

Investigation report

Report	
Report title	Activity number
Hydrocarbon leak on the Ula P facility, 12 September 2012	010019010

Security grading		
<input checked="" type="checkbox"/> Public	<input type="checkbox"/> Restricted	<input type="checkbox"/> Strictly confidential
<input type="checkbox"/> Not publicly available	<input type="checkbox"/> Confidential	

Summary
<p>A substantial hydrocarbon leak occurred on the Ula P facility on 12 September 2012.</p> <p>The direct cause of the leak was the fracturing of the bolts holding together a valve in a separator outlet. Seepage in the valve exposed the bolts to produced water with a high content of chlorides and a temperature of about 120°C. This resulted in chloride induced stress corrosion, which weakened the bolts until they finally fractured.</p> <p>A precondition of the choice of material for the valve bolts is that these do not come into contact with the medium. This precondition was not followed up in the organisation after seepage in the valve was detected.</p> <p>The hydrocarbon quantities which flowed out in connection with the leak are estimated to total 125 barrels (20 cubic metres) of oil and 1 600 kilograms of gas.</p> <p>The oil released spread to large parts of the P01 mezzanine area, with equipment, walls and ceilings becoming coated with crude. Small quantities of oil were also observed in the sea.</p> <p>No people were injured in the incident. Production was shut down for 67 days as a result of the leak.</p> <p>The PSA considers that the incident had the potential to become a major accident, with the risk of a number of fatalities and substantial material damage.</p>

Involved	
Main group	Approved by/date
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1 Summary

Course of events

A substantial hydrocarbon leak occurred on Ula on 12 September 2012.

The Ula P (production) platform was in normal operation when the incident occurred. At 7.08.25, the first gas detector detected hydrocarbons in the P01 mezzanine separator module on Ula P. A few minutes later, all the detectors in the module detected gas. This indicated a major gas escape.

At that time, only three people were on Ula P because a red emergency shutdown (ESD) test was being prepared. They noted that a big leak had occurred and quickly evacuated to the Ula D (drilling) facility.

Other gas detectors sounded a high-level alarm at 07.08.44, which led automatically to activation of yellow ESD (the lowest level, ESD 3) and a general alarm. Yellow ESD includes disconnection of all ignition sources not critical for production or safety, automatic pressure blowdown and the closure of isolation valves – including those intended to isolate liquid outlets on the high pressure (HP) inlet separator. Because the leak arose from a fracture in a bypass valve across an ESD valve, the separator was not isolated from the leak point. Water, oil and gas therefore continued to flow from the separator until no overpressure remained in the latter.

The emergency response organisation mobilised, and personnel mustered in accordance with the emergency response plan.

Direct cause

The direct cause of the leak was fracturing of the bolts holding the valve together. These bolts are made of austenitic stainless steel. Leaks/seepage in the valve exposed the bolts to produced water with a high content of chlorides and a temperature of 120 °C. This resulted in chloride stress corrosion cracking, which weakened the bolts so that they finally failed in connection with a minor pressure increase in the system caused by an operational disruption.

Underlying causes

External seepage was detected on the valve on 29 March 2012. A risk assessment concluded that the valve could be replaced during the 2013 turnaround. A precondition of the choice of material for the valve bolts is that these do not come into contact with the medium (produced water). This requirement was not followed up in the organisation when seepage was detected in the valve.

Similar corrosion problems have occurred on Ula earlier, and BP was aware that this is a corrosion issue in the produced water system. An incident on Ula in 2008 involved the fracturing of two of four bolts as a result of the same corrosion mechanism. Routines were not established to ensure that this knowledge and experience were included in risk assessments related to seepage, and the experience was not applied when assessing the seep in question.

Actual consequences

BP has estimated that the hydrocarbon quantities which flowed out in connection with the leak were:

Oil: 125 barrels (20 cubic metres)

Gas: 1 600 kilograms in all, about 500 kilograms directly from the separator and roughly 1 100 kilograms vaporised from the oil

Produced water: 14 cubic metres.

The oil released spread to large parts of the P01 mezzanine area, with equipment, walls and ceilings becoming coated with crude. Small quantities of oil were also observed in the sea.

No people were injured in the incident. Production was shut down for 67 days as a result of the leak.

Potential consequences

We consider the timing of the leak to have been arbitrary. This means people could have been present in the module. Those close to the leak site could have died from burns inflicted by hot steam and water. Other people in the module could have died from the narcotic effects of the gas if they were unable to escape immediately because of injury or reduced visibility.

Had the hydrocarbons ignited, the result could have been an explosion with subsequent fire or simply a fire. Personnel in the module would probably then have died. The possibility that the gas could have ignited under slightly different circumstances cannot be excluded. That would have caused extensive damage in the process area.

Ula P has deficiencies in both explosion and fire protection. This means that an explosion or fire could have escalated out of the module and posed a threat to large parts of the facility.

Our investigation has identified 11 nonconformities:

- Inadequate follow-up of preconditions for the choice of materials in the valve
- Inadequate documentation of the valve
- Inadequate execution and follow-up of own analyses
- Inadequate strategies and principles for designing, using and maintaining barriers
- Inadequate passive fire protection
- Inadequate explosion resistance
- Inadequate follow-up of identified nonconformities
- Deficiencies in the ESD system
- Deficiencies in maintaining the process safety system
- Deficiencies in emergency preparedness and action plans
- Inadequate risk assessment when planning and executing normalisation and cleaning work

2 Introduction

A hydrocarbon leak occurred in area P01 on BP's Ula P facility on 12 September 2012. The Petroleum Safety Authority Norway (PSA) resolved to conduct its own investigation of the incident.

Composition of the investigation team:

- Øyvind Lauridsen, investigation leader, organisational safety
- Kjell-Gunnar Dørum, process safety
- Ove Hundseid, process safety
- Odd Hagerup, structural safety
- Vidar Kristensen, technical safety¹
- Hanne Etterlid, process safety¹

The following have also contributed specialist input:

- Odd Tjelta, technical safety
- Inger Helen Førland, emergency preparedness
- Sigvart Zachariassen, physical chemical working environment

We have conducted our investigation through interviews with personnel in the land-based and offshore organisation, through the assessment of governing documents and BP's own investigation report, and through a verification on Ula. Interviews have also been conducted with valve supplier Score. In addition, use has been made of analyses and reports commissioned by both the BP and PSA investigation teams. BP has made good provision for us to conduct our investigation.

¹ Has not participated in the final phase because of a change of job.

3 Course of events

This chapter describes the incident and the timeline of the course of events, including the relevant history up to the first few days of clear-up and repair work in order to return the process plant to its normal operating condition.

The Ula complex comprises three facilities for quarters, drilling and production respectively, linked by bridges as shown in the photograph below.



Figure 1. The Ula complex

The incident occurred in the process plant on the P facility's mezzanine deck in module P01.



Figure 2: The Ula production facility, with the module locations drawn in.

A bypass valve was installed in 1994 across the ESD valve on the produced water outlet from the separator. This valve is normally in the closed position. It is used for pressure equalisation in connection with start-ups.

The bypass valve was replaced in 2004 because it had become locked in a closed position.

When the line incorporating the valve was inspected on 29 March 2012, the build-up of a layer of salt was discovered on the valve as the result of a small leak/seepage. After an assessment of the seepage, it was decided to replace the valve during the 2013 turnaround. The leak was recorded in a seep register and inspected roughly every other week.

The production facility was producing normally on 12 September 2012. It was planned to carry out a test of red ESD (the highest level) that day, and staffing on Ula P was accordingly reduced. There were only three process technicians on the facility.

At 07.06.59, a fault caused one of the gas compressors (UGU) to shut down automatically. This meant that the pressure in the HP inlet separator, which delivers gas to the compressor, rose from about 18 barg to roughly 24, which is within the design limit. This was the direct reason why the bolts fractured in the XXV-4950 four-inch bypass valve on the separator's water outlet. Pressure in the line split the valve as shown in Figure 3, and produced water followed by oil and gas flowed at a high rate onto the P01 mezzanine deck.

