PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation report after the fire on Statfjord A of 16 October 2016	Activity number 001037031

Security grading

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

Summary

A fire broke out in the utility shaft on the Statfjord A (SFA) platform on 16 October 2016.

This incident occurred during the transfer of oil from the storage cells on SFA to a shuttle tanker. The circuit breaker which was to shut off power to the motor driving one of the loading pumps failed in such a way that the pump continued to operate even though information on displays in the control room indicated that it had stopped. The failure was caused by a fatigue fracture of a shaft in the circuit breaker intended to shut off power to the pump. This meant that crude oil was pumped against a closed valve for 51 minutes, with its temperature rising from 33°C to 344°C. The high temperature combined with powerful vibration in the pump meant that crude oil eventually leaked through the pump seals on both sides of the pump and ignited. In addition, fire broke out in crude oil which had leaked out into an insulation box connected to the seal oil system. Ignition probably occurred spontaneously as the hot crude oil came into contact with the air. Ignition in the insulation box could also have been caused by a heating cable.

The fire was confined by the quantity of oil which leaked around the pump seals on the loading pump and from the seal oil piping. The loading pump was eventually halted by disconnecting the power with the aid of another breaker. At a later stage in the incident, the loading pump was unintentionally energised again. After about five minutes, the current was turned off once more by disconnecting all main power.

The fire was first detected by a flame detector on the loading pump deck. It was eventually extinguished through activation of the deluge system in the room.

Three nonconformities and four improvement points have been identified in connection with the investigation of the incident.

Involved

Main group	Approved by/date
T-1	Kjell Marius Auflem, Supervision coordinator T-1
Members of the investigation group	**Investigation leader**
Bente Hallan Rune Solheim Ole J Næss Eivind Jåsund	Eivind Sande

Contents

1 Summary

While crude oil was being transferred from storage cells on Statfjord A (SFA) to a shuttle tanker, a fire broke out on 16 October 2016 on the loading pump deck (U68M) in the platform's utility shaft. Since the loading operation was approaching its end, the tanker signalled the platform to reduce flow. This was done by stopping one of the three loading pumps in operation, with a shutdown signal sent from the central control room (CCR) to loading pump D. The circuit breaker which was to shut off power to the motor driving the pump failed in such a way that the pump continued to operate even though information in the CCR indicated that it had stopped. This meant that pumping continued against a closed valve for 51 minutes, and that the temperature of the crude oil in the pump rose over these 51 minutes from 33°C to 344°C. The high temperature of the crude oil combined with powerful vibration in the pump meant that crude oil eventually leaked through the pump seals on both sides of the pump and ignited. In addition, fire broke out in crude oil which had leaked out into an insulation box connected to the seal oil system at the drive end of the pump. Ignition probably occurred spontaneously as the hot crude oil came into contact with the air. Ignition in the insulation box could also have been caused by a heating cable.

During the 51 minutes that the pump operated against a closed valve, the CCR received a number of vibration and temperature alarms related to the motor and pump for loading pump D. The vibration alarms were assumed to be caused by a fault in the probes and therefore false. This was because the CCR operators were certain that the pump was shut down on the basis of display information. They did not pick up the temperature alarms.

The fire was confined by the quantity of oil which leaked around the pump seals on the loading pump and from the seal oil piping. The loading pump was eventually halted by disconnecting the power through manual operation of a busbar breaker. About 17 minutes later, the loading pump was unintentionally re-energised from connecting generator C to that part of the busbar which was shut down. About five minutes later, the current was turned off once more by disconnecting all main power. During these five minutes, the loading pump did not rotate because the failure of the circuit breaker meant that one of the current phases was not connected.

The fire was initially detected by a flame detector on the loading pump deck. It was eventually extinguished through activation of the deluge system in the room. The deluge solution also helped to prevent fresh ignition by cooling fire-exposed equipment.

It emerged from the investigation that a similar incident with a fractured shaft in a circuit breaker had occurred on 3 March 2003. On that occasion, the loading pump was stopped before the incident developed into a fire. Personnel on SFA during 17-19 October 2016 were not aware that a shaft in a circuit breaker had fractured earlier on the facility.

Three nonconformities and four improvement points have been identified in connection with the investigation of the incident.

2 Introduction

The PSA was informed of the incident by Statoil Monitoring and Emergency Preparedness (SOB) at 0820 on 16 October. The authority decided on the same day to conduct its own investigation of the incident.

Three members of the PSA investigation team were on SFA from 17-19 October 2016. The police requested support from the PSA for their investigation of the incident, and were on SFA at the same time as the PSA investigation team. In their time on SFA, the PSA investigators assisted the police during site inspection and interviews with personnel offshore.

After their time offshore, the police conducted further interviews with support from the PSA, and the team has acquired additional information through conversations with relevant personnel.

Statoil's investigation report was received on 19 December 2016. Statoil presented its assessments and recommendations for measures after the group's investigation to the PSA in a meeting of 20 December 2016.

A human, technological, organisational (HTO) approach has been used as the methodology in the investigation process. This utilises the concepts of operational, organisational and technical barrier elements.

2.1 Mandate

The mandate for the PSA's investigation team has been as follows.

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

Letter h in the mandate has been excluded from the investigation work, in that the team has considered it to be irrelevant to this incident.

The purpose of the PSA's work is to help prevent similar incidents by identifying improvement points at the players involved and by transferring experience to other players in the industry.

2.2 Composition of the investigation team

The PSA's investigation team has comprised:

Eivind Sande	–	electrical facilities, investigation leader
Bente Hallan	–	technical safety
Rune Solheim	–	emergency preparedness, investigation leader offshore
Ole J Næss	–	material technology
Eivind Jåsund	–	maintenance management

3 Background information

Statfjord A (SFA) is a Condeep platform with three concrete shafts. On stream since 1979, it features a module support frame sitting on the shafts and supporting the rest of the topside. The living quarters are located directly over the utility shaft.

