PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation report following a condensate leak on Gjøa	Activity number 027153036

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

Summary

A condensate leak occurred in the Gjøa process module at 20.01 on 21 June 2017. This incident led to gas detection, a general alarm, automatic shutdown of the process plant, pressure blowdown and mustering in accordance with the alarm instructions.

Engie has estimated the leak rate at 1.06kg/s and the total quantity leaked as about 1.25m³. Analyses show that the fluid consisted largely of produced water with small quantities of hydrocarbons in the form of gas and condensate. The leak was halted after about 30 minutes. The direct cause of the leak was a fatigue fracture in a weld on a ½-inch pipe nozzle installed on a condensate pump connected to the gas recompression system. The condensate did not ignite during the incident.

The failure of an emergency shutdown valve (ESV) to close upstream from the leak site was registered during the emergency shutdown.

The emergency response command on the facility decided to evacuate 19 people to shore. The operators centre for evacuated personnel and next of kin (OSEP) in Florø was mobilised to receive those evacuated.

There were 49 personnel on board (POB) before the evacuation.

The position on Gjøa was normalised at 22.09.

Involved	
Main group T-2	Approved by/date Odd Rune Skilbrei 8 December 2017
Members of the investigation team Ole Jacob Næss, Sandra Gustafsson, Vivian Sagvaag, Kristi Wiger and Espen Seljemo	Investigation leader Kristi Wiger

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1 Summary

At 20.01 on 21 June 2017, the plant operator discovered a leak on the lower deck in the Gjøa process module. This proved to be a condensate leak from a fractured weld on a pipe nozzle installed on a condensate pump connected to the gas recompression system. The plant operator went to the leak site and tried to close a valve on the same nozzle, and was then exposed to condensate. The operator immediately notified the CCR about the leak.

Soon afterwards, at 20.03, the deluge system was activated following confirmed gas detection in the area. ESD was activated, followed by a general alarm, pressure blowdown and mustering in accordance with the alarm instructions.

POB were mustered and under control after 11 minutes. A total of 49 people were on the facility at the time of the incident. The emergency response organisation on Gjøa mobilised immediately, and Engie mobilised its emergency response team at Forus.

During ESD and pressure blowdown of the process plant, it was quickly discovered that one of the ESVs had failed. This valve is meant to close on an ESD signal in order to sectionalise the process and thereby limit the scope of a possible leak and also hinder escalation of the incident. The failed ESV was positioned directly upstream from the fracture. Failure of the sectioning meant that the volume in the scrubber tank which the condensate pump was connected to was fully or partially emptied through the fractured pipe. The failure in sectioning the process plant represented a failure of this barrier function and increased the level of risk posed by the incident.

Several attempts to close the ESV were made from the CCR without success. The operators then decided to open a manual valve on the deck above the leak, which was connected to the closed drain. This diverted some of the condensate flow away from the scrubber tank to the closed drain tank, which reduced the leak from the fracture on the pipe nozzle to some extent.

Because of the challenges with the ESD system, the emergency response organisation on Gjøa decided to evacuate 19 people to land. These were non-essential personnel without defined response assignments. Two helicopters were requisitioned to Gjøa, a Sea King and a SAR machine from Oseberg. In addition, two ships in the vicinity offered assistance. The operators centre for evacuated personnel and next of kin (OSEP) in Florø was mobilised and received the 19 evacuated people.

During the incident, it also became clear than another ESV – in this case for blowdown – had failed to open towards the flare as intended. This affected the time it took to depressurise the process plant.

Engie estimated the initial leak rate at 1.06kg/s and the total quantity leaked as about 1.25m³. Fluid pressure at the facture was 26-30bar. When the pump stopped, this fell to virtually atmospheric pressure or the static pressure in the fluid column. The leaked fluid from the scrubber tank was a mixture of produced water and hydrocarbons (condensate and gas).

The position on Gjøa was normalised at 22.09, and personnel on the facility were thereafter followed up with a debriefing on the incident.

Only point gas detectors were activate during the incident, and no line detectors. Given detector positioning and those which activated, no spreading is estimated to have reached higher up the module, with no gas being spread to other areas of the facility either.

The leak occurred in a pipe nozzle on condensate pump 23PA005B. This belongs to the gas recompression (system 23) and involves two pumps in parallel, A and B. These two pumps on Gjøa have a history of vibration and breakdown. They have been sent ashore for repair and modification on several occasions. On behalf of Engie, Force Technology carried out risk-based inspection in 2015 and 2016 with corrosion assessment, vibration and strain gauge measurements, and fatigue calculations of piping and equipment components which could be subject to such degradation. Necessary measures described in the 2015 report have been implemented. The vibration measurements show periods of high vibration before improvements to the pumps and pump base (3). Crack propagation in the pipe nozzle weld was caused by an internal weld fault and fatigue owing to pump vibrations. The fatigue fracture started from an internal crack point/fabrication fault in the pipe weld. When the weld in the ½-inch pipe nozzle fractured, a condensate leak of 1.06kg/s occurred. The pipe did not fracture completely.

Faults in two of the ESVs were caused by water intrusion in the actuators and consequent corrosion over a long period. Results from the regular tests of these valves show that the problems have been known for a number of years. The investigation shows that Engie has not taken sufficient measures to ensure that the ESD system – which is a safety system – retains its functionality. Lack of maintenance of the actuators has resulted in two of the ESVs failing to function as they should during the incident.

Summary of the main findings and observations

Pipe fracture
An X-ray examination established an internal welding fault in the pipe nozzle which led to fracturing. In addition, the same type of fault was identified in four of five similar nozzles on the other condensate pumps.

Faults in the ESD system
Failure of two ESVs, 23ESV1509 and 24ESV1166. This represented known degrading caused by problems with water intrusion and corrosion in the actuators. The failure of 23ESV1509 to close led to an escalation of the incident in terms of duration and potential.

Figure 1 - Fracture in the pipe nozzle out of the condensate pump.
The photograph belongs to Engie E&P

1.1 Abbreviations and terminology

CCR	Central control room
Comos	Maintenance portal for Gjøa. Used to follow up equipment and maintenance management on the facility. Contains reports and actions for planned and implemented tasks organised at equipment level
ESD	Emergency shutdown
ESV	Emergency shutdown valve
HMI	Human-machine interface
HSE	Health, safety and the environment
HTO	Human, technology, organisation. Analysis tool
IMS	Information management system
LEL	Lower explosive limit
MEG	Monoethylene glycol
NDT	Non-destructive testing
OSEP	Operators centre for evacuated personnel and next of kin
P&ID	Piping and instrument diagram
POB	Personnel on board
PSA	Petroleum Safety Authority Norway
SAR	Search and rescue
SAS	Safety and automation systems
SD	Safety delegate
SIL	Safety integrity level
SRS	Safety requirement specification
TEG	Triethylene glycol
VSD	Variable speed drive

2 Introduction

A condensate leak occurred on 21 June 2017 in the process module on the Gjøa quarters and production facility.

