PETROLEUMSTILSYNET

Investigation report

Report	
Report title Report of the investigation into the fire of 24 March 2015 in a HVAC unit on *Petrojarl Knarr*	Activity number 411003011

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

Summary

A fire broke out during the early morning of 24 March 2015 in the HVAC system on the *Petrojarl Knarr* floating production, storage and offloading unit on the Knarr field. The unit concerned supplied air to the engine room beneath the living quarters. This event had been preceded by a power cut which shut down the fans in the HVAC unit. However, steam continued to be supplied to its heat exchanger. That caused high temperatures to develop in the unit, and air filter cassettes ignited eight hours later. Technical investigations by the vessel's owner have been unable to identify the direct cause of the filter ignition with any certainty. Had the fire damper valves failed to operate, smoke could have spread into the living quarters. The incident led only to material damage. External emergency response resources and response teams on board were mobilised. Personnel with no role in the response organisation mustered in the lifeboats.

Involved	
Main group T-F	Approved by/date
Members of the investigation team Anthoni Larsen, Eivind Sande, Svein Harald Glette og Jan Erik Jensen	Investigation leader Jan Erik Jensen

(Source: teekay.com)

Contents

1 Summary

Petrojarl Knarr (PJK) is a floating production, storage and offloading (FPSO) facility on the Knarr field. Teekay Petrojarl Production AS (TKPJ) is its owner and responsible for operating. BG Norge Limited (BG) is the operator of the Knarr field.

At 01.32 on 24 March 2015, an alarm was received in the central control room (CCR) that smoke had been detected in the forward engine room on PJK's deck four. Plant operators were asked by the CCR to verify the alarm in this room. At 01.40, they reported to the CCR that a fire had broken out in the HVAC unit in the relevant area. This supplied air to the engine room beneath the living quarters.

Once the fire had been confirmed, a general alarm was sounded and mustering began. Fire-fighting was initiated by personnel who had observed the fire and the emergency response team took over extinguishing work after smoke-diving equipment became necessary. All personnel not in the emergency response organisation were mustered in the lifeboats. The fire was extinguished after about 30 minutes. External emergency response resources were assembled on and near PJK and preparations were made to reduce or evacuate personnel. The emergency was terminated about four hours after the fire was discovered.

The Petroleum Safety Authority Norway (PSA) arrived on the PJK on the same day that the incident occurred, interviewed personnel involved in the incident and inspected the site.

Damage caused by the fire was only material. One member of the response team was sent for examination on board because of stress caused by the extinguishing work. The incident otherwise caused no personal injury. Smoke was smelt in the living quarters.

A power failure occurred on PJK the afternoon before the fire. This shut down the fans in the HVAC unit. However, steam continued to be supplied to its heat exchanger. That caused high temperatures to develop in the unit, and air filter cassettes ignited eight hours later.

The fact that the supply of heat in the form of steam does not shut down when the fans halt is regarded as a design weakness with the HVAC unit.

TKPJ has commissioned fire tests and technical investigations to identify the direct cause of the ignition. These have failed to provide an unequivocal cause for ignition of the filters.

Had the response team failed to extinguish the flames, the fire could have caused greater material damage in the engine room where the HVAC unit was located. Nevertheless, it is considered unlikely that the blaze would have spread to other parts of the FPSO. Some smoke from the fire entered the living quarters, and its smell was recorded there. Had the density of smoke increased, damper valves in the HVAC system for the living quarters would have prevented further diffusion into this area.

Nonconformities and improvement points in relation to regulatory requirements were identified during the investigation of the incident. These are described in chapter 7 of this report. They include nonconformities concerning requirements for start-up and operation of the HVAC unit in addition to technical conditions. Nonconformities and improvement points were also identified with regard to emergency preparedness, including deficiencies related to analyses and to training of the emergency response team.

2 Introduction

PJK is an FPSO on the Knarr field. It received an acknowledgement of compliance (AoC) from the PSA on 31 October 2014. BG Norge Limited (BG) is operator for Knarr.

