been utilised in the investigation