PETROLEUMSTILSYNET

Investigation report

Report	
Report title Updated report of the investigation into personal injuries on Heimdal on 28 November 2019	Activity number 001036022

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

Involved	
Team T-1	Approved by/date Kjell M Auflem, by authority, head of supervision/26 May 2020
Members of the investigation team Sissel Bukkholm, Jorun Bjørvik, Anita Oplenskedal and Kristi Wiger	Investigation leader Sissel Bukkholm/Kristi Wiger

Contents

1 Summary

In connection with pressurising a nitrogen gas cylinder on 28 November 2019, two people were injured on Equinor's Heimdal facility. The Petroleum Safety Authority Norway (PSA) decided on the same day to investigate the incident. It also provided technical support to the accident inquiry conducted by the police.

The weekly inspection round revealed insufficient pressure in a nitrogen gas cylinder for manual release of the CO_2 used as an extinguishing agent in the Heimdal facility's turbine rooms. This can be released automatically from the control room or manually from outside the turbine rooms. In both cases, pressurised nitrogen gas from a cylinder is used to release the CO_2. The gas cylinder involved in the incident had a capacity of 3.4 litres. A booster pump was used to achieve the desired pressure of 200 barg.

Three people were present during this pressurisation operation. The cylinder burst and broke into several pieces. Two people were seriously hurt, and one suffered life-threatening injuries.

Under slightly different circumstances, the incident had the potential to become a fatal accident.

Note that this report has been published before the results from the technical examination of the gas cylinder and booster pump are available. Once they are received, these results will be published as a supplement to the report. The decision to publish before the technical examinations are completed has been taken in order to communicate important lessons, which the PSA considers to be independent of the technical studies, However, the latter could contribute further lessons and information on the causes related to the incident.

The investigation has identified five nonconformities in relation to the incident:
- inadequate safety clearance of activities
- lack of barriers against overpressure
- lack of competence
- inadequate planning and risk assessment
- lack of procedures and routines.

2 Background information

2.1 Description of the facility

Heimdal is a gas field located in block 25/4 in the central part of the Norwegian North Sea, where the water depth is about 120 metres. The field has been developed with an integrated production, drilling and quarters platform supported by a steel jacket (HMP1).

The plan for development and operation (PDO) of Heimdal was approved in 1981, and the field came on stream in 1985. Approved in 1999, the Heimdal gas centre (HGS) embraces a riser platform (HRP) connected by a bridge to HMP1. Heimdal produces gas and some condensate, but is now primarily a processing centre for other fields. Atla, Skirne, Vale and Valemon deliver gas to Heimdal.

Equinor is the operator for Heimdal.

2.2 Local conditions

Heimdal lies 212 kilometres north-west of Stavanger, west of Sveio in Hordaland and close to the boundary with the UK continental shelf. Flight time to the HMP1 facility, where the incident occurred, is about 55 minutes from Sola, Stavanger, and 50 minutes from Flesland, Bergen.

Figure 1: Map of the area. (Source: Norwegian Petroleum Directorate)

2.3 Position before the incident

On the day of the incident, 28 November 2019, normal activity was under way on Heimdal in addition to some maintenance and modification work. There were 70 people on board. Some personnel arrived on the facility during that day.

According to the board in the emergency response room, the wind speed on Heimdal was 34 knots and the wave height was 4.4 metres. The weather on the day had no negative effects on helicopter flights.

2.4 Abbreviations

Definitions	
Person 1	Person involved in the incident. Automation technician in Equinor. Long experience of working on Heimdal.
Person 2	Person involved and injured in the incident. Automation technician in Equinor. On their second offshore tour.
Person 3	Person involved and injured in the incident. Apprentice mechanic in Equinor. On their third offshore tour.
Work permits level 1 and 2	WP level 1 is required for high-risk activities which call for coordination and clearance at facility level. WP level 2 is used for work where the risk requires coordination and clearance within an area or system (Equinor's definition in governing document OM105.01).
Abbreviations	
CCR	Central control room
EPN	Exploration and production Norway (Equinor designation)
Equinor	Equinor Energy AS
JRCC	Joint rescue coordination centre
NCS	Norwegian continental shelf
O&M	Operations and maintenance
OIM	Offshore installation manager
OJT	On-the-job training
PDO	Plan for development and operation
PM	Preventive maintenance
POB	Personnel on board
PSA	Petroleum Safety Authority Norway
PV	Planned maintenance
SAR	Search and rescue
SO document	System and operations document
WO	Work order
WP	Work permit

3 PSA investigation

The PSA was notified by Equinor at 17.50 on 28 November 2019 of a serious incident on the Heimdal facility. A nitrogen gas cylinder had burst during pressurisation and two people were seriously injured. Both were employed by Equinor.

Both of the injured had been flown to land by helicopter, one to Haukeland University Hospital in Bergen and the other to Stavanger University Hospital.

On the basis of the information received from Equinor, the PSA immediately activated its emergency response centre in order to follow developments. The decision to investigate the incident was taken the same evening.

3.1 Investigation team's mandate

The PSA investigation received the following mandate.

a. Clarify the incident's scope and course of events (with the aid of a systematic review which typical describes the timeline and events)
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
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 contribute to – further follow-up

3.2 Investigation team

Name	Position	Discipline
Jorun Bjørvik	Principal engineer	Process integrity
Anita Oplenskedal	Senior adviser	Logistics and emergency preparedness
Kristi Wiger	Principal engineer/ investigation leader	Process integrity
Sissel Bukkholm	Principal engineer/ investigation leader	Occupational health and safety

The investigation team arrived on the Heimdal facility together with the police at about 14.30 on Friday 29 November 2019.

3.3 Methodology

The investigation was conducted through interviews with personnel in the land and offshore organisation for Heimdal, verifications and inspections on the facility, and a review of governing documents and other documentation relevant for the incident. Equinor’s investigation report was also reviewed.