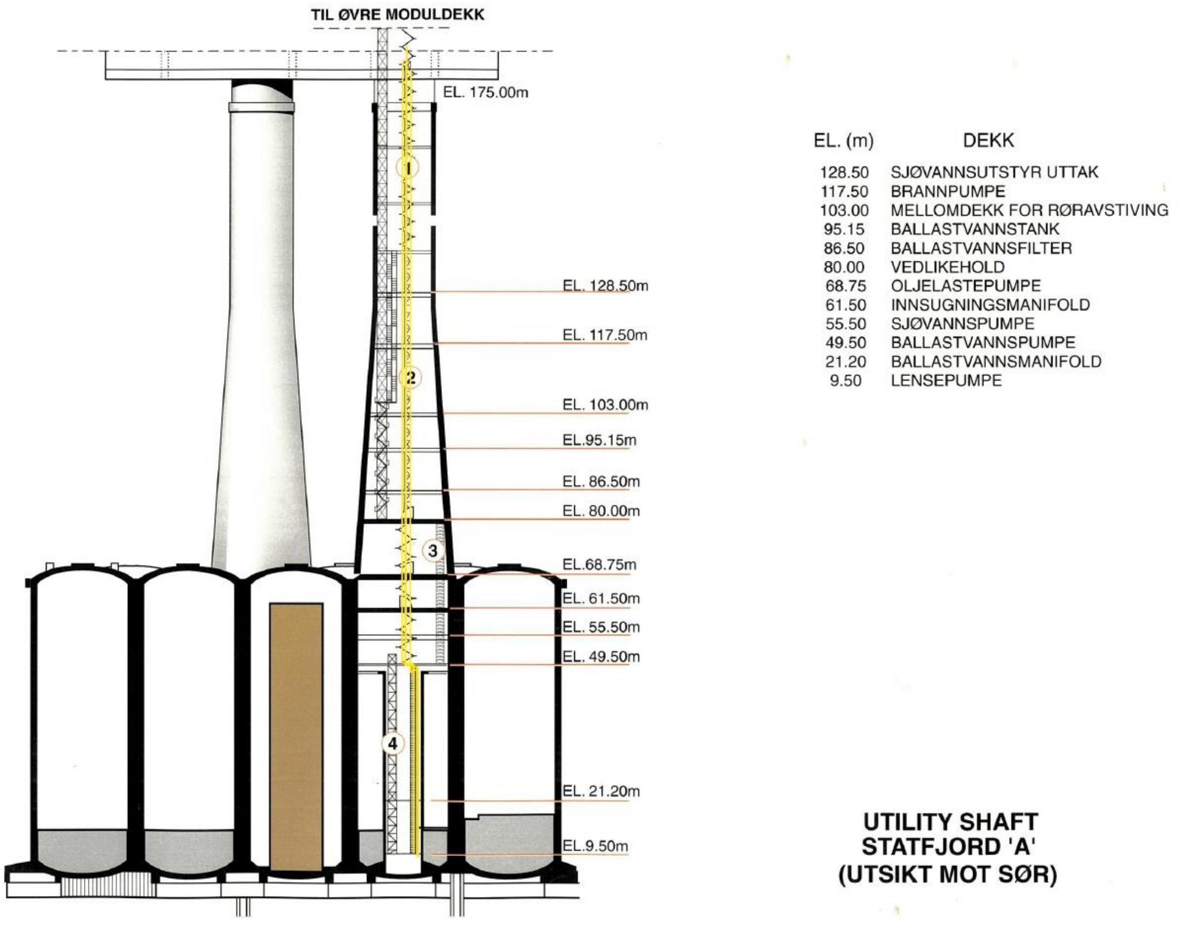

Figure 1 – Statfjord A utility shaft (Statoil).

Sixteen storage cells with a total capacity of 1.2 million barrels hold the crude oil. These are arranged in three groups – two of five cells and one of six.

Crude oil flows by gravity through pipes from coolers on the cellar deck to the cells, which are part of the concrete support structure and partly filled with seawater. The crude is driven by a hydrostatic pressure higher than the pressure in the ballast water system, and ballast water corresponding the quantity of oil flowing into the cells is removed by pumping. In this way, oil can flow continuously from the wells to storage in the cells and is then periodically transferred or pumped out from the same cells to shuttle tankers.

The storage cells are refilled with ballast water as the oil is removed. Differential pressure is about five bar over the cell walls, where the external pressure is highest. This differential is maintained by removing or adding ballast water. The correct operating pressure is regulated through the water pressure provided by the level in the ballast water tank.

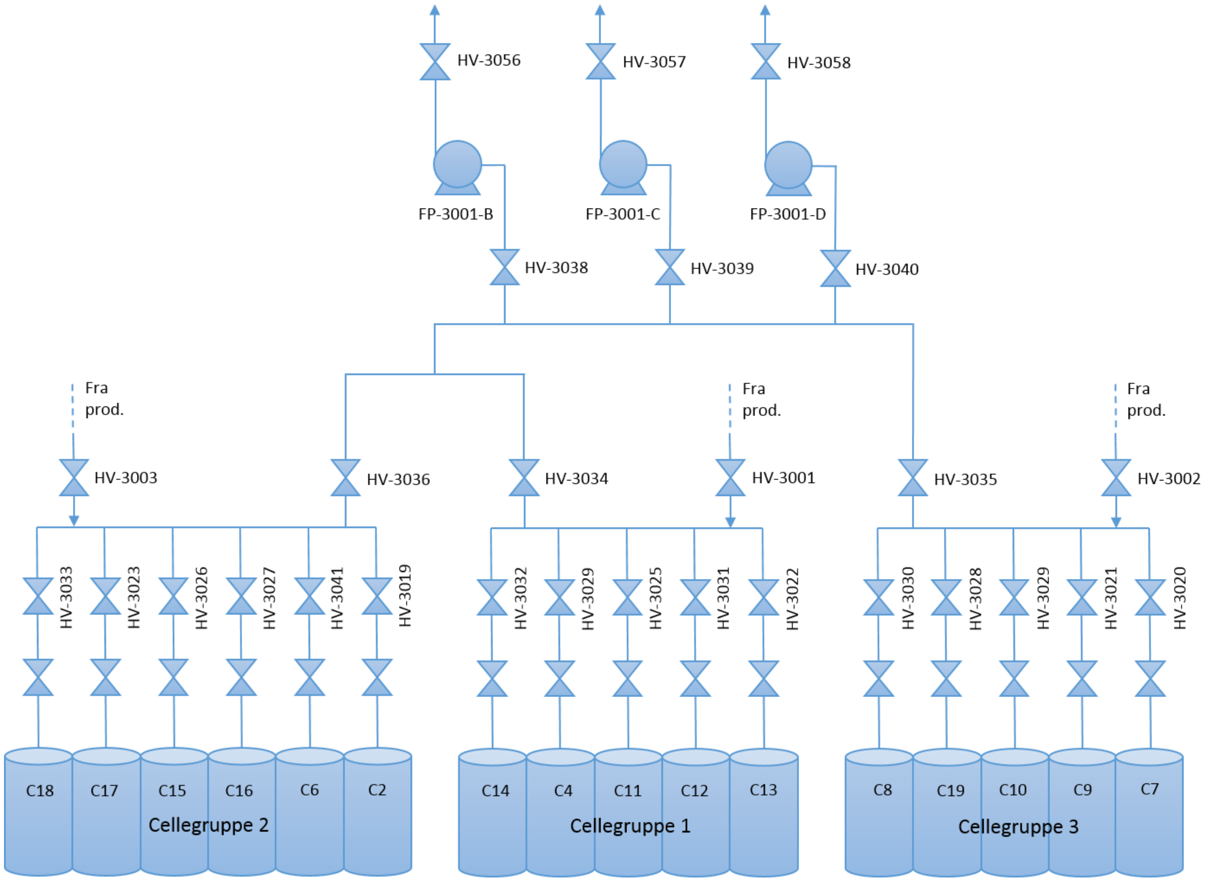

Figure 2 – Simplified diagram of the Statfjord A loading system.

Crude oil is removed from the storage cells with the aid of three loading pumps – FP-3001-B/C/D – installed in the utility shaft at level US68M. These pumps are electrically driven 13.8kV, three-phase, 60Hz two-stage centrifugal units supplied from the storage cells through 24-inch pipes connected to a 36-inch crude oil manifold which links the storage cells. The pumps are operated in parallel. The electronic logic system from control and protection of the pumps is implemented in a process control and data acquisition (PCDA) system. The logic is designed to ensure safe start-up and normal operation of the motor and pump units and to initiate alarm and disconnect functions in the event of error signals. Start and stop signals from the CCR and error signals for emergency shutdown (ESD) are all transferred to the KC0001 switchboard.

