Havtil
Havindustritilsynet

Investigation report

Report	
Report title Report of the investigation into a gas leak at Hammerfest LNG on 31 May 2023	Activity number 001901051

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☐ Public	☐ Not publicly available

Involved	
Team T-L	Approved by/date [redacted] 29 February 2024
Members of the investigation team [redacted]	Investigation leader [redacted]

Contents

1 Summary

A gas leak occurred on 31 May 2023 at Equinor’s Hammerfest LNG (HLNG) plant.

Located in area G on the process barge, this incident involved the cooling medium system for subcooling of liquefied natural gas (LNG).

The cooling medium for subcooling is a closed circuit, where the medium comprises 53% methane, 35% ethane and 11% nitrogen. This medium is liquefied under the operating conditions at the leak point of about 43 barg and -151°C.

The incident occurred when removing insulation from a one-inch piping segment upstream of a safety valve, which was due to be taken out for planned recalibration. This valve was connected to the cavity of a manual valve in the cooling circuit.

Insulation workers at the site detected the leak, which was confirmed by the area technician. The central control room (CCR) was notified and immediately initiated general and evacuation alarms. Shortly afterwards, it announced over the PA system that all personnel had to evacuate the inner industrial area at HLNG. Ignition-source disconnection was also initiated from the CCR. The gas detection system initiated no automatic actions during the incident, since the detectors close to its location initiated no alarm.

A modular (compact DB&B) valve is located in the line upstream of the safety valve to isolate towards the cooling system when removing the latter.

The direct cause of the leak was that the bleed plug on the bleed line in the modular valve stood in the open position at the same time as the actual bleed valve was a little open. The latter had probably been moved a little during the insulation removal process.

The bleed plug (anti-blowout type) involved in the incident is left-hand threaded. That differs from the plug type normally found at the plant and has to be screwed out to close.

Since the valve arrangement and bleed plug were enclosed in insulation, the natural conclusion is that the plug has been open since the most recent calibration of the safety valve in 2021. With the plug screwed in, detecting that it remains open is not easy for someone not familiar with its type.

Following the incident, Equinor has established that the plant has six bleed plugs of this kind. A search of the company’s own incident database has also identified several earlier incidents related to bleed plugs in the wrong position.

Equinor established three possible plans for dealing with the incident.

- Plan A: enter the area with smoke divers and place the manual valve in fully open position, which would close the connection between the valve cavity and the process medium through the valve and thereby halt the leak.
- Plan B: manually reduce pressure in the cooling circuit by isolating parts of it and moving/draining the liquid, followed by placing the manual valve in the fully open position when the pressure in the circuit was sufficiently reduced.
- Plan C: initiate ESD and pressure blowdown.

Plan A was initiated and personnel began to enter the area, but were halted when CCTV images showed a possible increase in the gas leak. As a result, plan B was implemented to handle the leak.

The actual consequence of the incident was a gas leak lasting about 6.5 hours. Its estimated quantity was in the order of 9 300 kg with an initial rate of 0.8 kg/s. No permanent harm to personnel has been identified, but one person was followed up by a nurse after being sprayed with cold cooling medium. The plant was shut down for eight days as a result of the incident.

In connection with its investigation, the Havtil team engaged Safetec to carry out a simplified dispersion analysis of a gas leak with the same initial operating conditions as the incident.

This showed that the gas would thin out rapidly given the wind speed at the time of the incident. The team has therefore concluded that ignition or explosion was unlikely. Both when the incident occurred and during the response to it, a potential existed for further exposure of personnel.

The open bleed plug was a hidden fault which could have had a different outcome if the leak had not occurred. This plug is included in the activity for verifying depressurisation before opening the system and demounting the safety valve. Unfamiliarity with the plug's function could have resulted in the system being opened without being depressurised.

As part of its investigation, the team has assessed direct and underlying causes of the incident as well as the response. It has also examined available safety systems for exposing and dealing with the incident.

The investigation has identified nonconformities related to:

- knowledge about and documentation of equipment components
- procedures and training
- gas detection
- dealing with barrier impairment
- documentation
- inadequate radio communication in the response/smoke-diving team
- inadequate warning system – PA system in Oddasit building.

Furthermore, an improvement point has been identified related to:

- inadequate documentation on and description of preparing risk assessments and tactical emergency response plans.

1.1 Other information

The Petroleum Safety Authority Norway (PSA) changed its name on 1 January 2024 to the Norwegian Ocean Industry Authority (Havtil). This report accordingly refers to the PSA before 1 January and Havtil after that date.

2 Background information

A gas leak occurred at Equinor's onshore plant in Hammerfest on 31 May 2023 during the removal of insulation from piping upstream of a safety valve in the cooling medium circuit for LNG subcooling.

2.1 Description of plant and organisation

HLNG is a reception and processing plant for natural gas and condensate from the Snøhvit field (Snøhvit, Askeladd and Albatross) in the Barents Sea. On stream since 2007, it was developed by and is now operated by Equinor (formerly Statoil).

This facility stands on Melkøya island off Hammerfest. Access is via an underwater road tunnel from Meland on the mainland, where reception and security for access control of personnel and vehicles are located.

Production from Snøhvit is piped 143 km from subsea installations to HLNG, which has systems for processing the wellstream as well as for storage and loading. End products are LNG, liquefied petroleum gas (LPG) and condensate. These are stored in tanks for loading into vessels or road tankers for onward transport.

HLNG is part of Equinor's marketing, midstream and processing – onshore plants (MMP OPL) organisation. Each of its plants has its own production team (PRO) and units for maintenance (MAIN), projects (PPC) and technical support (TPO).

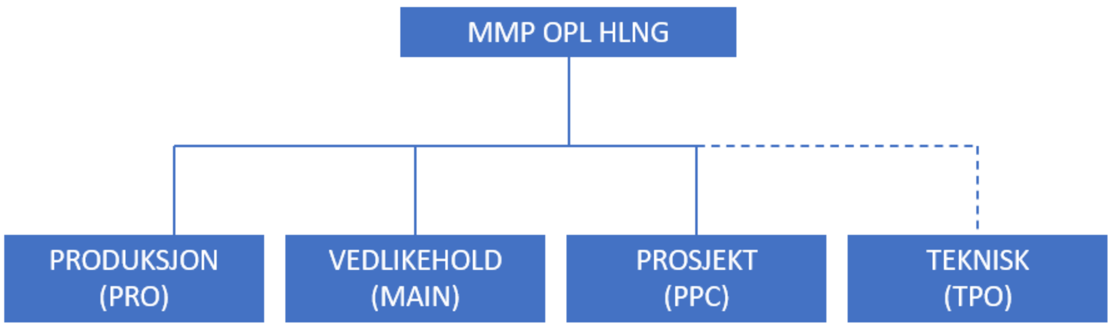


Figure 1 Simplified organisation chart for HLNG.

2.2 Position before the incident

The plant was operating normally before the incident, with a number of activities ongoing.

One of these activities was the removal of insulation from a piping segment upstream of a safety valve in the cooling medium circuit for LNG subcooling. This was required in order to take out the valve for planned recalibration. Work was also ongoing to start a turbine in the subcooling circuit.

A modular-type isolation valve – a compact DB&B with bleed plug on the bleed line – is installed on the line upstream of the safety valve. A gas leak was discovered in connection with the insulation removal work, and the bleed plug was subsequently found to have been in the open position.

One line gas detector in the area was faulty ahead of the incident. Another detector registered the fault message *dirty optics* over a lengthy period before the incident.

2.3 HLNG area where the incident occurred

The incident occurred in area G on the process barge, where equipment for cooling down the natural gas is positioned. The leak arose in the cooling medium circuit for subcooling the LNG.

2.4 Abbreviations

C&E	Cause and effect diagram
CCR	Central control room
CCTV	Closed circuit TV
CIM	Crisis management system
DB&B	Double block and bleed
DSHA	Defined situations of hazards and accidents
ERT	Emergency response team (first line)
ESD	Emergency shutdown
Flir	Forward-looking infrared (camera)
GA	General arrangement (drawing)
Havtil	Norwegian Ocean Industry Authority
HLNG	Hammerfest LNG
IMT	Incident management team (second line)
IR	Infrared
LEL	Lower explosive limit
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
PA	Public address (system)
P&ID	Piping and instrumentation diagram
PS	Performance standard
PSA	Petroleum Safety Authority Norway
SV	Safety valve
WP	Work permit

3 Havtil's investigation

The PSA was notified by Equinor about the HLNG incident at 19.29 on 31 May 2023. A meeting took place on 1 June 2023 where Equinor provided a briefing on the incident. The PSA decided on the same day to launch an investigation, and the police requested its support for site inspection and investigations after the incident.