The field came on stream on 16 March 2015. A fire broke out during the early morning of 24 March 2015 in the HVAC unit on deck 4 beneath the living quarters on PJK. The unit where the fire occurred serves the forward engine room.

The PSA decided on 24 March 2015 to conduct an investigation of the incident.

Composition of the investigation team:

- Jan Erik Jensen F-logistics and emergency preparedness, investigation leader
- Svein Harald Glette F-process integrity
- Eivind Sande F-process integrity
- Anthoni Larsen F-logistics and emergency preparedness

The investigation team travelled out to PJK and worked there from 24-26 March 2015. Interviews were conducted with the emergency response command, the response team, and other relevant personnel on board. The site was inspected and documents reviewed. Technical investigation of equipment related to possible ignition was coordinated by the vessel owner's investigation team. The PSA team received a report from this work on 19 June 2015, and the investigation report from the vessel owner and operator on 6 August 2015.

The mandate for the team was established in accordance with section 4.1.2 of the PSA's investigation procedure:

a. *Clarify the incident's scope and course of events (normally with the aid of a human, technology and organisation – HTO – diagram), with an emphasis on safety, working environment and emergency preparedness aspects.*
b. *Assess the actual and potential consequences*
    1. *Harm caused to people, material assets and the environment.*
    2. *The potential of the incident to harm people, material assets and the environment.*
c. *Assess direct and underlying causes, with an emphasis on HTO 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. *Assess the player's own investigation report. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.*
g. *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).*
h. *Recommend – and normally contribute to – further follow-up*

The investigation has not given any emphasis to checking conditions related to fabrication, installation and system-testing of the unit during the construction and start-up period.

3 Description of the HVAC plant on PJK

Several HVAC systems have been installed on PJK. These include dedicated systems for the living quarters and the aft engine room. The unit involved in the incident on 24 March 2015 is located on deck 4 beneath the living quarters and supplies several rooms within the hull in this area. It is described as the HVAC unit for the forward engine room. A system drawing of the unit can be found in appendix E.

The air intake for the unit is located on the forecastle (C deck), where the air intakes for the living-quarters HVAC system are also positioned. The actual HVAC unit was delivered by Hi Air in Korea and stands on deck 4 down in the hull with its own local control panel on deck 2.

Figure 1 *Camfil Opakfil filter (source: www.camfil.com)*

The HVAC unit which ignited consisted originally of a Camfil Ecopleat pre-filter and a Camfil Opakfil main filter. During docking in Haugesund before installation on the field, the pre-filter was replaced with a C-Cell Minipleat filter. After the filters come units for heating and cooling the air. Heating utilises a steam system. The HVAC unit has a separate housing with motor and fan before the air is distributed via automatic damper valves to the various rooms supplied by the unit. Sensors in the air stream in and out of the HVAC unit regulate the temperature with the aid of valves controlling the supply of steam and cooling medium.

The unit is normally operated in automated mode, and the steam valve (see figure 2 below) regulates the temperature automatically on the basis of a desired set point. The manual mode is used for maintenance work, such as replacing fan belts in the system. In manual mode, the steam valve’s position is determined via the local human-machine interface (HMI) control panel on deck 2.

Figure 2 *TAC-type steam valve, model number VGS211F-25-10, with Schneider M800 actuator (source: TKPJ).*