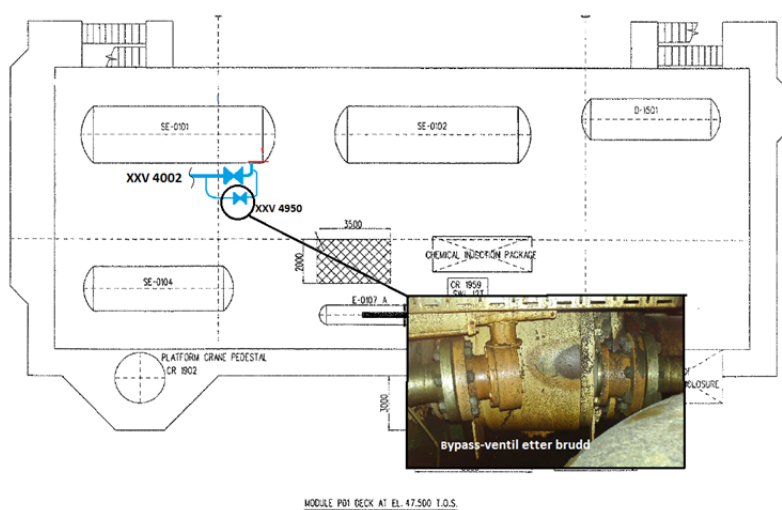


Figure 3: P01 mezzanine deck, showing the position of the bypass valve in the module, and a photograph of the valve after its failure.

At 07.08.25, the first gas detector sounded a low-level alarm on the P01 mezzanine deck. At 07.08.37, the first gas detector on the mezzanine deck changed to a high-level alarm. The three process technicians on Ula P were informed of this by the control room operator. They headed for P01 from various parts of the facility to check out the gas alarm. All three discovered that large volumes of water vapour/gas were pouring from the ventilation panels in the module. They evacuated to Ula D.

At 07.08.44, other gas detectors sounded high-level alarms. This automatically activates yellow ESD (the lowest level, ESD 3) and a general alarm. See /83/. Yellow ESD includes disconnection of all ignition sources not critical for production or safety, automatic pressure blowdown and the closure of isolation valves – including those intended to isolate liquid

outlets on the HP inlet separator. Because the leak arose from a fracture in a bypass valve across an ESD valve, the separator was not isolated from the leak point. Water, oil and gas therefore continued to flow from the separator until no overpressure remained in the latter.

P01 mezzanine filled with gas, and virtually all the gas detectors in the area sounded a high-level alarm within two-three minutes of the first gas detection.

At 07.12, Ekofisk, the Joint Rescue Coordination Centre (JRCC) and shipping in the area were alerted.

At about 07.17, the forward on-scene command was established on Ula D with a view of the P01 mezzanine module. See /3/. From here, a cloud of steam/gas was seen emerging from the module, and oil was observed on the sea. The three people on Ula P were registered as having come across to Ula D. In addition, a scaffolder on his way to tag a scaffold had turned back on the bridge (cf. interview).

At 07.18.21, orange ESD (ESD 2-P) was activated on Ula P from the control room. This was done to achieve complete disconnection of all ignition sources on Ula P. Because the control system nodes for the fire and gas (F&G) detection system are placed on Ula P, the system was disconnected at ESD 2-P. This meant that F&G detection could no longer be monitored from the control room. However, a new F&G system was being installed on Ula P, which could remain operational after an ESD 2-P. Although this system had not been taken over by operations, installation had come so far that it could be used to check gas levels on Ula P.

At 07.23, an overview of all personnel on board was established, see /3/.

At 07.28, it was decided to send a firefighting team together with an operator (all wearing smoke diving gear) to P01 mezzanine to locate the source of the leak. See /3/ and interview.

At 07.30, the JRCC notified the PSA of the leak.

At 07.37, the Forus Alarm Centre (FAC) was notified by the facility manager, see /3/.

At 07.40, the JRCC notified the PSA that the leak was genuine.

At 07.45, the firefighting team confirmed that the leak was under control, see /3/.

At 07.57, smoke divers entered the P01 mezzanine module, see /3/ and /85/. Interview statements say that oil and sand lay on the deck and whole module was covered with oil. According to BP, there was no indication of hydrocarbons. See /85/.

At 08.00, the JRCC notified the PSA that the leak had ceased and that BP was working to locate the leak site.

At 08.24, the decision was taken to secure radioactive sources in the HP separator, and smoke divers were sent in with the on-site commander and an operator – both of them wearing filter masks. This work terminated at 09.00. No indication of radioactivity and hydrocarbons was found. See /3/ and /85/.

At roughly 08.30, the personnel muster was terminated (interview).

At 09.15, the JRCC notified the PSA that the situation had been clarified immediately before 09.00.

At 09.20, BP notified the PSA verbally about the leak.

About two-three hours after the leak, personnel with filter masks and boiler suits entered the module to check its condition (interview).

At 14.16, BP confirmed the notification in writing to the PSA.

About 16.00, the whole emergency response team conducted an inspection of the area wearing filter masks. The team was accompanied by two members of the firefighting team. No indication of hydrocarbons was found. See /85/.

On 13 September, BP briefed the PSA verbally on the scope of the leak.

On 13 September, personnel were sent into the area to check detectors and valve isolation, and to reverse the orange ESD. According to BP, there was no indication of gas or radioactivity. See /85/.

On 14 September, by agreement with BP's investigation team, cleaning was initiated with brushes and sludge vacuum cleaners. The personnel used disposable suits, rubber boots and filter masks. See /85/.

On 14 September, BP updated the PSA in writing on the incident.

On 16 September, cleaning with high pressure water jetting began. Based on hydrocarbon measurements, personnel were required to use respiratory protection in all work. Personnel who were to carry out high-pressure jetting used overpressure gas masks because of the aerosol problem. Repeated measurements of hydrocarbons were made. After four-five days, no indication could be found because many of the fractions from the HP separator had been removed through washing. See /85/.

4 System failings and equipment faults

System failings and equipment faults identified as a result of the incident are described below.

4.1 The bypass valve

A bypass valve was installed ahead of the ESD valve for produced water out of the inlet separator. It was used in connection with start-ups, and stood in the closed position during normal operation. It was replaced in 2004 after becoming stuck in the closed position

When the line was inspected on 29 March 2012, the build-up of a layer of salt was discovered on the valve as the result of a small leak/minor seep. A work order was established to replace the valve no later than the 2013 turnaround. A seep register was created in order to follow its development. See /50/.

The valve with bolts and gaskets was replaced in 2004 with a unit with the same specification as the original (like for like). This was in accordance with the company's policy of using the same specification when replacing equipment, even if it did not conform to the latest revision of Norsok M-001 or the company's most recent material specifications.

We have not identified why the seepage occurred. It could have been due to faulty installation, the quality of the gasket material, wear and tear, pollution, temperature fluctuations, aging of the gasket material, faulty dimensions and so forth. This cannot be clarified now, since only parts of the gaskets were found after the incident.

Damage to the bypass valve was analysed by Exova A/S, see /63/. Fracturing of the bolts in the four-inch valve resulted from chloride stress corrosion cracking of austenitic stainless steel, AISI 316 and AISI 304.²

The valve was delivered with gaskets and bolts and fully coated externally. Exova's analyses confirm that produced water from inside the valve caused the bolts to fracture.

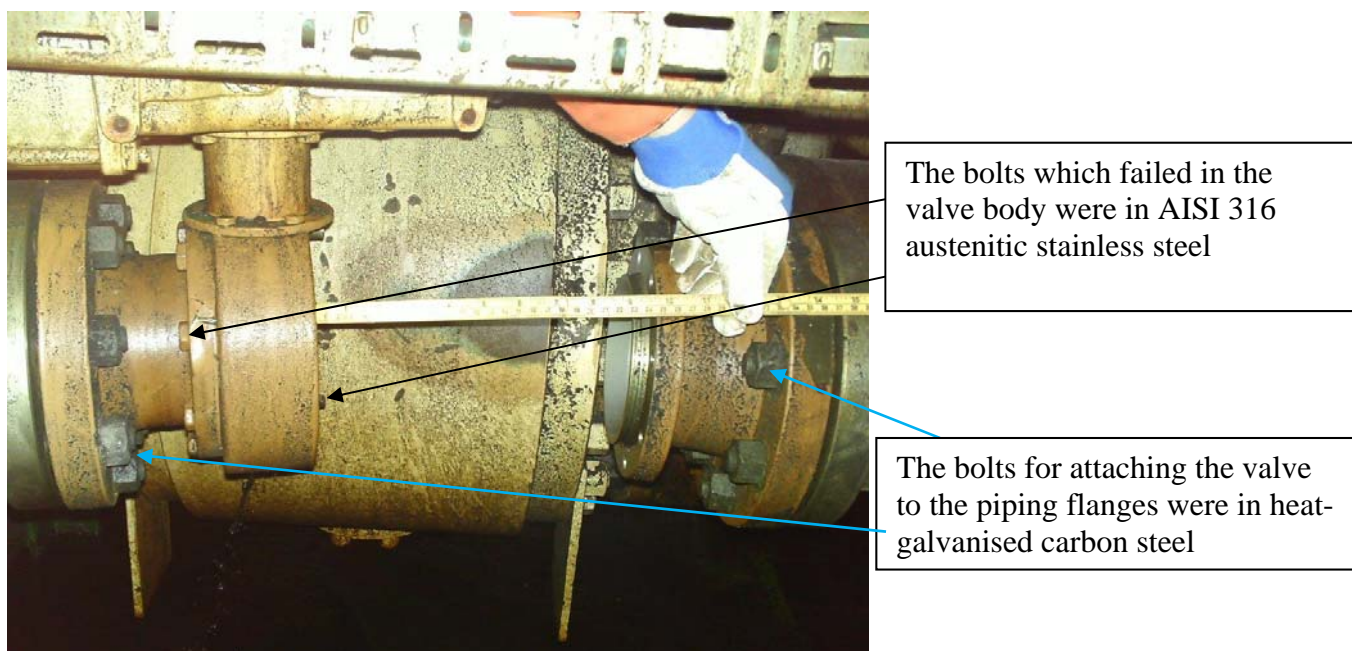
Corrosion of valve bearings and signs of stress corrosion cracking in bolts in the valve stem adaptor show that water must have come from the inside. A valve stem bearing in carbon steel will corrode in carbon dioxide and chloride-bearing produced water. Similarly, crevice corrosion has occurred on the valve stem adaptor. Intrusion of a corrosive medium is not normally expected in this area.