3.1 The investigation team's mandate

The following mandate was adopted for the investigation team.

a. Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes the timeline and events)
b. Assess the actual and potential consequences
c. Assess direct and underlying causes
d. Assess the response to the incident, including interaction with external emergency services
e. Identify nonconformities and improvement points related to the regulations
f. Discuss and describe possible uncertainties/unclear aspects
g. Discuss barriers which have functioned (in other words, those which have helped to prevent a hazard from developing into an accident, or which have reduced the consequences of an accident)
h. Assess Equinor's own learning and experience transfer from earlier incidents
i. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template
j. Recommend – and normally contribute to – further follow-up

3.2 The investigation team

The investigation team was established and some members travelled to Hammerfest on 1 June 2023 to support the police inspection of the incident site. The rest arrived in Hammerfest on 5 June 2023 for interviews, further inspection and meetings.

Composition of the investigation team

- [redacted]

3.3 Methodology

The investigation was conducted through interviews of personnel in the HLNG operations organisation, verifications and plant inspections and reviews of governing documents relevant to the incident. The SAP maintenance system for the equipment involved was also reviewed. Follow-up conversations were conducted via Teams.

To assess the potential of the incident and of the gas detection system, a simplified gas dispersion analysis was carried out by Safetec as part of the investigation. This was intended to provide an indication of the size of the detectable and ignitable cloud and to identify important factors which must be considered when designing a gas detection system in order to detect cooling medium/LNG leaks. More details about the preconditions for the analysis and its results are provided in section 5.2.

4 System descriptions

4.1 Overall description of the subcooling circuit, including the PSV arrangement with upstream valve

4.1.1 General

Gas liquefaction involves three cooling cycles. First comes a precooling, where the heaviest components are separated out, followed by cooling of the light components to liquefaction. The final stage is subcooling of the LNG.

Three separate cooling medium circuits serve the individual cycles in this process.

The incident occurred in the cooling medium circuit for LNG subcooling. This is a closed circuit carrying a blend of 53% methane, 35% ethane and 11% nitrogen. A simplified description of the subcooling circuit is provided below.

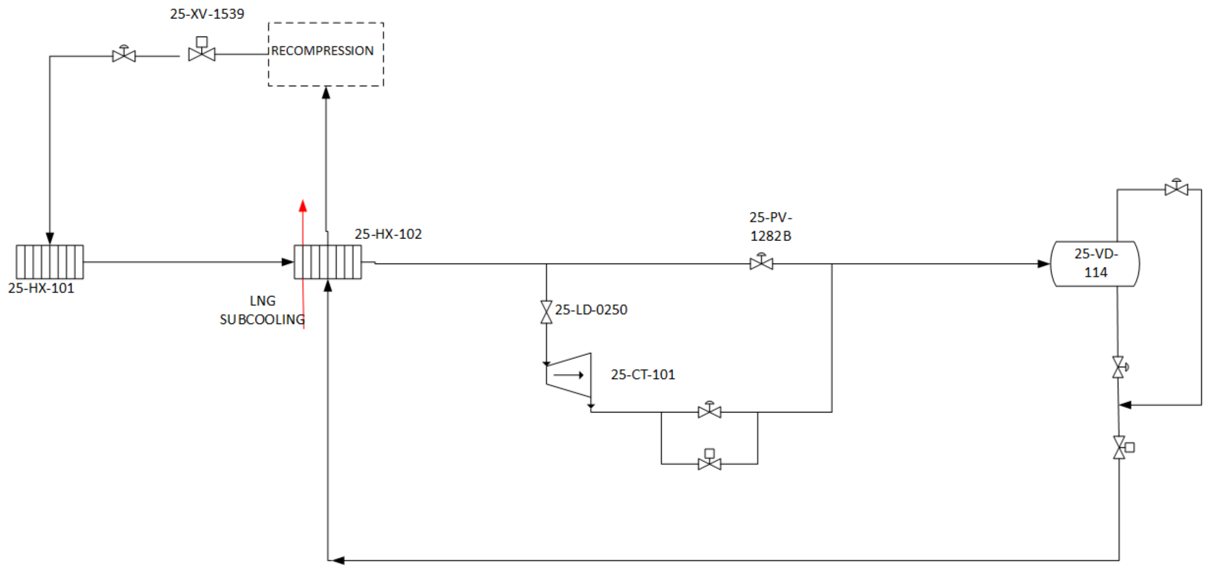


Figure 2 Simplified diagram of the cooling medium circuit.

The liquid cooling medium is held in the *subcooling cycle refrigerant receiver* (25-VD-114) under a pressure of about 3.1 barg and a temperature of -157°C. It flows from there to the shell side of subcooler 25-HX-102, where the process stream (LNG) is subcooled.

Heat exchange over the subcooler causes the liquefied cooling medium to evaporate, and it is sent in a gas phase to the compression system where it passes through a two-stage recompression before being cooled with seawater. The cooling medium is recondensed via heat exchange against one of the other cooling circuits (which liquefies the process stream) in 25-HX-101.

Now in liquid phase, the cooling medium is further subcooled through a countercurrent exchange in 15-HX-102.

The final stage in the cooling medium circuit once again involves reducing the pressure to 3.1 barg, via either valve 25-PV-1282B or turbine 25-CT-101. The latter is connected to an electric generator feeding the plant’s power grid. If the pressure is reduced over the turbine, the final pressure reduction will occur over a valve.

As described above, temperature and pressure conditions differ in the closed circuit. Where parts of the circuit are concerned, the need to maintain low temperatures will require particularly good insulation. Some of the equipment is thereby mounted together in an insulated cold box. That applies to components 25-HX-101, 25-HX-102 and 25-VD114.

A manual double expanding gate valve (25-LD-0250) is installed upstream of turbine 25-CT-101. This will be placed in the closed position when the turbine is not operating. At the time of the incident, the turbine was non-operational but preparations were under way to start it up. These were practically complete, so that the valve was in the open position when the incident occurred.

To handle thermal expansion of the enclosed volume in the cavity of the manual valve, a safety valve (SV) connected to the valve cavity is installed. This was the valve to be removed for recalibration.

A modular valve (compact DB&B with a needle type as the bleed valve) is installed on the line upstream of the safety valve. A bleed plug is installed in the bleed line. This is an anti-blowout type and left-hand threaded.

The figure below provides a simplified diagram of the valve arrangement upstream of the safety valve, and its components are described in more detail in chapter 4.1.2.

