PETROLEUMSTILSYNET

Investigation report

Report	
Report title Report of the investigation into a fire in the inlet separator on Snorre B	Activity number 001057042

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

Involved	
Team T1-Equinor	Approved by/date Kjell M Auflem/15 August 2019
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Contents

1 Summary

A fire broke out on 1 May 2019 in the inlet separator on Equinor's Snorre B (SNB) facility. The Petroleum Safety Authority Norway (PSA) resolved on 2 May 2019 to investigate the incident.

The incident occurred the day before the start of a planned turnaround, with the process plant depressurised, drained and purged with inert gas. One of the turnaround activities involved replacing the inlet separator's internals. The fire started in connection with preparatory activities ahead of entering the separator. Primary cleaning of the separator had been completed and it was being vented when the incident occurred. Analyses of the separator contents after the fire revealed the presence of iron sulphide. The PSA team's view is that the fire was caused by spontaneous combustion of iron sulphide in contact with the air, which then ignited oil deposits remaining in the separator.

It emerged from the investigation that iron sulphide was not known to be present in the separator. Nor did anyone know about the problem posed by pyrophoric iron sulphide. No measures for handling this as a potential ignition source had therefore been assessed or implemented.

The actual consequence of the incident was a fire lasting for about three hours in the inlet separator on Snorre B (SNB). Subsequent analyses show that the integrity of the actual separator had not been weakened by the fire. No personal injuries were suffered in connection with the incident. The wind direction was favourable for avoiding smoke exposure.

Where potential consequences are concerned, the fire was unlikely to spread beyond the separator. The process plant had been depressurised and drained in connection with the turnaround, and no other flammable materials were in the vicinity. However, the incident could have had more serious consequences had the fire broken out when personnel were inside the separator or the wind direction was more unfavourable, so that exposure to smoke could have been greater.

No assessment had been made of the waste as a potential ignition source, with no special measures therefore implemented to prevent spontaneous combustion when handling or transporting it. However, it emerged from interviews that this material was treated as low radioactive (LRA) waste, which means it is kept moist, and therefore also indirectly prevented the iron sulphide in the waste from igniting. The team therefore considers it unlikely that handling of the waste could have resulted in a fire elsewhere on the platform.

The investigation has identified three nonconformities related to:

- risk assessment before starting the activity
- experience transfer
- procedures.

2 Background information

2.1 Description of facility and organisation

SNB became operational in 2001 and is an integrated semi-submersible production, drilling and quarters platform in the Tampen area of the North Sea. The facility is operated by Equinor and received a producing life extension in 2018 to remain on stream until 2040.

The facility produces oil from a sandstone reservoir and has an increased water cut. Seawater is injected for pressure support. Produced water was injected up to 2006. The process plant consists primarily of corrosion-resistant materials.

In connection with the forthcoming turnaround, manning totalled 121 people at the time of the incident. In addition to Equinor's own turnaround team and operations personnel, employees from several contractors were present.

Personnel from Wood and IKM Testing were on board in part to carry out activities related to cleaning and replacing the internals in the inlet separator.

SNB is part of the Tampen emergency response area, and the area standby ship is normally located centrally on Statfjord. This vessel is a primary resource in the event of acute oil spills, but also available in the event of fires, for instance, where external assistance is required.

2.2 Position before the incident

The process plant had been shut down and depressurised for about six weeks before this incident occurred because of a riser incident on 4 March 2019. However, the plant was not emptied of hydrocarbons at that time since it was uncertain whether production could resume before the planned turnaround started on 2 May. As a result of this unplanned shutdown, changes were made to the 2019 turnaround plans. That included bringing forward and launching some preparatory activities ahead of the actual turnaround.

One of the planned turnaround activities was modifications to the inlet separator's internals. Preparations to make the separator ready for entering and inspection/modification were initiated earlier than originally planned. This activity began with draining and jetting the system on 24 April 2019.

When the incident occurred, a primary clean of the separator had been carried out with steaming and vacuuming. The unit had been drained after cooling and was being vented. An air-driven ejector was placed in one manway to extract air and thereby provide good ventilation in the separator. Work had begun on physical blinding of pipes connected to the separator.

2.3 Description of activity and equipment involved

The separation facility on SNB comprises a three-stage separation plus an electrostatic coalescer. The inlet separator receives the incoming wellstream from the subsea templates and separates oil, gas and water for further processing in downstream equipment.

Gas is dehydrated and compressed before being exported via Statpipe or injected back into the reservoir. Oil is routed via two further separators and an electrostatic coalescer before being piped to Statfjord B (SFB), while the produced water is treated and routed overboard.

The inlet separator is located on the main deck in the P63 area together with the test and second-stage separators. It incorporates a jetting system for removing possible sand which may accompany the wellstream. Experience shows that the effect of the installed jetting system will be reduced between turnarounds because sand blocks some of the nozzles.