This means that several (all) of the gaskets in the valve have failed against the stuffing box/actuator side. Small quantities of produced water could have leaked out at the stuffing box, intruded between the valve housing and flange, and moistened bolt holes and bolts.

Furthermore, the analysis suggests that the bolts have fractured at different times. The first of them could have broken without causing an external leak. Because a number of the bolts are broken between the valve housing and the flange, the breaks are hard to detect since the bolts

² Analyses of materials in the valve confirm that ASTM A354 Gr CD4MCu is used in the valve body, flanges, bearings, valve seat and valve stem. The bolts are confirmed to be of ASTM A351 Gr B8M (AISI 316) and A2-70 (AISI 304) respectively in accordance with valve drawing 01 09 1334 CE01 from the manufacturer. The analyses show carbon steel assumed to be AISI 1522 for valve bearings 1 and 2 and AISI 316 for the stuffing box, while they should have been ASTM A354 Gr CD4MCu (superduplex).

do not fall out, the nuts are covered in paint and the bolt is held in place. When several bolts fail, the strength of the remaining bolts, weakened by corrosion cracking, will ultimately be insufficient.



Photograph 4: shows the valve body bolts in AISI 316 with breaks, and the bolts in heat-galvanised carbon steel for attaching the valve to the piping flanges.

Austenitic stainless steels such as AISI 304/316 are subject to chloride stress corrosion at temperatures above roughly 60°C when exposed to a chloride-containing environment, such as produced water or seawater/spray, and stress. Austenitic stainless steels such as AISI 304/316 are also subject to crevice corrosion and pitting.

The material certificate for the valve specified 25 per cent Cr superduplex, A351 GrCD4McU, for body, flanges and bolts. The analysis of the certificate from the manufacturer confirms 25 per cent Cr superduplex for body and flanges, but the bolts are analysed to be in AISI 316, A193 GrB8M. Had the bolts been in superduplex, as stated in the specification section of the certificate, they would probably have coped with the exposure to produced water.

4.2 Ignition source disconnection

Activating ESD-2P disconnects all ignition sources on Ula P. This includes the ventilation systems which ensure overpressure in local utility spaces. As a result, these are no longer protected from gas intrusion, and all ignition sources in these spaces must therefore be disconnected automatically. Some equipment in such spaces has uninterruptible power supplies (UPS), which deliver power when the supply fails. These batteries must therefore also be disconnected to ensure the equipment is voltage-free. In connection with the incident, one of these battery breakers failed, which meant ignition sources were still present in the space after overpressure protection had been disconnected.

4.3 Fire water system

Activating ESD 2-P also disconnected the fire water pumps on Ula P, so that these would have been unavailable had fire water been required. The ESD system should not normally disconnect fire water pumps, and this represents a design error. The pump on Ula P is one of three available fire water pumps in the Ula complex. The two other pumps were still available, and were in a position to supply Ula P with sufficient fire water if necessary.

4.4 Process safety system

The break-up of the bypass valve meant that the level of liquid in the separator began to fall. If this level declines below a certain point, the process safety system should shut down the process plant. This is detected in the separator by a level switch, designated LSSL-4005. Among other actions when a low level is detected, the wellstream flow to the separator is shut down. The level switch failed during the incident, in that it only detected a low level about two minutes after the level had fallen below the detector's set point. This meant that the process plant continued to produce until the F&G detection system detected gas in the module. The process plant was then shut down by the ESD system. If LSSL-4005 had functioned as intended, it would have reduced the amount of liquid which flowed out by shutting the inlet to the separator at an earlier stage.

The process safety system only shuts down production, and does not initiate pressure blowdown of the separator. Automatic pressure blowdown is activated by the F&G detection system. Pressure blowdown would not have started earlier if the level switch had worked, but the volume which leaked out would have been reduced.

According to the maintenance programme, the level switch should have been tested annually. However, it had not been tested for the three years prior to the incident. See /97/.

5 Actual consequences

Based on calculations and assessments conducted by BP, see /40/, the leak involved some 14 cubic metres of produced water, about 125 barrels (20 cubic metres) of oil and 1 600 kilograms of gas, including roughly 500 kilograms from the damaged valve and around 1 100 as vaporisation/boil-off from the oil released. Gas was detected by all the gas detectors on the P01 mezzanine and by one on the P01 main deck. We have no objections to the calculations and assessments carried out by BP in this area, and accordingly base this report on the assessments in reference /40/.

The oil released spread to large parts of the P01 mezzanine, covering equipment, walls and ceiling. In addition, oil covered virtually the whole deck in the area. Based on observations, oil also escaped from the area and ran down the outside of modules P01 and P02.

Oil was also observed on the sea. We have not had an adequate basis in this investigation for assessing how much oil was discharged to the sea. BP has estimated it as less than 6.25 barrels (one cubic metre).

In addition come other material and financial consequences of the incident, such as a 67-day production shutdown and costs associated with cleaning up and improvements.

6 The potential of the incident

6.1 Potential consequences of the actual leak

This chapter provides an assessment of the potential consequences of the actual leak which occurred on 12 September. The time the incident happened, the number of people on Ula P and the rate and duration of the leak are assumed to be the same as the description provided in chapter 5 above. The main difference between the assessments in this chapter and those in chapter 5 is that we consider here the possibility of ignition and the potential consequences of a fire and/or explosion which could then have been caused.

6.1.1 Possibility of ignition

Immediate ignition

The possibility that the leak could have ignited immediately or in the course of the first few minutes of the incident is considered to be small or non-existent. Although the water which leaked out initially contained some gas, see /40/, the gas distribution was too low at that time to create a combustible atmosphere.

Delayed ignition

In the period between gas detection by the first detector in P01 mezzanine (about 1.5 minutes after the leak began) and the point when the leaking segment was depressurised (about 11 minutes after the leak began), a combustible concentration of gas existed in large parts of the P01 mezzanine area. Despite equipment being certified and approved for zone³ 1 or 2, a fault in the equipment could have created an ignition source in the area.

We have not found it appropriate to assess how likely it was that the incident could potentially have ignited⁴. However, we cannot exclude the possibility that the leak, under slightly different circumstances, might have been ignited.

6.1.2 Potential consequences had the actual leak ignited

Ignition of the leak could have resulted in an explosion with subsequent fire, or simply a fire. The crucial factors for the potential outcome are the time when ignition occurred, the size and concentration of the gas cloud, and the location of the ignition source. This chapter provides first an assessment of the potential consequences of an explosion, and then an assessment of the consequences of a potential fire.

³ Areas on the facility must be classified into zones in accordance with the probability for the presence of gas.

⁴ We consider that starting from a generic ignition probability for various types of equipment and then using these in models to calculate ignition probabilities for various cloud sizes (as is typically done in a quantitative risk analysis (QAR) context), is an inappropriate and unsuitable approach for assessing ignition opportunities in a specific incident. Similarly, an insufficient basis exists for starting from the area classification in assessing ignition opportunities. The relevant issue is how far this incident, on this facility and at this time could have ignited, not what generic data might possibly provide in the way of information. In our view, a more professional approach would accordingly have been to assess technical condition in relation to possible failure modes, maintenance, testing and inspection routines and history of the individual potential ignition source, combined with a detailed assessment of the gas concentration in the individual sub-area of the module during the course of events. Only then would an adequate basis be available to assess the ignition opportunity as small or large. We have not found such an assessment appropriate as part of our investigation, since it would be very extensive and would not have made an appreciable contribution to fulfilling the investigation's mandate.