The Rogaland police district led the investigation. Two tactical and two technical investigators flew out to Heimdal the day after the incident. The PSA team was asked to support the police inquiry, and flew out at the same time. It took part in seven interrogations and inspections conducted on board. In agreement with the police and the interviewees, the team asked its own questions during the interrogations. It also conducted some interviews with personnel on the facility without the police being present. The team returned to land on 1 December 2019.

The police interviewed the injured people in December 2019 and January 2020 with the PSA team present. In addition, the team attended the interrogation of the booster pump manufacturer and a supplementary interview with personnel who were part of the work team when the incident occurred.

A meeting was held on 17 January 2020 with the land organisation covering Heimdal. The team was then given a presentation and explanation of governing documents for work related to pressurising nitrogen gas cylinders and using the booster pump. On the same day, a meeting took place with the second-line incident commander. A group interview was also conducted on 27 January 2020 with offshore personnel from another shift on Heimdal to gain a better understanding of the work being done when the incident occurred.

Technical examinations of the booster pump and nitrogen gas cylinder were not finished when this report was completed. Their results will be assessed and compared with the report and published as an appendix when the examinations are completed.

The team has not gone into details in describing barriers which functioned. No barriers prevented the cylinder from bursting. The chapter on emergency preparedness describes factors which limited the consequences of the incident.

Documents requested and received in connection with the investigation are listed in chapter 13.

4 System description and planning

4.1 Equipment involved in the incident

4.1.1 General details of relevant equipment and systems

Nitrogen gas is used for a number of purposes on Heimdal, including in the fire-extinguishing system as propellant gas for the CO_2 and water mist release mechanisms, in leak testing, as a purge gas, in pressure testing of piping and equipment, and in pressurising/charging hydraulic accumulators.

Heimdal has a central system for nitrogen gas, with several filling connections in the process modules which can deliver gas with a pressure up to about 130 barg. Operations or cylinders where a pressure higher than this is not required can therefore be supplied directly from the central system. A booster pump is when needing a higher pressure. The maximum nitrogen gas pressure requirement identified on Heimdal is 548 barg.

CO_2 is used on Heimdal as an extinguishing agent in the turbine rooms, and can be released automatically from the control room or manually from outside the turbine rooms. In both cases, pressurised nitrogen gas from cylinders is used to release the CO_2. The incident involved a 3.4-litre gas cylinder located in a locked cabinet on the outside of the turbine room. According to the preventive maintenance (PM) programme for the system, the cylinder must maintain a minimum pressure of 100 barg. No automatic pressure monitoring of the nitrogen gas cylinders is installed, but the pressure is checked by automation technicians during weekly inspection rounds on the facility and in connection with more extended PM activities to test the whole system. The pressure is read off from a local manometer installed in the cabinet. If low pressure is found during a weekly round, a notification is established in the SAP maintenance system for further action. The established requirement for correcting such deficiencies is five days.

If its observed pressure is below 100 barg, the nitrogen gas cylinder must either be replaced with one from store with sufficient pressure or be pressurised. The latter raises it to 200 barg – the maximum operating pressure for this type of gas cylinder. A portable booster pump is used for pressurising the cylinders.

On removal from the cabinet for replacement or pressurisation, cylinders are disconnected from the manometer. This remains in the cabinet. The cylinder is connected directly to the pump and the manometer for the pump's delivery pressure is the only indication of cylinder pressure during the operation.

A simplified diagram of the pressurisation system using a booster pump is show below.

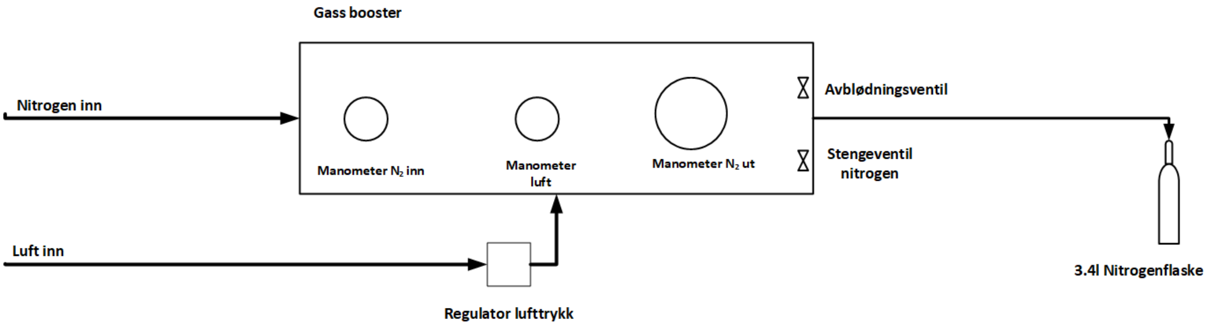

Figure 2: Simple system diagram.

4.1.2 Booster pump

The booster pump used to pressurise nitrogen gas cylinders is a double-acting reciprocating device, where the pressure delivered depends on the operating pressure on working air and nitrogen gas in the pump. The air pressure can be adjusted with a control valve on the pump inlet as shown in the diagram. Delivery pressure for the pump is provided by the following equation, where P = pressure.

$$P_{gas\ out} = 75 * P_{air\ in} + P_{gas\ in}$$

Figure 3: Booster pump. (Source: Safety Alert/Equinor)

According to the supplier documentation, this type of pump can be supplied with an adjustable pilot valve to limit its delivery pressure as well as with a safety valve for overpressure protection.

The pump involved in the incident had neither pilot nor safety valve for limiting maximum delivery pressure. Given a delivery pressure from the central nitrogen gas system of about 130 barg and a maximum available pressure for working air of close to nine barg, delivery pressure could be varied from about 250 to 805 barg by adjusting air pressure. Other than that adjustment, this pump does not permit presetting the desired delivery pressure. Reducing air pressure into the pump will also extend the time required for pressurisation.

This pump has a self-limitation of 1 000 barg.