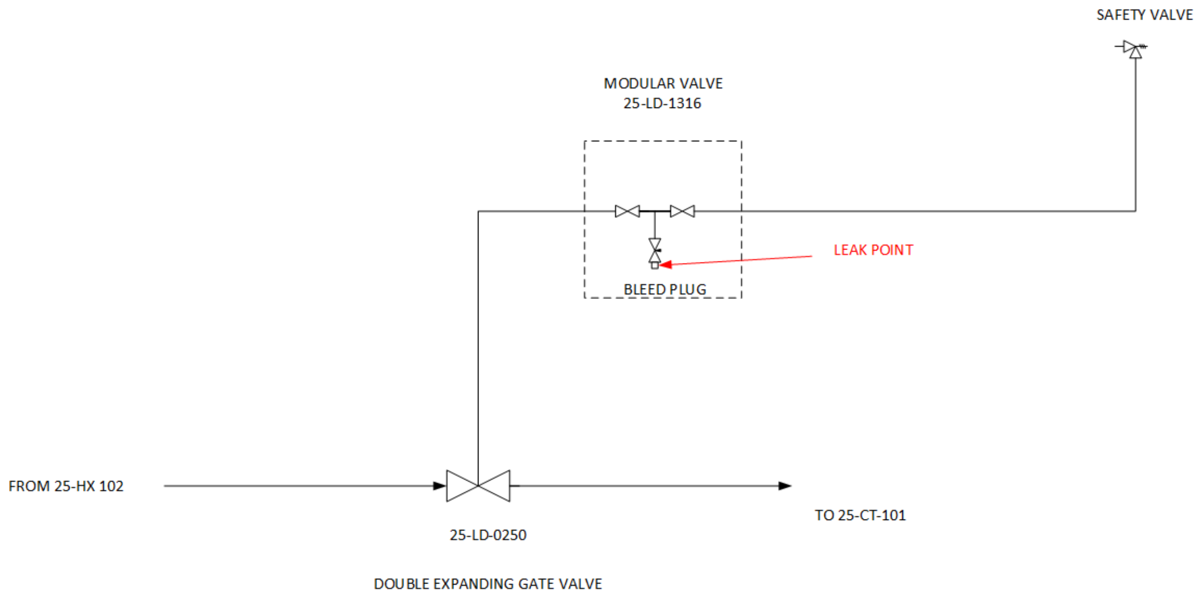


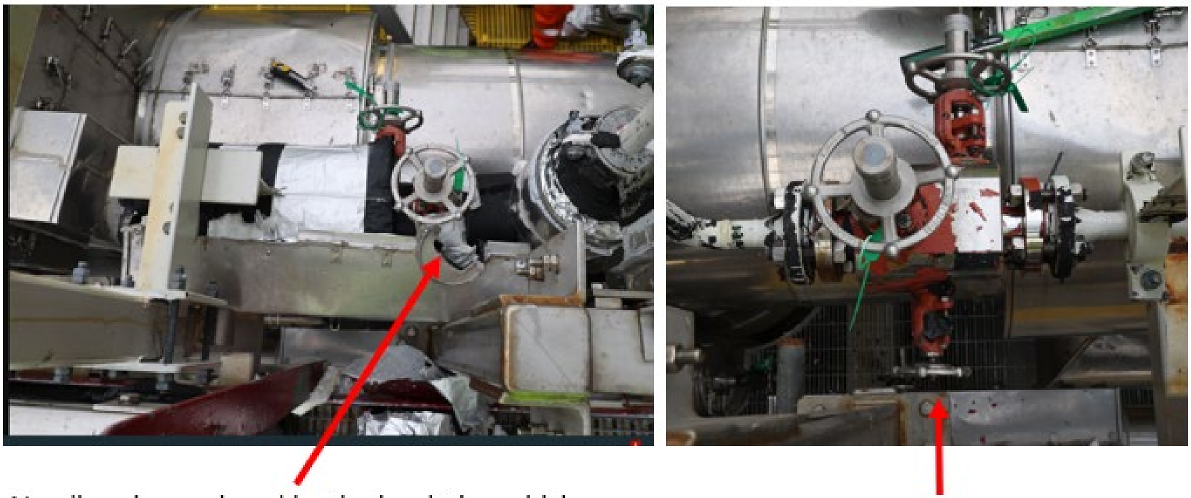
Figure 3 Simplified diagram of the safety valve and upstream valve arrangement.

The piping segment upstream of the safety valve was modified in 2017 because of challenges with a screwed connection. Preparatory work for this job began in 2014.

Recalibration of the safety valve takes place every other year, and the last time it was removed for this purpose was in 2021 (before the incident).

The piping upstream of the safety valve is insulated and the valves, with the exception of their wheels, are enclosed in this insulation. That includes the bleed plug. Stripping insulation from the piping upstream of the safety valve was under way when the leak was discovered. After the incident, the bleed plug was found to be in the open position. The needle valve upstream of the plug has probably been moved somewhat in connection with insulation removal. See chapter 11. Operating conditions in the cooling medium at the leak point were about 43 barg and -151°C, with the medium in the liquid phase at this point.

The photographs below show the area around the needle valve.



Needle valve enclosed by the insulation which was removed during the ongoing job. The needle valve itself is not visible in the photo. The area around the insulation box which was going to be removed was very restricted.

Needle valve without insulation box.

Figure 4 The photo on the left shows the insulation box enclosing the needle valve. The opening for the valve wheel is not shown. The needle valve was tightly enclosed in insulation and conditions were restricted around the box being removed. The right-hand photo shows the needle valve after removal of the box. Source: police force.

4.1.2 Components involved

4.1.2.1 Double expanding gate valve (25-LD-0250)

The manual valve is a double expanding gate type. It is normally open, providing communication between the flow medium and the valve cavity. When the valve is closed or fully open, a seal can be created between cavity and flow channel so that the medium is not in communication with the cavity – known as putting the valve in the back-seat position.

Cooling medium which is subcooled and in liquid phase will expand as the temperature rises. The safety valve is connected to the valve cavity to handle thermal expansion of the volume enclosed in the latter.

Pursuant to HLNG procedures, the safety valve can be removed when the plant is operating, providing the manual valve is normally in the open position.

4.1.2.2 Isolation valve upstream of the safety valve with bleed plug (25-LD-1316)

In normal operation, the isolation valve upstream of the safety valve is secured in the open position and will only be used in connection with recalibration or maintenance of the safety valve. The bleed (needle) valve and the bleed plug in the compact valve will normally be in the closed position. The bleed system is used to ensure the system has been depressurised before valve removal.

The photo below shows the compact valve.

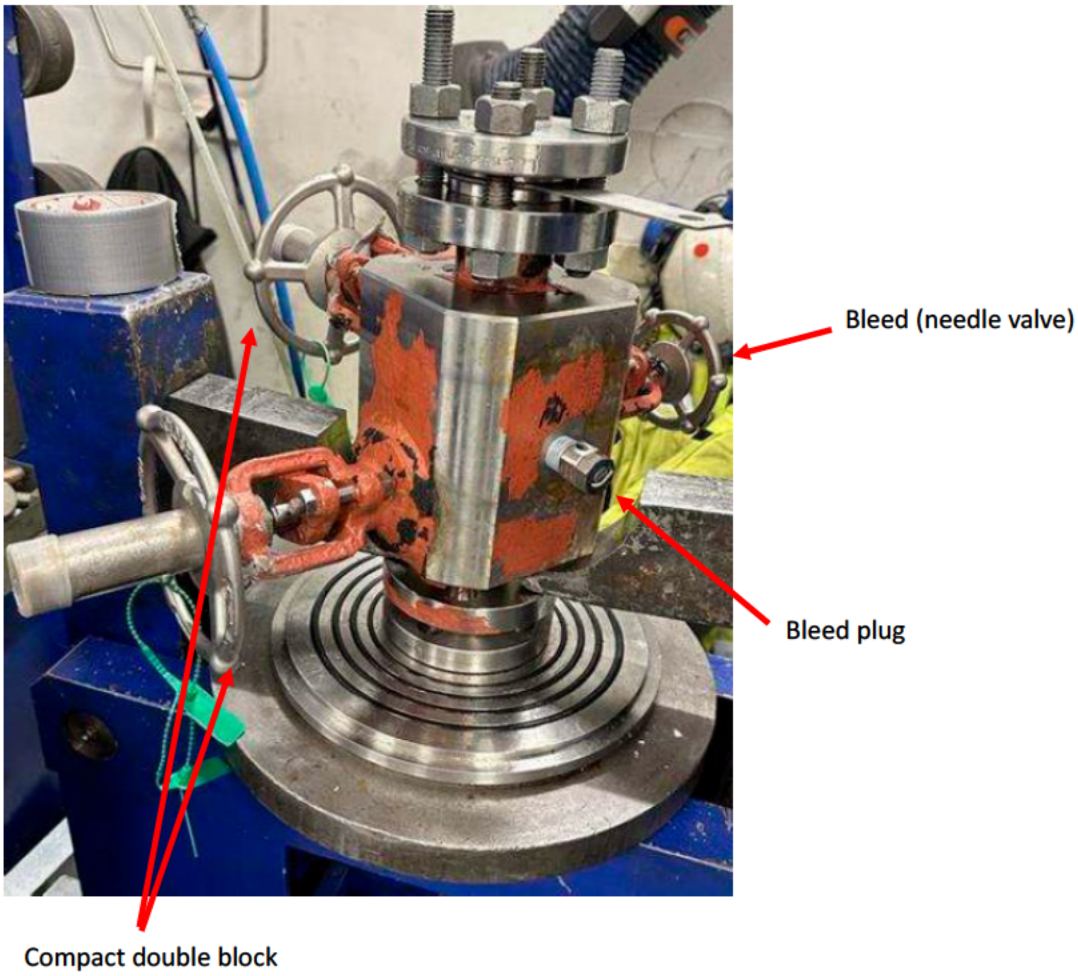


Figure 5 Modular valve upstream of the safety valve. Source: Equinor.