The incident occurred at 20.01 during normal operation of the process plant. The condensate did not ignite and nobody suffered an acute injury during the incident. During ESD and pressure blowdown of the process plant, it quickly became clear that an ESV had not closed as intended. Located directly upstream from the leak site, this valve failure extended the duration of the leak and thereby led to some escalation and increased risk during the incident. That prompted the emergency response command on Gjøa to decide on the evacuation of non-essential personnel to land. The position was normalised after roughly two hours, at 22.09.

The PSA decided on 22 June 2017 to conduct its own investigation of the incident.

Figure 2 - Condensate pump with pipe nozzle. The photograph belongs to Engie E&P

Figure 3- Crack in pipe weld which led to a condensate leak. The photograph belongs to Engie E&P

Figure 4- ESV with actuator installed. The photograph belongs to Engie E&P

Figured 5- Opened actuator housing of the ESV, showing corrosion on the inside of the gasket. The photograph belongs to Engie E&P

2.1 About the investigation

The PSA's work on the investigation was initiated by a meeting with Engie the day after the incident. Interviews were thereafter conducted with relevant personnel in operations, maintenance and management, both in the land organisation and offshore on Gjøa.

It was decided that the PSA's investigation team would not travel out to Gjøa.

Observers were present during the interviews. A total of 13 of these were held in the period June-August 2017. Most took place in the days immediately after the incident. The interviews were held in Engie's premises at Forus. Relevant people on Gjøa were interviewed by video conference. In addition, meetings have been held with Engie to review the findings of the technical materials report when this had been completed.

The team has prepared its investigation report on the basis of presentations, interviews and documents received. The report addresses direct and underlying causes, both technological and operational in character.

2.2 Investigation team's mandate

1. Clarify the incident's scope and course of events from its start until the position on the facility was returned to normal.
2. Assess the actual and potential consequences.
3. Assess direct and underlying causes, with an emphasis on technological, operational and organisational aspects.
4. Discuss and describe possible uncertainties/unclear aspects.
5. Identify nonconformities and improvement points related to the regulations (and internal requirements).
6. Discuss barriers which have functioned.
7. Assess the player's own investigation report.
8. Prepare a report in accordance with the template.
9. Recommend – and contribute to – further follow-up.

Composition of the investigation team

Espen Seljemo	Process integrity
Sandra Gustafsson	Structural integrity
Ole Jacob Næss	Structural integrity
Vivian Sagvaag	Working environment
Kristi Wiger	Process integrity (investigation leader)

3 Background

Description of the facility, area and equipment involved in the incident.

3.1 Gjøa

Gjøa is an oil and gas field located about 65km south-west of Florø and 70km north-east of the Troll B facility. The water depth in the area is 360-380m. The Gjøa facility is tied to the Vega subsea field. This semi-submersible quarters and production facility came on stream in 2010. Gjøa receives power from shore via a cable from Mongstad. Its gas is piped to St Fergus in Scotland via the Flags pipeline, while its oil travels to the Mongstad refinery through the TOR2 pipeline.

The Gjøa development project was executed in 2007-10. While the topside was built at Aker Solutions' Stord yard, the hull came from the Samsung yard in South Korea. Statoil was development operator before the operatorship was transferred to GdF Suez E&P Norge when production started in 2010. GdF Suez changed its name to Engie in 2015. Engie E&P Norge has its head office at Forus in Stavanger.

Figure 6 - The Gjøa facility. The photograph belongs to Engie E&P

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Engie E&P Norge AS (30 per cent), Petoro AS (30 per cent), Wintershall Norge AS (20 per cent), A/S Norske Shell (12 per cent) and DEA Norge AS (eight per cent).

3.2 Area

The condensate leak was localised on the lower deck in the process module (P0).

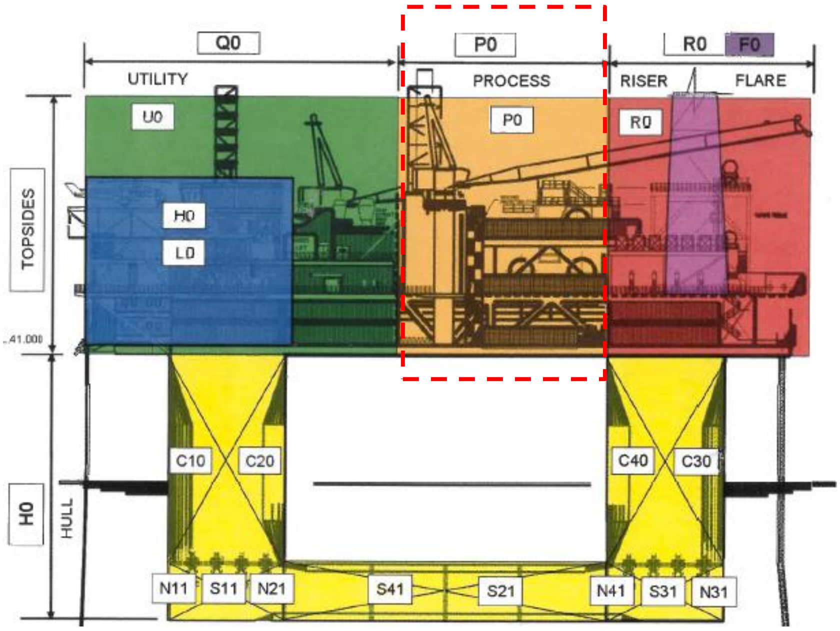

Figure 7 - The condensate leak occurred in process area P0, lower deck. The diagram belongs to Engie E&P

3.3 Equipment and process involved in the incident

An extract from the process flow diagram for the gas recompression system (23) with pump and valve arrangement is shown in figure 8 below, while figure 9 shows a 3D drawing of the pump with pipe nozzle, but without the installed valve used for maintenance/flushing.