In connection with the turnaround, the inlet separator was to be opened for cleaning, inspection and replacing much of its internals, including jetting nozzles.

The figure below presents a simplified diagram of the inlet separator.

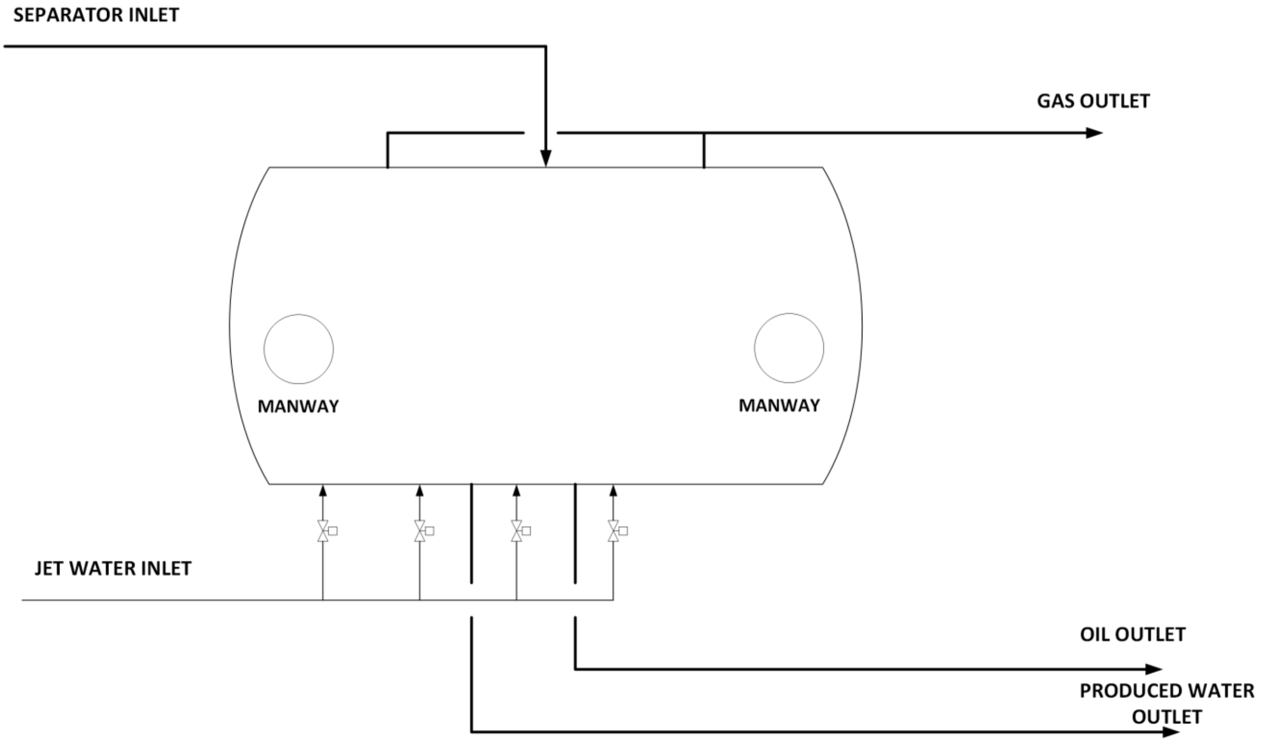

Figure 1 Simplified diagram of the inlet separator on Snorre B.

Work on the separator comprised the following main activities.

- **Preparing for entry**
  - draining hydrocarbons/jetting/gas purging
  - primary cleaning (steaming, vacuuming)
  - handling of waste during the cleaning process
  - cooling (water-filling)
  - drainage of cooling water
  - venting (opening manway cover, installing ejector)
  - blinding.

- **Entry**
  - removing residual products not eliminated during the steaming process (mechanical cleaning)
  - disassembling existing internals
  - inspection
  - installing new internals.

Primary cleaning of the separator ahead of entry was conducted with steaming and vacuuming. No chemicals were used in this context, unlike work on the separator in earlier turnarounds. The duration of the cleaning sequences has been extended to compensate for this.

Vacuuming was used during the cleaning process to remove waste from the separators. This waste was delivered to the mud skips.

The inlet and liquid outlet are centred on the separator, with gas outlets at each end. Two manways are provided. Plans called for both to be entered simultaneously. The separator is relatively tightly packed with internals.

Several work permits (WPs) were prepared ahead of actual entry for the various activities on the separator in connection with preparing for entry. The WP for blinding was active when the incident occurred.

A “draft” safe job analysis (SJA) for entry had been conducted before the incident. The final version was to be prepared ahead of the actual entry activity.

Work on preparing the entry permit had not begun.

2.4 Equinor’s governing documentation, other standards and guidelines

Risk related to the presence of iron sulphide is described in several places in Equinor’s governing documents in connection with entry activities, waste handling and opening of pig launchers/receivers.