Acquired in 2002, the pump is not registered with a tag number and therefore has no maintenance programme or history in the SAP system. It is sent ashore for an annual maintenance programme, including manometer calibration, in accordance with the supplier's recommendations. Certification of the pump is documented in that the equipment is marked with the dates of latest and next recertifications. According to the marking on the pump, it should have been sent ashore for annual maintenance on 1 October 2019. The PSA has been informed that the general rule for handling due dates in the preventive maintenance programme is that the work should be done by the end of the following month, which in this case would have been 30 November. The next due date would be set to a year after the original date, or October 2020 if the interval is 12 months. Other documentation for the pump, such as a description, user manual and possible maintenance history, was not available on the facility and was not traceable by the investigation team after the incident.

A second booster pump was acquired in 2012. This is the same model as the 2002 unit, but installed in a larger bench. The 2012 pump has an internal pressure control set to 690 barg and is included in the maintenance system. Documentation for this pump is available.

4.1.3 Nitrogen gas cylinders

The Heimdal facility has various sizes of nitrogen gas cylinders. The largest are fixed and must be filled in situ. They are fitted with manometers which show the internal pressure in the cylinder during pressurisation.

Used only for manual release of CO_2, the type of cylinder involved in the incident is certified for an operational pressure of 200 barg and has a test pressure of 348 barg.

Figure 4: A 3.4 litre nitrogen gas cylinder. (Source: Safety Alert/Equinor)

Spare cylinders are available on board to supplement those in use at any given time. Their location is specified in the PM programme for the extinguishing system. No routines have been established to ensure that pre-pressurised cylinders are available when required.

A PM programme exists for follow-up of gas cylinders on Heimdal, covering various activities for yearly, five-yearly and 10-yearly checks. The cylinders lack a tag number, but have an approval year stamped on their neck.

4.2 Planning and execution

4.2.1 Equinor's procedures and work descriptions

Inspections are conducted on the facility daily, weekly or at other frequencies. If faults or deficiencies are noted on these rounds, a notification is written which results in turn in a work order (WO). This is prepared by the discipline lead for the relevant department, and processed and prioritised in approval and prioritisation meetings on board. Based on the WO information, a work permit (WP) at level 1 or 2 is prepared as and when required.

Equinor has defined a general WO for PM to test the fire-extinguishing system. See the more detailed description in section 4.2.4 below.

Heimdal had no procedure, work description or the like for filling or pressurising the nitrogen gas cylinders. Nor were these available on other Equinor facilities with corresponding booster pumps. Heimdal had no user manual for the relevant booster pump.

4.2.2 Work permit

General
Equinor has described its WP process in governing document OM105.01 – work permits (WP) – upstream offshore. This document describes the WP level required for various activities. WP level 1, for example, is specified when disconnecting safety systems.

The WP system is based on the internal control principle, which means several independent parties are involved in approving, checking, coordinating and managing activities. Equinor's document describes the requirement that one group has area/operational responsibility and another is responsible for execution, and both have specific duties and responsibilities in the WP process. One party is defined as the "owner", and has area/operational responsibility for equipment and plant, while the other is the "supplier" and is responsible for technical execution of the work to be done on the equipment/plant.

According to the process description, the WP is normally prepared by the entity responsible for executing the work. The WP applicant must describe the work, identify risk and propose operational and safety preparations for the specific work.

OM105.01 also gives examples of which activities can typically be conducted without a WP. Each facility can establish its own solution and system and operations (SO) document. An SO document has been developed for Heimdal covering work which does not require a WP: SO08204 – system independent – work not requiring a work permit – Heimdal. Pressurising nitrogen gas cylinders is not mentioned as an activity which can be conducted without a WP.

WPs are dealt with in the coordination meeting for WPs and parallel activities. These meetings are usually attended by the discipline leads, the supervisors for area/operations, planned maintenance (PV), operations and maintenance (O&M), and health, safety and the environment (HSE), and the offshore installation manager (OIM).

WP for the relevant activity
A WP level 1 was created for the nitrogen-gas refilling job by the mechanical discipline head. The use of level 1 rested on the disconnection of a safety system, since the CO_2 extinguishing system had to be shut down when the nitrogen gas cylinder was taken out of operation.

The WP identified crush injuries, noise and lack of fire cover in the hood (turbine room) as risks. Risk associated with pressurising the cylinder was not identified. The WP specifies that a toolbox talk should be held.

4.2.3 Roles and responsibilities

Heimdal complies with the normal organisational pattern in Equinor EPN.

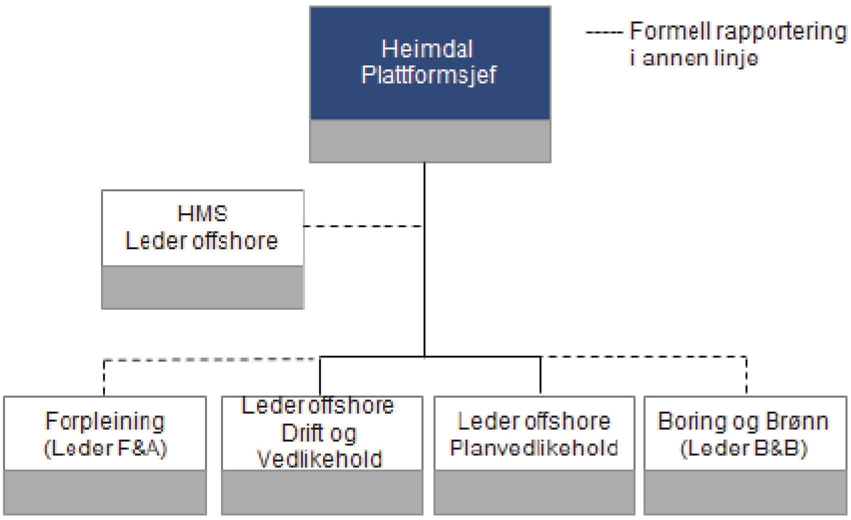

Figure 5: Organogram showing reporting lines. (Source: Organogram Heimdal, Equinor)

The automation/instrumentation and mechanical departments belong to the PV function on Heimdal. Both had a role ahead of or during the incident. Responsibility for checking pressure in the cylinder and correcting it if required rests with automation, while mechanical is responsible for the booster pump should pressurisation be required.