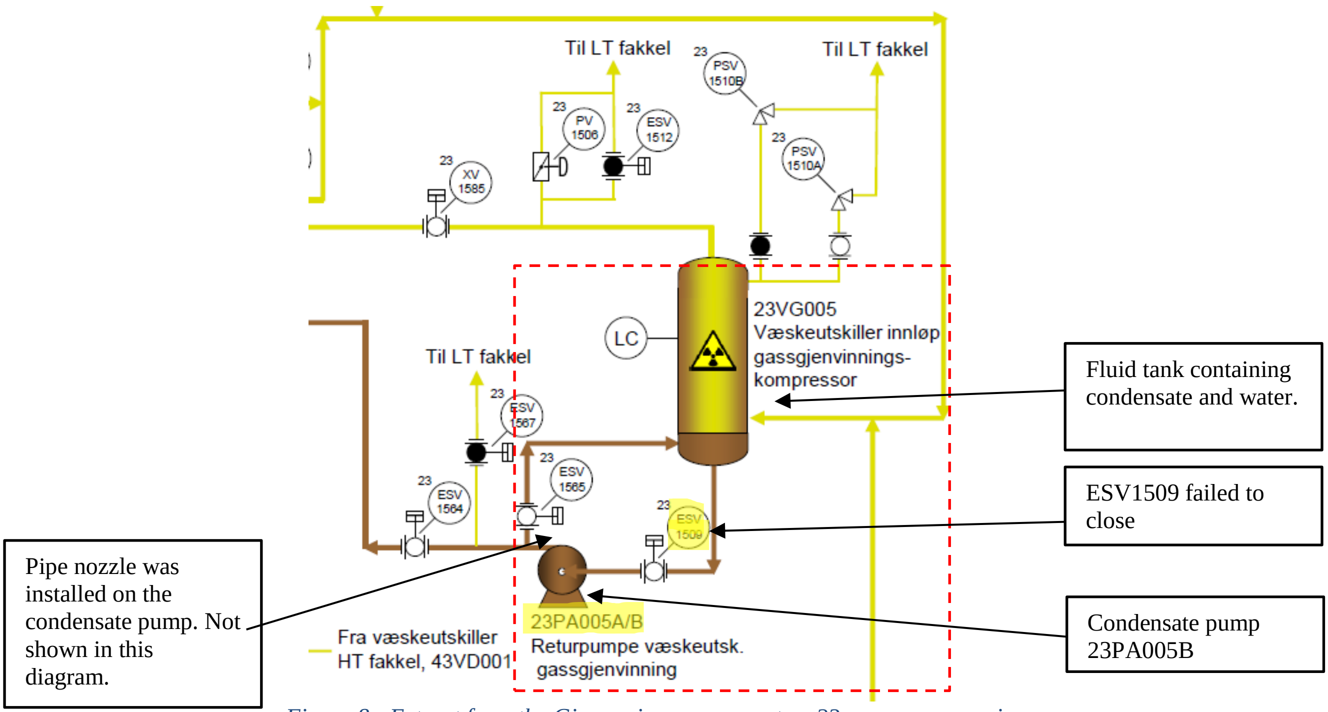

Figure 8 - Extract from the Gjøa main process, system 23 gas recompression. The diagram belongs to Engie E&P

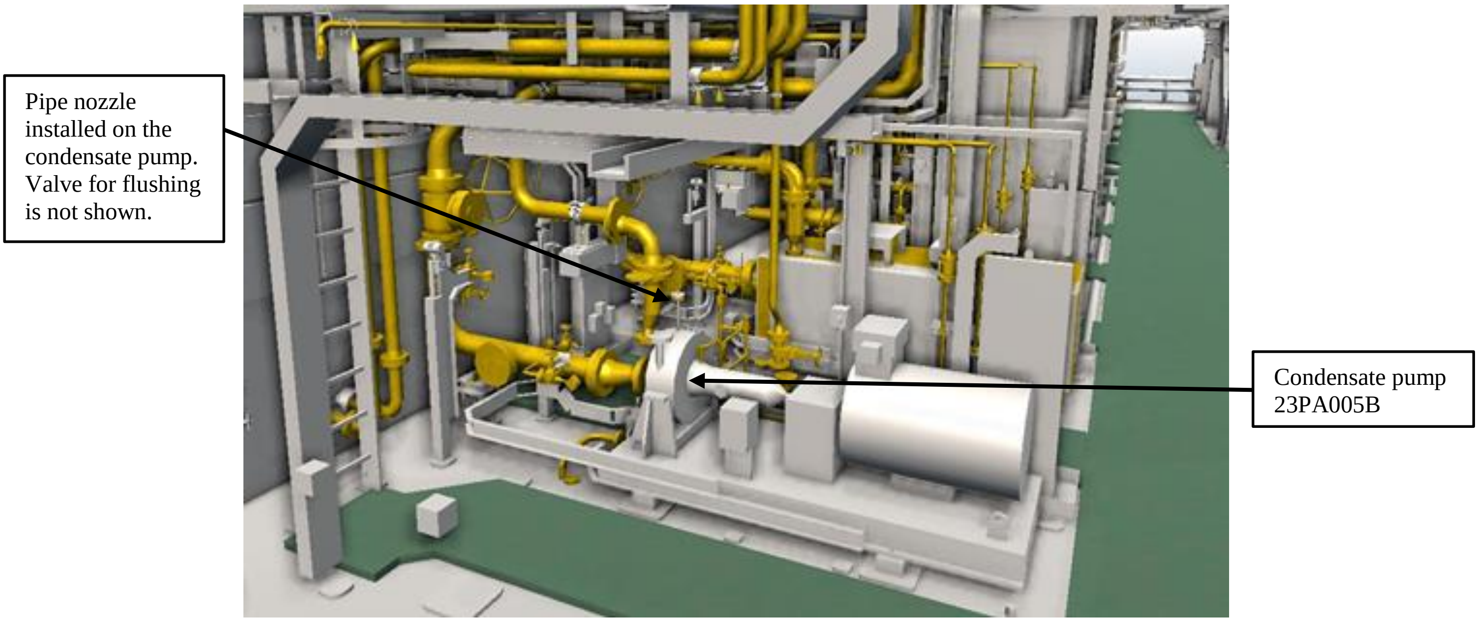

Figure 9 - Process area and condensate pump in a 3D illustration. The illustration belongs to Engie E&P.

3.3.1 System 23 for gas recompression

The leak occurred as the result of a fracture in a pipe connected to system 23 for gas recompression. This pipe nozzle was installed on a condensate pump located downstream from a scrubber tank in order to pump condensate into the second-stage separator while simultaneously recirculating condensate from the scrubber tank. Connected to the gas recompression system, the equipment is intended to collect gas from the various stages in the separation process, cool it down and separate out the fluid. The gas is recompressed, while the fluid – or condensate – is removed in the scrubber and returned to the separators. The relevant scrubber tank also contained inlets from the system for both MEG and TEG regeneration. In addition, input came from units in the produced water system. As a result, the condensate contained a good deal of water.

The relevant scrubber tank operates at low pressure, and condensate leaves it more or less at atmospheric pressure. Pressure in the second-stage separator is 21 bar, and the minimum pressure rise in the pump is specified as 22.3 bar. The pump's design pressure is 45 barg.

3.3.2 Condensate pumps 23PA005A/B

The condensate pumping arrangement is 2 x 100 per cent pumps, A and B. That is a normal solution for this type of system in order to run the installation with one pump out of operation. A reserve pump is also provided in this case. The pumps operate at varying revolutions with the aid of a variable speed drive (VSD). Maximum revolutions per minute (rpm) are 3 155.