6.1.2.1 Potential consequences had the actual leak caused an explosion

Given the explosion resistance of the wall in P01 (0.05 barg), see /43/, and assuming that gas ignited in the area during the incident, our assessment is that the wall would very probably have been exposed to accidental loads substantially above its tolerance. That accords with the assessment provided in reference /81/.

We consider that it would not be possible to assess the consequences of potential explosions in a sufficiently refined manner without conducting new simulations based on relevant leak scenarios and the specific configuration of the area. Questions would include the further consequences if the explosion had damaged the wall of P01, other segments and barrier elements in P01, or the surrounding modules.

6.1.2.2 Potential consequences had the actual leak caused a fire

We have not carried out own studies and analyses to clarify the potential consequences of a fire. We have accordingly opted to base our assessment on studies and analyses carried out by BP for Ula, see /44/ and /4/, and supplied to us.

The risk analysis for Ula, see /4/, notes that a diffuse gas fire has been assessed as a dimensioning fire scenario for module P01. This is repeated in the applicable performance standard for passive fire protection on Ula, see /19/. It is unclear to us why a diffuse gas fire has been chosen as dimensioning for module P01. In an incident, various types of fire could arise from relevant leak media and pressure conditions, such as jet, spray, diffuse gas and pool fires. We consider that the Ula risk analysis fails to provide a sufficient basis for evaluating the potential of the 12 September incident had it resulted in a fire.

On the other hand, the fire analysis conducted for Ula in 2009, see /44/, has assessed both gas and liquid fires. A separate memo, see /77/, describes the scenarios assessed in this analysis as well as the input and assumptions applied. Some of the assumptions applied include:

- pressure: 27 barg, temperature: 124°C, volume: 85 cubic metres, liquid density: 710 kilograms per cubic metre
- process segment 1 (segment 1 from the risk analysis) is isolated from neighbouring segments on both liquid and gas sides
- blowdown functions – reduces pressure in the tank to seven barg in 15 minutes
- liquid volume in the tank will represent 50 per cent of the tank volume
- no effect on the leak is attributed to the weir plate.

Scenario 1 in the analysis is a full breach of the MP or HP separator. It assumes that all 29 tonnes of liquid are released in such a way that the leak rate is the same as the total vaporisation rate from the largest pool which could form (limited by drainage outlets and the capacity of the drainage system), assuming that the liquid gets heated by a fire. Based on this approach, the analysis assumes that the scenario will apply to all potential liquid leaks.

Although the relationship between liquid and gas in the separator during the incident, see chapter 5 **Feil! Fant ikke referansekilden.**, differed from the assumptions/input in the 2009 fire analysis, we consider scenario 1 in this analysis to be a relevant starting point for assessing the potential of the 12 September incident. Note that this only applies to the period covered by the simulations in the analysis (about 20 minutes).

With regard to the gas released from the separator and vaporised from the oil (as a result of the high oil temperature), we have opted to assess this in the chapter on potential explosions above. In other words, we have not assessed the potential in scenarios other than that covered by scenario 1 in the 2009 fire analysis.

Load-bearing structures in P01 mezzanine have not been provided with passive fire protection. Based on the 2009 fire study, see /44/, the consequences of an ignited liquid fire of this size and duration would be a loss of structural strength and large deformations, ignoring the effect of fire water. On the other hand, the further consequences of these deformations have not been assessed – including the potential for spreading to other equipment and to other underlying levels and modules.

Passive fire protection has not been provided on equipment in P01 either. Reference /81/ concludes that the outcome of a fire of this size would probably have destroyed most of the equipment in P01, which again suggests that a fire would have gained access to hydrocarbons from other segments passing via P01. Our conclusions are identical with those of reference /81/ in this area. We have not assessed when hydrocarbons could have been supplied and possibly from which segments.

As discussed in chapter 4.3, the fire pump on Ula P would not have started had fire water been required after ESD 2-P was activated. The fire pumps on Ula Q and D would have had sufficient capacity to meet fire water needs in P01 and P02.

Our investigation has not assessed how far pressure blowdown and fire water lines and their attachments would have been available in sufficient time had a fire occurred. Nor have we assessed the potential effect of fire water on the potential course of a fire and the loads it could have generated. In the event, the potential consequences of a fire would regardless have been extensive even if these barriers had functioned as intended.

We conclude that a fire could in this case have caused extensive damage to large parts of the facility.

6.1.3 Potential consequences for people, the environment and material assets at the actual time of the incident

We consider that the actual location of the three people on Ula P when the incident occurred was arbitrary. Their job was to look for faults in instrument air, so it was purely coincidental that one or more of them were not in the module affected. Without ignition, we consider that the consequences of exposure to water vapour, hot oil or gas could have been serious personal injuries or loss of life (see also chapter 6.2.1). Personnel could also have been hit by fragments from the broken valve (bolts, etc).

The leak could have ignited after about 1.5 minutes, so that those who were not injured immediately would have had a chance to escape from P01 mezzanine if they were at the other end of the module. People injured or unable to orient themselves because of the vapour cloud would have been unable to escape and could have died if the leak ignited.

The timing of a possible leak ignition would have been highly significant for whether personnel in P01 sustained injuries. The three people on Ula P when the incident occurred headed for the accident site to establish what was happening. That accords with the reaction

of the alarm response team described in appendix D of the emergency response plan, which states that area operations technicians on Ula P must check the area before mustering. See /99/. The possibility that one or more of the three were closer to the accident site and could have been exposed to a potential fire or explosion accordingly cannot be excluded.

Consequences for personnel in other parts of Ula P would have depended largely on the level of accident loads and the facility's ability to handle/withstand these. One factor difficult to clarify in detail is the way smoke and heat from a fire in the wake of a powerful explosion would have affected escape opportunities to the facility bridge. Our assessment is that fatalities or serious personal injuries could have been sustained by personnel who were outside P01 mezzanine in the event of ignition. Based on analyses and studies received, however, we believe that the bridge to Ula F would probably have been accessible after a possible explosion and fire in P01 mezzanine.

Ignition would mean that search and rescue for possible missing/injured people on Ula P could have been rendered difficult or impossible until the fire was under control.

With regard to potential consequences for the environment, we consider that the incident is unlikely to have resulted in a large or lengthy oil spill. The quantity of oil which could potentially have escaped would probably have been limited to the oil in the process plant on Ula P, less the volume consumed by a possible fire. We have not assessed how far the loss of structural strength from a fire or escalation to other areas as a result of an explosion might have caused leaks from risers on Ula P.

We have not assessed the potential consequences for material assets if the incident had resulted in a fire or explosion, other than to note that either would probably have caused extensive material damage and a lengthy production shutdown

6.2 Potential consequences under slightly different circumstances

6.2.1 Timing of the incident

The incident occurred at the time it did because of a pressure build-up in the HP separator as a result of the unintended shutdown of the UGU compressor. We accordingly consider that no connection exists between the preparations for the planned ESD test and the direct cause of the leak. Our assessment is accordingly that the incident could potentially have occurred at any time of day, and on a different day.

Had the incident happened at a different time, the following conditions could have prevailed.

- The volume of liquid and gas in the HP separator could have been different, since the liquid level had been lowered as part of preparations for the ESD test. Given the same leak, this would have released a larger volume of oil and thereby a higher proportion of gas in the module as a result of boil-off.
- A number of people could have been on both main and mezzanine decks in P01. On the other hand, we have not drawn any conclusions about how many might potentially have been in the area or where personnel might potentially have been in P01 mezzanine. We assume from comments made in interviews, on the other hand, that more than 10 people could occasionally be found in the area during daytime – in connection with maintenance activities, for example. Based on this information, we consider that a number of people could potentially have been exposed to water and oil vapour at temperatures of 120°C as well as to hazardous gas concentrations. Such

exposure could have caused serious personal injuries or death. The following description of potential consequences is derived from the report by Proactima, see /84/, which was prepared for BP at the PSA's request.