The bleed plug involved in the incident was an anti-blowout type and left-hand threaded. This kind of plug must be screwed out to close it.

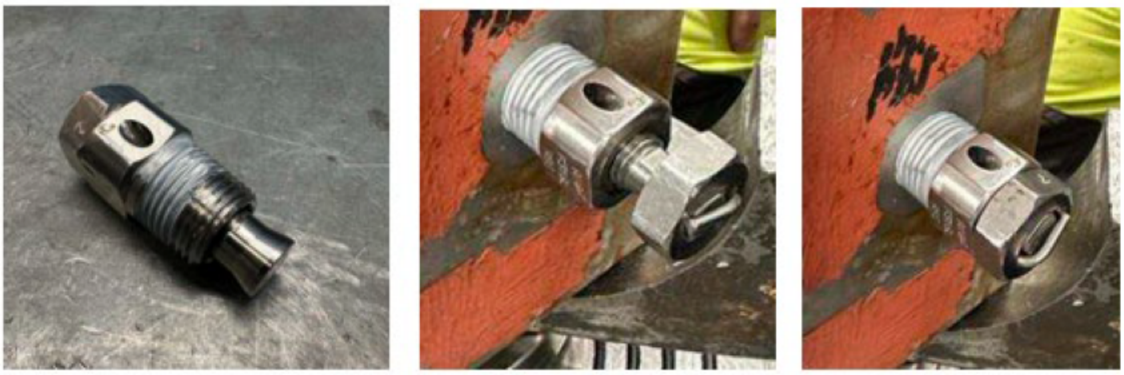


Figure 6 Left: The type of bleed plug used. Centre: The bleed plug in closed position. Right: the bleed plug in open position. Source: Equinor Synergi 2531047 external HC leak in area G.

4.2 Cooling medium/LNG leaks

As described above, the cooling medium is a blend of hydrocarbons and nitrogen, with higher contents of ethane and nitrogen than in the LNG produced at HLNG. It comprises 53% methane, 35% ethane and 11% nitrogen.

Methane and ethane are gaseous at room temperature and atmospheric pressure.

Operating conditions for the cooling medium at the leak point were about 43 barg and -151°C. At this pressure and temperature, the medium is liquefied.

As part of the Havtil investigation, a simplified dispersion analysis was conducted by Safetec. This found that no liquid pool is expected to form at the estimated leak rate for the cooling medium because sufficient air becomes entrained to vaporise the drops before they have the opportunity to collect in a pool. The temperature of the gas/air mix is lower than the ambient air, so that it has a higher density and will sink.

This also applies for produced LNG, which primarily comprises methane, even though the latter has a substantially lower mole weight (16 g/mol) than air (28.96 g/mol). The temperature of the methane/air mix becomes so low that it counteracts the effect of the lower mole weight compared with air, and the mix thereby acquires a higher density than the ambient air and will sink.

The main findings of the dispersion analysis are presented in section 5.2.

4.3 Managing gas leaks

4.3.1 General

Equinor has produced guidelines for managing hydrocarbon leaks at HLNG (GLO744 – *Guidelines for managing HC leaks)*. These describe the expected pattern of behaviour in responding to hydrocarbon leaks. The anticipated response is assessed in accordance with a factor calculation. The factor is a numerical value which sums up the number of gas detectors and their detection level. A matrix has been developed on the basis of calculated factor values which illustrates the interventions to be made. The defined options in this matrix are:

- activate ESD
- controlled running down of all or part of the plant
- continuous assessment of the position.

Had the gas leak ignited and developed into a fire scenario, fire monitors in the vicinity of the area would have provided fire-water coverage.

4.3.2 Pressure blowdown and drainage of the subcooling circuit

As described in the previous section, the response to a detected hydrocarbon leak above a certain size will be either to initiate ESD in the relevant area or to launch a controlled run down of the plant without resorting to ESD.

At HLNG, ESD and blowdown for most systems are initiated manually via buttons in the CCR. The plant is divided into various zones for this.

A brief description of the system for ESD and blowdown of the subcooling circuit is provided below.

The process barge where the incident occurred forms ESD group 2, which is further divided into various sections/subsections. As described in section 4.1.1, subcooling is a closed circuit and this is defined separately as section 5 in ESD group 2.

A chapter on system protection is included in the description of system 25, which includes the subcooling circuit. This specifies in the introduction that "the ESD and pressure blowdown system is used to minimise leaks of flammable liquids in emergencies or in the event of plant damage in order to prevent such risks as fire or explosion".

The system response after initiating ESD 05 and blowdown is described in C&E and project documentation.

Earlier studies have revealed that some segments will be left pressurised after ESD with subsequent blowdown. A memorandum was produced for the response management in the autumn of 2022 to highlight which segments are involved.

The simplified diagram below indicates which valves in the cooling medium circuit will close with ESD 05 (blue) and which blowdown valves (BDVs) will open with subsequent blowdown. Piping and equipment marked in green will remain pressurised after ESD and blowdown have been completed for segment 5.

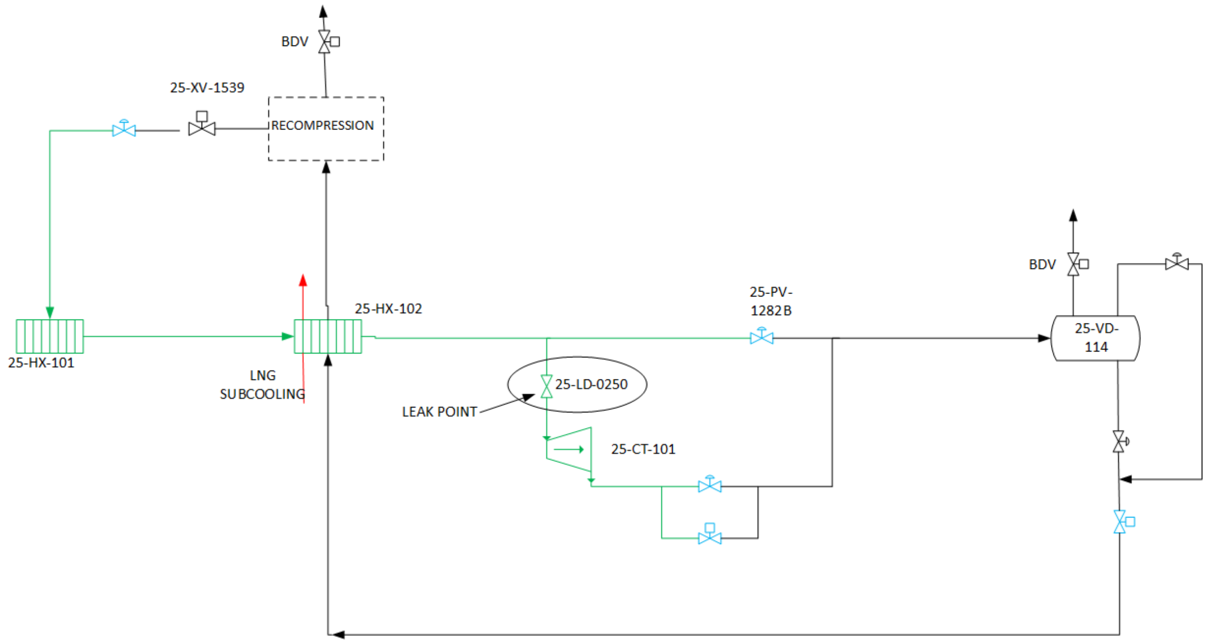


Figure 7 Diagram showing interventions in the event of ESD/blowdown of the cooling circuit.

The actual leak point is in a segment which will remain pressurised after ESD with subsequent blowdown.

ESD 05 was not initiated in connection with the incident.