Many repairs and modifications have been made to the pumps during their operating life. A great many faults and measures are registered for both A and B pumps. They have therefore been sent ashore several times. It emerged from interviews and after reviewing the system for handling report faults that these two condensate pumps have experienced design and vibration challenges. Reasons for the vibrations have been both noted in interviews and described in the Comos maintenance portal. The consequences have been broken bolts and consequent bearing failures. During interviews, the causes have been identified as imbalances in the pump because it was designed for a higher inlet pressure, as well as challenges with the pump base and a weld seam which meant that the base had insufficient contact with the deck. This unevenness was dealt with in 2015. The pumps were also modified in 2016 to rebalance the axial forces by creating a channel or hole to even out the pressure differences on either side of the impeller, with new wear rings installed at the same time. This appears to have reduced the problems with vibration and subsequent breakdowns.

The integrity report for rotating equipment issued in March 2017 stated that pumps A and B were running well and that no incidents had been registered after the modifications (3).

3.3.3 Pipe nozzle

A pipe nozzle with a manual valve is installed on the condensate pump for maintenance flushing of the pump. The relevant nozzle with pipe, flanges and valve weighs altogether about 5.3kg. The length from pump housing to the valve centre is 18.5cm. No support is provided for this valve arrangement. The actual pipe is specified in the drawing with a ¾-inch dimension, but a ½-inch dimension in duplex steel and schedule 160, which gives 4.78mm of nominal wall thickness, are found to have been used on both pumps. According to the DNV GL report (2) and X-ray images, the internal diameter of the pipe is virtually identical on both sides of the weld. The external diameter of the pipes varies somewhat because of differing material thickness in welded piping. Pipe nozzles and pipes welds do not have a full V joint or full penetration. That creates an internal crack point for possible fatigue.

Figure 10 - Pipe nozzle and manual maintenance valve installed on condensate pump 23PA005B. The photograph belongs to Engie E&P.

Figure 11 - Facture in the weld on ½-inch pipe nozzle. Duplex steel. The photograph belongs to Engie E&P.

Figure 12 - Fracture surface seen from the side in connection with DNV GL investigation. The photograph belongs to Engie E&P.

The pipe nozzle and valve installed on the pump are part of the condensate pump package delivered to the Gjøa development project. No modifications have been made to the actual pipe nozzle or valve during the time Gjøa was on stream up to the incident.

3.3.4 ESD system

The purpose of the ESD system is to prevent escalation of an undesirable incident and limit its duration and outcome. It can be activated automatically or manually. In the Gjøa case, ESD was activated automatically because gas was detected in process area P01 on the lower deck. On activation, the ESVs are meant to isolate and sectionalise the process. Regular testing of valve functionality and closure time is meant to see to it that the system's reliability and integrity comply with the requirements.

Two ESVs failed during the Gjøa incident. One of these, 23ESV1509, was positioned between the fracture site and the scrubber tank which the pump was connected to. The valve is intended to reduce the volume and duration of a possible leak. This six-inch ball valve has a pneumatic actuator installed. It transpired that several actuators are exposed in such a way that water has penetrated them and caused corrosion.

Figure 13 - ESV with installed actuator 23ESV1509, which failed during the incident. The photograph belongs to Engie E&P

The other failed valve was 24ESV1166 for pressure blowdown, intended to open to the flare in the event of an ESD. It is placed in the gas dewatering system and connected to the outlet from the TEG contactor. This eight-inch valve has a hydraulic actuator.

3.4 Health effects of condensate exposure

The medium which leaked from the scrubber consisted mainly of produced water containing small quantities of hydrocarbons in the form of gas and condensate.

Condensate consists primarily of propane, butane, pentane and other heavier hydrocarbon fractions. In addition come small quantities of such components as benzene. This is regarded as posing the biggest health threat. It has both acute and chronic health effects, and is a known carcinogenic and mutagenic substance. Benzene is volatile and vaporises quickly. Its vapour is heavier than air. Benzene is also highly flammable. Exposure to hydrocarbon gas and benzene can have a narcotic effect in concentrations lower than those which pose a threat of explosion or suffocation. The risk of such an effect is higher with a condensate leak than with crude oil or gas escapes.

4 Course of events on 21 June 2017

The course of events centres around the gas recovery system, condensate pump and ESD system. The most important events are listed below in chronological order.

Time-date	Description
21.06.2017	The plant operator makes a normal inspection tour of the lower deck.
20.01	The operator discovers the leak from the condensate pump. Reports the discovery to the CCR. Seeks to halt the leak by turning the valve wheel on top of the pipe nozzle where the leak is emerging. The operator is exposed to condensate over parts of their body.
20.03	Confirmed gas, ESD level 2 with deluge is activated, the operator withdraws to a safe area. ESV 23ESV1509 fails to close.
20.14	Mustering in accordance with the alarm instructions and POB check 49 people.
20.28	Offshore installation manager decides to evacuate non-essential personnel to shore.
20.33	Condensate leak confirmed halted.
21.15	Final evacuation to land by SAR, POB Gjøa 30 people, 19 sent ashore.
21.27	Deluge deactivated after one hour and 26 minutes.
22.09	Position normalised.
22.25	Debriefing of personnel on Gjøa.
01.15	Demobilisation of second and third lines.

On 21 April 2017, the plant operator made their regular inspection tour of the lower deck in the process module. They observed a leak at 20.01 from a pipe nozzle from condensate pump 23PA005B. Going to the leak site, they sought to close a manual valve installed immediately above the leak. At the same time, they notified the CCR of the leak. The manual valve had no effect on the course of events because it was installed on a pipe used for flushing the pump house. The operator came into brief contact with the fluid in the stomach and thigh regions. They were equipped with standard personal protective equipment.

The alarm was sounded by the control system at 20.03 for confirmed gas in the condensate pump area. This initiated ESD level 2, followed by a general alarm and mustering in accordance with the alarm instructions. Deluge was activated in the area on the lower deck and the operator went to a safe zone. The emergency response team mustered on Gjøa in accordance with instructions. Second and third lines mustered on land.

ESV 23ESV1509 out of the scrubber tank failed to close, and the Gjøa platform management therefore decided to evacuate 19 non-essential personnel to land. Helicopters were requisitioned – a SAR machine was called from Oseberg and a Sea King from Florø.

Engie has reported that the pressure in the condensate pump when the incident occurred was about 26bar and the condensate temperature was roughly 50°C. The pump stopped when the leak was detected and ESD initiated. The leak pressure then fell more or less to atmospheric level, or more precisely to the static pressure in the fluid column upstream from the leak.

The leak lasted about 30 minutes before the emergency response team confirmed that it had ceased. Engie calculated the total volume of tank and piping upstream from the leak at 3.7m^3.

A manual valve to the closed drain is located at the deck level above the leak, and it was decided to open this to reduce the leak volume. Engie's investigation report states that this valve opened after eight minutes. That meant part of the volume in the piping and the scrubber tank was conducted to the closed drain while the remainder continued to escape at the leak site and to vaporise or be washed by the deluge water into an open drain.