- Exposure to steam or hot water released from the initial produced water release with an initial temperature of 120°C. If personnel are exposed to the steam or hot water in the near vicinity of the leak point, it is assumed that extensive and potentially lethal burns will develop in a limited time (a few seconds).
- Steam will rapidly fill the whole module and reduce visibility. Personnel in the module will probably lose orientation, be trapped in the module, and after a short time experience narcosis from inhaling ethane/methane. Personnel in the opposite end of the module from the HP separator will probably be able to escape before they are trapped by the steam cloud.
- Gas from the unstabilised crude oil will rapidly fill the module and displace the air in the module. Personnel in the module will suffer narcosis and suffocation.
- Shortly after the breakthrough of gas in the leak (two-three minutes), the emission of gas into the area is assumed to be lower than the gas ventilated out of the area through openings and louvered walls. However, the gas concentration in the area is assumed to remain lethal for the next 15-20 minutes and acutely toxic for another 15-20 minutes. One hour after the incident, it is assumed that most of the gas would have been ventilated off the module.”
- Wind direction and speed could have been different. Gas and steam could then have spread to other areas of the facility, which could in turn have caused exposure to other ignition sources. Different wind direction and speed would also have affected ventilation in and out of the area, affecting the size of the flammable cloud and associated explosion loads.

We have not considered whether the leak might have happened differently – in other words, whether the hole size could have been smaller if only one or some of the bolts had fractured. This means we have assumed the actual fracturing and hole size in our further assessments.

We will discuss the above-mentioned conditions below in our assessments of potential consequences. Only conditions not mentioned in chapter 6.1, and/or which change the assessments in chapter 6.1, are included.

6.2.2 Opportunities for ignition

DNV's assessments of consequences, see /81/, have identified a number of ignition sources which could have been exposed under different wind directions and speeds, as described above. Since the incident occurred at an arbitrary time, and could also have been initiated without the UGU compressor tripping, the possibility exists that this compressor could have functioned as a potential ignition source if the incident had happened at a different time. As noted in chapter 4.2, not all ignition sources were disconnected when ESD 2-P was activated.

6.2.3 Potential consequences from ignition

6.2.3.1 Potential consequences in the event of explosion

As noted for nonconformity 8.1.3, we consider that the explosion analyses carried out for the P01 mezzanine area provides an inadequate basis for assessing the potential of this incident.

We note that results from the explosion analysis conducted in 2004, see /82/, indicate that the gas concentration and explosion loads in the areas assessed are strongly influenced by ventilation. That also applies for other wind directions and speeds, which would have affected ventilation in P01 and flammable concentrations in the module.

The size of the leak means that an explosive atmosphere would probably have formed in the module even with other wind directions and speeds.

6.2.3.2 Potential consequences in the event of fire

We consider that other wind directions and/or speeds during the start of a potential fire would have little significance for its potential. A fire would have embraced the whole or large parts of the module, regardless of the wind. On the other hand, alternative wind directions and/or speeds would have been significant for smoke distribution and thereby also for access to escape routes locally on Ula P and the opportunity to escape across the bridge to Ula D.

6.2.4 Potential health consequences for personnel involved in the response team and in normalisation work, including cleaning the modules

6.2.4.1 Potential health consequences for personnel who entered the module in the first few hours after the incident

Smoke divers entered the P01 mezzanine module at 07.57, see /3/ and /85/. Interviewees reported that oil and sand lay on the deck and the whole module was covered in crude. At that time, the module could still have contained hazardous gas concentrations. Nevertheless, there was no indication of hydrocarbons, see /85/. We consider that the personnel were adequately protected against exposure to hydrocarbons by the smoke diving gear with a fresh-air supply.

At 08.24, it was resolved to secure radioactive sources in the HP separator, and smoke divers were sent in together with the on-scene commander and an operator – the latter two with filter masks. This work ended at 09.00. No indication of radioactivity and hydrocarbons was found, see /3/ and /85/. Most of the gas is estimated to have been ventilated out of the module within an hour of the leak, see /84/, but this had not been fully verified at the time and we consider that a half-mask with filter could have given insufficient protection unless personal tightness testing of the respiratory protection was conducted in advance.

6.2.4.2 Potential consequences for personnel who participated in normalisation work, including cleaning.

Personnel were sent into the area on 13 September to check detectors and valve isolation, and to reverse the orange ESD. Gas and radioactivity measurements showed no indications, see /85/. No safe job analysis (SJA) was conducted before carrying out this work, see /101/.

On 14 September, by agreement with BP's investigation team, cleaning was initiated with brooms and sludge vacuum cleaners. The personnel wore disposable suits, rubber boots and filter masks. See /69/.

On 16 September, cleaning with high pressure water jetting began. Based on hydrocarbon measurements, personnel were required to wear respiratory protection in all work. Personnel

who were to carry out high-pressure jetting used overpressure gas masks because of the aerosol problem. Repeated measurements of hydrocarbons were made. After four-five days, no indication could be found because many of the fractions from the HP separator had been removed through washing. See /85/. An SJA was conducted before this work, see /68/ and /70/.

Cleaning work continued for two weeks. Based on available information, Proactima concludes that personnel involved in normalisation and cleaning were well protected throughout the cleaning period, and neither the discharge/emission nor the clean-up operation posed any increased health hazard. See /84/. Proactima's conclusion could be based on insufficient information, see chapter 6.2.4.1. How far the presence of gas in the area could be verified with the relevant methodology is unclear.

7 Direct and underlying causes

7.1 Direct cause

The direct cause of the leak was the fracturing of bolts which held the valve together. The material in the bolts is austenitic stainless steel AISI 316. Chloride stress corrosion can arise in this material at temperatures above about 60°C. Produced water on Ula has a high content of chlorides and a temperature of roughly 120°C, so that this type of corrosion was quickly initiated when the bolts came into contact with the water. We consider that such contact was established as a result of leaks in the internal gaskets in the valve.

7.2 Underlying causes

External seepage was detected on the valve on 29 March 2012. A risk assessment concluded that the valve could be replaced during the turnaround in the summer of 2013, see /9/ and /50/. The technical specialist on materials was not involved in this assessment (cf. interview).

Materials for piping and valves in the produced water system have been selected on the basis that the water is salty and corrosive and has a high temperature of 120°C. External corrosion protection for the materials, including the bolt heads, is paint. See figure 4. A precondition for the choice of material (AISI 316) in these bolts is that they do not come into contact with the medium. This was not followed up in the organisation when seepage occurred in the valve.

Chloride stress corrosion was described in the Ula risk assessment. The risk-based inspection (RBI) programme is described in document 310-20044-017 *Risk assessment Ula*, see /96/. The issue was described in the inspection programme/drawings, along with other forms of corrosion.

The valve installed in 2004 was purchased in accordance with the original material specification for Ula. BP's philosophy for replacing valves on existing facilities was to swap "like for like" – in other words, apply the original specification. However, BP had prepared a new material specification for bolts. This specified other materials, which would have prevented this type of fracture. No routines existed for checking the specification against the latest version to ensure that experience and new knowledge are picked up. On the other hand, bolts which accorded with BP's new material specification and NORSOK M-001 –, i.e. hot-galvanised carbon steel – were used for installation in the Ula piping system.

Similar corrosion problems have arisen earlier on Ula, and BP was aware that this is a corrosion issue in the produced-water system. An incident occurred on Ula in 2008 when two of four bolts fractured as a result of the same corrosion mechanism. No routines were established to ensure that this knowledge and experience were included in risk assessments related to seepage, and experience was not applied when assessing the seepage in question.

The interviews revealed that the division of responsibilities for static equipment was somewhat unclarified, including ownership of inspection results for static equipment.

8 Observations

Generally speaking, our observations fall into two categories:

- nonconformities – observations where we believe the regulations have been breached
- improvement points – observations where we see deficiencies, but do not have enough information to be able to establish a breach of the regulations.

8.1 Nonconformities

8.1.1 Inadequate follow-up of preconditions for the choice of materials in the valve

Nonconformity

When seepage was detected, the problem of chloride stress corrosion in the produced-water system was not included in the risk assessment which underpinned BP's decision to leave replacement of the valve until the 2013 turnaround.

Grounds

After seepage was detected in the valve, a risk assessment concluded that it could be replaced during the turnaround in the summer of 2013. See /50/. A precondition for the choice of materials for the bolts was that these did not come into contact with the medium. BP was aware of the corrosion mechanisms in the produced-water system. These were described in risk assessments and the inspection programme for Ula. See /96/.

Similar corrosion problems have arisen earlier on Ula, and BP was aware that this is a corrosion issue in the produced-water system. An incident occurred on Ula in 2008 when two of four bolts fractured as a result of the same corrosion mechanism. No routines were established to ensure that this knowledge and experience were included in risk assessments related to seepage. The knowledge and experience were not applied when assessing the seep in question. See /83/.

It emerged during interviews that the inspection results were not checked with people who possessed relevant materials expertise, so that the corrosion risk was identified. It also emerged that the division of responsibility for static equipment was unclear, including ownership of inspection results for such hardware.