The team has received Equinor’s work process for entry (OM105.02) as input for its investigation. This work process also includes clearance of entry permits and applies to SNB.

The specified purpose of the work process is to ensure than entry is conducted in a safe and secure manner, and that personnel are not exposed to undesirable media on entry.

When preparing an entry permit, risk assessments must be conducted in part to identify hazardous chemical substances and evacuation routes as well as the need for guards and personal protective equipment (PPE). An SJA must be carried out.

Once an approved entry permit has been issued, safety preparations must be made before entering. These preparations are conducted as specified in the entry permit.

The procedure provides examples of other possible supplementary requirements/preparations which should be assessed. This includes: "If the presence of iron sulphide is suspected, the tank/container must be cleaned with water. Iron sulphide deposits must be moistened and removed (risk of spontaneous combustion)". That also accords with section 4.2.3 concerning entry into confined spaces in Norwegian Oil and Gas guideline 088 on a common model for work permits.

Equinor’s checklist for entry in the annual edition of the manual for safe working (*Sjekklister for sikkert arbeid på offshoreanlegg*, rev 7, 15 February 2019) includes iron sulphide as a component whose presence must be assessed, with samples taken to identify it.

Chapter 3 of Norsok S-001 on terms and definitions for ignition sources describes chemical reactions with iron sulphide as an example.

2.5 Iron sulphide

2.5.1 Ignition source

Ignition sources can be categorised as either electrical or non-electrical. Chemical reactions represent one type of the latter. Exothermic reactions (chemical reactions developing heat) can provide an ignition source if they develop enough heat to either spontaneously combust or ignite other material.

Iron sulphide is a pyrophoric material which creates an exothermic reaction on contact with oxygen. This reaction generates substantial heat and incandescence of the particles. The white smoke produced is sulphur dioxide (SO_2) and can be misinterpreted as steam.

In the petroleum sector, iron sulphide can be present in both offshore and land-based plants. When the plant is shut down and equipment/tanks/pipes are opened for inspection, maintenance or modifications, iron sulphide will be exposed to oxygen and can then spontaneously combust and ignite nearby flammable material, such as hydrocarbon residues.

2.5.2 Preventing spontaneous combustion of iron sulphide

To avoid spontaneous combustion of iron sulphide when opening separators, knowledge about the presence of this material is important before work on hydrocarbon equipment takes place. If iron sulphide is present, measures must be established before opening/venting the equipment and in connection with waste handling, as described in governing documentation.

2.5.3 Formation of iron sulphide

Formation of iron sulphide requires sources of hydrogen sulphide and iron in an anaerobic atmosphere. One source of hydrogen sulphide is reduction of sulphate by sulphate-reducing bacteria (SRB). Iron can come from such sources as high salinity formation water (particularly typical of sandstone reservoirs) or from various corrosion processes in production piping or the plant. Varying concentrations of hydrogen sulphide and iron lead to the formation of different types of iron sulphide.

2.5.4 Indications that iron sulphide is present

Some indicators that iron sulphide could be present in the plant are:

- aging facility with a high water cut (tail production)
- facilities with water injection
- facilities with internal corrosion problems – equipment/piping with such corrosion combined with sour conditions/H_2S could lead to iron sulphide formation
- emulsions in the separator, which could be explained by iron sulphide accumulation
- build-up of scale.

2.6 Earlier incidents with iron sulphide

Iron sulphide has been identified as a fire hazard with exposure to oxygen on other offshore and land-based facilities where Equinor is operator or technical service provider (TSP). During the investigation, the PSA team was referred to various incidents involving heat build-up/fires.

1. **SFB** in September 2016 – heat build-up in waste from a sand trap.

2. **Norne** in September 2012 – heat build-up from chemical reactions in an accumulation of iron sulphide.
3. **SFB** in May 2012 – personnel exposed to steam from CD 2201 when opening a tank.
4. **Kalstø** in January 2012 – fire in a pig trap when door opened.

A review of documents related to these incidents revealed the following experience and measures.

2.6.1 Incident on SFB in 2016

The incident occurred while dealing with waste from a sandtrap with a reflux of scale dissolver. This waste was stored in an oil barrel. Heat build-up in the barrel was discovered during an inspection tour of the plant. Iron sulphide was the suspected source.

A review of Synergi case 1486297 after the incident shows that a presentation of *Pyrophoric iron Statfjord B* at safety meetings for everyone on board is referenced as measures 2 og 3. No information has emerged that these presentations were shared with others than SFB.

2.6.2 Incident on SFB in 2012

From a review of Synergi case 1302004 SFB, the course of events appears to resemble that on SNB on 1 May. Strong heat build-up and smoke while venting after a steaming job prompted the lab technician on board to take samples of remaining bottom deposits in the tank to analyse for iron sulphide. Seven actions were written for the case. Their main emphasis is on exposure risk and the use of PPE. The final measures in the Synergi case describes experience transfer to other units. This states that: "experience transfer is considered to be complete in connection with this case, as well as the experience summary via the turnaround team's final report". The status of the measure is "carried out".