The leak site was on a ½-inch pipe nozzle installed on condensate pump 23PA005B. This nozzle was connected in turn to a manual valve and hose connection used for pump maintenance and flushing.

Foam was deployed in parts of the process area as a risk-reduction measure to prevent a possible escalation of the incident. During interviews, it was mentioned that a detector in another area indicated gas. On that basis, it was decided to keep the deluge active for about one hour and 26 minutes. It later transpired that the detector concerned was faulty, and no gas is thought to have entered the area concerned.

The position on Gjøa was normalised at 22.09 and personnel offshore were debriefed at 22.25. The helicopter resources were demobilised after the evacuation, with the second and third lines demobilised at 01.15.

No clearing up or cleaning was required after the incident. The deluge system had jetted the area with fire water, which had helped to wash the condensate into the drain system. During the hours after the area was declared safe, the methane concentration in the atmosphere was monitored with portable detectors. These gave no reactions. Benzene was measured in the atmosphere during the first day after the accident, at 15.00 on 22 June 20167 and then at 09.00 on 24 June 2017. These measurements showed low benzene concentrations – in other words, below or around the measurement device's detection limit of 0.05 parts per million.

5 Causes

Description of the direct and underlying causes of the incident.

5.1 Direct causes

The condensate leak resulted from a fatigue fracture in a weld on a ½-inch pipe nozzle attached to condensate pump 23PA005B. Vibrations from the pump set up fatigue stresses in the weld because the 11.5cm-long pipe nozzle with a 3.6kg manual valve installed on top gives a moment of force with associated bending stresses. The welding work appears to have been deficient in terms of both joint preparation and lack of penetration, as well as some misalignment between the pipes being joined. This is the reason why fatigue cracking was initiated in the weld. A sharp crack arose internally around the whole pipe, which created high local stress intensity. The fatigue crack thereby began to grow from the inside of the pipe weld. Had the weld been subject to volumetric NDT, the fault should have been detected. It would not have satisfied the general criteria for good welding performance with acceptance criteria. How the weld was designed with welding procedure specification or qualification has not been clarified, but the weld should have a V joint with root gap and full penetration.

5.2 Underlying causes

Underlying conditions which contributed to the incident are described below. This takes account of both the leak and the failure of the ESD system, including weaknesses in design, fabrication, follow-up, roles and responsibilities.

5.2.1 Design and welding execution

The relevant pipe nozzle in duplex stainless steel was part of the condensate pump delivery to Statoil's Gjøa project. Norsok standard M-601 on welding and inspection of piping specifies special qualification and follow-up requirements for suppliers of duplex. Where follow-up of design and fabrication is concerned, little attention was paid to welding with requirements for NDT and later completion testing of small-bore piping. Norsok M-601 is specified in the procurement package. The requirement for NDT in this standard is 100 per cent visual, volumetric (X-ray) and penetrant control for pressure classes above 600#. Had the X-ray requirement been followed, the fault should have been detected. Where the actual welding execution is concerned, requirements are set for welding competence and approved welders at the company, and the welding procedure to be followed should be specified on the drawing. Such documentation for the weld has been sought, but has not been obtainable as part of the input for the PSA's investigation.

The butt weld in the relevant ½-inch pipe nozzle investigated by DNV GL has a more or less similar internal diameter and wall thicknesses of 3.6mm towards the flange and 4.7mm towards the pipe. See the figure below, taken from DNV GL's report on the technical material investigation (2).

Figure 14 shows a pipe weld with internal crack point for possible further fatigue development. This primarily reflects faulty joint preparation for welding. There should have been a V joint here with a root gap, so that the welder can do the work correctly and achieve full weld penetration. That could have avoided the fault with lack of penetration.

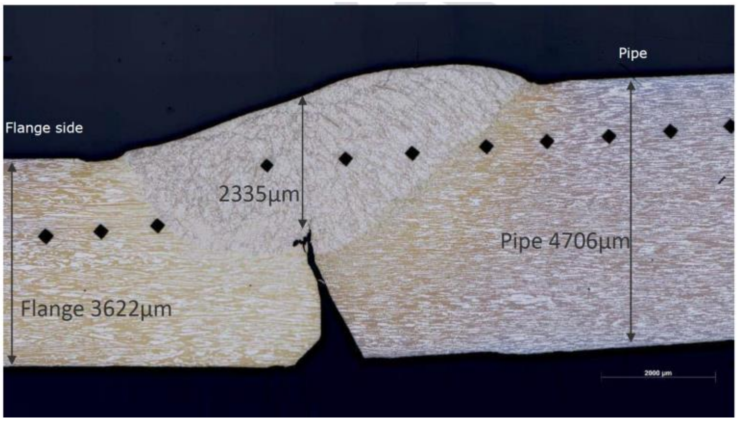

Figure 14 - Metallographic image of the fracture site on the pipe nozzle, showing lack of penetration in the weld. The photograph belongs to Engie E&P

These two factors raise questions about the supplier's welding expertise and follow-up of the delivery.

- The PSA has been unable to obtain any welding procedure or documentation from Engie/the pump supplier despite requesting this.
- Later X-ray examinations of five similar pipe nozzles have established the same fault in four of these.

The relevant pump with VSD has experienced challenges with vibration. Rapid vibration in the pump, which transfers to the pipe nozzle, and high local stress intensity at the crack point mean a fatigue crack can begin and propagate. The VSD pump can operate at up to 3 155 rpm. Pump speed is stated to have been about 84 per cent of full rpm. An estimate of the number of vibrations for a seven-year-old pump gives about 1.E+09 cycles. This lies in a high-cycle fatigue area. The DNV GL material investigation (2) shows clear fatigue. The threshold value for stress in high-cycle fatigue, which is the case here, can also be low (4).

Fatigue challenges, particularly on small bore piping, are well known in the oil industry. A number of sources claim that they may contribute to about 20 per cent of all hydrocarbon leaks (5).

Recent hydrocarbon leaks include one on Gudrun in a two-inch bypass pipe on 18 February 2015 and another at Kårstø on 7 January 2016 in an instrument connection. Both these occurred because of fatigue and possible relatively high-cycle vibration fatigue. The cause on Gudrun was vibration in a pressure control valve. At Kårstø, wind turbulence around a pressure manometer in a resonant frequency area was responsible. The PSA has investigated both these incidents (6), (7).

It is therefore reasonable to believe that insufficient vigilance has been displayed by the industry over possible faults of this type during both project and production phases. This applies particularly to small bore piping with installed components which produce moments of force when connected to equipment or larger piping which could be subject to vibration or high-cycle vibration.

5.2.2 Follow-up of vibration and condensate pump breakdowns

Operational problems have been common for both A and B pumps. These have related to vibration and breakdown. The pump foundation has been improved and the internal components have been modified to rebalance pressure and axial forces.