From the pumps, the oil is led through the fiscal metering system and on to the tanker via offshore loading system A (OLS-A).

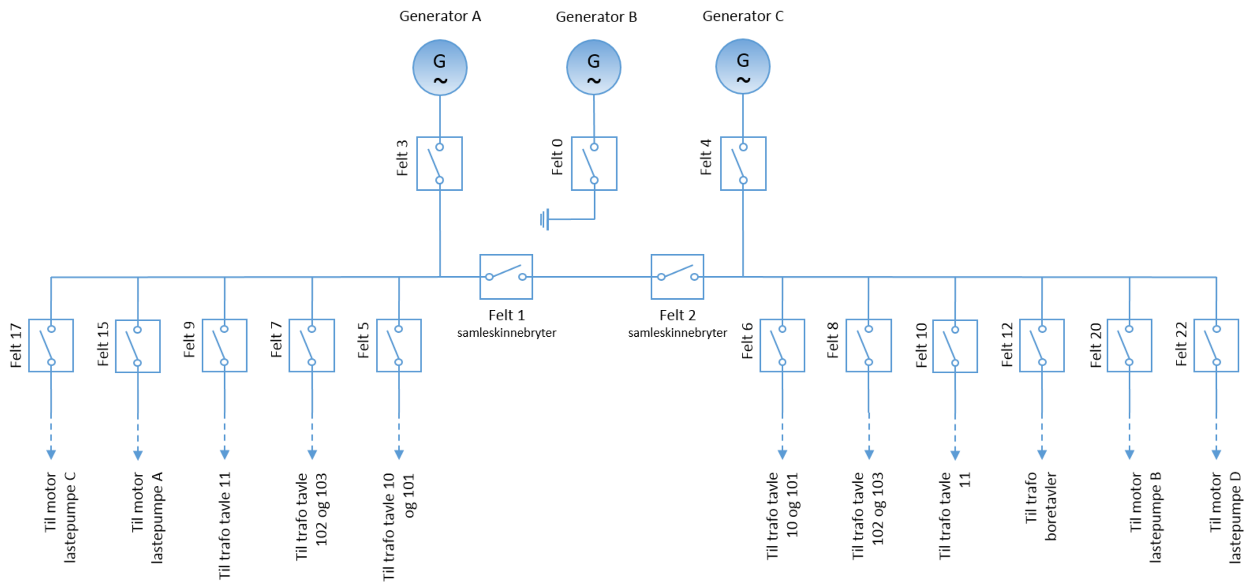

Figure 3 – Simplified design of the main power system on Statfjord A.

4 Course of events

4.1 Earlier incident

Through the police investigation of the fire, the PSA became aware that a similar event with a fractured shaft in a circuit breaker had occurred on 1 March 2003. On that occasion, the loading pump was stopped before the incident developed into a fire. Personnel on SFA during the team’s presence there on 17-19 October 2016 were not aware that a shaft in a circuit breaker had fractured earlier on the facility.

4.2 Description of the incident on 16 October 2016

The fire broke out on the morning of Sunday 16 October 2016 as oil transfer from the SFA cells to the tanker was being completed. The platform was operating normally. Personnel were otherwise engaged in a “Sunday washdown”, so that few work permits were active.

As the loading operation neared completion, the tanker signalled the platform to reduce flow. This was the normal routine for topping off the cargo tanks in a controlled manner. In line with routine, the outlet valve on loading pump D was closed and the stop signal was then sent to the pump from the CCR at 07.33. The CCR display showed the pump to be stopped.

Following the incident, it transpired that a shaft which controls connection/disconnection of the three current phases fractured after the stop signal reached the circuit breaker. This meant that only one phase was disconnected. The pump therefore failed to stop even though that was shown in the CCR. A fan in the turbine hood in module M4A stopped as a result of the imbalance in power supply. This component is production-critical, and attention in the CCR was concentrated on getting it working again.

Seconds after the stop signal had been given, a vibration alarm (H) was received from pump D. An improvement has been made the day before to a vibration probe which had given a false alarm on one of the other loading pumps. This contributed to a decision that a person from the automation department should check the reason for the vibration alarm with the area operator for the utility shaft. The latter continued washing down while waiting for automation personnel to become available. In the minutes after the stop signal was sent to pump D, the PCDA shows that a number of alarms were received from this pump and the loading pump system, including high (H) and high-high (HH) alarms for lube oil pressure and for temperature in the crude oil and on the housing for pump D. These alarms coincided with further trip alarms from the fan in M4A, but attracted no attention in the CCR. An HH alarm for crude oil temperature in the pump and its housing should have automatically shut down the pump. That did not happen because of the shaft fracture in the circuit breaker for pump D.

At 08.17, an alarm was received from an activated flame detector at level US68M where the loading pumps are located. The PCDA shows that automatic actions related to this detector were blocked by the CCR immediately after the alarm was received. Loading pumps B and C were stopped from the CCR (loading pump A is permanently out of operation). The alarm reaction team (ART) was sent down the shaft to check the position. While the ART was on its was down, the CCR observed smoke on the loading pump deck via CCTV. When the ART reached the deck, the door from the stairwell was opened to confirm smoke in the area. The ART also heard that at least one pump was still operating and informed the CCR of this.

The authorised person electrical[1] on board was instructed by the CCR to go to high-voltage switchboard room 1 (KC0001) in M16 to check whether the loading pump was stopped. He went to the room with another electrician. They observed that visual indication on the breakers for all the loading pumps showed they were not in operation. On the other hand, the ammeter for pump D showed that it was still running. An attempt was made to stop the pump manually by pressing on the breaker, with no response. The authorised person electrical told the CCR to open the busbar breaker in field 2 on the board to disconnect power supply to half of board 1, including pump D. He then went to the operating panel for the busbar breaker. When he reached the circuit breaker, the busbar breaker had still not been activated from the CCR. He therefore decided to open the breaker manually from the local operating panel. The PCDA shows that this was done at 08.25. The ammeter for pump D subsequently showed that the pump has ceased to receive current.

A general alarm was sounded on the platform at 08.23, and ESD2 was activated from the CCR at 08.29. The PCDA shows that an alarm was received from activation of another flame detector on the loading pump deck at 08.34. Since the first flame detector alarm received had been blocked, deluge was not automatically triggered in fire area US7. The second detector alarm was blocked soon after it was received.

Flames were seen on CCTV in the CCR at about 08.41, and deluge was triggered manually.

Both electricians in the high-voltage switchboard room 1 in M16 mustered as first-aiders when the mustering alarm sounded, but were quickly relieved of their emergency response roles since nobody was injured. On their own initiative, they toured the various switchboard rooms in M10 and M16 to check status after half of switchboard 1 had been disconnected. When they came back to the high-voltage switchboard room in M16, they confirmed that power to all the loading pumps still stood at zero. On their way out, they heard one or more switches being turned on and observed that the ammeter for pump D was showing full load.

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[1] Responsibilities of the authorised person electrical on the facility include operation of all its high-voltage facilities.

After the incident, it became clear that main generator C had unintentionally been connected by the CCR and thereby resumed current to pump D. This was because the main generators are converted from electrical to diesel operation at ESD2. Following the use of the busbar breaker to disconnect power from half of switchboard 1, main generator A was supplying the other half. This generator is connected to a waste heat recovery unit (WHRU), where diesel operation can cause soot to accumulate. The routine accordingly calls for main generator C to be primarily used during diesel operation, and it was therefore activated. The CCR was not aware that this would resume power supply to pump D.