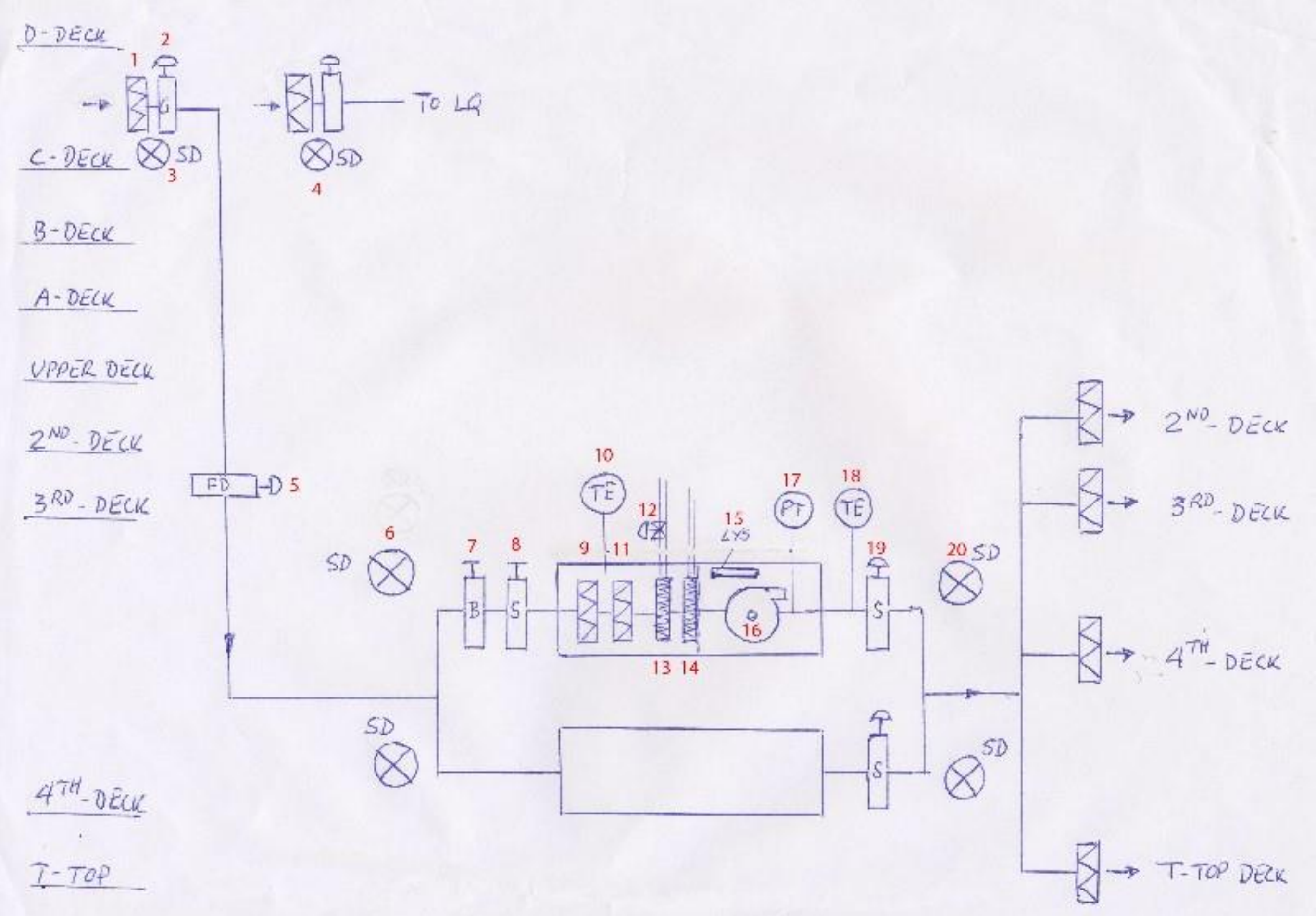

__Figure 3__ Outline of the HVAC system for the forward engine room.

Key to figure 3:

1. Coarse filter on the air intake (not installed when the incident occurred)
2. Gas-tight damper valve
3. Smoke detectors, two, on the HVAC intake to the forward engine room
4. Smoke detectors, two, on the HVAC intake to the living quarters
5. Fire damper valve
6. Smoke detectors in the room on the outside of the HVAC unit
7. Manual damper valve (balancing)
8. Manual damper valve (shut-off)
9. Pre-filter (originally Camfil Ecopleat with steel frame, replaced in Haugesund with C-Cell Minipleat with cardboard frame)
10. Temperature sensors for air entering the HVAC unit
11. Filter (Camfil Opakfil)
12. Valve for regulating steam supply to heating coil
13. Heating coil
14. Cooling coil
15. Light fixture in fan housing
16. Fan
17. Air pressure sensor downstream from fan
18. Temperature sensor for air leaving the HVAC unit
19. Damper valve on outlet from the HVAC unit (shut-off)
20. Smoke detectors in the room outside the HVAC unit

4 Course of events

This chapter describes the course of events from the fan stoppage in the HVAC unit for the forward engine room by a power failure at about 17.45 on 23 March 2015 until the fire was confirmed to be extinguished and the emergency declared over at 05.20 on 24 March 2015. PJK was in a start-up phase, and had experienced repeated operational disruptions ahead of the incident. A detailed listing of the course of events in chronological order is provided in appendix A.