A historical review of registrations in Comos and information obtained through conversations with personnel make it clear that the pumps have experienced big problems throughout their operating lives. These have been followed up operationally, and efforts made to correct the faults. However, no sign is to be found of any assessments of what the vibrations could have led to in the form of reduced operating life for equipment or piping. The vibrations have been measured, but the team cannot see that they have led to any assessments or measures related to the possible degrading of other barriers. The consequences of long-term vibration have not been on the agenda.

This table provides an overview of some of the observations and improvements made to pumps 23PA0005A/B since Gjøa came on stream in 2010.

Period	**Registrations for the condensate pumps in Comos**
2011-15	Repeated problems with pumps 23PA0005A/B. A number of registered incidents each year in this period. Many of the observations concern excess noise and vibration. Mention was made of broken impeller bolts and bearings as well as process fluid getting into seal fluid. This required necessary replacements, overhauls and measures to rebalance the pumps.
2014	Discovered that the pump frame stands on a weld seam in the deck, which creates a limited surface fit and could have increased pump vibration.
2016	Decision is taken on major modifications to the pumps (A/B) to level out the big difference in axial forces between their suction and pressure sides.

5.2.3 Follow-up of safety critical equipment and barriers

Governing documents are used throughout the design and operational life cycle of safety-critical equipment such as ESVs. These documents specify requirements for details in the maintenance programme as well as test intervals to safeguard the integrity of the equipment. Requirements for equipment and functionality are defined in relation to the SIL level and performance standard. Such governing documents as *Safety requirement specification (SRS) with appendices, SIL specifications for valves* and *SIL specifications for actuators* form part of the follow-up, operation and maintenance programme for safety-critical equipment.

Many of the ESVs on Gjøa have a history of corrosion and water intrusion in their actuators. After repeated failures during valve performance testing, mechanics carried out corrective maintenance with lubrication and repetitious testing. Implemented in 2016, the latest measure with ESVs which had problems opening or closing was to change the test interval from 12 to three months. This was done without opening their associated actuators to verify their status and condition. Maintenance of certain ESVs with associated actuators was planned for the turnaround in September 2017.

History of ESV testing
Brief summary of test results for ESV1509.

Period	Test details	Test result
09 Nov 2011	ESD testing in years after Gjøa came on stream.	
	Valve closes.	Test OK.
28 Aug 2012	Valve closes.	Test OK.
23 Oct 2013	Valve closes.	Test OK.
2014	Check for water intrusion in actuator.	
09 Apr 2014	Valve closes.	Test OK.
10 Feb 2015	Valve tested.	Test OK.
07 Dec 2015	Tripped. Long shutdown time registered.	Valve failed.
08 Feb 2016	Valve tested.	Test OK.
24 Oct 2016	Tripped.	Valve failed.
	Decision to reduce test interval from 12 to three months.	
13 Feb 2017	Valve tested.	Valve failed.
09 May 2017	Valve tested.	Valve failed.
21 Jun 2017	**Condensate leak incident.**	**Valve failed.**

The ESV failed to close because the actuator had suffered water intrusion and corrosion over a long period. Combined with an inadequate maintenance programme for the actuators, this means that the barrier function of the ESV has not been maintained.

Barrier panels are used on Gjøa to highlight faults and weakening in safety-critical barrier functions. The panel uses traffic lights – red, yellow and green – to show status on the basis of tag data from Comos and the facility's IMS data from the control system. Equipment in Comos is tagged with the status unwell, ill or dead, based on testing and verification. Equipment only gets red on the barrier panel if it is tagged as dead in Comos. The person who owns the case in Comos decides what status the equipment receives on the basis of results from maintenance and/or testing. In this case, where problems existed with ESVs ahead of the incident, the ESV has not been tagged as dead. It thereby never showed as red on the barrier panel. Only red lights on the barrier panel were reported back to the manager for technical integrity on Gjøa.

The team cannot see that requirements have been set for the number of times an operator can test a valve/actuator which fails to open/close before it must be given the status of dead. To satisfy the requirements in the regulations and governing documents, the function must be regarded as dead if the first test fails – assuming this was correctly planned and carried out. Practice on Gjøa has been to set the status as ill if a valve has failed. This has led to valves being tested and lubricated several times and given a clean bill of health without being disassembled and checked for the cause of the failure. The practice of accepting deficient test results has led to the ESD system on Gjøa failing to satisfy the requirements set by the regulations for functionality and reliability.

5.2.4 Organisation, roles and responsibilities

The Gjøa organisation established roles with system responsibility two years ago. Before then, only technical discipline responsibility was established for the individual items of equipment.

Although parts of the ESD barrier were non-functional, this did not appear on the barrier panel used on the facility for managing and monitoring risk. As a result, responsible and senior personnel on the facility and in the land organisation were unaware of the degrading of the ESD system.

Information about and measures related to degrading of safety-critical equipment and barrier functions appear to have been communicated in an informal and unsystematic manner.

In this case, where parts of the barriers failed to function satisfactorily, ownership has not been taken of or assessments carried out with the problem by those responsible for technical safety. The decision to change the test interval was taken jointly by the maintenance supervisor and the instrument technician. Nor has it been sufficiently communicated to the land organisation for registration and follow-up.

6 Potential of the incident

Actual and potential consequences.

6.1 Actual consequences

6.1.1 Discharge of condensate to the surroundings and to the sea

Engie has estimated the size of the condensate leak as about $1.25m^3$. Most of this discharge vaporised, and some was washed into the sea together with deluge water.

6.1.2 Loss of production

The condensate leak from the pipe nozzle led to the shutdown of Gjøa and a loss of production during improvements and readying after the incident. Gjøa was shut down from 21 June to 7 July 2017.

6.1.3 Exposure of personnel to chemicals

The plant operator was in direct contact with the medium from the leak, and was splashed with it in the stomach and thigh region while seeking to halt the leak between 20.01 and 20.03. Engie has reported that the operator spent about 40 seconds all told in the leak area. This person did not experience symptoms of acute exposure either during the incident or in the days following it.

The operator was soaked by deluge water a few minutes after their skin exposure. This water probably contributed to a strong dilution effect, and absorption by the skin is thought to have been small. The operator first changed their clothes about two hours after exposure. In other words, possible hydrocarbon residues could have been absorbed via the skin in this period.

Following the incident, Engie has estimated and modelled the possible concentration of benzene in the air immediately around the leak site. The worst estimated level of concentration 0.5m from the leak site one minute after the leak was $30mg/m^3$ (short-period $value_{15\ min}$: $8mg/m^3$) for benzene. Since the short-period value is calculated on the basis of 15 minutes of average exposure, the operator was exposed to a total of 17 per cent of the short-period value for benzene.

No biological sampling was conducted in the wake of the incident to verify whether the operator’s body had absorbed benzene or other hazardous components.