The electricians now decided to leave the room because of the uncertain position, and the authorised person electrical simultaneously told the CCR over the radio that it must immediately shut down all main power. This was done from the ESD button in the platform's power station and pump D ceased to be supplied with current.

Deluge was halted manually from the cabinet in the utility shaft after about 39 minutes (09.20) for a visual check of the area by CCTV. Flames were still observed to be present, and deluge was therefore reactivated. After a further 11 minutes, deluge was halted again for a new CCTV check, and resumed immediately afterwards. It now continued until 10.35. Personnel descended into the shaft and confirmed at 10.43 that no flames remained. The point of origin of the fire was confirmed at 11.05 to be loading pump D.

4.3 Timeline for the incident of 16 October

Table 1 – Timeline for the incident of 16 October 2016

Time	Event	Comment	Source
07.33.12	Outlet valve for loading pump D receives stop signal.	Tag HV-3058	PCDA
07.33.31	Pump D stopped from CCR.	It transpires later that the pump stays on because the circuit breaker in the switchboard fails.	PCDA
07.33.35	Outlet valve for pump D reports that it is closed.		PCDA
07.33.37	First vibration alarm from pump D.	Tag XAH-30072	PCDA
07.34.03	Report that the turbine-hood fan in module M4A has tripped.	Tag FK-2107A-F, FT2101 Corresponding alarms are received a further five times between this point and 07.59.27	PCDA
07.34.21	High pressure (H) alarm from lube oil for pump D.	Tag PT-3008	PCDA
07.35.33	High pressure (H) alarm from lube oil for pump D.	Tag PT-3012 2	PCDA
07.36.26	High temperature (H) alarm in M4A turbine hood.	Tag TT-8603-1 Corresponding alarms are received a further eight times between this point and 08.02.41	PCDA
07.36.52	High temperature (H) alarm in crude oil loading pump C.	Tag TE-3014A. Engineering flow diagram crude storage & transfer system (AP-000-ZE-035.006, rev C3) shows that this temperature transmitter is on pump D, not C.	PCDA
07.37.26	High temperature (HH) alarm in crude oil loading pump C.	Tag TE-3014A. Engineering flow diagram crude storage & transfer system (AP-000-ZE-035.006, rev C3) shows that this temperature transmitter is on pump D, not C. This alarm should have triggered automatic disconnection of pump D, but that did not happen because the circuit breaker in the switchboard had failed.	PCDA
07.38.48	High pressure (H) alarm in housing for pump D.	Tag TE-3009 4	PCDA
07.39.06	High temperature (HH) alarm in housing for pump D.	Tag TE-3009 4 This alarm should have triggered automatic disconnection of pump D, but	PCDA

Time	Event	Comment	Source
		that did not happen because the circuit breaker in the switchboard had failed.	
07.41.23	Second high pressure (H) alarm in housing for pump D.	Tag TE-3009 4	PCDA
07.41.24	Second high temperature (H) alarm in crude oil loading pump C.	Tag TE-3014A. Engineering flow diagram crude storage & transfer system (AP-000-ZE-035.006, rev C3) shows that this temperature transmitter is on pump D, not C.	PCDA
07.44.19	First vibration alarm (H) from this vibration probe on bearings in pump D.	Tag XAH-30071	PCDA
07.48.43	First HH vibration alarm on pump D.	Tag XAHH-30072	PCDA
07.49.59	High temperature (H) alarm in M4A turbine hood.	Tag TT-8603-1	PCDA
07.58.00	Pressure drop registered by sensor measuring outlet pressure from pump D.	Tag PT-30008. The temperature of the oil inside the pump housing was now about 210°C. At the same time, a pressure drop was registered on the transmitter which monitors pressure between the seals at the drive end of pump D. Stronger readings were simultaneously observed from the vibration probes on pump D.	PI Process Book
08.02.30	First vibration alarm (H) from this vibration probe on the pump D bearings.	Tag XAH-30074	PCDA
08.02.42	First vibration alarm (H) from this vibration probe on the pump D bearings. All four vibration probes on pump D have now given an alarm. There are two probes on each bearing.	Tag XAH-30073	PCDA
08.03.06	Second HH vibration alarm on pump D.	Tag XAHH-30074	PCDA
08.03.51	First vibration alarm with maximum reading on pump D.	Tag XX-30072	PCDA
08.05.45	Second vibration alarm with maximum reading on pump D.	Tag XX-30071	PCDA
08.08.45	Third vibration alarm with maximum reading on pump D.	Tag XX-30074	PCDA
08.09.48	Fourth vibration alarm with maximum reading on pump D. All vibration probes on pump D bearings have now shown maximum readings.	Tag XX-30073	PCDA
08.17.03	Flame detector alarm in the utility shaft on loading pump deck US68M.	Tag US7-FD-002. Designed so that alarm goes to CCR, but no automatic triggering of deluge system.	F&G
08.18.31	Flame detector US7-FD-002 blocked by CCR.		F&G
08.19.04	Deluge release US7 for loading pump deck blocked by CCR. Equipment (loading pumps) stop blocked by CCR. ESD2 + equipment blocked by CCR.		F&G
08.19.25	Outlet valve for loading pump C given closure signal.	Tag HV-3057	PCDA
08.19.29	Pump C stopped from CCR.	FP-3001C	PCDA
08.19.37	Outlet valve for loading pump B given closure signal.	Tag HV-3056	PCDA
08.19.45	Pump B stopped from CCR.	FP-3001B	PCDA
08.19.51	Outlet valve for loading pump C reports that the valve is closed.	Tag HV-3057	PCDA
08.19.56	High pressure (H) alarm measured in seal at drive end of pump D.	Tag PT-30271	PCDA
08.20.01	Outlet valve for loading pump B reports valve closed.	Tag HV-3056	PCDA
08.20.21	High pressure (H) alarm measured in seal at the drive end of pump D.	Tag PT-30271	PCDA
08.21.50	Gas detector gives alarm of dirty reflector.	Tag US7-GD-005	
08.22.00	High temperature (HH) alarm in bearings for pump D.	Tag TE-3009 1	PCDA
08.20-08.25	ART reports that smoke observed and that one loading pump is still running.		Conversations
08.23	Muster alarm.		PRS
08.25.01	Busbar breaker disconnected in switchboard room 1 by authorised person electrical to halt pump D.	Tags KC001_CUB.02 (bus-tie) and KC001_CUB.10. Half the board is disconnected and D stops. Trend in PI shows that D stops.	PI ProcessBook and PCDA
08.25.01	Emergency switchboard B and C register zero voltage. Emergency switchboard A is fed from opposite side and still has voltage.		PCDA
08.25	Temperature sensor in pump D reaches max of 344°C.		PI ProcessBook