4.1 Events ahead of the fire

Operations personnel on PJK had struggled for a time with repeated power failures as a result of problems with operating the gas turbines which deliver electricity to the vessel. A lot of equipment on board must be restarted following this type of failure. The HVAC unit supplying the forward engine room was run in a mode which meant that the fans had to be restarted manually following a power cut. This was not done after the failure which occurred around 17.45 on 23 March 2015.

Although the fans had not been restarted, steam from the steam heating system continued to be circulated through the heating coil in the HVAC unit where the fire occurred. The steam has a temperature of about 100°C. Lack of air throughflow as a result of the fan shutdown and heating as a result of the steam supply meant the whole HVAC unit was heated up. The CCR received a smoke detection notification and alarm at 01.32 on 24 March 2015.

A change of shift occurred at 19.00. This took place while start-up activities were under way following the power failure at 17.45.

4.2 Detection, mustering and fire-fighting

A smoke detection alarm was received at 01.32 by the CCR from the forward engine room on deck 4. Plant operators were asked by the CCR to verify the alarm in this room.

It took the plant operators some time to search the engine room. They eventually discovered smoke from the HVAC unit in the room, and immediately began to unroll fire hoses from the two nearby fire hydrants and prepared to extinguish the fire. While readying the hoses, they observed that these provided only limited amounts of water. The jet from one hose was directed at a bellows beside the air filters on the HVAC unit. The bellows fractured when hit by the water, air was admitted and the flames are described as shooting “ceiling-high” immediately after the bellows broke. Notification of the fire was given to the CCR at 01.40.

The quantity of smoke rapidly became so great that the plant operators could no longer remain in the engine room. They withdrew after leaving one of the fire hoses with the water on inside the HVAC unit.

A general alarm (GA) was activated by the CCR operator at 01.40 in response to the report of fire in the forward engine room. The emergency response command mustered in the response centre on board. The fire teams mustered at the fire stations. All personnel with no emergency response functions mustered at the lifeboats. Production was shut down. External emergency response resources were mobilised.

Figure 4 *- Burnt-out filter cassettes in AHU-A. (Source: PSA investigation)*

The response teams were ready at 01.51 to enter and continue the extinguishing work initiated by the plant operators. Fire water from stations in adjacent rooms was used. The site had large volumes of smoke and poor visibility as well as being very hot. Additional breathing gas had to fetched for the smoke divers.

The fire was reported to be extinguished at 02.10, and cooling of the site continued.

4.3 Normalisation

The emergency was terminated at 05.20. Personnel left the lifeboats and returned to their cabins or jobs. Work was initiated to air out and clean the vessel.

5 Direct and underlying causes of the incident

5.1 Direct cause

Filter cassettes were ignited in air handling unit A (AHU-A) for the forward (FWD) engine room as a result of design errors and faulty operation of the system.

Figure 5 *- Deformed cassettes in AHU-B, which is immediately adjacent to AHU-A (Source: PSA investigation).*

5.2 Underlying causes:

- Knowledge about and familiarity with the consequences of operating the system in various operational modes were insufficient, and a lack of clarity prevailed about roles and responsibilities for operating the system. It was run in manual mode, where temperature control and "fail close" of the steam valve are turned off.

- The system description and restrictions for running the system in manual mode were not clearly explained in the system documentation.
- The fan system was not restarted after the power failure the day before. Bringing fan systems back on line formed part of the “black start” procedure, but the latter was not followed.
- A design error meant that the valve for the steam heating system did not automatically close when the fans stopped. Steam temperature in the HVAC unit was about 100°C.
- The filter cassettes used had a maximum design temperature of about 70°C. They collapsed as a result of lengthy exposure to a temperature of roughly 100°C.
- Alarms in the CCR from the HVAC unit were not perceived as critical after the power failure the day before. They were given the lowest priority on the screen.