4.4 Description of gas detection – philosophy/coverage

4.4.1 Gas detection at HLNG

According to the safety strategy and system description (fire and gas) for HLNG, the philosophy for gas detection is that the system will give fast and reliable notification if gas leaks are detected in the plant. It will initiate an alarm to the CCR operator and personnel in affected areas. The alarm must give operators the opportunity to control the position and limit the extent of damage. Gas detectors must be installed in all areas where flammable gases could arise.

TR2237 *Performance standards for safety systems and barriers – onshore* describes requirements for gas detection, including standards for rapid and reliable identification of flammable gases, which types of detectors are to be used in various areas, positioning of detectors in relation to gas properties (heavy/light), and documenting design choices based on the assessment of possible leak scenarios in each area.

In the HLNG design phase, the performance standard set for gas detection was that hydrocarbon leaks of 0.5 kg/s in an open, naturally ventilated area must activate a detector alarm in 95 per cent of cases. See the fire and gas detection engineering report.

4.4.2 Gas detection in the area

Infrared gas detectors – both line and point – are used at HLNG. The former is the preferred type, used for detection on the periphery of the area.

Intended to detect possible gas leaks over large areas, line detectors comprise a transmitter which sends an optical (infrared) beam to a receiver. The latter will register possible absorption of radiation in the beam along the infrared spectrum and convert this to the gas concentration in LELm.

Point gas detectors are used in addition at strategic locations close to equipment where leaks are likely to occur. These devices detect at their installation point, which means that the gas must make physical contact with the detector to be measured.

Confirmed gas detection in open areas corresponds to a single detector giving an alarm, with an alarm limit of 1.0 LELm for a line detector and 10% LEL for a point detector. Automatic actions following confirmed gas detection include alarms in the CCR and the plant as well as ignition-source disconnection of non-critical sources.

The detectors in the area around the leak point were located high above the grating. See figure 8 below for more specific heights.

In area G (CAG1 level 4), where the incident took place, line gas detectors are positioned not only on the periphery but also within the area itself. Point gas detectors are also installed. The simplified diagram below shows gas detectors near the leak point. Of these, the closest to the leak point is line detector no 1 (height over grating about 2.6 metres). The closest point gas detectors (nos 5 and 6) are installed on a platform at a level above (to the side of) the area around the leak point. Detectors with a red edging activated during the incident but did not initiate an alarm. Only detector no 1 recorded gas during the incident. According to the trend report for readings by the detector, the maximum reading level was 0.445 LELm (alarm limit 1.0 LELm).

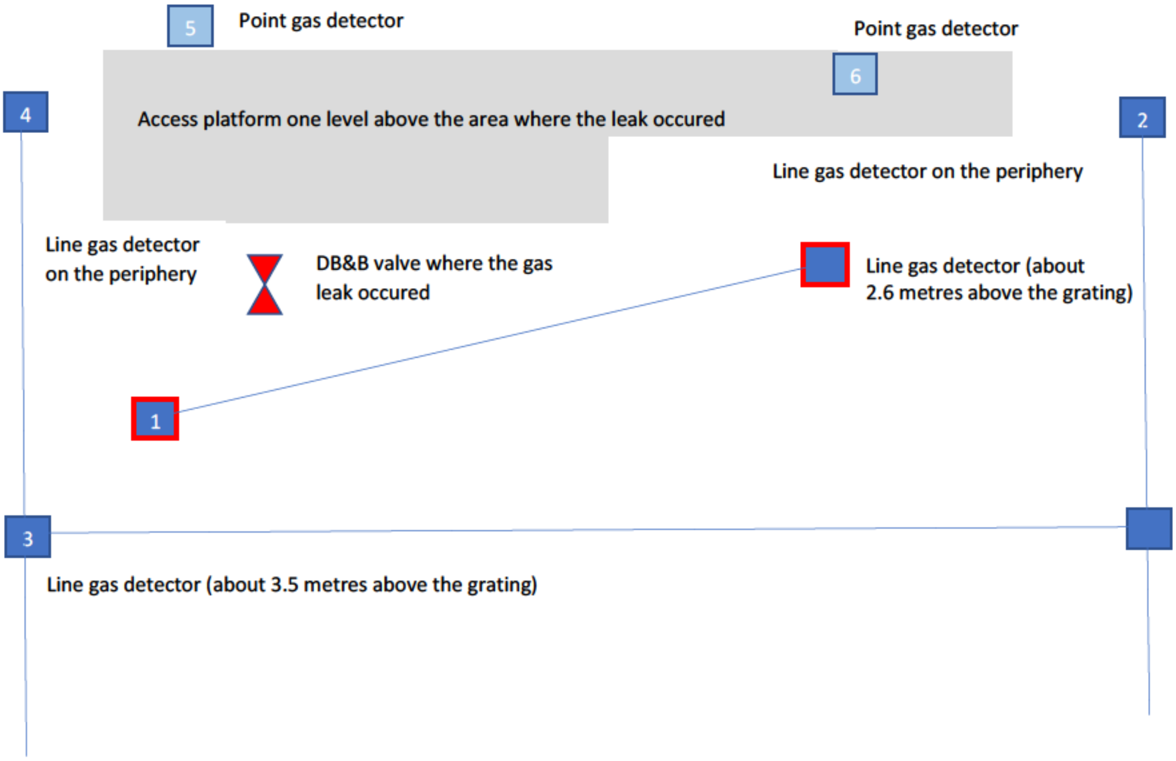


Figure 8 Overview of detection in the area where the incident occurred (viewed from above). The red edging on detector no 1 indicates that it was activated by gas but did not initiate an alarm.

During its inspection of the incident site, the Havtil team observed scaffolding which had been installed between the transmitter and receiver for line gas detector no 1. Since the latter measured gas during the incident, its line of sight was not completely blocked. The trend report for readings by the detector shows that its measurement range begins at -0.319 LELm, which corresponds to dirty optics. In addition, detector no 2 was registered with a fault during the incident and was therefore out of operation. Both detectors were registered with a fault/dirty optics over a lengthy period before the incident.

Both line and point gas detectors of the same types as on level 4 are installed on the level below (CAG1 level 3). Gratings separate the two levels. The diagram below presents gas detection at level 3 below the leak site. The area of the leak (on level 4) is indicated by a red gas cloud. Detectors with a red edging had readings during the incident but did not initiate an alarm. Maximum readings were 0.219 LELm (alarm limit 1.0 LELm) for detector no 8, 0.059 LELm (alarm limit 1.0 LELm) for detector 9 and 9.586% LEL (alarm limit 10% LEL) for detector 11.