Time	Event	Comment	Source
08.26.23	High pressure (H) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.26.33	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.26.57	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.29.51	ESD2 activated from CCR.	Includes production shutdown on SFA and closure signal sent to shutdown valves to storage cells. Emergency response (ER) log shows ESD triggered at 08.26.	F&G
08.30.26	PSD activated as consequence of ESD.		PCDA
08.30.27	ESD signal to Snorre B from SFA.	Tag ESD-SNB	PCDA
08.30.28	Shutdown signal sent to close oil/gas risers from Snorre A.		PCDA
08.30	Logistics offshore air (LOL) notified.	Logistics offshore air GFC.	ER log
08.31	Personnel on board (POB) OK.		ER log
08.32.21	Failure signal (valve failure) registered in relation to inlet valve to pump D.	Tag HV-3040. Reported after incident that this did not shut completely, but stayed 25 per cent open.	PCDA
08.33	Helideck staffed.		ER log
08.34.28	Alarm from further flame detector on loading pump deck US68M in the utility shaft.	Tag US7-FD-005. North side of module, pointing towards south/west.	F&G
08.35.09	Flame detector US7-FD-005 blocked from CCR.		F&G
08.39.18	Vibration probe on pump D gives failure alarm.	Tag XAF-30071	PCDA
08.41.05	Deluge triggered on loading pump deck US68M. Naked flames seen on CCTV.	ER log gives 08.38 for deluge triggering and observation of naked flames.	F&G
08.41.51	Vibration alarm (HH) from bearings on motor driving pump D.	Tag XAHH-30081	PCDA
08.41.51	Vibration alarm (max) from bearings on motor driving pump D.	Tag XX-30081	PCDA
08.42.00	Emergency fire pumps activated.		ER log
08.42.39	Generator C connected to the grid.	Tag KC001_CUB.00. (Single line shows CUB.04 for gen C) This feeds that part of switchboard 1 which supplies pump D. The motor for pump D therefore re-energised. The revolution counter shows that the pump does not rotate this time, because only two phases are energised from circuit breaker to motor.	PI ProcessBook and PCDA
08.47.08	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.47.23	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.47.24	Generator C halted by local emergency stop in power station.	Tags EHS-70338C and FT7001C	PCDA
08.47.24	Circuit breaker KC001_CUB.00 opens (breaker in field 4 belonging to generator C).	Current to pump D disconnected.	PCDA
08.47.35	Loss of main power. Generators disconnected with the emergency stop button in the power station.	Power supply to pump D disconnected.	F&G
08.47.50	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.47.52	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.47.53	High pressure (HH) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA
08.48.09	Generator A halted by local emergency stop in power station.	Tags EHS-70138C and FT7001A	PCDA
08.48.09	Circuit breaker KC001_CUB.03 opens.	Breaker for generator A	PCDA
08.48.09	Emergency generator A registers zero voltage. The whole switchboard is now de-energised.	Tag NG7002A	PCDA
08.49.25	Emergency generator A connected to emergency switchboard.	Tag KC011 +H07	PCDA
08.49	Thirteen people from lifeboat to helideck.		ER log
08.50.06	Emergency generator B connected to emergency switchboard.	Tag KC011 +H01	PCDA
08.50.24	High pressure (H) alarm measured in seal at free end of pump D.	Tag PT-30272	PCDA

Time	Event	Comment	Source
08.50.42	High temperature (H) alarm in stator for pump D.	Tag TE-30284	PCDA
08.50.45	High temperature (H) alarm in stator for pump D.	Tag TE-30286	PCDA
08.50.57	Emergency generator C connected to emergency switchboard.	Tag KC011 +H06	PCDA
08.51.12	High temperature (H) alarm in stator for pump D.	Tag TE-30285	PCDA
08.51.17	High temperature (H) alarm in stator for pump D.	Tag TE-30282	PCDA
08.51.36	High temperature (HH) alarm in stator for pump D.	Tag TE-30284	PCDA
08.51.43	High temperature (HH) alarm in stator for pump D.	Tag TE-30286	PCDA
08.51.50	High temperature (HH) alarm in stator for pump D.	Tag TE-30085	PCDA
08.52.20	High temperature (HH) alarm in stator for pump D.	Tag TE-30282	PCDA
08.52.36	High temperature (HH) alarm in stator for pump D.	Tag TE-30285	PCDA
08.57	Three people from SAR to level 80 in utility shaft.		ER log
09.07	Sharp eye established for observation of oil on the sea.		ER log
09.18.50	High (H) motor temperature alarm for emergency drain pump A.	Tag TT-5031. FP3007A	PCDA
09.21.41	High temperature (HH) alarm in stator for pump D.	Tag TE-30285	PCDA
09.20	Deluge valve closed level 80 in utility shaft.		ER log
09.24	Flames registered – deluge started.		ER log
09.28.44	High temperature (HH) alarm in bearings pump D.	Tag TE-3009 1	PCDA
09.30.54	High temperature (HH) alarm in bearings pump D.	Tag TE-3009 1	PCDA
09.33.55	High temperature (H) alarm in stator for pump D.	Tag TE-30285	PCDA
09.35	Deluge stop for CCTV check.		ER log
09.35.22	High pressure (H) alarm measured on seal at drive end of pump D.	Tag PT-30271	PCDA
09.36	Deluge started.		ER log
09.36.59	High pressure (H) alarm measured on seal at drive end of pump D.	Tag PT-30271	PCDA
09.40	Oseberg SAR in readiness on helideck.		WR log
09.42.39	High temperature (HH) alarm in stator for pump D.	Tag TE-30286	PCDA
09.58.13	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
09.58.20	High temperature (H) alarm in stator for pump D.	Tag TE-30282	PCDA
09.58.20	High temperature (H) alarm in stator for pump D.	Tag TE-30286	PCDA
09.58.20	High temperature (H) alarm in stator for pump D.	Tag TE-30284	PCDA
09.58.20	High temperature (H) alarm in stator for pump D.	Tag TE-30285	PCDA
10.00.10	High temperature (H) alarm in stator for pump D.	Tag TE-30286	PCDA
10.07.39	High temperature (H) alarm in stator for pump D.	Tag TE-30283	PCDA
10.17.16	High temperature (H) alarm in stator for pump D.	Tag TE-30283	PCDA
10.20.30	High temperature (HH) alarm in stator for pump D.	Tag TE-30282	PCDA
10.20.36	High temperature (HH) alarm in stator for pump D.	Tag TE-30282	PCDA
10.21.10	High temperature (HH) alarm in stator for pump D.	Tag TE-30282	PCDA
10.34.21	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.34.23	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.34.35	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.34.37	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.34.44	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.34.45	High coolant temperature (H) alarm in motor for pump D.	Tag TE-30085	PCDA
10.35	Deluge stopped.		ER log
10.40.14	High temperature (HH) alarm in crude oil pump C.	Tag TE-3014A. Engineering flow diagram crude storage & transfer system (AP-000-ZE-035.006, rev C3) showed that this temperature transmitter is on pump D, not C.	PCDA
10.43	Visual check – no fire.		ER log
10.46.25	High temperature (HH) alarm in stator for pump D.	Tag TE-30282	PCDA
10.50	Check with thermal camera – no heat, no gas, a little smoke.		ER log
10.55	Lifeboat 1 demobilised, personnel without emergency response functions muster to the mess.		ER log
10.55.46	High temperature (HH) alarm in crude oil pump C.	Tag TE-3014A. Engineering flow diagram crude storage & transfer system (AP-000-	PCDA

Time	Event	Comment	Source
		ZE-035.006, rev C3) showed that this temperature transmitter is on pump D, not C.	
10.58.17	Attempt to reset inlet valve for pump D. Still gives valve error.	Tag HV-3040. After the incident, it was reported that this valve did not close completely, but remained 25 per cent open.	PCDA
10.58.50	High temperature (HH) alarm in stator for pump D.	Tag TE-30284	PCDA
10.58.58	High temperature (HH) alarm in stator for pump D.	Tag TE-30284	PCDA
10.59.25	High temperature (HH) alarm in stator for pump D.	Tag TE-30284	PCDA
11.05	Origin in loading pump D confirmed.		ER log

4.3.1 Site investigations

4.3.1.1 High-voltage switchboard room

Investigation of the circuit breaker for loading pump D revealed a fracture in the shaft which operates connection/disconnection of the three current phases to the pump. Phase L1 was found to be correctly disconnected, phase L2 was in an intermediate position so that an electric arc occurred in the circuit-breaker cabinet, and phase L3 was still connected.