These departments are led by a discipline lead, who discharges the role of technical guide/ trainer in the discipline. This person is responsible for notifications and their quality assurance, and allocates work between personnel in the department.

4.2.4 Practice for this type of work

The relevant activity of pressurising this type of cylinder is done infrequently. As noted in section 4.2.1, low pressure found on the weekly round will result in a notification which leads in turn to a WO and then a WP before execution. A WP is required because the safety system is disconnected on removal of the cylinder, and does not relate to a possible risk associated with pressurising the cylinder.

In addition to the weekly inspection, a PM programme is also defined for a more extensive test of the whole system. If low pressure is identified when conducting this type of PM, low pressure in the nitrogen gas cylinder will be corrected as part of the programme. The work description for the PM template specifies the following if pressure in the cylinder is too low: "new cylinders are located in HVAC room M20, or get the mechanical department to refill the one in place."

The descriptive text for WOs to correct insufficient pressure can differ somewhat, and practice related to pressurising or replacing the cylinder varies. Practice on Heimdal is that the executing personnel decide whether to replace or pressurise.

5 The incident

During its weekly inspection, the automation department noted that pressure in a nitrogen gas cylinder for manual CO_2 release was too low, and established a notification of this. The mechanical discipline head established a WO and a WP level 1. The job was first allocated to the mechanical department, but this maintained the work was not its responsibility because the cylinder stood in a cabinet which automation was responsible for and had access to.

The job was then transferred to the automation department before execution.

Arbitrarily assembled, the work team comprised Persons 1 and 2, who were both automation technicians. The technical operator with area authority came to the room where the cylinder was located to prepare the job. The WP was activated. The two work-team members took the cylinder out into process area M30 (see figure 7), where air and nitrogen gas outlets were available. They connected the cylinder to the nitrogen gas outlet and filled it to about 130 barg.

The team then went to the mechanical workshop for assistance in pressurising the cylinder. Person 3 fetched the booster pump, and all three entered the plant together. Another mechanic came out and helped to connect the hoses to the pump. This operated unevenly, but worked as it should after a restart. The three others positioned themselves around the pump – Person 3 closest and Person 1 a little further away, while Person 2 held the cylinder standing on the deck. There was no discussion about whether they had positioned themselves appropriately. The second mechanic then left the worksite.

How long the pressurisation lasted is unclear. The team noted that the cylinder grew hot, but did not manage to react before it burst.

Figure 6: The burst cylinder. (Source: the police)

Two people were badly injured. Person 2, who was holding the cylinder, suffered serious injuries to his legs and one hand. Person 3 was injured when the booster pump collided with his legs, probably after it had been hit by parts of the cylinder.

Person 1 shut off the air and nitrogen gas supplies before yelling to the workshop to call the HSE leader (nurse). Both the injured people were quickly taken care of by the nurse and other response personnel, first at the incident site and then in the Heimdal hospital – where the nurse was assisted in treating them by the duty doctor on land via video link.

At the same time, an incident command was established on Heimdal and two helicopters were requisitioned. Both the injured people eventually reached hospital on land – one at Haukeland University Hospital and the other at Stavanger University Hospital. The first helicopter reached Heimdal 1.5 hours after the incident.