6.2 Potential consequences

The team takes the view that the incident, in other circumstances, could have led to a bigger leak. During the incident, the operators succeeded in diverting some of the fluid to the closed drain. Had this not been possible, it is estimated the leak would have increased to about $3.2m^3$.

No dispersion analyses or identification of possible ignition sources in the area have been carried out. But the gas cloud was large enough to be detected, and thereby represented a real explosion risk.

However, the fact that the fluid in this segment largely comprised produced water has contributed to downscaling the assessment of the possible consequences, since the quantity of gas in the segment appears to have been limited.

7 Observations

The PSA's observations fall generally into two categories.

- **Nonconformities**: observations where the PSA believes a breach of the regulations has occurred.

- **Improvement point**: observations where the PSA sees deficiencies, but lacks sufficient information to establish a breach of the regulations.

The investigation has identified four nonconformities from the regulatory requirements and one improvement point.

7.1 Nonconformities

7.1.1 Barriers and the barrier management system

Nonconformity
Inadequate maintenance and follow-up of barriers.

Grounds

- **Inadequate follow-up of safety-critical equipment**
  Failures in the ESD system were known but not adequately dealt with. The two ESVs which were known to be degraded also failed during the incident. These failures helped to increase the discharge and the risk related to the condensate leak. Historical data show that this type of valve has had problems on Gjøa since 2014, with water intrusion and corrosion in the actuator. Repeated faults were registered with ESV1509 from December 2015 until the incident on 21 June 2017. The reason for the valve failure was not understood and improvement measures were not given priority.

- **Lack of risk assessment over degrading of ESD functionality**
  The investigation has identified inadequate understanding of the function of ESVs as a safety system and how degrading of this function affects risk. Furthermore, a systematic and formalised cross-organisational collaboration between different disciplines is lacking. So is follow-up of people with system responsibility. In this case, with repeated faults which were not dealt with, changes to the test interval would not be an adequate measure to secure maintenance of the safety function. The SIL level of the valve is not maintained when it is known that the functionality fails.

- **Failure to highlight degrading on the barrier panel**
  A barrier panel is used on Gjøa to highlight faults in and degrading of safety-critical barrier functions. In this case, where problems had long been encountered with ESVs, the deteriorated functionality of the ESD system was not displayed on the panel. It therefore never appeared as red there. Only red lights on the panel were reported back to the technical integrity leadership on Gjøa

  The conditions listed above are described in more detail in chapter 5.2.3.

Requirement
Section 5 of the management regulations on barriers.

7.1.2 Management and maintenance system

Nonconformity
Inadequate maintenance and deficiencies in the management and maintenance system.

Grounds

- **Inadequate maintenance programme for ESVs**
  Historical data show that the valves failed repeatedly. The problems were caused by corrosion in the movable parts. Despite repeated failures, the valves were not adequately maintained. They were not disassembled, investigated and repaired. These conditions are described in more detail in chapter 5.2.3.

Requirements

Sections 45 and 47 of the activities regulations on maintenance and maintenance programme respectively.

7.1.3 Responding to vibration

Nonconformity
Failure to take measures and use collected data when responding to vibration over time.

Grounds
- The problems with vibration in the condensate pumps are described in chapter 5 and particularly 5.2.2 of this report. The vibration issue has been assessed and measures taken to ensure uptime and operation of the pumps, but inadequate use has been made of the data in assessing or initiating measures related to safety and a possible degrading of barriers beyond this.
- Data showing big pump vibration did not lead to an assessment of fatigue in attached pipe connections, nor to inspection of such possible degrading. Possible consequences in terms of reduced operational life and fracture risk were not analysed.

Requirements
Section 19 of the management regulations on collection, processing and use of data.
Section 10 of the facilities regulations on installations, systems and equipment.

7.1.4 Organisation and management

Nonconformity
Inadequate discharge of roles and responsibilities.

Grounds
- **Inadequate exercise of system responsibility for safety-critical equipment**
  Responsibility for safety-critical equipment is not adequately exercised and defined in the organisation. This is described in more detail in chapter 5.2.4.

- **Inadequate involvement of and information to management and the person responsible for technical integrity**
  The investigation finds that information related to the degrading of safety-critical equipment has been communicated and documented in an informal manner. Communication between management and discipline teams, and between different disciplines, has been inadequate. See chapter 5.2.4.

Requirement
Section 11, paragraph 3, of the management regulations on the basis for making decisions and decision criteria

7.2 Improvement point

7.2.1 Carcinogenic and mutagenic chemicals

Improvement point
Inadequate system for following up personnel exposed to benzene, inadequate routines for mapping benzene, and inadequate understanding of health risk.

Grounds
The medium which leaked from the pipe nozzle on the condensate pump consisted in part of gas and condensate containing benzene. The latter is classified as carcinogenic (IARC category 1) and mutagenic. A number of examples indicate that Engie had inadequate systems

for following up exposed personnel, inadequate routines for mapping the exposure potential in the incident area, and inadequate understanding of health risk.

- Engie's emergency preparedness plan for DSHA 11 "acute medical incident" was adequate for exposures resulting in acute health effects. But it could not point to a plan or process for following up personnel exposed to chronic hazardous substances which did not have acute health effects.
- The exposed plant operator was not called in for follow-up by a nurse until the afternoon of the day after the incident. No biological exposure measurements were made which could have been used to assess the operator's actual level of exposure.
- The operator did not change their soiled clothes until about two hours after the exposure and did not shower until several hours later. Despite being soaked by deluge water, possible hydrocarbon residues could have remained on their skin and clothes, and caused unnecessary skin exposure for a period which could have been avoided.
- LEL measurements were made for assessing the fire and explosion hazard in the period after the incident had normalised. On the other hand, no benzene measurements were carried out to assess the exposure potential before 15.00 on the day after the incident. Personnel working in the area have not considered the use of respirators since they had not recorded appreciable levels of LEL.
- Engie had established a register of employees exposed to carcinogenic or mutagenic chemicals and lead. Criteria for inclusion in the register were based on limit values for chemicals and significant exposure in an incident. The exposed plant operator was not included in the register. Engie had assessed that this person did not meet the inclusion criteria. The requirements in the regulations specify that employees who are or could be exposed to carcinogenic or mutagenic chemicals must be registered.

Requirements

Regulations relating to the performance of work, the use of work equipment and the related technical requirements

- *section 3-15 on response plan for emergencies when working with chemicals*
- *section 31-1 on register of employees exposed to carcinogenic or mutagenic chemicals and lead*

8 Barriers which have functioned

The investigation report does not go systematically through barriers which functioned during the incident. However, the team takes the view that emergency response and evacuation functioned given the way the incident developed.