Photograph 1 - Circuit breakers in switchboard room KC0001.

Photograph 2 - Fractured shaft in the circuit breaker for loading pump D.

Photograph 3 - Meter showing number of connections/disconnections[2] for pump D.

4.3.1.2 Loading pump deck

Inspections of the site showed clear signs that the temperature of the crude oil in the pump had been high, and that there had been naked flames at the seals on both sides of the pump as well as inside an insulation box.

Photograph 4 - Fire damage at the drive end of loading pump D.

[2] The meter registers the number of complete connection/disconnection cycles – in other words, 0.5 per connection or disconnection.

Photograph 5 - Fire damage at the free end of loading pump D.

Photograph 6 - Melted insulation box at the drive end of pump D.

4.3.2 Material technology investigation of fractured shaft

The broken shaft in the circuit breaker for loading pump D was sent to Statoil's material technology department at Rotvoll for investigation. This concluded that the fracture was caused by fatigue. See appendix B to the *Materialteknisk undersøkelse av brukket stag fra brytervogn, SFA* report.

5 Potential of the incident

5.1 Actual consequences

The actual consequence was an ignited hydrocarbon leak with a varying but limited leak rate. In its investigation report, Statoil assesses the leak rate to have been less than 0.1kg/s. This estimate is based on an overall assessment of the leak sites. In the team's view, this estimate seems realistic. Flames were observed over more than an hour. It is uncertain whether the fire burnt throughout this period or blazed up again when the deluge was halted. The fire damage indicates that fire was small, but melted aluminium in an insulation box suggests that the temperature has exceeded 630°C. Based on the site inspection, the team estimates that flames have occurred at three different leak points on the loading pump.

No people were injured during the incident.

Material damage from the incident relates to heat damage to the motor stator and pump, causing pump D to be taken permanently out of operation. It will not be replaced, since the two remaining loading pumps are sufficient today.

In the switchboard room, the material damage is limited to the fractured shaft and arc damage to the tulip contact and pin in the L2 circuit-breaker cabinet for loading pump D.

Statoil has calculated the loss of production from the incident at 5 206 scm of oil and 8.5 million scm gas. Production was completely shut down from the time the incident occurred on 16 October 2016 to 21 October 2016.

5.2 Potential consequences

The size of the fire was confined by the leak rate. This rate would have potentially risen had the seal oil pipe fractured inside or close to the insulation box, or had the shaft seals failed. Statoil has calculated the potential leak rates at 0.146kg/s and 0.85kg/s for seal oil pipe and shaft seals respectively.

The seal oil system is directly supplied by crude oil from the storage cells via the pump housing and valves as shown in Figure 2. Efforts were made during the incident to close inlet valve HV-3040 for pump D against the cell groups, but it stopped in the three-quarters-closed position. It was already known that the shut-off valves between the cells and HV-3040 had internal leaks. Should a seal oil pipe have fractured or shaft seals failed, it is therefore uncertain how far it would have been possible to limit the leak by closing the shut-off valves. The team has concluded that the fire would not have escalated even with a long-lasting leak, given that the fire water system functioned.

The stators in the motor could have caught fire because of the temperature rise after main generator C was reconnected to the power grid. Statoil's investigation report has documented that the generator's unbalance protection would have caused it to switch off very quickly even without an emergency stop. A fire in the motor is unlikely to have affected surrounding equipment.

A secondary fire in the switchboard room could have started in the cabinet because of a potential blowout of hot oil from the circuit-breaker cabinet following the arcing which occurred in the breaker for phase L2. The cabinets are designed to prevent such secondary fires spreading to surrounding cabinets or presenting a hazard to people in the room.

As long as the deluge on the loading pump deck was activated and functioned, the team considers that the incident did not have a major accident potential.

6 Direct and underlying causes

6.1 Direct cause

The direct cause of the fire was a fatigue fracture of the shaft in the circuit breaker to FP-3001-D (loading pump D). This failure meant that neither the manual stop signal to the pump nor automatic trip functions had any effect.

6.2 Underlying causes

6.2.1 Concurrent events

The shaft fracture created an imbalance in the power grid on SFA, causing a fan in the turbine hood in module M4A stopped. This fan is production-critical, and attention in the CCR was concentrated on getting it going again. That probably contributed to the failure to perceive that loading pump D was still in operation after the stop signal had been given.

6.2.2 Information in the CCR and interpretation of fault alarms

Because the pump continued operating, it pumped for 51 minutes against a closed valve and the temperature of the crude oil inside the pump rose over that period from 33°C to 344°C. Big vibrations occurred in the pump which, combined with the high crude oil temperature, lead to leaks.

The CCR display showed that pump D was stopped. The CCR operators could have established that the pump was still operating, but would then have had to navigate from the primary display to the revolution counter for the relevant pump. Because the display showed the pump to be stopped, and because a vibration probe had failed the day before, the repeated vibration alarms received were not perceived as a signal that pump D was still operating. Furthermore, errors in the alarm text from the temperature sensor on pump D meant that a high-level alarm showed up as coming from pump C (which was operational) rather than the correct pump. Nor was the connection made that the high-level alarm from the temperature sensor on the housing for pump D could mean that the pump was still operational.

6.2.3 Lack of investigation into similar incidents on SFA

A similar shaft fracture in a circuit breaker occurred on SFA in 2003. Personnel on board were not aware that such a fracture could occur, or what consequences it would have – including the failure of stop-signal and automatic-disconnect functions. No investigation was conducted in 2003 to identify the causes of the circuit-breaker failure or whether a similar condition was under development on other equipment.

7 Observations

The PSA's observations fall generally into three categories.

- Nonconformities: this category embraces observations which the PSA believes to be a breach of the regulations.
- Improvement points: these relate to observations where deficiencies are seen, but insufficient information is available to establish a breach of the regulations.
- Conformances/barriers which functioned: applies to proven conformance with the regulations.

7.1 Nonconformities

7.1.1 Investigation of and improvement measures after earlier incident

Nonconformity
The incident involving a circuit-breaker failure in 2003 was not adequately investigated to prevent repetition. Nor were changes made to the maintenance programme.

Grounds
During the investigation, it emerged that a similar circuit-breaker failure had occurred on SFA in 2003. The relevant circuit breaker supplied loading pump A. On that occasion, the continued operation of the pump was observed and stopped before the incident developed into a fire. Statoil has been unable to document that the failure was reported to the manufacturer (Siemens), or that investigations were carried out to identify why the circuit breaker failed.