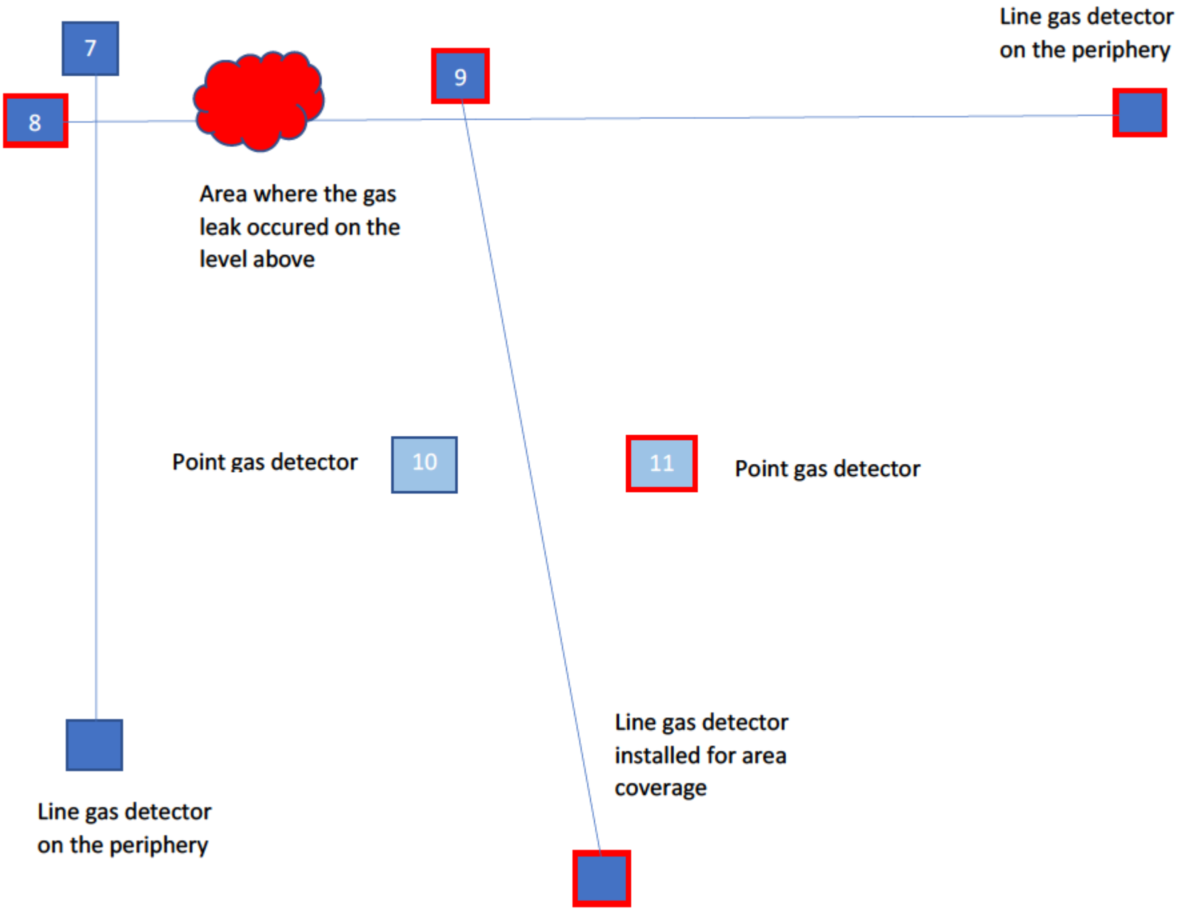


Figure 9 Overview of detection on the level below the one where the incident occurred.

Point gas detector no 11 (on the level below the leak point) had the highest reading during the incident. It is located 14.5 metres (diagonally) from the leak point, as shown in the diagram below.

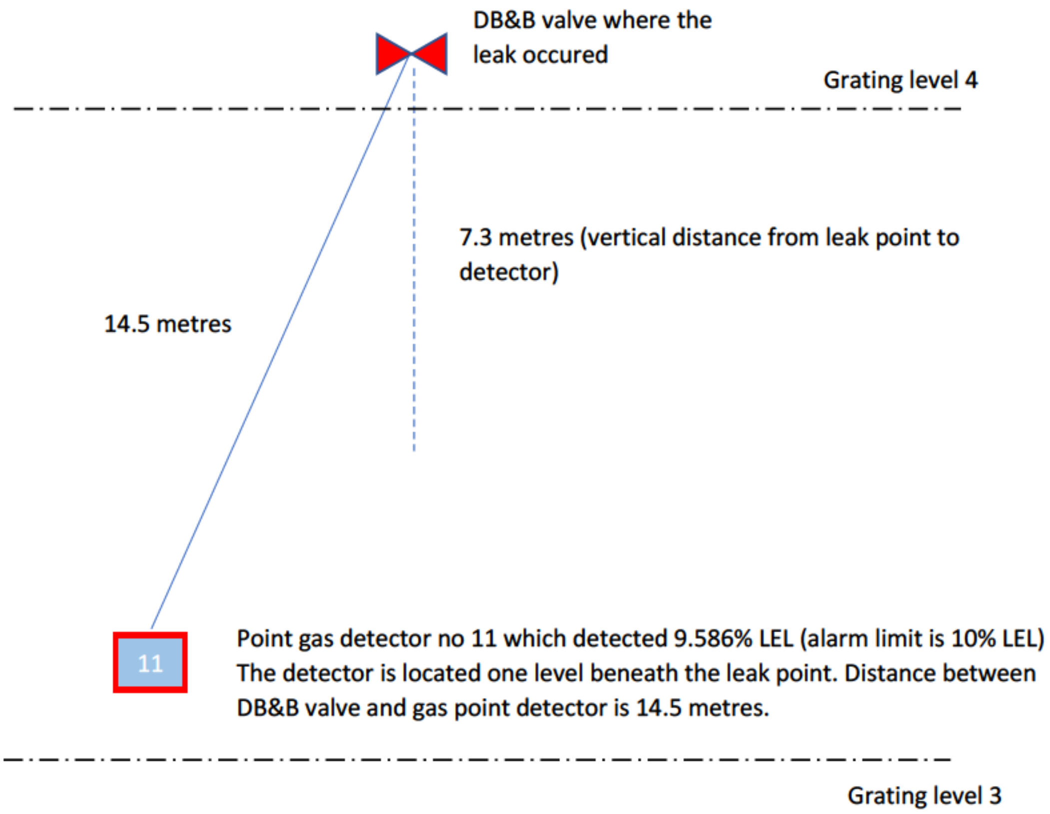


Figure 10 Overview of distance from the leak point to the point gas detector with a reading of 9.586% LEL on the level below. The alarm limit for initiating automatic actions with point gas detectors is 10% LEL.

When the incident occurred and throughout its course, no detectors initiated an alarm. Detection was confined to personal gas detectors – two on insulation workers one and two, and one carried by one of the three area technicians called to the site. This form of detection resulted in the CCR operator initiating manual actions. The CCR has a button for manual ignition-source disconnection of non-critical sources. Disconnection was activated manually when personal detectors confirmed a gas leak. If the detection system had received a single reading of 10% LEL or 1.0 LELm, non-critical ignition sources would have been disconnected automatically.

4.4.3 Installation of scaffolding

Scaffolding had been installed close to the leak point on 10 May 2023. Installing such structures requires an approved level-two work permit (WP). The responsible operator for the area is contacted by the executing personnel to coordinate the scaffolding work. The operator activates the WP, follows it up during execution, and signs it off when the job is completed. The Havtil team has been told that a typical checkpoint when executing such work is to verify positioning of the scaffolding in relation to detectors in the area in order to avoid any blockage. According to the WP received for installing the scaffolding, the risks of the job are considered to be dropped objects as well as injuries from falls or crushing. Various checks related to the identified risk were implemented. No information was included about not blocking detection.

The scaffolding was installed between the transmitter and receiver of the line gas detector closest to the leak point. The trend report for detector no 1 (see figure 8) shows that the structure partly blocked the line/signal between transmitter/receiver (see section 4.4.2) from its installation on 10 May 23 to the incident on 31 May 2023.

4.4.4 Handling of impaired safety barriers

Equinor's work process OM105.06.03 *Measures for unplanned weakening of safety system* is to be used if various safety systems are impaired. It provides guidance on compensating measures which should be assessed for the various safety barriers (performance standards – PSs). Where gas detection (I-102464) is concerned, requirements are described for implementing compensating measures if gas detectors are faulty or blocked (by scaffolding). Measures must be assessed on the basis of faults, number of detectors in the area, duration and location in order to maintain an acceptable level of safety.

When inspecting the incident site, the Havtil team observed scaffolding installed between transmitter and receiver of line gas detector no 1 in figure 8. Since this measured gas during the incident, its line of sight was not completely blocked. The trend report for the detector readings showed that its measurement range started at -0.319 LELm, corresponding to dirty optics. The trend report for detector no 2 in figure 8 was faulty during the incident, putting it therefore out of operation. According to the report, this fault occurred at around 11 May 2023. No compensating measures were implemented for these line gas detectors.

4.5 TR2000

TR2000 is a specification developed by Equinor for piping and valves. Each facility/ plant has its own version, and the specification is updated as required. TR2000 will include details on valve selection.

The TR2000 pipe specification for relevant pipe where the manual valve was installed has been revised several times. At the time the project kicked off, revision A from 2010 applied. This specifies which types of valve are to be used as compact isolation units. Where the selected valve is concerned, the description states that it must have a bleed plug of anti-blowout design. This is also specified on the mechanical drawing for the actual valve.

5 Course of events

The piping segment upstream of the safety valve was modified in 2017 because of challenges with a screwed connection. Preparatory work for this job began in 2014.

5.1 Timeline

The table below lists activities which could have been significant ahead of the incident, as well as during the actual event. Its content is taken from logs received and information provided in conversations.