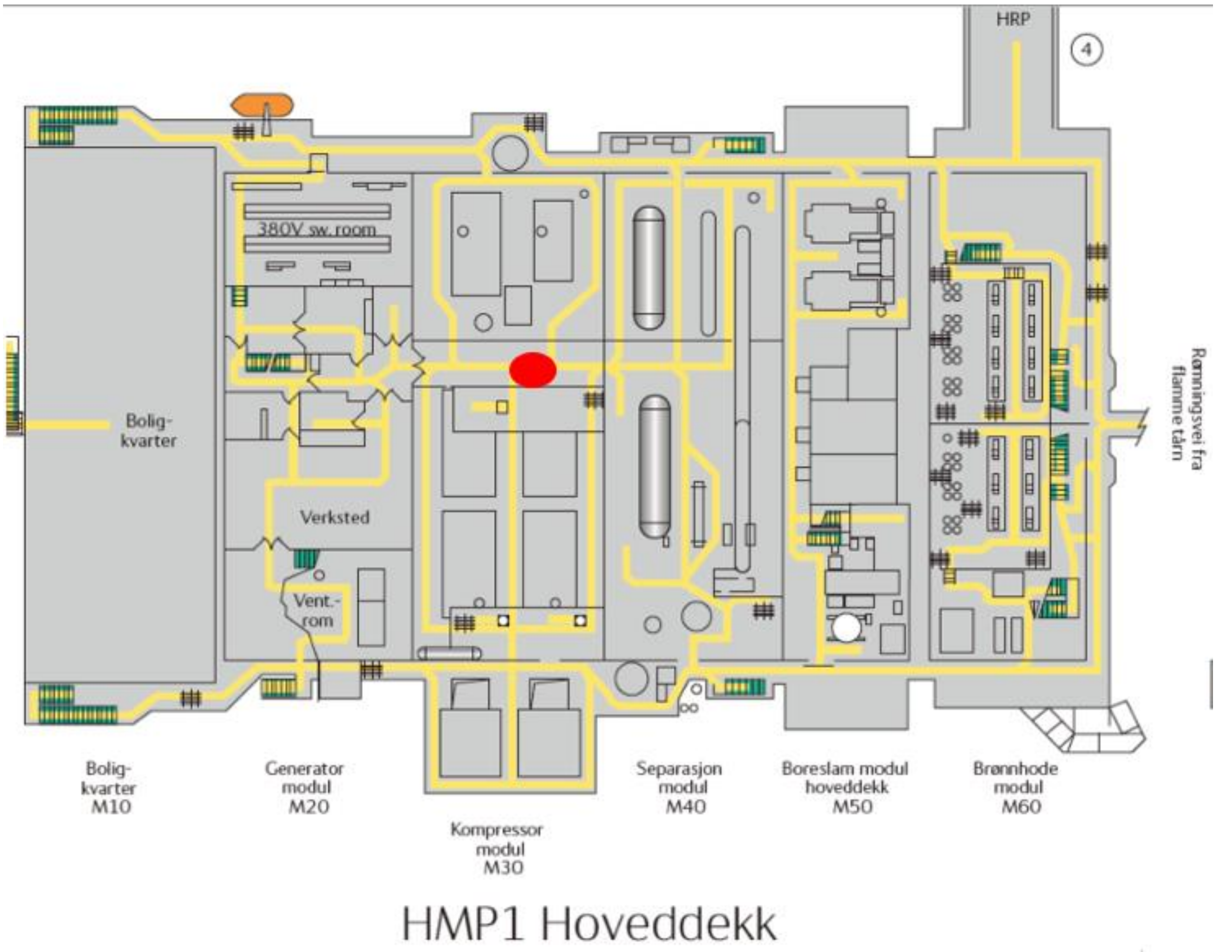

Figure 7: Diagram of the HMP1 main deck. (Source: Equinor). The incident site is shown by a red circle.

5.1 The incident in chronological order

The incident occurred in connection with pressurising a nitrogen gas cylinder. The table below presents activities ahead of this work which could be significant for the incident, as well as events during the actual incident.

Time	Event	Comment
2002	Purchase of the relevant booster pump	
2012	Purchase of a second booster pump	Not used in the incident
Oct 2018	Last time the relevant pump was serviced	
24 Nov 19	Low pressure observed in nitrogen gas cylinder in the cabinet for manual release of CO_2	
24 Nov 19	Notification for correction established	
26 Nov 19	WP for correction established	

Time	Event	Comment
27 Nov 19	WP established and discussed in WP meeting. WP released for 28 Nov 19	
28 Nov 19	Job allocated to mechanical department. After toolbox talk, transferred to automation department.	
28 Nov 19	Job started	
	Cylinder pressurised to 130 barg from central nitrogen gas network	
28 Nov 19	Assistance sought from mechanic who fetched the booster pump. Pump connected to nitrogen gas, working air and the gas cylinder. Pump started	
28 Nov 19, 18.06[1]	During pressurisation, the cylinder burst. Two people seriously injured	
	OIM arrived in the control room, ordered general alarm and PA announcement	Mustering at alternative muster point indoors
	HSE leader quickly on the scene	
	Stretcher transport to the hospital	
18.27	Personnel on board (POB) checked	
18.40	Nearest search and rescue (SAR) helicopter (from Johan Sverdrup) unable to take off because of hydraulic problems	With an estimated flight time of 30 minutes, Johan Sverdrup SAR would have reached Heimdal at 19.05
18.53	Second-line response mobilised	
19.07	PSA notified orally by the second line	
19.29	SAR Tampen arrived	
20.06	Sea King arrived	
19.50	SAR Tampen took off with Person 2	
20.24	Sea King took off with Person 3	
20.48	Person 2 arrived at Haukeland University Hospital, Bergen	
21.30	Person 3 arrived at Stavanger University Hospital	
23.00	Crisis team arrived on Heimdal	Two offshore nurses, a psychologist and a North Sea chaplain

[1] Times from the first-line log.

6 Potential of the incident

6.1 Actual consequences

The actual consequence of the incident was that two people were badly hurt, and one suffered life-threatening injuries. Both spent a long period on sick leave. The third person in the work team was struck, probably by one of the hoses, but without being injured.

Heimdal ceased production the day after the incident to take care of the personnel who were involved, and remained shut down for 5.5 days.

Material damage to equipment in the area where the incident occurred was insignificant.

6.2 Potential consequences

Three people were present when the job was being done, and Person 1 or Person 3 could also have been injured by projectiles from the cylinder.

Had the cylinder burst or struck in another way, or had the people been positioned differently, other potentially more or less serious injuries could have been caused to those present.

No assessment has been made of whether the equipment in the area could have been damaged if projectiles from the cylinder had struck any of it.

The nurse was quickly on the scene and both the injured people rapidly received first aid on the spot before being removed to the hospital where treatment continued, and where the nurse was in touch with the duty doctor throughout using telecommunications. The nurse described this support as “invaluable”.

The incident is considered to have had the potential to become a fatal accident under slightly different circumstances.

7 Direct and underlying causes

7.1 Direct cause

The direct cause of the incident was that the nitrogen gas cylinder burst during pressurisation because it was probably exposed to a pressure significantly above its design level.

7.2 Underlying causes

The most important elements identified by the investigation which may have been significant for the incident are listed below. They are further described in the subsequent sections.

1) Lack of barriers against overpressure

- No protection against overpressure on the booster pump or gas cylinder
- Only one manometer, which shows pressure in the cylinder during pressurisation
- Manometer function was not tested before work started

2) Risk of using the pump had not been dealt with

- The activity for pressurising the nitrogen gas cylinder was regarded as a routine operation, but was seldom done with this type of cylinder
- No assessment was made of the possible need for procedures covering the various work operations or for a user manual related to the booster pump
- No conscious choice between replacing or refilling the cylinder
- No routine for having ready-filled cylinders available
- No assessment of the pressure required in the cylinder to maintain its function
- The pressure which the pump could deliver was known, but this was not taken into account
- The activity was not basically safety-critical, since the turbine normally protected by the extinguishing system was out of operation
- Only the risk of disconnecting the safety system was assessed in the WP. Pressure was not identified as a risk.