9 Assessment of the player's investigation report

Engie E&P established its own investigation team with a mandate to investigate the incident of 21 June 2017. The team's report has by and large identified the direct cause of the condensate leak as inadequate weld quality and unsatisfactory follow-up in Statoil's development project. Where the two ESVs which failed because of corrosion are concerned, the report notes that the valves with actuators were not sufficiently well designed for offshore use as well as a somewhat inadequate description from the supplier of requirements for necessary testing and maintenance in the operational phase. Engie gives emphasis to inadequate maintenance and pays less attention to inadequate care of the ESD system's functionality. The summary notes weaknesses in communication with a clarification of roles and responsibilities related to relevant safety systems, and the absence of adequate compensatory measures to correct errors when testing the valves.

Engie writes that it is difficult to calculate the exact leak rate, and gives no figure for this in its report.

A couple of factual differences also exist between the Engie and PSA reports.

- Engie has subsequently received some more welding information from the pump supplier than the PSA has received and described in this report.
- Engie's report states that all five of the welds investigated on pipe nozzles have unacceptable faults. The PSA has received documentation that this applied to four out of five welds.

The PSA does not consider these differences to be significant for the conclusions of its investigation.

10 Discussion of uncertainties

The investigation has concentrated on how the leak could have occurred. Its work has been directed at design and maintenance of equipment which failed during the incident, and at the management of risk.

Some uncertainty prevails about the water content of the condensate which leaked out. Engie has taken post-incident samples, and calculated the water content at 99.9 per cent. This means a gas content in volume terms of about 10 per cent under atmospheric conditions. That estimate was communicated to the PSA when Engie's investigation report was submitted on 1 November 2017.

The PSA was told that the calculated initial leak rate was 1.06kg/s. Pressure in the nozzle – in other words, the outlet pressure of the pump – was then set at 28.8barg, while the Engie report sets this at 26barg. This is of minor significance for mapping the incident, but could mean that the specified leak rate is uncertain.

11 References

References referred to in the report.

1. Engie investigation report, *Uncontrolled Release of Hydrocarbons and Produced Water 21st June 2017*

2. DNV GL report, *Failure investigation of fractured pipe*, dated 11 August 2017

3. Force Technology technical memo, *Gjøa Vibration Campaign*, January 2017

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6. PSA investigation report, hydrocarbon leak on Gudrun, 18 February 2015 http://www.ptil.no/getfile.php/1338344/PDF/2015_245%20Granskingsrapport.pdf

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Appendix A. Other documents

Documents utilised in connection with the investigation.

1. 23ESV1509 CM PM History
2. 23PA005 Cross sectional
3. 23PA005 GA drawing
4. 23PA005A - photographs
5. 23PA005B CM PM History
6. 24ESV116 23ESV1509 (002) photographs
7. 24ESV1166 CM PM History
8. Blocking lists at 20.03, 21 June 2017
9. Datasheet with materials
10. Event and alarm log 30 minutes before and 60 minutes after the incident
11. Figure 23-39 process control scrubber inlet gas recovery compressor 23VG005
12. GA 23GT4047 with weight
13. Miscellaneous drawings, ISOs of piping upstream from the pump
14. Shutdown verification, 19.31-20.31, 21 June 2017
15. Organisation charts - Gjøa Asset
16. Piping spec DD201 corresponding class flange to class 600
17. P&ID C097-AKG-P-XB-2333-01
18. Walkinside23PA005B marked Nozzel N5 and Piping in and out – 3D diagram
19. WO331190 report. ESV and XV with reduced test intervals three months
20. Image of: focus action display, photo Gjøa incident 21 June 2017
21. Image of: weather data and wave 21 June 2017
22. HMI screen dump
23. SOW from metallurgy
24. Scope analyse broken pipe
25. Drawings of nozzle Finder mail
26. Drawings of nozzle GA 23PA005
27. Drawings of nozzle, cross-section 23PA005
28. Platform layout lower deck
29. Maintenance data Comos 23PA005A CM PM History
30. Maintenance data Comos 27ESV1008 CM PM History
31. Vibration data - 23PA005A and B
32. Miscellaneous datasheets for and drawings of 23ESV1509 and 24ESV1166
33. PM manual actuator 23ESV1509, C097-ALL-L-MB-0008
34. PM manual valve 23ESV1509, C097-ALL-L-MB-0003
35. Plan and mandate, ToR Investigation Gjoa Condensate Leakage 21 June 2017
36. Comos maintenance, 44ESV1543 CM PM History
37. Overview of jobs on ESVs - RS2017
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41. Technical Integrity Report - Rotating Discipline 2016
42. Vibration report Force, C097-FRC-L-RA-0213
43. Analyse verify and report (Gjoa) - rev 0
44. ESVs with running time development
45. SIL in operations, Gjøa 2016
46. SRS system 79, C097-AKG-J-SP-0102
47. SRS system 87, SRS C097-AKG-J-SP-0104
48. SAR, C097-ALL-S-RA-0001
49. Startup after ESD 2 with blowdown
50. Name of person with system responsibility, technical department
51. IMS report shutdown 22 May
52. Nonconformity Synergi - long-term from construction period
53. Nonconformity Synergi
54. NDT findings, PT report pump house 317-20002.22

55. NDT findings PT Gjøa
56. NDT findings, RT report 317-20002.22
57. NDT findings, RT report 317-20002.22
58. NDT findings, preliminary report from Force NDT WO346378
59. Report SKL nurse, supplementary question
60. Report SKL nurse, benzene exposure
61. ESV test procedure 23ESV1509 24ESV1166
62. Dimensions valve pumps A and B condensate
63. Fire and gas detector layout area P133
64. Fire and gas detector layout area P143_P243
65. Gas detectors area 100A
66. Images, emergency response screen offshore
67. Escape route and safety equipment lower deck
68. Trim list ballasting 210617
69. Comos WO 320539 - ESV check 24 months
70. Comos WO302623 - ESV check 24 months
71. Vibration measurement and FG detector layout
72. 23PA005B N5_RT failed nozzle – various X-ray images
73. Height valve
74. Procurement package specification - process and utility pumps package ER 254
75. Gjøa main process C097-GDF-P-XA-0001-01_02
76. P&ID scrubber C097-AKG-P-XB-2331-01
77. Appendix 1 presentation 24ESV1166
78. Appendix 1 report 23ESV1509
79. Drawing - P_ID 24ESV1166 - C097-AKG-P-XB-2403-01
80. Vibration 23PA005B - Engie_Gjøa_2017_Aug_23PA005A_B
81. Maintenance report - History 23PA005A
82. Vibration 23PA005B - - TN_GJO_170626_FW 23PA005A&B info
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94. Calculation leak rate 21 June 17
95. Calculation leak rate 21 June 17 ver 2. 5 October 2017 (updated)
96. Assessment of exposure related to incident Gjøa 21 June 17
97. C097-FRC-L-RA-0203 rev 02 IAB
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Appendix B. Participant list and interviewees