The turnaround team's final report for SFB 2012 (*Erfaringsrapport fra Drift – Statfjord B)* mentions the problem with iron sulphide in section 5.1 when ramping down production. This states that opening to vent should wait until blinds are set and rigging for cleaning has been completed in order to avoid oxidation of iron sulphide. Nothing is said about the problem posed by iron sulphide with regard to spontaneous combustion.

2.6.3 Incident on Norne in 2012

Heating and smoke development was observed in slag (which contained iron sulphide) removed from a pipe bend to produced water. According to Synergi case 1323040, the measures taken were to moisten the material with water and prevent its exposure to oxygen. Experience transfer or other measures are not described.

2.6.4 Incident at Kalstø in 2012

A review of Synergi case 1276943 concerning a fire when opening the pig trap at Kalstø reveals that the presence of iron sulphide (black powder) was known, but that the amount was much greater than expected. The black powder which dropped from the pig trap began to smoulder, and a fire arose. A subsequent in-depth study was intended to contribute to the learning effect in order to prevent recurrence. The study refers to several earlier cases of smouldering fires in black powder at both Kalstø and Kårstø.

Measures adopted following the incident include several which deal with the need to change the type of PPE to protect against heat and possible fire, in addition to technical steps to prevent iron sulphide becoming exposed to air. No description is provided of measures for experience transfer to other units in the company.

2.7 Abbreviations

ART	Alarm response team
CCR	Central control room
DSHA	Defined situations of hazards and accidents
FiFi	Firefighting
JRCC	Joint rescue coordination centre
LRA	Low radioactive waste/scale
LTT	Air Transport Tampen
PDO	Plan for development and operation
POB	Personnel on board
PPE	Personal protective equipment
PSA	Petroleum Safety Authority Norway
SAR	Search and rescue
SFB	Statfjord B
SJA	Safe job analysis
SNB	Snorre B
SRB	Sulphate reducing bacteria
S&R	Search and rescue team
TSP	Technical service provider (responsible for operation)
WP	Work permit

3 The PSA's investigation

3.1 About the investigation

The PSA was notified by Equinor of the incident on SNB at 13.27 on 1 May 2019, and established its own response centre at 16.40 to follow up the operator's handling of the incident. A meeting was also held at the PSA's premises on 2 May 2019 where Equinor representatives provided a short briefing on the incident. The PSA decided on the same day to investigate the incident. An investigation team was established and dispatched to SNB on Saturday 4 May 2019. Equinor sent out its own investigation team in the same period.

The PSA team interviewed people on SNB directly and indirectly involved in the incident. They included offshore personnel from the operator, both those on board in connection with the turnaround and operations employees associated with the area containing the separator, as well as personnel from Wood and IKM Testing. Conversations were also conducted offshore with the chief safety delegate. After the offshore investigation, a video meeting was held on land on 29 May 2019 with representatives from Equinor's onshore organisation.

An inspection of the damage site was conducted. At that time, the separator was closed and water-filled, making it impossible to view the location of the fire. Relevant WPs, procedures and other documents were reviewed before, during and after the offshore investigation.

In connection with the 2 May briefing on the incident, the possibility was advanced that the fire was caused by spontaneous combustion of iron sulphide which in turn ignited oil residues in the separator. Analyses conducted with the residual contents of the separator after the fire revealed the presence of iron sulphide.

The PSA has not identified any other plausible cause of the fire, and its investigation has concentrated on possible reasons why personnel were not prepared for the possibility that iron sulphide might be present in the separator.

The investigation team has drawn up its report on the basis of presentations, interviews with personnel from Equinor, Wood and IKM Testing, and documents received.

3.2 Mandate

The mandate for the investigation of the incident on SNB on 1 May 2019 was established in consultation with the investigation team and relevant discipline leaders.

It is to be tailored to the circumstances, and normally covers the following points:

- a. *Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes the time line and incidents).*
- 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 (barriers which have not functioned).*
- d. *Identify nonconformities and improvement points related to the regulations (and internal requirements).*
- e. *Discuss and describe possible uncertainties/unclear aspects.*
- 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.*
- h. *Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.*
- i. *Recommend – and normally contribute to – further follow-up.*

Composition of the investigation team

- Liv Ranveig Nilsen Rundell — Process integrity
- Aina Eltervåg — Logistics and emergency preparedness
- Eva Hølmebakk — Occupational health and safety
- Jorun Bjørvik — Process integrity, investigation leader

4 Course of events

As described in section 2.2, primary cleaning had been completed ahead of the incident. A short description of the activities with their timing is provided below. In connection with these activities, gas measurements were made as required in the checklist for the individual WPs. These gave no reactions. No samples of scale in the separator were taken. In preparing for another cleaning job to be carried out during the turnaround (degassing tank), samples were taken in January 2019 of scale from the hydrocyclones in the produced water plant. These samples indicate the presence of iron sulphide.