Requirements

The management regulations section 11 on the basis for making decisions and decision criteria, section 20 on registration, review and investigation of hazard and accident situations, and section 23 on continuous improvement.

8.1.2 Inadequate documentation of the valve

Nonconformity

Documentation is not available to show that the ESD valve satisfies regulatory requirements for fire resistance, and documentation in the materials certificate is inadequate.

Grounds

The documentation submitted on fire resistance is a statement of conformity dated 12 November 2012 from the QA manager at valve supplier Somagrep, see /92/. This does not represent verifiable documentation that the valve delivered in 2002 complied with the fire resistance requirements.

Two different materials are entered for the bolts in the materials certificate – superduplex in the specification and AISI 316 in the analysis. See /30/. This does not appear to have been picked up in the quality control process.

Requirements

The facilities regulations section 82, sub-section 2, see regulations for production and auxiliary systems on production installations, etc, issued by the Norwegian Petroleum Directorate on 3 April 1978 with later amendments of 1 July 1980, chapter 8.4.1 on ESD valves, see chapter 6.4.1 on general technical fire requirements for materials and equipment.

The framework regulations section 23 on general requirements for material and information and section 19 on verifications.

8.1.3 Inadequate execution and follow-up of own analyses

Nonconformity

Analyses have not been conducted which provide an adequate and appropriate decision base for assessing risk related to explosions in modules P01 and P02 on Ula P.

Grounds

Based on documents reviewed, including an assessment of earlier explosion analyses for Ula P, see /43/, and the impact assessment carried out in connection with BP's internal investigation, see /81/, our view is that BP, at the time the leak occurred, had not adequately assessed the consequences of a possible explosion developing in the P01 mezzanine area. We consider that it would not be possible to assess the consequences of potential explosions in a sufficiently refined manner without conducting new simulations based on relevant leak scenarios and the specific configuration of the area.

The analyses with associated results utilised by BP until now as part of the basis for assessing whether the risk in module P01 is acceptable are based on inadequate assumptions and input. See /4/, /43/ and /82/. These analyses have been pitched, for instance, at too general a level to provide a sufficiently refined picture of the potential consequences of explosions in module P01. A coarse equipment geometry and layout for the P01 mezzanine deck, based on the configuration of the P02 main deck, has been applied, for example. Furthermore, the leak scenarios which could occur the P01 mezzanine deck have not been applied. Nor have the consequences of different wind directions and speeds been adequately assessed in relation to potential explosions on the facility.

Requirements

The management regulations section 16 on general requirements for analyses.

The management regulations section 17 on risk analyses and emergency preparedness assessments.

8.1.4 Inadequate strategies and principles for designing, using and maintaining barriers

Nonconformity

The strategies and principles applied in designing, using and maintaining barriers were inadequate.

Grounds

The area risk chart and barrier strategy for the P01 separation module, see /27/, were not designed to provide relevant personnel with a shared understanding of the basis for the requirements set, including the relationships between risk and hazard assessments and the requirements for the individual barrier in this area. Weaknesses with implemented solutions, for example, in terms of handling an explosion or fire in this area, see chapter 6.1.2 above, did not emerge other than in general remarks about fires and explosions.

The area risk chart and barrier strategy for the P01 separation module, see /27/, did not cover hazard or accident conditions other than hydrocarbon leaks.

Applicable requirements for maintaining and testing barriers did not emerge, either in the strategy document or the performance standards to which it refers, see, for example, /19/. Cases also exist where test programmes have not been carried out, see section 8.1.9.

The consequences of failing to conform with performance-standard requirements were not adequately assessed. Nor was an assessment made of the seriousness of the nonconformity, how far it failed to conform with the regulations, when it was discovered, whether it was assessed as acceptable, and which decisions might have been taken with a view to following it up. Examples of this are nonconformities described on page 10 in the performance standard for passive fire protection, see /19/.

Requirements

The management regulations section 5 on barriers.

8.1.5 Inadequate passive fire protection⁵

Nonconformity

The P01 mezzanine has inadequate passive fire protection, which does not prevent a liquid fire from spreading.

Grounds

Inadequate measures have been implemented to reduce the consequences of a possible liquid fire in P01, see /98/:

- passive fire protection has not been provided for process equipment
- passive fire protection has not been provided for the load-bearing structure
- deficient classification and follow-up of ESD valves, including the XXV-4950 valve in question.

Requirements

The facilities regulations section 82, sub-section 2, see regulations for production and auxiliary systems on production installations, etc, issued by the Norwegian Petroleum Directorate on 3 April 1978 with later amendments of 1 July 1980, chapters 6.1 on general requirements for passive fire protection, 6.5 on separation of areas and 8.4.3 on isolating.

⁵ BP was given an order in connection with this nonconformity on 23 November 2012.

8.1.6 Inadequate explosion resistance⁶

Nonconformity

The explosion resistance of the firewall at the south end of P01 is too low in relation to the dimensioning explosion load for P01.

Grounds

Hazardous areas or spaces must be configured as far as possible so that the production facility's load-bearing components, ceiling and walls will not collapse or be spread (blown) outwards in the event of an explosion. The explosion resistance of the P01 fire wall is too low in relation to the dimensioning explosion load. See /43/ and /81/.

The frequency for an explosive pressure higher than the wall's design pressure (0.05 barg) exceeds the acceptance criteria of 10^{-4} per annum, see /43/.

Requirements

The facilities regulations section 82, sub-section 2, see regulations for production and auxiliary systems on production installations, etc, issued by the Norwegian Petroleum Directorate on 3 April 1978 with later amendments of 1 July 1980, chapters 6.5 on separation of areas and 6.5.1 on dimensions and locating of firewalls, with chapter 4.2.2 on dimensioning accidents in the associated guidelines on safety assessment of platform concepts, Norwegian Petroleum Directorate, 1981.

8.1.7 Inadequate follow-up of identified nonconformities

Nonconformity

Installation of foam in the sprinkler system for P01 was identified and planned as a compensatory measure in the 2005 application on extended producing life for Ula. This had still not been done when the incident occurred.

Grounds

Foam was not installed in the sprinkler system for P01 in order to limit a liquid fire, even though this had been listed as a planned compensatory measure in the 2005 application on extending the producing life of Ula, see /89/. The measure has been identified by BP as uncomplicated to implement and with a high utility value, see /93/. It had still not been done when the incident occurred in 2012.

Requirements

The management regulations section 22 on handling of nonconformities.

8.1.8 Deficiencies in the ESD system

Nonconformity

The ESD system shuts down the start-up system for the fire pumps.

⁶ BP was given an order in connection with this nonconformity on 23 November 2012.

Grounds

Activation of orange ESD (ESD 2-P) isolates the start-up batteries for the diesel engine which drives the fire water pumps on Ula P, so that the pump cannot be started if fire water is required. See /94/ and /95/.

Requirements

The facilities regulations section 82, sub-section 2, see regulations for production and auxiliary systems on production installations, etc, issued by the Norwegian Petroleum Directorate on 3 April 1978 with later amendments of 1 July 1980, chapter 8.6 on equipment exempted from ESD.

8.1.9 Deficiencies in maintaining the process safety systemNonconformity

The maintenance programme for parts of the process safety system has not been implemented as specified in the plan.

Grounds

The LSSL-4005 level switch which failed to shut down the process facility was inadequately maintained. According to the maintenance programme, it should be function-tested annually. No such test was carried out in 2010, 2011 or 2012. The switch was tested twice in 2009 because it failed the first test. See /97/.

Requirements

The activities regulations section 45 on maintenance.

8.1.10 Deficiencies in emergency preparedness and action plansNonconformity

The emergency preparedness and action plans were not updated with requirements for evacuating Ula P, and give an inadequate description of responses to hydrocarbon leaks.

Laminated action plans in the emergency response centre were not updated in accordance with the applicable emergency preparedness plan.

Grounds

The emergency preparedness analysis for Ula, see /100/, states that “Should a hazard or accident condition arise on Ula P, the most important measure is to evacuate to a safe platform within five minutes”. According to the performance requirements, such incidents include hydrocarbon leaks. This is also described as a compensatory measure in the exemption application dated 4 November 2010 concerning deficient fire protection for the main structure in the P01 and P02 process areas on Ula. See /87/. It is reported and documented that this requirement forms part of exercises, making it generally known on Ula.

However, the emergency preparedness or action plans do not specify that personnel must evacuate Ula P within five minutes if a hazard or accident condition arises. The applicable emergency preparedness and action plans provide no guidelines for such actions as initiating

orange ESD (ESD 2-P). Remembering and taking a decision on activation is accordingly left to the individual emergency response team⁷.