Minor discrepancies in logged times between the various logs (CIM-ERT/IMT and CCR log) have been observed by the Havtil team, but they are not considered significant for describing the actions normally taken immediately after or before the logged time.

The ERT and IMT do not agree over the dialogue with the police concerning the ability to place the manual valve in the back-seat (fully open position). The table below reflects the entries in the IMT log presented by Equinor at the kick-off meeting. It also concurs with the information provided in conversations.

Time	Event	Comment
	Activities ahead of the incident	
2014	Project initiated to upgrade piping upstream of the SV	
2017	Project to upgrade piping upstream of the SV completed	
2021	Previous occasion when the SV was removed for recalibration	The bleed plug has probably been in the open position since this job was done
2023	Concurrent Synergi cases in Equinor's system where bleed plugs in the wrong position have been identified 5 May 2023 GFC 23 May 2023: Troll A 23 May 2023: Snorre A	Also identified on GFA after the HLNG incident (8 June 2023)
10 May 2023	Scaffolding installed in the area	The scaffolding partly blocks the line of sight for the line gas detector in the area
	Day the incident occurred	

Time	Event	Comment
11.06	Insulation workers report possible gas leak	Ongoing activity to isolate the relevant segment
11.07	Leak confirmed by area technician	CCR notified
11.08/11.09	General alarm followed by evacuation alarm, and PA announcement shortly afterwards	Information in the event log received
11.08	Manual ignition-source disconnection	
11.15	IMT mustered	
11.27	Emergency services on their way	WPs deactivated
11.31	ERT – first meeting held	
11.32	Nybyen/Oddasit emptied, emergency services have arrived	
11.37	Hot/warm zone established	
11.43	Started establishing tactical plans with emergency services	
12.07	Tactical plans A, B and C adopted	See the description below the table. Personnel with valve expertise were involved in establishing tactical plans to ensure that returning the valve to the back-seat position would halt the leak
12.20	Manual action initiated – Plan A	Smoke divers entering the plant
12.29	Plan A halted – smoke divers withdrawn	Negative development – CCTV seems to show increased leak
12.33	Plan B initiated	
12.37	25-ESV-1695 closed	Closing 25-ESV-1695 means halting feed gas supply into the plant for cooling
12.39	Power plant security staff mustered	
12.42	25-XV-1539 closed	25-XV-1539 is the valve in the subcooling circuit. Closing it isolates some of the volume in the circuit
	25-PV-1282 B operated	Moving liquid to 25-VD114 begins
13.00	Pressure in cooling circuit reduced to 17 barg	

Time	Event	Comment
13.06	Smoke divers enter plant to open manual valves	12 manual valves opened to drain cooling medium liquid to the flare system (valves are positioned some distance from the leak site)
14.08	Pressure in the circuit reduced to 2 barg – smoke divers withdraw	
15.00	Emergency services demobilise	
Abt 15.00	Shift change	
15.29	The police incident commander gives permission by phone to place the valve in back-seat position	Open valve fully so that no communication exists between flow media and valve house, thereby halting the leak
16.00	IMT demobilises	
16.58	Smoke-diving team enters to put the valve in back-seat position	
17.21	Valve in back-seat position and leak halted	
17.43	Damage site cordoned off	
19.25	Written notice sent to the PSA	
19.43	Hot plant opened	

As noted in the incident log, three plans were established – A, B and C. A brief description of each is provided below.

Plan A
Plan A involved halting the leak by entering the area with smoke divers and placing the manual valve in the back-seat position, thereby closing the connection between the production line and the leak point to stop the leak.

Plan B
Plan B involved shutting down feed gas into the plant and reducing pressure/draining the cooling circuit in a controlled manner. An isolation plan was then required to achieve this. That included operating valves both from the CCR and manually in the field. The main points in the isolation plan were:

- shut down feed gas into the plant (25-ESV-1695)
- isolate parts of the cooling circuit by closing 25-XV-1539
- operate control valve 25-PV-1282B to move liquid towards 25-VD-114
- start draining to the flare via manual valves when the pressure was low enough (12 valves identified)
- place valve in back-seat position when pressure in the circuit was low enough.

Plan C
Initiate ESD and blowdown for the area involved.

5.2 Post-incident investigations

As part of its investigation, the Havtil team engaged Safetec to perform a simplified dispersion analysis. The actual analysis was carried out to provide an indication of the gas cloud size (10% LEL) and the ignitable gas cloud (≥100% LEL). It also describes important conditions which must be assessed when designing a gas detection system to detect leaks of cooling medium/LNG. A brief description of the preconditions for the analysis and its main conclusions is provided below.

Simulations were run with and without a geometric model. The latter was a general version regarded as representative for a typical process area, rather than identical to the area where the incident occurred. In other words, details from the incident area are not included in the model. The analysis results indicate possible scenarios for how a leak of cooling medium would behave were it to occur in an area with a normal range of process equipment.

Simulations were run for leak rates of 0.1, 0.5 and 0.9 kg/s. Operating conditions utilised during the simulations were:

- cooling medium (53% methane, 36% ethane and 11% nitrogen)
- leak-point size of five millimetres
- leak point located about 1.5 metres above the grating (where the leak pointed down)
- initial temperature -153°C
- pressure 43 bar.

Combinations of various parameters, such as wind speed, droplet size/emission speed, liquid fractions and emission angles, were applied in the simulations.

The simulations showed that the gas cloud which forms moves down in the direction of the wind.

HLNG's detection system will initiate an alarm if an individual point gas detector has a reading equal to 10% LEL (the alarm limit for line detectors is one LELm, equal to a 10% LEL gas cloud extending for 10 metres). The table below summarises the largest 10% LEL gas clouds (largest detectable) from the simulations for various rates and wind conditions.

Wind speed (m/s)	Leak rate (kg/s)	10% LEL cloud (m^3)	Side length of a cube with the corresponding volume (m)	Dispersal of the cloud downwind (m)
1.5	0.1	447	8	15
1.5	0.5	3 318	15	30
1.5	0.9	5 549	18	31
10	0.1	21	2.8	7
10	0.5	143	5.2	15
10	0.9	372	7.2	22

The following conclusions for a cooling medium/LNG leak in a generic process area were drawn on the basis of the results of the simulations performed.

- At a leak rate <0.9 kg/s and pressure above two barg, no liquid pool is expected to form. This is because sufficient air is entrained to evaporate the droplets before they can form such an accumulation. With a pressure below two bar and a leak close to the ground, a pool might conceivably form at the leak site (but its size would be limited).
- At a leak rate <0.9 kg/s and pressure above two barg, the extent of the detectable cloud (10% LEL) will be fairly similar to a leak of heavy gas at the same rate.
- With a medium wind speed and relatively good ventilation in the module, the ignitable cloud (100% LEL) will be limited. For rates down to 0.1 kg/s, a cloud (10% LEL) will also be limited in size.
- With low wind speed or poor ventilation in the module (and the leak centrally located within it), large detectable clouds (10% LEL) will form which are probably detected relatively swiftly. An ignitable cloud will be limited in size providing conditions are not a virtual calm.

6 Potential of the incident

6.1 Actual consequence

The actual consequences of the incident were:

- gas leak – quantity and initial rate calculated by Equinor on the basis that the opening in the bleed plug is the limiting factor for the leak rate:
    - estimated initial rate 0.77 kg/s
    - maximum emission rate 0.88 kg/s (pressure rise in system under confinement)
    - estimated total leak quantity 9 278 kg
- personnel exposure

  - insulation worker hit by spray from leak – no identified permanent harm, insulation worker followed up by nurse after the incident
- plant downtime totalled eight days.

6.2 Potential consequences

The dispersion analysis shows that the gas will rapidly thin out at the prevailing wind speeds when the leak occurred. As a result, the Havtil team has concluded that ignition or explosion were unlikely.

Both when the incident occurred and during the response to it, the potential existed for further exposure of personnel not only during the insulation activity but also when responding to the incident.

The open bleed plug was a hidden fault which might have had a different outcome had the leak not occurred. This plug is included in the activity for verifying depressurisation before opening the system and removing the safety valve. Unfamiliarity with the plug's function could have led to the system being opened before it was depressurised.