5.3 Reasons for the ignition

Fire tests conducted by SP Fire Research (ref 18) have failed to identify clear ignition causes. A probable cause is self-ignition of the filter units, which were exposed to great heat for many hours. Traditional fire tests show critical ignition temperatures of more than 400°C for the materials used in the filter units. This is well over the estimated maximum temperature of 120°C.

The HVAC unit where the fire occurred was fitted with Camfil Opakfil air filters. A long-term heat test was conducted with this product. The filters were placed in a heat cabinet with the temperature gradually increased from 120°C, and ignited after 10 hours at a temperature of 180°C. The door to the cabinet was open for one minute before ignition occurred.

A number of investigations have been conducted with the light fitting in the fan room. This displayed damage after the fire which suggested that it might have been an ignition source. The background for this was that the fitting in the HVAC unit was certified for a maximum of 50°C and was, like the filter cassettes, exposed to high temperatures over a long time. The light was on during the incident and the fuse on the lighting circuit was afterwards found to have blown.

These investigations revealed that the fitting bore no signs of fire damage, short-circuiting or electric arcing which might have started the fire. Melting of the cover and damage to contacts can be explained by external heat from the fire. After the incident, soot formation was observed on one fluorescent tube and the component track in the fitting. A probable cause of this is smoke from plastic labels in the fitting which have melted from the heat.

__Figure 6__ - Picture of light fitting in the fan housing in AHU-A (Source: PSA investigation)

The investigation team has not found it appropriate to conduct further investigations or fire tests in order to determine an unequivocal ignition cause. In its view, design error and faulty operation of the system caused the fire.

6 Potential of the incident

Actual consequences

The incident led to full mustering on board and mobilisation of external response resources. The AHU-A filter unit was burnt out. Similarly, the fire caused overheating in AHU-B, but material damage there was limited. HVAC ducts affected by the incident were coated with soot and required extensive cleaning. Equipment and ducts exposed to a high heat load (AHU-B) were returned to service relatively quickly after an overhaul.

No personal injuries were caused by the incident in itself. However, it was reported that a member of the response team was taken off duty and sent for examination on board because of the stress caused by the extinguishing work.

Production was shut down because of the incident, which accordingly caused a loss of revenue for the company. The vessel came back on stream within a few days. The steam heating system for the HVAC units on board were shut down after the incident. Plans call for them to be restarted after modifications have been carried out in the fourth quarter of 2015.

Potential consequences
The response of the fire-fighting personnel limited the material damage. Without their efforts, this would probably have been greater for both AHU-A and AHU-B. The limited quantities of flammable materials in these units mean the fire is unlikely to have spread to other equipment in the area.

Had the automatic fire damper valves failed to function during the incident, smoke could have spread into the living quarters. It could also have disseminated via other rooms.

A similar incident in the AHU serving the living quarters is regarded as unlikely. This is because a system shutdown like this over a number of hours would probably be detected by the alarm system on the vessel or by personnel in the living quarters.

7 Observations

The PSA’s observations fall generally into two categories.

- Nonconformities: observations where the PSA believes that regulations have been breached.
- Improvement points: observations where deficiencies are found, but insufficient information is available to establish a breach of the regulations.

7.1 Nonconformities

7.1.1 Use of and knowledge about the start-up procedure for the HVAC unit after a power cut

Nonconformity
Lack of knowledge about the start-up procedure and the various operating modes for the HVAC system in operation.

Grounds

- The description of the system and the various operating modes was insufficiently detailed in the necessary operating documents. *HVAC control philosophy for FWD*, ref (15), was little known among operations personnel
- The system was run in manual mode, where temperature control and “fail close” of the steam value are turned off. On-board knowledge about and familiarity with the consequences of operating the system in various operational modes were insufficient. It was explained during conversations on board that manual mode was used since temperature regulation did not function in automatic mode.
- No overview of which systems were to be manually restarted after a power failure could be produced. According to TKPJ, the black start procedure should show this information.