Time	Event	Comments
	Activities before the incident with a fire in the inlet separator 1 May 2019	
31 Jan 19	Sample of scale in hydrocyclone inlet chamber taken ahead of the turnaround. Results showed iron sulphide.	Sample taken to determine cleaning method for degassing tank.
8 Mar 19	Plant shut down because of a riser incident on 4 March 2019.	
10 Mar 19	Process plant depressurised.	
24 Apr 19	Drainage and jetting/purging of process plant began.	
27 Apr 19, 15.00	IKM Testing started work on steaming separator.	
28 Apr 19, 15.00	IKM Testing completed work on steaming separator Started water-filling to cool separator.	Long duration of steaming to compensate for washing without chemical additives.
28 Apr 19, 17.20	Separator 65 per cent filled with water for cooling.	
28 Apr 19, 22.50 – drainage completed	Cooling water drained from inlet separator during night shift (Equinor operations).	
30 Apr 19, 14.00	First manway cover (west) opened. No reaction from gas detector.	
30 Apr 19, during day shift	Second manway cover (east) opened and ejector positioned.	When the second cover was opened and the ejector started is uncertain. The ejector was started to improve venting in the tank.
1 May 19, 07.00 – day shift		A lot of condensed water was registered in the ejector vent hose. Much vapour was observed from the hose during the day shift. This was assumed to be normal since the separator was being vented/ cooled.
1 May 19, 08.15	Wood started blinding job on the tank. Two blinds were installed on the underside of the tank. No reaction from gas detector.	Reacted to the fact that the water running out was warm.

Time	Event	Comments
Incident	**Smoke from inlet separator manway 1 May 19**	
12.55	Personnel from IKM Testing passed the area, noticed an unusual smell in the plant and observed smoke coming from the ejector on the inlet separator. Responsible area operator and CCR contacted by VHF radio.	
13.10	Responsible area operator went to the area, reported smoke back to the CCR and confirmed a fire.	Sharp smell of smoke, light-grey smoke, eventually darker as fire increased. The smoke came from the manways and rose towards the east. IKM Testing personnel and responsible area operator (ART) deployed hoses and started hosing the tank with water through the western manway. They then mustered to the lifeboats and the incident command centre respectively.
13.10	CCR activated general alarm with mustering in accordance with the muster instructions.	The emergency response leadership mustered immediately in the response centre on board, and acted in accordance with DSHA 3 – fire in process plant. The remaining personnel mustered pursuant to the alarm instructions and POB = 121 was confirmed after 16 minutes.

During the incident, the smoke was observed to change colour several times from white to grey-white.

Figure 2 The inlet separator with manway cover closed. Photo PSA

5 Potential of the incident

5.1 Actual consequence

The actual consequence of the incident was a fire lasting for about three hours in the inlet separator. Subsequent inspection shows that the integrity of the separator has not been weakened. Production had already been shut down before the incident.

No personal injuries were suffered by personnel in the area or those involved in extinguishing the fire. The wind direction on 1 May was favourable in relation to the muster point and for the personnel who discovered the fire and started extinguishing work. Exposure to SO_2 and other possible vapour from components hazardous to health in the smoke was thereby low. Interviews revealed that no health complaints had been reported by personnel on board. Equinor’s investigation report specifies that exposed personnel have subsequently been subject to routine checks, and that no injury has been identified with any of them.

5.2 Potential consequences

In connection with the turnaround, the process plant was depressurised and drained. The fire was unlikely to be able to spread beyond the separator, since there were no flammable materials in the vicinity.

No assessment had been made of the waste as a potential ignition source. But it emerged from interviews that this material was handled as low radioactive (LRA) waste, which means it is kept moist, and therefore indirectly also prevented the iron sulphide in the waste from igniting. The team therefore considers it unlikely that waste handling could have resulted in a fire elsewhere on the platform.

However, the incident could have had more serious consequences for personnel had the fire broken out when people were inside the separator or the wind direction was more unfavourable, so that exposure to smoke from the fire could have been greater.

6 Direct and underlying causes

6.1 Direct cause

The direct cause of the fire was spontaneous combustion of iron sulphide which came into contact with oxygen during the venting process after primary cleaning of the separator had been completed. This led in turn to ignition of remaining oil residues in the separator.

6.2 Underlying causes/discussions

6.2.1 Failure to follow up suspicions of iron sulphide

As described in section 2.4, hazardous chemical substances must be identified in connection with risk assessments as the basis for an entry permit.

In the “make safety preparations for entry” activity, iron sulphide is specifically described in governing documentation as a risk with a threat of spontaneous combustion, and measures are identified which must be implemented if the presence of iron sulphide is suspected.