No maintenance programme was established which included a check for an emerging failure in shafts similar to the one which fractured in 2003.

Statoil has explained that the failure was considered a one-off incident on that occasion.

Following the incident on 16 October 2016, ultrasonic and penetrant inspections have been conducted on shafts for the other circuit breakers in switchboard 1. This identified early crack formation in another three breakers.

Requirements
Section 20, paragraph 1 of the management regulations on registration, review and investigation of hazard and accident situations
Section 19, letter e of the management regulations on collection, processing and use of data
Section 45 of the activities regulations on maintenance
Section 47 of the activities regulations on maintenance programme

7.1.2 Maintenance of shut-off valves

Nonconformity
Deficiencies in the maintenance programme for shut-off valves against the storage cells.

Grounds
The maintenance programme for shut-off valves against the storage cells on SFA does not include leak testing. These valves can play a crucial role in the event of leaks in the utility shaft. This was also a finding from the condition monitoring of technical safety (TTS) review in 2016. These valves were known to have internal leaks.

Requirements
Section 45 of the activities regulations on maintenance
Section 47 of the activities regulations on maintenance programme
Section 5 of the management regulations on barriers

7.1.3 Blocking of safety systems

Nonconformity
Automatic actions in the event of confirmed flame detection were blocked[3] from the CCR.

Grounds
It emerged from conversations that a practice of blocking automatic actions had developed. This meant that:

- in the event of an alarm from one flame detector, the CCR blocked actions (deluge and ESD2) which would be activated automatically with confirmed flame detection (two of N detectors giving an alarm)
- At the same time, a watch was to be mounted on the fire and gas (F&G) panel in the CCR to remove the block if alarms were received from other flame detectors.

When the first flame detector (US7-FD-002) alarm on the loading pump deck was received during the incident, automatic actions were blocked. When the second detector (US7-FD-005) was received, the block on US7-FD-002 was maintained while a block was also placed on US7-FD-005.

Requirements
Section 77 of the activities regulations on handling hazard and accident situations
Section 26 of the activities regulations on safety systems

7.2 Improvement points

7.2.1 Alarm texts

Improvement point
Alarm texts provided inaccurate information of where the hazard had arisen.

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[3] A manual operation carried out by CCR operators which overrides incoming or outgoing signals in the system.

Grounds
The alarm list from the PCDA shows that alarms were received on high crude-oil temperature in loading pump C. The relevant temperature transmitter belonged to pump D. The alarm text in question therefore gave erroneous information about where the hazard had arisen.

Requirement
Section 34a of the facilities regulations on control and monitoring system

7.2.2 Conflict of roles in the emergency response organisation

Improvement point
Conflict of roles in that the authorised person electrical has a role as a first-aider in the emergency preparedness organisation.

Grounds
The authorised person electrical has a role as a first-aider in the emergency response organisation. In the event of responses involving the power system on board, this could have negative consequences for an effective and acceptable handling of the incident. Should personal injuries have been suffered, the authorised person electrical would not be available to the response organisation for actions involving the power system.

Requirements
Section 75 of the activities regulations on emergency preparedness organisation
Section 77, letter b of the activities regulations on handling hazard and accident situations

7.2.3 Expertise and training

Improvement point
CCR operators carried out operations which they lacked the necessary expertise and training for, given that the facility was in an abnormal operating condition.

Grounds
After the authorised person electrical had opened the busbar breaker in the main switchboard to disconnect the power supply to loading pump D, this was reported back to the CCR. The significance of this information was not understood by the CCR operators. That meant they later switched from main generator A to main generator C without appreciating the consequences of doing this (pump D was unintentionally energised). The authorised person electrical was not in the loop when this decision was taken.

Requirements
Section 21 of the activities regulations on competence
Section 14 of the management regulations on manning and competence

7.2.4 General alarm and establishing emergency response organisation

Improvement point
General alarm triggered and emergency response organisation established too late.

Grounds
The normal reaction is to trigger a general alarm when a flame detector is activated and the CCR can observe smoke and flames on CCTV from the damage site. Triggering the necessary measures as soon as possible is crucial in the event of hazards and accidents. In this case, flame detectors were activated and smoke/flames could be observed on CCTV.

Requirements
Section 77, letter b of the activities regulations on handling hazard and accident situations

8 Barriers

The table below is based on Statoil's definition of barriers. It presents the investigation team's assessment of how the various relevant barriers functioned during the incident on 16 October 2016 in terms of technical, organisational and operational barrier elements.

Table 2 – Identified barriers related to technological, organisational and operational factors.

Barriers	Technological elements	Organisational elements	Operational elements
PS 1 – Containment	Loading pump D was subject to vibrations and temperatures which exceeded its design spec, which led to leaks.		
PS 2 – Natural ventilation and HVAC	Ventilation in the utility shaft was maintained during the incident to remove smoke.		
PS 3 – Gas detection	Line gas detector on the loading pump deck gave a number of alarms of dirty mirror/interrupted beam (first time 08.21), probably because of smoke in the area.		
PS 4 – Emergency shutdown (ESD)		CCR operators/PLS.	ESD2 was activated manually around 08.30 – in other words, earlier than automatic activation as a result of confirmed flame detection would have occurred.
PS 5 – Open drain	System lacked the capacity to handle the quantity of liquid from the deluge, and water ran down to the minicell at the lowest level.		Emergency drain pump started to drain water from minicell.
PS 7 – Fire detection	The fire was automatically detected by two flame detectors on the loading pump deck.		Automatic actions with confirmed flame detection were blocked in the CCR when the first alarm was received. This block was not removed with the second flame detector was received.
PS 9 – Active fire protection	Deluge helped to extinguish the fire and cool flammable media (crude oil) to below the spontaneous ignition level, and to cool		Deluge was activated manually from the SCR about 24 minutes after the first flame detector gave an alarm, and roughly six minutes after deluge would

Barriers	Technological elements	Organisational elements	Operational elements
	surrounding equipment to counter further leaks.		have been automatically activated following confirmed flame detection (if this was not blocked).
PS 10 – Passive fire protection	An H-60 divider is placed at level 80. No smoke was observed above this.		
PS 11 – Emergency power and lightning	Emergency power activated automatically when main power was shut down.		
PS 12 – Process safety	Stop signals to loading pump D had no effect because of the fractured shaft in the circuit breaker.		
PS 13 – Alarm and communication system for use in emergency situations		CCR operators.	The CCR did not include the authorised person electrical in its communication when the decision was taken to switch from generator A to generator C.
PS 14 – Escape, evacuation and rescue (EER)		Emergency response personnel.	General alarm was triggered at 08.23. This was a few minutes late in relation to flame detection at 08.17 and observed flame/smoke on CCTV. People without emergency response or key functions during the incident were evacuated to neighbouring facilities. A total of 20 people in three helicopter lifts. Authorised person electrical has a role as a first-aider in the emergency response organisation. In the event of emergencies involving electrical facilities on board, this could have negative consequences for effective and acceptable handling of the incident (irreconcilable duties in the event of personal injuries).
PS 22 – Human-machine interface & alarm management	Visual indication showed that pump D was not in operation, operators would have needed to navigate to the pump to see the revolution counter. An error in the high-temperature alarm text meant that the alarm appeared to come from pump C when it was from pump D .	CCR operators.	It took a long time before pump D was found to be still in operation after the stop signal had been given. Alarms were overlooked.