Requirement
Section 24, paragraph 2, of the activities regulations on procedures.

7.1.2 Inadequate testing of the system

Nonconformity
Inadequate testing of the system before start-up.

Grounds
The yard which built the FPSO (Samsung) was responsible for commissioning the system before start-up. A verification of the commissioning documentation, ref (13), shows that the steam valve and associated temperature control functions were not tested.

Requirement
Section 16, paragraph 2, of the activities regulations on installation and commissioning.

7.1.3 Responsibility for operation of the HVAC system

Nonconformity
Unclear division of responsibility for day-to-day operation and follow-up of the system.

Grounds
- It emerged from conversations on board that clear roles and responsibilities for day-to-day operation of the system had not been established.
- TKPJ had not appointed a technical authority on land for HVAC units, as it had for other important systems on board.

Requirement
Section 6, paragraph 2, of the management regulations on health, safety and the environment.

7.1.4 Design and documentation of the system

Nonconformity
Deficiencies in the design of and documentation for the system.

Grounds
- Necessary safeguards had not been incorporated to ensure that the steam valve shut down in the event of the fans stopping and/or loss of air circulation.
- No temperature alarms were installed on the system to inform the CCR operator of the abnormal conditions.
- Belts were used to drive the fans in the system. Norsok standard H-003 recommends direct operation of fans unless belt drive is technically advantageous.
- The coarse filter on the intake to the HVAC unit had been removed without a reason for this being given in the drawings or in other documentation.
- The ducting and instrumentation drawing (D&ID) for the system did not accord fully with the “as built” condition.

Requirement
Section 14, paragraph 1, of the facilities regulations on HVAC and indoor climate.

7.1.5 Maintenance documentation

Nonconformity
Deficiencies in the maintenance documentation for the system.

Grounds
- The maintenance history for the system was inadequate. It was explained that inspections were conducted and local instrument readings taken, but that these were not always documented in the Star maintenance system.
- A job routine for inspecting and replacing fan belts in the system was not entered in Star, even though the maintenance history showed that fan belts in systems had already been replaced as a corrective job.

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

7.1.6 Emergency preparedness assessment

Nonconformity
Deficiencies existed in the emergency preparedness assessment.

Grounds
It emerged from the documentation review and interviews that the emergency preparedness assessment for PJK includes a defined situation of hazards and accidents (DSHA) for fire in utility systems. This assessment does not describe the hazard posed by a fire in the HVAC systems for the living quarters and equipment/engine rooms. The hazard is not adequately covered even though both fire points in the living quarters are located in areas covered by the same HVAC system.

Requirements
Section 17 of the management regulations on risk analyses and emergency preparedness assessments, see section 7 of the facilities regulations on main safety functions.

7.1.7 Design of fire hydrants and hose points

Nonconformity
Fire hydrants and hose points in the forward engine room lacked sufficient capacity and were not equipped for effectively fighting the outbreak of a fire and preventing its spread.

Grounds
- Two hydrants used in the first phase of fighting the fire failed to provide an adequate supply of water. Testing after the incident (27 March 2015) showed a capacity of 4.8 m^3/h for one hose point and 8.4 m^3/h for the three others in the area. The capacity requirement in Norsok S-001, the standard recommended in the regulations, is a minimum of 20 m^3/h for hydrants and 15 m^3/h for hose points outside the living quarters.
- It was difficult to extract the cotter pins in order to swing out the hose reel, and spray nozzles with pistol grip were not used.

Requirements
Section 46 of the facilities regulations on manual fire-fighting and firefighters' equipment, see chapter 20.4.8 of Norsok S-001.

7.1.8 Testing hose points

Nonconformity
Deficiencies in maintenance routines for testing hose points.

Grounds
- Documentation could not be produced to show that the fire hoses were capacity tested in connection with starting up the FPSO.
- Test routines in the maintenance system did not specify capacity requirements for hydrants and fire hoses.
- Hose-point testing conducted after the incident which showed a flow of 8.4 m^3/h was approved by TKPJ, even though the capacity requirement is significantly higher.