Laminated action plans located in the emergency response centre, which forms part of the central control room, describe actions and responsibilities for each defined hazard and accident situation (DFUs). Interviewees reported that these laminated plans were used, and provided a simplified presentation of the emergency preparedness plan. The card for responses to gas leak explosions had not been updated in accordance with the applicable emergency preparedness plan, and the two plans disagree in form, actions and responsibilities for carrying them out. The applicable plan, for example, states “do not start deluge”, while the laminated card reads “consider the use of deluge”.

Requirements

The activities regulations section 76 on emergency preparedness plans.

8.1.11 Inadequate risk assessment when planning and executing normalisation and cleaning work

Nonconformity

Inadequate safety clearance when planning and executing normalisation work and cleaning of the module.

Grounds

No SJA was carried out before entering the module for reversal of ESD, and occupational hygiene expertise was not utilised in the SJA or assessments before cleaning began.

No SJA was carried out before entering on 13 September to check detectors and valve isolation, and to reverse ESD 2-P. This was justified by BP on the grounds that the nature of the work did not require an SJA, see /101/. We consider that entering modules soiled by hydrocarbons could present a risk regardless of the kind of work to be carried out, and would thereby be subject to the requirement for advance safety clearance. An SJA is the tool normally used by BP to provide safety clearance.

In the three SJAs carried out before cleaning work began in the modules on 14 September, it was noted under the item “expertise” that others should have attended the SJA meeting. Who these should have been is not specified. No personnel with occupational hygiene expertise participated in the SJA or the assessments. See /68/, /69/ and /70/. However, the safety leader reportedly carried out measurements of hydrocarbons before and during work in the modules, and that these also included volatile organic compounds. See /84/.

Requirements

The activities regulations sections 30 on safety clearance of activities and 36 on chemical health hazard.

The management regulations section 14 on manning and competence.

⁷ Orange ESD was activated during the incident in order to isolate ignition sources.

8.2 Improvement points

8.2.1 Ensuring that water traps in the drainage system are replenished

Improvement point

The company's routines for ensuring that water traps in open drainage systems are liquid-filled, so that they prevent the spread of gas, could be improved.

Grounds

Routines have been established for replenishing water traps in the open drainage system in P01 in order to prevent gas spreading through the system. Each drain contains two outlets, one leading to a collection tank and the other serving as an overflow to the sea. Conversations with operators revealed that only the outlet to the tank was replenished with water. The replenishment procedure does not specify that both outlets should be replenished with water. Dry water traps means that gas can penetrate through the gas-tight decks in the module via the drainage system.

Requirements

Section 5 of the management regulations on barriers.

8.2.2 Deficient notification of the PSA

Improvement point

BP did not immediately notify the PSA of the incident by phone.

Grounds

The JRCC informed/notified the PSA three times before BP itself provided direct notification. That occurred two hours and 12 minutes after the incident (the PSA was notified at 09.20). The PSA was not informed of the scope and seriousness of the incident until the next day.

Requirements

Section 29 of the management regulations on notification and reporting of hazard and accident situations to the supervisory authorities.

8.3 Other comments

8.3.1 Deficiencies in the follow-up of the valve manufacturer by the valve supplier

Score A/S has not adequately followed up its own valve manufacturers.

Located in Randaberg, Score is BP's valve supplier and undertakes maintenance, service, modifications and repairs of valves both at its workshop and offshore. This company has been used for many years, and delivered the valve in question with gaskets and bolts which was replaced in 2004. Score is certified to ISO 9001:2008.

BP conducted an audit of Score in May 2011. One finding was that the company did not have a plan for following up suppliers and sub-suppliers. See /90/.

Score A/S or Score Group Ltd cannot document that it has followed up the valve supplier around the time when the valve in question was delivered. See /91/.

9 Barriers

9.1 Barrier elements which failed

- Gaskets in the valve failed, allowing the bolts holding the valve together to become exposed to produced water.
- The bolts fractured as a result of chloride stress corrosion cracking.
- The process safety system failed to shut down production because of late detection of a low liquid level in the separator (the ESD system later activated shutdown after gas had been detected).
- When ESD 2-P was activated, overpressure protection was also cut off in spaces with ignition sources which had not been disconnected.
- The fire water pump on Ula P was disconnected when ESD 2-P was activated.

9.2 Barrier elements which functioned

- The gas detectors registered the gas leak less than two minutes after the leak started, see /83/.
- ESD, isolation of ignition sources⁸ and pressure blowdown were activated on confirmed gas detection.
- Evacuation of Ula P was speedily implemented.
- The emergency response organisation was rapidly mobilised.
- A people on board (POB) check was established within 15 minutes.
- Personnel gave feedback in interviews that they felt the emergency response leadership had handled the incident in a good way.

⁸ Isolation of ignition source at the lowest level (welding and 220V sockets).

10 Discussion of uncertainties

Since all the gaskets were not found, it has not been possible to document the cause of the leak – such as damage, degradation or wear – or whether all required gaskets had been installed in the valve.

Two different materials are entered for the bolts in the materials certificate – superduplex in the specification and AISI 316 in the analysis. It has not been clarified whether the bolts were delivered in the correct material or whether the specifications were wrong.

It is unclear how far the safety delegates were involved in planning the normalisation and cleaning work over and above participation in SJAs. Information on this is conflicting, but we consider that the information provided to the safety delegates could have been better.

In our view, it is impossible to establish with any certainty on the basis of the available information how far personnel were exposed to hazardous chemicals when entering the module wearing only filter masks during the first couple of days after the leak and during the cleaning work.

Appendix A – references

- /1/ Mandate for BP's internal investigation.
- /2/ Print-outs of alarm logs and screen displays for gas detection during the incident.
- /3/ Emergency response and control room logs for 12 September 2012.
- /4/ Extract from the risk presentation for the Ula platforms, DNV report no 2009-4126, rev 04, dated 11 April 2011, pages 17-80, and chapter 9 on sensitivity, pages 1-9.
- /5/ P&ID and process flow diagram for the Ula P platform
- /6/ Emergency response team report Ula, dated 18.05 on 11 September 2012.
- /7/ Cabin overview Ula, dated 15.32 on 20 September 2012.
- /8/ PSV certificate for PSV-4022, PSV-4023, PSV-4890, PSV-4891 and PSV-4892.
- /9/ Description of the seep register and the register for seepage from XXV-4950.
- /10/ Pressure trends for the HP separator during the incident.
- /11/ Flow diagram for separation, gas compression and produced water.
- /12/ Inspection routines No EPV 104, P 318, P 353, extract from tag equipment history, failure mode, dated 21 September 2012.
- /13/ Maintenance routines: PM-002836, PM-006712, PM-014505, PM-002299, PM-013663.
- /14/ Procedure for describing important work procedures for maintenance, BPN document no 1.70.023, dated 2 March 2012.
- /15/ Performance Standard no 3 – Fire and Gas Detection Systems, Doc no 70.S.76.0003, dated 28 August 2009.
- /16/ Performance Standard no 4 – Emergency Shutdown ESD, Doc no 70.S.76.0004, dated 28 August 2009.
- /17/ Performance Standard no 5 – Ignition Source Control, Doc no 70.S.76.0005, dated 10 June 2010.
- /18/ Performance Standard no 7 – Control of Spills, Doc no 70.S.76.0007, dated 1 November 2008.
- /19/ Performance Standard no 9 – Passive Fire Protection, Doc no 70.S.76.0009, dated 31 May 2010.
- /20/ Performance Standard no 14 – Process Safety, Doc no 70.S.76.0014, dated 17 November 2008.
- /21/ Barrier mapping for Ula, PS 1 – Layout and Arrangement, dated 29 October 2010.
- /22/ Barrier mapping for Ula, PS 13 – Blowdown, dated 09.12.2010 – 21 December 2010.
- /23/ Barrier mapping for Ula, PS 8 – Active Fire Protection, dated 29 October 2010.
- /24/ Barrier mapping for Ula, PS 14 – Process Safety, dated 17 January 2011.
- /25/ Barrier mapping for Ula, PS 18 – Rescue and Safety Equipment, dated 29 October 2010.
- /26/ Organisation chart for BP Upstream – North Sea Region – Norway
- /27/ Area risk chart and barrier strategy for P01 separation module, Doc no 2006-4143, rev 01, dated 21 June 2007.
- /28/ 14''-WW-4205-N3A- RBI and inspection results, e-mail from BP, dated 21 September 2012.
- /29/ HSEE Directive No 35 – *Processing of undesired incidents and exemptions*, dated 30 December 2011.
- /30/ Material certificate, 109181-0001, dated 28 January 2002.
- /31/ Routines for preventive maintenance, routines no I 008, I 054, I 055, I 102, M 841 and I 138.
- /32/ Drawing of shut-off valve, Soma GEP, drawing no 01 09 1334 CE01.
- /33/ Drawing which shows location of bolts and valve components after the incident.
- /34/ Extract from post-Hazop report for Ula – Crude Oil System, pages A-43 to A-47, dated 30 January 2008.