However, no description is given nor reference made to another procedure which describes what should arouse suspicion that iron sulphide is present, how this presence is to be identified and who is responsible for formulating such a suspicion.

The actual issue is related in governing documentation to entry and exposure. If iron sulphide is present, however, the risk of spontaneous combustions relates to access to oxygen combined with the scale being dry. This can thereby occur ahead of entry in connection with venting, in connection with entry or when handling waste from the cleaning process.

SNB has been on stream for a long time and has a rising water cut. In the meeting with the land organisation, it emerged that no system has been initiated to follow up when precautions related to “suspicion of iron sulphide” are relevant.

Conversations with personnel involved in the turnaround work revealed that a checkpoint in the governing documentation related to iron sulphide was not assessed.

6.2.2 Knowledge of the consequences of iron sulphide as a pyrophoric compound

Conversations with personnel involved in the turnaround work revealed a lack of expertise about the possibility that iron sulphide can be present in scale in the separator and that it can be a pyrophoric compound. See also section 6.2.3.

Ahead of the turnaround, indications that iron sulphide could be present were provided by analysis results of a sample taken from scale in the inlet chamber of the hydrocyclone downstream from the inlet separator. This sample was taken in preparation for the turnaround in order to test the method for cleaning the degassing tank, which was also due to be done. In addition to a sample sent to IKM Testing for checking the cleaning method, another was sent to the lab for analysis. This revealed that the sample primarily comprised iron sulphide. The sample sent to IKM Testing proved insoluble with both available cleaning materials and the use of acid.

Since the issues associated with iron sulphide were not known, the risk of a possible presence of this material was not dealt with in the draft SJA or when preparing the WP for opening the manway cover and starting venting. Nor were waste handling measures established. Possible consequences of the analysis results from the cyclones and the need for further samples were not assessed.

6.2.3 Learning from earlier incidents

The risk of spontaneous combustion from iron sulphide exposed to oxygen was not known to turnaround personnel from IKM Testing and Wood interviewed by the team on SNB.

Equinor has experienced challenges with heat build-up and fires where iron sulphide has been exposed to oxygen. The incidents on SFB and Norne were categorised as green – in other words, the lowest level of seriousness in Equinor's matrix for categorising and classifying undesirable HSE incidents. The Kalstø incident was categorised as yellow – possibly serious – for personnel injury and green for the threat to the plant from fire/explosion.

The way risk posed by iron sulphide was documented, categorised and named after the various incidents appears to have been significant for the lack of attention to and learning about the possible spontaneous combustion of and fire hazard posed by this material across the organisation.

7 Emergency response

The emergency response organisation on SNB is described in the appendix to *Beredskap på norsk sokkel – Snorre B*, final version 12, published on 11 January 2019.

Weather conditions were favourable for fire-fighting, rescue and possible evacuation. Wind speed was 21 knots, wave height 1.1 metres, temperature 7°C and visibility +10.

Personnel from IKM Testing passed the area at 12.55 and observed smoke emerging from the ejector on the inlet separator. They had worked on steaming the day before and, although subsequent steam is common, they reacted to its persistence a day later. The IKM Testing personnel contacted the responsible area operator and the CCR by walkie-talkie. The responsible area operator went to the area, reported smoke to the CCR and confirmed a fire. The CCR activated a general alarm with mustering in accordance with the muster instruction at 13.10. The IKM Testing personnel and the responsible area operator (who also functioned as the ART) deployed hoses, began hosing the tank with water through the west manway and mustered to the lifeboat and the incident command centre respectively. The emergency response leadership mustered immediately in the incident centre on board and acted in accordance with DSHA 3 – fire in process plant. Remaining personnel mustered pursuant to the alarm instructions and POB = 121 was confirmed after 16 minutes. The CCR notified Air Transport Tampen (LTT), which in turn notified the joint rescue coordination centre (JRCC), Equinor's second line and the PSA pursuant to the applicable response plans. The search and rescue (S&R) team mustered in accordance with plans and prepared for action on the main deck, P23. A secure incident command centre was established by the south-east crane, and the nurse arrived to assist with the first aid team.

The S&R team, with fresh-air masks, began to extinguish with water and then foam. They extracted the ejector from the manway and two people stood at each manway and hosed with water and foam. No damage was observed to the ejector. The manways were closed and the separator filled with nitrogen and water via the jetting water system. The response team devoted about three hours to extinguishing work. Personnel rotation functioned well.

At the request of the S&R team, deluge was not activated in the area where the separator is located. The emergency response command decided not to activate deluge because the fire was confined inside the separator and activation would complicate manual extinguishing by hose from outside the separator. Equinor's second line confirmed this decision. The separator was isolated by passive fire protection and deluge would therefore have a limited cooling effect.

Other personnel who mustered to the lifeboat sat there for two hours before being moved to the alternative muster area in the canteen. When the incident was normalised, the offshore installation manager informed personnel of the course of events.