9 Discussion of uncertainties

The actual course of events as set out in the timeline has been established through interviews/ conversations and log reviews. Logs used are from the fire and gas system, the PCDA and the PI, and the emergency response log during the actual incident. Since these are not synchronised, some uncertainty exists about the times specified when comparing information from the various systems. The uncertainty is estimated to lie within +/- two minutes.

The course of events is considered to be established with certainty, based on the concurrence between information obtained through interviews/conversations and log reviews.

No uncertainty exists in the finding of the material technology study concerning the direct cause of the shaft fracture in the circuit breaker.

10 Review of Statoil's investigation report

The incident has been investigated by Statoil's corporate audit unit (COA INV), and its investigation report was submitted to the PSA on 19 December 2016.

The report's description of the causes and the course of events largely coincide with the PSA investigation team's own data and assessments.

Recommendations and measures related to technical, operational and organisational conditions are defined and explained.

As part of Statoil's investigation, its material technology department at Rotvoll has examined the fractured shaft and analysed the material in the isolation box on the seal oil system.

The PSA investigation team has taken note of the assessments of actual and potential consequences and the material technology study and analysis.

11 Document list

The following documents have been used in the investigation.

- Statoil's investigation report from the incident: *Brann i lastepumpe i utstyrsskaft på Statfjord A*, Report no A 2016-15 UPN L2, dated 16 December 2016
- *Materialteknisk undersøkelse av brukket stag fra brytervogn, SFA*, Report no MAT-2016126, material technology department (Statoil), Trondheim (FT MMT MI), dated 3 November 2016
- Received form for reporting the incident, dated 16 October 2016
- Statoil HSE report: *Brudd i aksling – høyspennings effektbryter – varmgang i pumpe*, published 21 November 2016, Synergi no 1488309
- Single line diagram for 13.8kV switchboard No 1, EEMO 1350-00-31-00-405, rev E3, dated June 2016
- Print-out of alarm list from fire and gas system (F&G)
- Print-out from PCDA
- Plot of trends from PI ProcessBook
- Print-out of displays from CCR
- Images of switchboards in the emergency response room on SFA after the incident

- Fire protection data sheet, US7, Crude loading pump deck (68.7m), document no AP-DS-FX-0005, rev B3, dated 31 January 2014
- Appendix B *Sikkerhetsstrategi – Statfjord A, Tekniske og faglige krav*, TR1055, final version 1, dated 4 December 2014
- Addendum to performance standards for safety systems and barriers – Statfjord A, TR1055, final version 1, dated 4 December 2014
- Maintenance programme for valve HV3040
- Fault history from maintenance system (SAP) for valve HV3040
- Engineering flow diagram. Crude storage & transfer system, AP-000-ZE-035.001, rev D8, dated 18 July 2014
- Engineering flow diagram. Crude storage & transfer system, AP-000-ZE-035.002, Rev B15, dated 26 February 2015
- Engineering flow diagram. Crude storage & transfer system, AP-000-ZE-035.003, Rev B6, dated 14 July 2014
- Engineering flow diagram. Crude storage & transfer system, AP-000-ZE-035.004, Rev B9, dated 26 February 2015
- Engineering flow diagram. Crude storage & transfer system, AP-000-ZE-035.005, Rev C4, dated 14 February 2013
- Engineering flow diagram. Cooling medium distribution main headers, AP-000-ZU-041.001, Rev A5, dated 01 September 2004
- "Result of ultrasonic investigation of circuit breaker shafts SFA for circuit breakers of the same type as the one which failed on 16 October 2016", e-mail from Statoil received 30 October 2016
- "Account of recommendations from material technology investigation", e-mail from Statoil received 10 November 2016
- "Description of changes to the PCDA which ensure that the control room can verify that the loading pump has physically come to a stop", e-mail from Statoil received 15 November 2016
- *Service report Statfjord A after urgent callout on 19-21 October 2016 to inspect and check oil-filled circuit breakers following the incident with heat buildup/fire in a loading pump*. Siemens report 856298431-03, dated 23 October 2016.
- *System PE – Lastesystem for råolje – Systembeskrivelse*, SO00216, Version 9, dated 9 September 2016
- *System PE – Lastesystem for råolje – Operasjonsprosedyre*, SO00122-Opr, Version 1, dated 9 September 2016
- *Lagring av råolje og ballastvann – PB, UJ*, SO0198, final version 3, dated 22 November 2007
- Siemens operation instructions, *T-bryter 3 AC med manuell betjening HN, HK motorbetjening EK, EU*, dated June 1978 (Corresponds to SW 8335-220)
- Siemens operating instructions *T Circuit-breaker H515 T Circuit-breakers 3AB with motor-operated mechanism EU*
- Statoil preventive maintenance programme: *48M elektro: crude/lube oil pump D, Crude loading pump 3001D*
- Synergi long case report 211207. *M16. Feil på bryter i tavle 1 til lastepumpe A*, dated 1.3.2003
- Memo to operations supervisor SFA dated 5 March 2003, "Vedr. feil på 13,8kV bryter til lastepumpe FP3001A"
- Report of undesirable incident dated 1 March 2003 concerning "Feil på bryter i tavle 1 til lastepumpe A"

- M2 notification 40243133, "Feilsøking bryter til lastepumpe FP3001A", dated 2.3.2003
- Extract from documentation from United Centrifugal Pumps concerning loading pump system, start-up procedure and motor instrumentation for motor: "Make Smit Slikkerveer, 2425 kW – 1751 rpm, 13,8kV 3 Ph, 60Hz, type: DMK 110/65, Ser. No: 1-2605-1/B 1-4", dated 24 April 1975
- Piping drawing for flushing, bleed-off, vent and drain for loading pump, dated 3 January 1975, type of pump 16x26 BFD – 2 stage, serial no 43PC14116-1,2,3,4.
- Response to question asked in meeting with the PSA on 23 November 2016 in connection with the investigation of the incident on SFA on 16 October 2016, dated 21 December 2016
- Main AC Power System Single Line Diagram, AP_ESML-001.001, rev B3, dated July 2008
- Fire and gas area plan US7, AP-US7-BL-001.001, rev B4, dated 6 May 2014
- Instrument layout, US7 instruments, AP-US7-KL-001.001, rev B1, dated 10 December 2007
- Instructions for authorised person electrical – offshore, from Statoil requirement R-13162

12 Abbreviations

ART:	Alarm reaction team
CCR:	Central control room
CCTV:	Closed-circuit television
ESD:	Emergency shutdown system
ESD2:	ESD level 2
GFC:	Gullfaks C
H:	High
HC:	Hydrocarbon
HH:	High-high
HTO:	Human, technological, organisational
LT:	Level transmitter
PCDA:	Process control and data acquisition
PLS:	Platform manager
PS:	Performance standard
PSA:	Petroleum Safety Authority Norway
PSD:	Process safety system
PT:	Pressure transmitter
SAR:	Search and rescue
SFA:	Statfjord A
SNB:	Snorre B
TE:	Temperature element
TT:	Temperature transmitter
TTS:	Condition monitoring of technical safety
WHRU:	Waste heat recovery unit

13 Appendices

A: Overview of participants in the investigation

B: Material technology investigation of fractured shaft in circuit breaker, SFA