- /35/ Valve testing job sheet, 109181-0001, dated 1 February 2002.
- /36/ Photographs taken by BP's internal investigation team.
- /37/ Job titles: Ula/Tambar Area Operation Manager, Engineering Authority, Ula/Tambar Inspection and Corrosion Management Engineer, HSSE & Engineering Manager/S&OR Manager BP Norway, Maintenance & Tar Team Leader, Material & Corrosion Engineer, Mechanical System Engineer for Static Equipment, Technical Safety Advisor, UT AST Mechanical Engineer, UT AST Electrical Engineer and Ula/Tambar OIM.
- /38/ *Ula produced water trends – ionic composition*, e-mail from BP, dated 24 September 2012.
- /39/ *BP Ula 2012 XXV 4950 Valve Failure – Protocol for Metallurgical Investigation*, rev 0B, dated 17 September 2012.
- /40/ Calculation report – Ula HP separator leak, dated 19 November 2012
- /41/ *Hydrocarbon Release Reduction*, UKCS-SOP-012, February 2011.
- /42/ Appendix C – Process Accidents, Report no/DNV Reg No 2009-4126/ 128LG59-15, rev 02, dated 11 April 2011.
- /43/ Attachment C-1 – Explosions summary, Report no 2006-4143, rev 01, dated 20 June 2007.
- /44/ *Ula Future – Fire Analysis of ULA-P – Including AS-IS – and proposed segmented process system*, document no 100141-B00003-001, rev 02, dated 28 May 2009.
- /45/ MoC – Postponing Red ESD test 2011 to 2012, traction: 2012-EVENT-4115908, dated 8 March 2012.
- /46/ BP audit report for Score AS, Report No 11204, dated 11 May 2011.
- /47/ Contract between BP Norge AS and Score AS, dated 24 March 2011.
- /48/ 6WPR – Ula & Tambar Maintenance – Sept 2012.12.17
- /49/ BPN Technical Requirements to Norsok standard L-001 piping and valves, BPN-L-001, issue no 05, dated October 2003.
- /50/ Work order KAO-093766, seepage in body of XXV-4950. Water out from HP-SE, established 29 March 2012.
- /51/ Comments on paint pilot hot duplex piping, ref KOA-011609. Dated 23 October 2009.
- /52/ RACI chart Corrosion Management.
- /53/ RACI chart Mechanical Static.
- /54/ Minutes from meeting in coordinating working environment committee (AMU) 5 September 2012.
- /55/ Valve Specification, Brown & Root (UK) Ltd, Specification No ULA3-G00-00-PI-4001, dated 11 May 1983.
- /56/ *Corrosion Management Status Report – Ula/Tambar PU – Period 1Q 2012*, dated 7 May 2012.
- /57/ *Corrosion Management Status Report – Ula/Tambar PU – Period 2Q 2012*, dated 14 August 2012.
- /58/ List of overdue work orders (incl future overdue) on Ula, print-out dated 30 September 2012.
- /59/ *Shutdown Philosophy – Ula field*, BPN document no 1.76.180, dated 2 March 2011.
- /60/ *Integrity Management Strategy*, BP Norway PU, BPN document no 1.70.121, dated 5 May 2010.
- /61/ Appendix 1 – Emergency Response Equipment, BPN document no 1.70.121, dated 7 October 2008.
- /62/ Appendix 6 – IM Strategy for Pressure Systems, BPN document no 1.70.121, undated.
- /63/ *Evaluation of Broken Valve Bolts*, Exova AS, document ref TRN201816, dated 8 October 2012.

- /64/ Photographs of action plans for Ula utilised during the incident for fire in the process area and for gas leaks. These were taken during the offshore visit, 22-24 October 2012.
- /65/ Copy of action plan for Ula, which describes the incidents threat of fire and fire.
- /66/ Summary of exercises in 2010, 2011 and 2012. Memo from BP, dated 3 September 2012.
- /67/ Minutes of safety delegate-main safety delegate (VO-HVO) meeting no 11, dated 13 November 2010.
- /68/ SJA-002006 6, Cleaning in oil-polluted areas on Ula P, dated 15 September 2012.
- /69/ SJA-002004 6, Work in oil-polluted area in P01 mezzanine, dated 14 September 2012.
- /70/ SJA-002018 6, Cleaning on Ula P, dated 19 September 2012.
- /71/ Print-outs of screen displays in the control room, dated 22 October 2012.
- /72/ Ula Incident follow-up plan, print-out of plan received 22 October 2012.
- /73/ Data sheet, DrägerSensor Smart PID – 83 19 100.
- /74/ Test certificate, X-am 7000 w/pump, TC-101125, dated 30 April 2012.
- /75/ Test certificate, X-am 7000 w/pump, TC-100577, dated 26 January 2012.
- /76/ Incident Report: 2012-IR-4231076, *Materialsvikt på stuss til PSV for tank til FWS*, dated 14 September 2012.
- /77/ Memo – BP, *Ula platform: Process leak scenarios*, DNV Energy, ref no 11ZODHL-9/TMAR, dated 20 January 2009.
- /78/ *Shutdown philosophy, Ula field*, BPN document no 1.76.180, rev no 01, dated 2 March 2011.
- /79/ Table of XXVs with critical assessment, spreadsheet taken from procedure 1.70.029, dated 27 September 2012.
- /80/ Traction follow-up of measure 539927.
- /81/ *Ula-P incident – consequence assessment*, DNV report no 2012-1469, dated 6 November 2012.
- /82/ Memo – *Ula explosion analysis*, DNV Consulting, ref no SJERN/63504734, dated 16 July 2004.
- /83/ *Incident Investigation Report HP Separator Loss of Containment, Ula Platform*, BP Norway. 10 December 2012.
- /84/ *Ula-P HP separator incident. Assessment of possible health consequences*. Proactima, 8 February 2013.
- /85/ BP's letter to the PSA of 16 October 2012: *BPs svar på henvendelse 3.10.2013*.
- /86/ *Midlertidig unntak gis for Ula vedr mangelfull brannbeskyttelse av hovedstruktur i prosessområdene P01 og P02*, PSA 2010/596/Ovh, dated 15 December 2010.
- /87/ *Unntakssøknad vedr. mangelfull brannbeskyttelse av hovedstruktur i prosessområdene P01 og P02 på Ula*. BP Norge AS, dated 4 November 2010.
- /88/ Minutes of meeting, including pictures shown at the meeting, meeting 24 June 2010. PSA and BPN – BPN system for identifying and following up technical and operational barriers.
- /89/ Application for consent to extend the operation of Ula, 11 February 2005.
- /90/ BP audit report of 11 May 2011, rev 1, report 11204
- /91/ E-mail from Score AS of 21 November 2012 concerning audits of Somagrep.
- /92/ *Statement of Conformity, Fire Safe Standard*, Somagrep, 12 November 2012.
- /93/ Application for exemption related to inadequate fire protection of the main structure in process areas P01 and P02 on Ula, 28 May 2010.
- /94/ Ula ESD CE P platform P00-23-IN-5100-001, rev ZH. 13.4.2012
- /95/ E-mail from BP about tripping fire pump and telecoms during orange ESD on Ula P, 27 November 2012.

- /96/ E-mail from BP on 21 September 2012 FW14 – WW- 4205-N3A-RBI and inspection results.
- /97/ E-mail from BP on 2 January 2013 concerning preventive maintenance programme for the equipment which failed.
- /98/ BP's letter of 14 November 2012 to the PSA. *Svar på spørsmål relatert til brann og eksplosjonsbeskyttelse på Ula - Møte 09112012.*
- /99/ Emergency response plan for the Ula field, doc 1.63.015, rev 17, dated 23 April 2012.
- /100/ Emergency response analysis for Ula, Proactima, BP document no 9.63.040 rev 2, 16 January 2008.
- /101/ E-mail from BP dated 17 April 2013 *Svar på spørsmål ifm med granskning av hendelse på Ula.*
- /102/ E-mail from BP dated 17 April 2013 *RE: Oppfølgingsspørsmål Ula granskning.*

Appendix B – personnel interviewed

This list is not published on the internet and is placed in a separate document.