Requirement
Section 47 of the activities regulations on maintenance programme.

7.1.9 Systematics related to the conduct of training for emergency response teams

Nonconformity
No system was in place to ensure adequate training of emergency response teams.

Grounds
It was observed through interviews and the document review that the system for training emergency response teams does not provide a check of completed training. The following observations were made.

- No overview of who was expected to attend training sessions which ensured at least one session per role per response team during a tour.
- The system did not ensure that team members who miss a training session compensate for this. Nor did criteria exist for when compensatory training should take place.
- No system to ensure that all team members hold the correct certificates and are sent on a course before their certificates expire.
- No distinction in the system between training and drills.
- No goals or requirements set for training sessions related, for example, to a curriculum.
- No requirements for training and education in substitute roles.
- Inadequate knowledge of performance requirements among team personnel and the emergency response command.
- No system to handle nonconformities from the implemented training plan.
- No system for registering follow-up measures and lessons learnt from training sessions, and for transferring these measures and lessons between shifts.

Requirements
Section 6 of the management regulations on management of health, safety and the environment.
Section 23 of the activities regulations on training and drills.

7.2 Improvement points

7.2.1 Monitoring of the HVAC unit

Improvement point
Inadequate monitoring of the HVAC unit for the forward engine room.

Grounds
- All alarms from the system had the lowest priority. Work was initiated to assess the alarm philosophy in order to establish better control of important alarm functions. Information was provided that some alarms should probably be classified as safety-critical.
- No alarms were installed to warn of high temperature in the HVAC unit.

Requirements
Section 8, paragraph 1, of the facilities regulations on safety functions.
Section 31, paragraphs 1 and 3, of the activities regulations on monitoring and control.

7.2.2 Risk assessments for modifications

Improvement point
Lack of documentation and risk assessments concerning the removal of the coarse filter on the air intake of the HVAC unit.

Grounds
The coarse filter on the intake for the HVAC unit was removed without a reason for this or an assessment of its potential negative consequences being provided on the drawing or in other documentation.

Requirement
Section 11 of the management regulations on the basis for making decisions and decision criteria.

7.2.3 Use of procedures

Improvement point
The procedure for the alarm reaction team (ARL) was not followed or possibly adapted for this type of DSHA (fire in utility systems).

Grounds
Instructions for ARLs (ref 17) in the event of an unconfirmed alarm say that the ARL, after confirming the alarm, should transfer to its emergency response duties. In this case, fire-fighting was initiated before the ARL left the room to take on roles in the emergency response team. The procedure does not make provision for this. The relevant conditions in this incident are not untypical of circumstances which ARL members could face.

Requirement
Section 24 of the activities regulations on the use of procedures to prevent faults and hazards and accidents.

7.2.4 Compliance with performance requirements

Improvement point
TKPJ's performance requirements for the time taken to establish personnel on board (POB) and ready the emergency response team in the event of fire were not met during the incident.

Grounds
The emergency response plan sets performance requirements for permitted times.

- Control of POB is set at 10 minutes. In this case, about 15 minutes were taken.
- Response team ready is set at five minutes after the PA announcement. In this case, it took roughly 10 minutes.

The performance requirement for establishing the on-scene command is two minutes. This could not be verified because it was not noted on the boards in the emergency response room.

Requirement
Section 77, sub-section d, of the activities regulations on handling hazards and accidents.

7.3 Other comments

The emergency response plan contains a compatibility matrix which shows which response functions cannot be combined. The investigation team has seen that the matrix was not followed in this case, in that the CCR operator also has a role in the emergency response team. No documentation in the form of a nonconformity assessment or other information were presented to explain why the recommendation in the plan had not been followed. It emerged from interviews that the CCR operator had an overview picture of the incident from the CCR. Interviewees said they felt it was unfortunate that this post was relieved by the off-duty operator, who then had to get to grips with the position in the CCR while the duty operator mustered with the response team.