SNB is part of the Tampen emergency response area, which comprises the following the fixed facilities: Statfjord A, B and C, Gullfaks A, B and, C, Snorre A and B, Visund, Kvitebjørn and Valemon.

The area standby ship is centrally located in the Tampen area on Statfjord. This vessel is the main resource in the event of an acute oil spill, but is also a resource for:

- personnel in the sea following a helicopter accident
- personnel in the sea following an emergency evacuation
- a collision threat
- a fire with the need for external assistance.

Stril Merkur, the area standby ship (with FiFi), arrived at SNB at 14.45, within the three-hour response requirement, and took up position outside the 500-metre zone. Other arrivals on the Snorre field were standby ship *Norman Ferking* (with FiFi) and a SAR helicopter after 45 minutes. The JRCC for southern Norway also dispatched three naval vessels to SNB.

Patrols were organised in the P63 area during the night.

The PSA was notified of the incident and established its own emergency response centre, where it monitored Equinor's handling of the incident. The impression is that the Equinor first line tackled the incident in a good way, and that the PSA received adequate and updated information from Equinor's second-line emergency response.

In the team's view, the emergency response functioned well.

8 Observations

The PSA's observations fall generally into two 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.

8.1 Nonconformities

8.1.1 Risk assessment before starting the activity

Nonconformity
When planning and implementing the activity for primary cleaning of and entry to the inlet separator, inadequate efforts were made to ensure that important contributors to risk were kept under control.

Grounds
When planning the activity, important contributors to risk and changes to risk as a consequence of the activity (supply of oxygen) were not identified and no compensatory measures were thereby adopted.

- No assessment was made of whether iron sulphide might be present, and no measures were thereby taken to prevent spontaneous combustion in connection with venting.
- Knowledge that iron sulphide can be a pyrophoric compound was lacking. The analysis results for scale in the hydrocyclone downstream from the inlet separator revealed the presence of iron sulphide, but this was not incorporated in further planning of the job.
- Waste from the cleaning process was not handled in accordance with the requirements for waste which might contain iron sulphide.

Requirement
Section 29 of the activities regulations on planning

8.1.2 Experience transfer

Nonconformity
Experience transfer from similar incidents has not been adequately secured in Equinor.

Grounds
Equinor has failed to ensure adequate transfer of lessons learnt with iron sulphide from various facilities and plants to the teams and facilities in its own business which could face problems with this compound. Incidents registered in Synergi concerning tank work or pig handling at offshore and land-based facilities were not assessed in connection with work on SNB.

- Earlier experience with iron sulphide incidents was not known on the facility or by the turnaround team, and could therefore not be assessed in the risk reviews.
- Categorisation of earlier incidents may have contributed to the failure of relevant personnel to pick up on the problem in connection with turnaround planning.
- The course of events on SFB in 2012 was similar to the occurrence on SNB in May. The *Erfaringsrapport fra Drift – Statfjord B* report does not specify the problem of spontaneous combustion with iron sulphide. This could have contributed to the failure of other Equinor units to pick up on the report and on the iron sulphide problem.
- Varying use of terms where iron sulphide has occurred in the Synergi cases and documentation reviewed by the PSA team could also help to explain why this issue failed to secure the attention needed to ensure awareness that experience should be transferred to other units. Iron sulphide has been variously described, directly or indirectly, as “black sticky stuff”, “black powder”, “bottom deposit”, “waste, “scale” and “pyrophoric iron”. That has made the incidents actually relating to iron sulphide challenges less visible.

Requirements
Sections 15, 20 and 23 of the management regulations on information, on registration, review and investigation of hazard and accident situations, and on continuous improvement respectively

8.1.3 Procedures

Nonconformity
The work process for ensuring that account is taken of the possible presence of iron sulphide in venting, entry activities and waste handling was not adequately formulated to ensure that it fulfilled its intended function.

Grounds
Existing work processes and checklists for entry include information related to iron sulphide and identify measures to be implemented if the presence of this compound is suspected. The work process provides no description of what would give rise to such suspicion, who is responsible for identifying it and when.

The work process for entry deals with iron sulphide in relation to the actual entry activity. If iron sulphide is present, however, the risk of spontaneous combustion will arise with the provision of oxygen and the scale being dry. Spontaneous combustion can occur before entry in connection with venting, in connection with entry or when handling waste from the cleaning process.

Requirement
Section 24 of the activities regulations on procedures

9 Barriers which have functioned

Smoke from the manway was discovered through observation by personnel and notification to the CCR. Both smoke and fire were confirmed when the responsible area operator (ART) checked the tank and confirmed smoke development with fire to the CCR.

Emergency response on board functioned in accordance with the preparedness plans. Resource personnel present for the turnaround were consulted, and also took part in the rotation as part of the S&R team. Area emergency response resources arrived as intended. Extinguishing the fire was confirmed after filling the tank with water. Patrols were instituted in the P63 area during the night.