3) Expertise and quality in the underlying preparations for the work operation

- Limited knowledge in the organisation on the danger of high pressure and the risk of pressurising cylinders
- Lack of knowledge about this type of activity among personnel drawing up the WO, which contained an erroneous description – it specified "refill with CO_2"
- Lack of knowledge among discipline leaders with regard to interfaces/area of responsibility for pressurising this type of cylinder
- Lack of experience with this specific work operation (small cylinder, short time, no manometer, unclear division of responsibility)

4) Lack of documentation

- No technical documentation for the pump
- The relevant pump lacked documentation on requirements for training, use and maintenance
- No traceability of the background for choosing this type of booster pump or possible specifications related to the purchase

- No procedures available for using the pump
- Documentation for the second pump on Heimdal, purchased in 2012, does not correspond with respect to the actual overpressure protection

5) Training

- No documented training – practical, on-the-job learning, but no training in the risk of using the pump
- No awareness of how long pressurisation is expected to take

6) The system design

The points below contributed to the outcome of the incident

- Short hose between gas cylinder and pump – which must stand close to the cylinder to reach the valves
- Not easy to read the manometer at a distance
- No fastening arrangement for the cylinder
- No “warning” or “specific restrictions on use” on the pump

7.2.1 Lack of barriers and assessment of risk

The pump is not equipped with pressure regulation or overpressure protection. However, the delivery pressure can be reduced by adjusting the valve for air intake. That option was not utilised, either in this case or with earlier use of the pump. Reducing the air pressure would mean that the pumping job took longer. The pump is used for various purposes. Based on the list from Equinor, the investigation team sees that the desired delivery pressure for relevant work operations on Heimdal can vary between 150 and 550 barg. If the whole operational range is to be covered by a single pump, it will be an overpressure source in certain of the operations where it is used. As described in section 4.1.2, the pump has a capacity to overpressurise gas cylinders used for manual release of CO_2 in turbine generator rooms.

Based on information which emerged in meetings and interrogations, it appears that knowledge exists in the organisation about the pressure which the pump can develop but that little is known about the danger of high pressure and the risk of pressurising gas cylinders. The lack of barriers against overpressure was not assessed, nor was the need established or assessed for measures to compensate for a lack of overpressure protection when pressurising this type of cylinder. The risk of high pressure and overpressure had not been assessed for similar activities conducted earlier.

Although these 3.4-litre cylinders are seldom pressurised, this is regarded as a routine job. The need for procedures or training related to the activity has not been assessed. When using the tool this pump represents, the executing person represents the only barrier. Training and use of procedures are therefore crucial and would have reduced the probability of such an incident occurring.

The manometer on the pump is the only source of information about the pressure reached in the cylinder being pressurised. No procedure or established practice has been developed which ensures that the manometer is tested before starting the pump. No procedure or establish practice has been established for using the opportunity to adjust air pressure and thereby tailoring the maximum delivery pressure to the individual work operation.

No marking appeared on the pump to specify hazards and possible restrictions on use. Nor was anything done in 2012, when a similar pump was purchased, to assess the risk of using these devices and adapting/securing them for use in different pressure areas.

The actual pressure this cylinder must be at to maintaining its function has not been assessed. When releasing CO_2, the required pressure is lower than the defined requirement of 200 barg. The available pressure from the central network would have been sufficient. It was therefore unnecessary to use this pump to increase the pressure.

7.2.2 Executing the activity – management of the work

The possible risk of using the pump does not appear in the WO or WP, and does not appear to have been known in the organisation. Established practice on Heimdal is that employees who are to do the job choose for themselves whether to pressurise the cylinder or replace it with a pre-pressurised one. This means the choice is made after the WP has been approved and the job has been allocated, and after the possible risk of the work is supposed to be identified and discussed. The need for assistance from other disciplines is thereby not identified and cleared in connection with work planning, but arises as an ad hoc requirement along the way. In this case, the WP specified that the booster pump was to be used in the job and the opportunity to swap the cylinder was not considered.

The WO in this case did not cover the work which was to be done, and the work description referred to adding CO_2 rather than nitrogen gas. In the WP meeting and in connection with planning the following day’s activities, the correct activity was not discussed and it was not handled by the department which had responsibility for the actual execution.

However, it emerged from interviews that the executing personnel were in no doubt that the nitrogen gas cylinder was the one to be pressurised.

7.2.3 Training

The investigation has looked at whether training has taken place with this equipment and, if so, what kind. It cannot establish that any systematic or documented training has taken place on using the booster pump. On Heimdal, the pump is "owned" by the mechanical department and responsibility for filling nitrogen gas cylinders during maintenance or after a test of the extinguishing system has largely rested with mechanics.

No requirement for or practice of systematic or documented training with this pump type has existed on Heimdal or elsewhere in Equinor. The only training which the investigation has become aware of is more the casual "on-the-job" type.

Person 2 had not used the booster pump before. The day before the incident, Person 3 had gained experience of using the pump when they participated with an experienced mechanic in pressurising large fixed nitrogen gas cylinders for the water mist facility. Inquiries indicate that this type of equipment is not included in the training curriculum for industrial mechanics.

By and large, executing personnel such as mechanics and automation technicians know what pressure the pump can provide, but have limited awareness of the possible consequences of erroneous use or faults with the equipment. Supervisory personnel and people in the land organisations appear to have known little about the risk of using the pump.

8 Emergency response

Person 1 immediately alerted the mechanic in the workshop, who in turn notified the central control room (CCR) by phone. A misunderstanding about the incident site meant the nurse arrived quickly and could start treatment immediately. The nurse thought the incident was in the mechanical workshop, and therefore did not take time to don personal protective equipment. It was not until they arrived at the workshop that it became clear that the incident had occurred out in the process area.

Two of those involved in the incident were part of the first-aid team, but the nurse mobilised members of another response team with first-aid competence. Both the injured people were eventually taken to the hospital for further treatment. The duty doctor participated via video to provide advice and support for the nurse.

A SAR helicopter came from the Tampen area response organisation and a Sea King from Sola. The Oseberg SAR was on land because of work on the hangar and the Tampen SAR was therefore quickest. The Johan Sverdrup SAR, which is the closest resource, encountered problems with its hydraulics when it attempted to take off for Heimdal.