Plant operators went to the location where a smoke detector had sounded an alarm in the CCR as part of the procedure for the ARL. Their response very probably reduced the material damage. Nevertheless, combating fires without fire-fighting garments poses a risk. Their response also helped to identify the incident site before the room became smoke-filled. Interviewees said that, had smoke filled the space, it would have been very difficult to identify which unit in the engine room was on fire. It was also mentioned during the interviews that, in such cases, a heat-seeking camera would have been needed to navigate through the smoke-filled room to the damage site.

Insufficient breathing gas in prefilled cylinders was available on board during the incident. The prefilled cylinders were quickly used up at one of the fire stations. Personnel were taken from the lifeboats to prefill breathing gas.

8 Barriers which have functioned

8.1 Fire detection

The fire was detected by smoke detectors at an early stage. Plant operators in the ARL were quickly on the scene to confirm the alarm.

8.2 Fire damper valves in HVAC ducts

Fire damper valves in the intake air ducts closed automatically through the action of a safety fuse, thereby preventing the spread of smoke and heat. See figure 3, item 5.

8.3 GA and mustering

A GA was activated manually before being automatically activated following confirmed smoke detection. According to the interviewees, the subsequent announced by the CCR operator over the PA system was very clear and understandable. The announcement made it clear that the position was genuine and gave no room for misunderstanding.

8.4 Fire-fighting

The response by those on the spot when the fire was first detected was important for clarifying the fire location in the room on deck 4. At that time, smoke had still not entered the actual space outside the HVAC unit. When the emergency response team arrived about 15 minutes later, the room was filled with smoke which would have made it more difficult to locate the fire. It emerged from interviews that visibility was only about 0.5m.

Extinguishing efforts by personnel sent to verify the alarm have very probably had a good effect in restricting the scope of fire damage.

9 Assessment of TKPJ's investigation report

A decision to conduct a joint TKPJ/BG investigation, with TKPJ's representative as investigation leader, was taken on the day of the incident. This investigation was conducted in accordance with TKPJ's own *Administrative Procedure AP 512.*

As part of the TKPJ investigation, external parties were also used for analysis and testing of the elements regarded as possible ignition sources. These parties were SP Fire Research and Glamox. Their tests and investigations have been unable to reach an unequivocal conclusion on the cause of ignition in the HVAC unit.

The descriptions of the course of events and of the direct and underlying causes related to technical conditions largely coincide with the PSA team's own observations and assessments. Recommendations and measures related to *certain* technical, operational and organisational conditions are defined and explained.

TKPJ's own investigation report does not contain a complete list of the measures which have been proposed after the incident. This list is recorded internally by the company in the Synergi follow-up system, but does not appear in the TKPJ investigation report.

The mandate for the BG/TKPJ investigation team does not include emergency response aspects related to the incident.

TKPJ's own investigation fails to identify any nonconformities from regulatory or internal requirements.

10 Discussion of uncertainties

It emerged during interviews that views differed on the way the HVAC unit should be operated on board. A lack of clarity also prevailed about the way the unit worked.

The power failure and subsequent start-up activities took place during a shift change on the evening before the fire. It is uncertain how far the routines involved in the shift change might have been significant for the course of events, particularly with regard to restarting the HVAC unit.

The fire tests carried out proved unable to establish the ignition cause unequivocally. Long-term tests with the Camfil Opakfil filters in a heater showed after 10 hours that ignition could be achieved at 180°C. That is higher than the estimated temperature in the HVAC unit. It is nevertheless impossible to recreate the exact conditions offshore in the laboratory's heat cabinet. Other factors could have played a part, such as pollution in the HVAC unit which might have reduced the ignition temperature of the filters.

During docking in Haugesund before production began, the pre-filters in the HVAC unit had been replaced by a different type than the one originally installed when the FPSO was built. It is uncertain how far the change of pre-filter has been significant for the course of events. Tests conducted by SP Fire Research show that the ignition temperature for both the old (Camfil Ecopleat) and the new (C-Cell Minipleat) pre-filters was more than 443°C. No long-term testing of the kind conducted with the main (Camfil Opakfil) filter was carried out with these units.

11 Appendices

A: Chronological course of events

B: Documents used in the investigation

C: Overview of participants and personnel interviewed

D: Abbreviations used in the report

E: System drawing for the AHU forward engine room