Fire and flames were confined inside the inlet separator, and the fire was therefore not detected by the flame detectors. As a result, deluge was not automatically activated. This is in accordance with the logic. Smoke detectors are not normal practice in process areas, since they are used in mechanically ventilated enclosed areas rather than open modules.

10 Discussion of uncertainties

10.1 Origin of iron sulphide in the inlet separator

The investigation has not identified the reason why the iron sulphide was present in the inlet separator or how long this has been a challenge. Conversations with personnel from the land organisation has revealed that no major changes have been experienced in operating parameters but that the water cut has risen. SNB produces from a sandstone reservoir where iron and sulphate have been identified in the formation water (information from the PDO). Water injection (seawater and produced water) has been under way since SNB came on stream. Produced water injection ceased in 2006 because of souring of the reservoir and corrosion in production/injection tubing [43]. These points are some of the indicators for the possible presence of iron sulphide.

10.2 Potential consequences of waste handling

As described in section 5.2, waste from the cleaning process was treated as material containing LRA and was thereby also indirectly protected against spontaneous combustion of iron sulphide. The report has not assessed the potential consequences if the waste had been handled differently. Scale containing iron sulphide will be a potential ignition source when in contact with oxygen.

11 Assessment of the player's investigation report

Equinor established its own investigation team on 2 May 2019 with a mandate to investigate the incident of 1 May 2019. The investigation was placed in Equinor's internal category 3.

Equinor's investigation report was received on 5 June 2019. The course of events largely coincides the PSA team's description. Although section 5.2 on similar incidents refers to several incidents registered in Synergi, only the one involving SFB in 2012 is assessed in the report. No assessment is made of inadequate experience transfer and learning across the Equinor organisation from this or other incidents involving iron sulphide.

12 Appendices

A: The following documents have been drawn on in the investigation

1. Mechanical drawing of inlet separator 20B-VA001, internals general arrangement No 1, doc no S6-DF-MAG-2020, rev 6)
2. Process P&I diagram – inlet separator doc no S6-KA-PBP-2002, rev 22
3. Work permit level 1 no 9508802999 (open manway cover inlet separator)
4. Work permit level 1 no 9508724515 (blind first-stage separator)
5. Snorre B RS2019 cleaning of inlet separator - 20B-VA001
6. Work description RS2019 running down process plant before RS2019
7. Emergency preparedness turnarounds 3 January 2012 (in force from 2 May). Drilling demobilised 2 May
8. Emergency response report 1 May
9. Log from emergency response centre 1 May
10. Personnel involved during the incident
11. Synergi no 1302004 from SFB
12. Description of incident at 20B – VA001 (first-stage separator) 1 May 2019, 13.05
13. WR 1146 Requirements for working environment DPN (revision 3)
14. OMC01 Operations south (DPN OS), operations west (DPN OW), operations north (DPN ON) – *Organisasjon, ledelse og styring*, *Mennesker og lederskap (PL) - Organisasjon, ledelse og styring*, Final, ver 4, published 22 March 2019
15. Evaluation from Aibel HAM
16. Evaluation exposure to steam
17. Experience report from SFB RS 12
18. OM105.01 – work permit (WP) – upstream offshore
19. OM105.02 – entry – upstream offshore (rev no 2.42)
20. Procedure second-stage separator (WOs nos 24596068 and 24596070)
21. Log prepared by IKM – timeline for work carried out
22. Photographs taken during inspection 4 May 19
23. WP no 9508804099
24. Laboratory report Snorre B
25. Objective: analysis of solids from hydrocyclone
26. SJA 88216
27. Synergi no 1323040
28. Synergi no 1486297 – SFB
29. Information received by e-mail 8 May 19 – overview of areas in the process plant where jobs during the turnaround involving corrosion damage have been identified
30. Information received by e-mail 8 May 19 – timing of pressure blowdown, draining of production content (pre-steaming), start ejector, drain cooling water (after steaming before opening of manway cover), start-up/caustic wash – blinding
31. Inspection conclusions on separator condition after the fire – DNV GL report (not received)
32. Presentation from meeting, 29 May
33. Photographs from the 2015 turnaround after primary cleaning of the separator
34. Appendix to Synergi 1486297, pyrophoric iron Statfjord B
35. Preliminary laboratory report – analysis of solid substances in Snorre B inlet separator after the incident
36. Equinor’s investigation report after the incident
37. Brief description of how experience has been transferred between various turnaround teams
38. 2015 SNB M3 440485513 inspection report 20B-VA001

39. 2015 SNB M3 44045915 inspection report 20B-VA001
40. Photographs of PBB on separator 20B-VA001
41. Product datasheet, Foamglas One Insulation
42. Information on PBB received by mail, 18 June 2019
43. Annual report, Norwegian Environment Agency 2017 – Snorre A and Snorre B, AU-SN-00073

B: Overview of personnel interviewed

(See separate appendix)