One of the injured was airlifted to Stavanger University Hospital and the other to Haukeland University Hospital. Person 2, who was critically injured, arrived at the hospital on land about two hours and 50 minutes after the incident, which is within the effectiveness requirement of three hours set by Norwegian Oil and Gas guideline 064 for injuries in this category.

The Joint Rescue Coordination Centre (JRCC), Equinor second line and the PSA were notified in accordance with the applicable response plan. Crisis personnel were dispatched to Heimdal that evening. A psychologist, a North Sea chaplain and two offshore nurses went offshore to assist the organisation on board.

In the investigation team's view, the response on the facility functioned well. It has not assessed the work or organisation of the operator's emergency response organisation on land since this fell outside its mandate.

9 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.

9.1 Nonconformities

9.1.1 Inadequate safety clearance of activities

Nonconformity
The assignment received insufficient safety clearance before the work began.

Grounds

- The personnel drawing up the WO lacked sufficient knowledge of the activity to be carried out, resulting in an inadequate work description and permit. This was not picked up by the WP meeting the day before the activity was executed.
- The WP described the use of a "hand tool nitrogen booster set". This could have resulted in the work team choosing not to fetch a ready-filled cylinder from store.
- The activity was initially allocated to the mechanical department before being transferred to the automation department. The mechanical unit had ownership of the booster pump, while automation held the key to the cabinet where the cylinder was located. Responsibilities for using the pump during pressurisation were unclear.

Requirements
Section 30 of the activity regulations on safety clearance of activities
Section 21 of the activity regulations on competence

9.1.2 Lack of barriers against overpressure

Nonconformity
Insufficient barriers were established to prevent overpressure of the nitrogen gas cylinder.

Grounds
Pressurisation of the nitrogen gas cylinder was done using a pump which can deliver pressures far above the design and test pressures for the relevant cylinder.

- No overpressure projection was installed on either cylinder or pump.
- The only barrier against overpressure was manual monitoring of the manometer on the pump. No routines or procedures were established for testing the manometer ahead of the pressurisation process.
- No routines were established for regulating air pressure in line with requirements.

Requirements
Section 5 of the management regulations on barriers
Section 10 of the facilities regulations on installations, systems and equipment

9.1.3 Lack of competence

Nonconformity
Competence was lacking in using the booster pump and pressurising nitrogen gas cylinders.

Grounds
Using this type of booster pump for pressurising gas cylinders involves substantial risk, and errors can have major consequences for the health and safety of personnel and for the facility. On Heimdal:

- no competence requirements were set for this type of work operation
- no training requirements were set for using the booster pump
- knowledge and awareness were lacking about the relationship between maximum pump pressure, cylinder design pressure and the possible consequences of overpressure in the cylinder.

Requirement
Section 21 of the activities regulations on competence

9.1.4 Inadequate planning and risk assessment

Nonconformity
Important contributors to risk were not identified and dealt with when planning and using the booster pump to pressurise nitrogen gas cylinders.

Grounds
The booster pump has been regarded on Heimdal as a tool. Based on information obtained from meetings and interviews during the investigation, it appears that the pressure the pump could deliver was known but that the risk and possible consequences of overpressure had not been assessed. That relates to procurement of the pump, assessing its areas of application, defining the need for training and executing individual jobs.

- A WP level 1 had been prepared for the relevant job because a safety system was disconnected. Pressure was not treated as a risk in the WP, and it was explained in interviews that using the pump and pressurising gas cylinders was regarded as a routine job. Using the pump for pressurisation is described in the PM programme for the system. It emerged from interviews that this type of cylinder is very seldom pressurised with a booster pump. Up to 10 years could pass between each time a shift did this type of job. There was therefore little experience and no established routine. The job differs from pressurisation of other gas cylinders in part through the way the pressure is monitored and the short time needed to pressurise.
- Spare cylinders are available, but replacing the cylinder rather than pressurising it was not assessed when planning or executing the work.
- The pump can be supplied with overpressure prevention – it is not known whether this was assessed at the time of purchase.
- Procedures and documentation for the CO_2 system specify that this type of cylinder must be pressurised to 200 barg if the weekly round observes the pressure is below 100 barg. The actual pressure required for the cylinder to perform its intended function of releasing CO_2 is lower than 200 barg and could have been reached by refilling from the central nitrogen gas network. This has not been assessed.
- No toolbox talk or the like was conducted by the executing work team before the job started. The WP was signed to show the talk was carried out.

Requirements
Section 4, paragraph 1, of the management regulations on risk reduction
Section 27 of the activities regulations on critical activities

9.1.5 Lack of procedures and routines

Nonconformity
The WO and WP do not describe what was actually to be done in the relevant activity.

Grounds
The booster pump was described as a tool in both interviews and meetings during the investigation. No user manual was available for the pump. Because this was delivered in 2002, it has not been possible to verify whether a manual was provided at the time. Equinor as employer has failed to ensure that the necessary information was provided on safe use of the work equipment which the employees were assigned to work with. User manuals are not available for this type of pump on other Equinor facilities either.

Requirement
Sections 10.4 and 10.5 of the regulations concerning the performance of work, use of work equipment and related technical requirements

10 Discussion of uncertainties

The investigation has encountered a number of uncertainties.

- **Possible faults in the pump (including manometer) and/or gas cylinder**
  Some unclear explanations have been given about the manometer on the booster pump. This showed 70 bar after the incident, and it is uncertain whether that was where it stopped during pressurisation. The pressure when the cylinder burst is uncertain. It is also uncertain whether the cylinder had weaknesses which caused it to burst before the maximum pressure it could handle was reached. How long the pressurisation lasted is not known. The technical investigations will hopefully provide answers here.

- **Specifications and documents for the pump**
  Uncertainty prevails about the requirements specified when the pump was purchased, and what documentation accompanied its delivery. That concerns documentation both for using the pump and risks associated with its use.

- **Date for annual certification of the pump**
  The pump with manometer should have been sent ashore in October 2019 for its annual certification and calibration. It is uncertain what significance this had for the incident but, since uncertainty prevails about a possible fault with the manometer, it could have been of significance. The investigation team hopes the technical investigations can provide answers about the condition of pump and manometer.

- **Personal injuries**
  It is uncertain whether Person 3 was hit by the pump or a projectile from the cylinder.

11 Other conditions

11.1 Similar incidents

The team is not aware that similar incidents involving the use of booster pumps have occurred in the petroleum industry. Through its follow-up of incidents, it is aware of incidents caused by pressurised nitrogen gas where equipment of different pressure classes or without overpressure protection have been connected.

11.2 Requirements for booster-pump design, manufacture and documentation

Appendix 1, section 1.1.2 b to the machinery directive provides clear guidelines for machinery design, manufacture and documentation. It emerges clearly from the regulations that the machine (pump) must be accompanied both on delivery and with later updates by a user manual containing information on necessary training, use and maintenance. These elements should be part of the risk assessment for the use of this machine.

Training requirements are also set by sections 10.4 and 10.5 of the regulations concerning the performance of work, which also apply to the petroleum sector. The guidelines to section 21 of the activities regulations refer to the regulations concerning the performance of work:

> Section 10-4
> The employer shall ensure that the employee receives the necessary training in the specific work equipment he or she is going to use. The training shall be adapted to the nature of the work equipment and shall ensure that the employee knows how to use the work equipment safely. Written documentation shall be provided confirming what work equipment the employee has received training in, who has provided the training and who has received it.
>
> Section 10-5
> The employer shall ensure that necessary information is provided about safe use of the work equipment that is provided for the employees in their work.
> In particular, the employer shall ensure that the employees are kept informed about the following:
> a) the risks they are exposed to when using the work equipment, including risks associated with possible irregularities
> b) precautions that, based on experience, they need to take when using the work equipment
> c) dangers caused by nearby work equipment

d) dangers caused by changes to nearby work equipment.

11.3 Requirements for checking and filling gas cylinders

The PSA's regulations do not set specific requirements for filling, handling and checking small pressure vessels like these gas cylinders. The regulations expect that these activities meet the same standards applied in land-based industry. The normative guidelines for land-based industry and transport are covered by the regulations on transportable pressure equipment and on land transport of dangerous goods.

11.4 Equinor's investigation report

Equinor itself investigated the incident on Heimdal and issued a preliminary report on 13 March 2020 while awaiting the outcome of the technical investigations.

This report is detailed. Its authors have reviewed, for example, the technical requirements for manufacturing and testing the nitrogen gas cylinder, and will also test similar gas cylinders.

To some extent, the Equinor and PSA reports emphasise different factors as underlying causes of the incident.

- Both reports emphasise the lack of barriers against overpressure.
- Equinor's report emphasises that the pump was untagged and that this could be the reason for the lack of user manual, annual inspection and training. The PSA considers that training was also inadequate for the similar pump (acquired in 2012), which was tagged.

Equinor has identified many lessons learnt from the incident in its preliminary report. The following are some of the most important.

- Eliminate the need to use the gas booster pump in refilling nitrogen where possible.
- Improve the quality of WPs.
- Increase safety when using a gas booster pump.
- Increase safety when filling gas cylinders from the distribution network or other cylinders.
- Increase safety when using pressure cylinders.

11.5 Safety alerts

Equinor produced a preliminary safety alert on 3 December 2019 with the most important lessons learnt from the incident. This was distributed internally in the company and to Norwegian Oil and Gas so that other companies in the latter's network could learn from the incident. The safety alert was updated on 22 December 2019 and redistributed both internally and to Norwegian Oil and Gas. However, the information has not been shared with other relevant players, such as the supplier industry through the Federation of Norwegian Industries. That also applies to the manufacturer of the equipment used in the incident. These potential recipients have not been informed in a managed way in order to prevent similar incidents within their area of responsibility.

12 Appendices

A: The following documents have been utilised in the investigation

- POB report, 25 November 2019
- Work order 25001518
- N_2 operations procedure SO08349-Opr, 4 July 2018
- N_2 system description SO08349, 2 August 2018
- Compressed air operations producer SO09372-Opr, 2 August 2019
- WP level 1 9509180998
- Emergency response report Heimdal, 28 November 2019
- Emergency response logs, first line, operations manager, offshore air and CIM log
- Image of board in emergency response room
- EP programme CO_2 system
- Function tests operation
- Inspection of CO_2 system
- Overview of maintenance jobs, N_2 cylinders for CO_2 system
- P&ID N_2 area, 32-1A-ABO-C78-10195, 32-1A-REV-C78-59050, 32-1A-REV-C78-59040, 32-1A-ABO-C78-10405
- P&ID CO_2 skid, 32-1A-FAB-F78-10350
- Organogram Heimdal 10 June 2016
- Calibration certificate manometer booster pump
- Synergi 1498922
- Buddy programme
- OM104.05.01 Reception new personnel offshore – upstream offshore
- Buddy. Criteria for nomination of buddy
- Emergency preparedness on the NCS – Heimdal, 9 August 2019
- Curriculum for industry mechanics, Upper Secondary 3, valid from 1 August 2009
- Training logs for those involved
- PM recertification of pressure cylinders
- Service report for recertification of N_2 gas cylinders, Sontum 2015
- Overview HMP1 main deck
- List of WPs, 28 November 2019

- Pump, service and calibration, 2017 and 2018
- Function tests, water mist system, HEM 806 and 805
- Description of HEM
- WO with WP: 24566123, 2378368, 23040966 and 22211923
- Overview of equipment with N_2 and relevant pressure
- Safety reports, preliminary 3 December 2019 and final version 20 December 2019
- Presentation from meeting 17 December 2020
- Use of supplier PM for recertification of pressure cylinders
- Supplier documentation Proserv, 32-1A-REV-M87-80004
- OM105.01 Work process WP – upstream offshore
- SO08204 – system independent – work not requiring a WP – Heimdal
- Organisation, management and control (OMC), OMC01

B: Overview of personnel interviewed