7 Direct and underlying causes

7.1 Direct cause

The direct cause of the gas leak was that the bleed-line plug in the valve arrangement upstream of the safety valve was in the open position, combined with incomplete closure of the actual bleed-off valve. The reason why the bleed-off valve was partly open has not been identified by the investigation. It had probably moved slightly in connection with the actual insulation activity. See chapter 11 on uncertainties.

The plant was in operation when the leak occurred, and the cooling medium circuit was in communication with the leak point.

7.2 Underlying causes/discussion

The investigation has identified several elements which have or could have been significant for the occurrence of the incident and the scope of the leak. These are described in the following subsection. During its work, the Havtil team has also looked at the system for detecting gas and dealing with gas leaks.

7.2.1 Familiarity with and documentation of the bleed-plug type involved in the incident

The bleed plug which was in the open position was an anti-blowout type and left-hand threaded. It must be screwed out to close. This differs from the plug type normally installed at HLNG. With the plug screwed in, detecting that it remains open is not easy for someone not familiar with its type.

The bleed plug was installed in connection with a project in 2017. The Havtil team is not aware of any training/information provided for this plug type when it came into use. Information given to the team indicates that the scope of training and a review of the system from project to operation can vary in line with project size and complexity.

GA drawings of the valve which incorporates the bleed plug show that this is an anti-blowout type. They do not state that it is left-hand threaded or refer to a type number which indicates this. Nor is that information given in the P&ID or noted in the isolation plan.

As described above, the valve arrangement and bleed plug are enclosed by insulation. It is therefore natural to conclude that the plug has been open since the most recent calibration of the safety valve in 2021 or its original installation in 2017.

The bleed plug is included in the activity for verifying tight barriers against a pressurised system before flanges are split. As described in chapter 4.1.2.1, the safety valve can be removed while the plant is in operation providing the manual valve is placed in the normally open position. This means the flow medium and valve cavity will be in communication, and the pressure in the latter will be same as in the line.

Unfamiliarity with the bleed plug's function could cause errors when verifying tight barriers (including leaks through isolation valves) before the safety valve is removed – which can in turn result in the system being opened while still pressurised.

In connection with the investigation, the Havtil team has been informed that six bleed plugs of this type have been identified at the plant in the wake of the incident.

A search by Equinor in its own incident system since the incident has identified a number of cases where bleed plugs have been found in the wrong position.

7.2.2 Managing gas leaks

As noted above, Equinor has produced guidelines for managing hydrocarbon leaks at HLNG (GLO744 – *Guidelines for managing HC leaks)*. The anticipated response is assessed in accordance with a factor calculation which is based in turn on gas detector activation.

In connection with this incident, no assessment was documented in relation to defined criteria in the guidelines for managing gas leaks. The decision not to initiate

ESD primarily reflected concern over the consequences of doing so combined with awareness that the leak point would probably fail to be depressurised by ESD 05.

As outlined in section 4.3.2, parts of the subcooling circuit would remain pressurised after an ESD with subsequent blowdown. To the best of the Havtil team's knowledge, information about pressurised systems is not implemented in other operating documents such as P&IDs and system descriptions.

It emerged from conversations that no procedure or guidelines are established for controlled shutdown of the plant should a gas leak occur. Nor is there a scenario which can be trained with. If the choice made not to initiate ESD in the event of a leak, plans must be prepared before a controlled shutdown can be executed.

7.2.3 Design of the safety system

Safetec's gas dispersion analysis shows that a cooling medium (and LNG) leak will behave like heavy gas. The gas detection system in the area close to where the leak occurred primarily comprised line detectors (see section 4.4.2). These are placed high above ground level (detectors no 1 and 3, for instance, are about 2.6 and 3.6 metres respectively above the grating – see figure 8). Gas detectors in the area did not initiate an alarm. Only one line detector registered gas (the maximum amount was 0.445 LELm, while the alarm limit is 1.0 LELm).

The point gas detector on the level below (no 11 in figure 9) registered the largest volume (9.586% LEL with an alarm limit of 10% LEL). This unit was about 14.5 metres (diagonally downwind) from the leak point.

TR2237 *Performance standards for safety systems and barriers – onshore* specifies that the properties of the gas (light/heavy) which might be leaked must be assessed when positioning gas detectors. See section 4.4.1. No detectors were installed at a low level over the grating at the point where the leak occurred.

No documentation/simulations showing the decision basis for positioning gas detection in the area were received by the Havtil team during its investigation.

8 Emergency response

The regulations require that licensees and other participants in the petroleum sector on the Norwegian continental shelf and onshore must maintain an effective emergency preparedness at all times for responding to hazards and accidents which could lead to loss of human life, personal injuries, environmental pollution or major material damage.

In this report, the Havtil team's description of the emergency response effort is based on interviews with technical personnel in the CCR during the incident, industrial safety and response personnel out in the field at the incident site, senior managers, and incident commanders. Emergency response plans and log entries for the incident were also used. An overall description is provided here of the response measures adopted during the alarm/notification, mobilisation and rescue/evacuation phases until normalisation began after the position was clarified and the gas leak halted.

8.1 Emergency response organisation

The emergency response organisation at HLNG is structured, dimensioned and founded on the basis of the emergency preparedness analysis for HLNG (DNV-GL report no 2018-1148, rev 2), and requirements for companies with a duty to maintain industrial health and safety.

A description of the administrative and operational response measures is provided in the emergency response plan for MMP OPL HLNG (WR-2181).

Each shift team at HLNG comprises 19 people, who are part of a six-shift system. They represent the primary personnel resources available for executing and taking care of the emergency response functions described in the plan. However, other personnel can be called in and mustered as and when required.

Organisationally, emergency response at HLNG comprises two levels, with the first line (ERT) providing leadership at the operational level and response efforts at the leak site, including initial reception of alarm and notification as well as interventions at the leak site using personnel resources and equipment from the health and safety department. Response efforts at the leak site can also be conducted in collaboration with local emergency services. The next level up is the second line (IMT), which is a support resource for the first line and also communicates with the third line at group level in Equinor's Stavanger head office.

The first alarm will normally be received in the CCR by one of its operators, either via automatic or manually initiated signals or through radio reports from personnel out in the plant, as was the case with this incident.

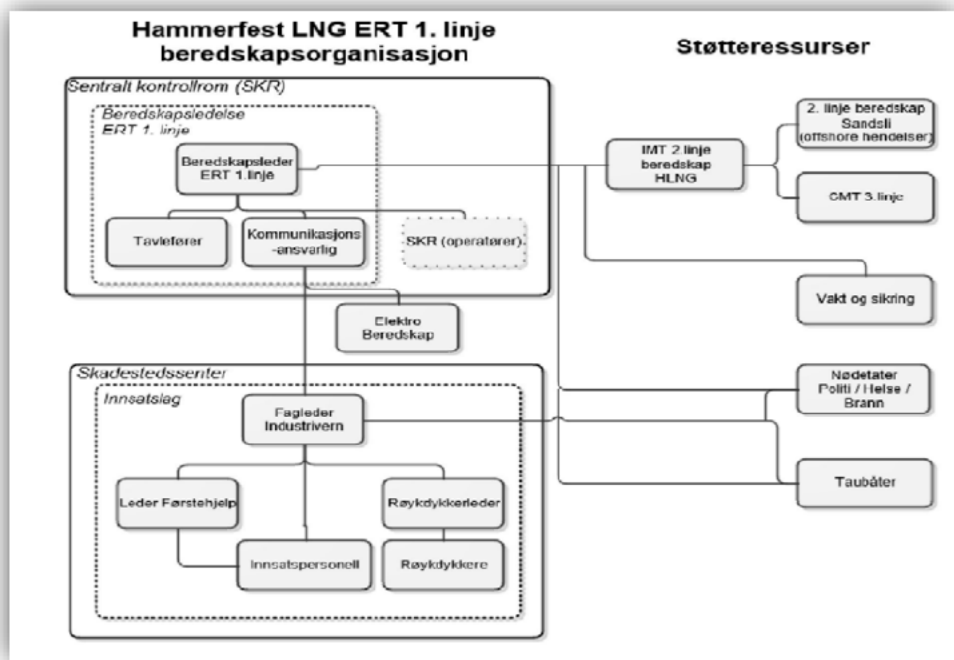


Figure 11 HLNG's ERT response organisation – first line. (Source: Equinor)

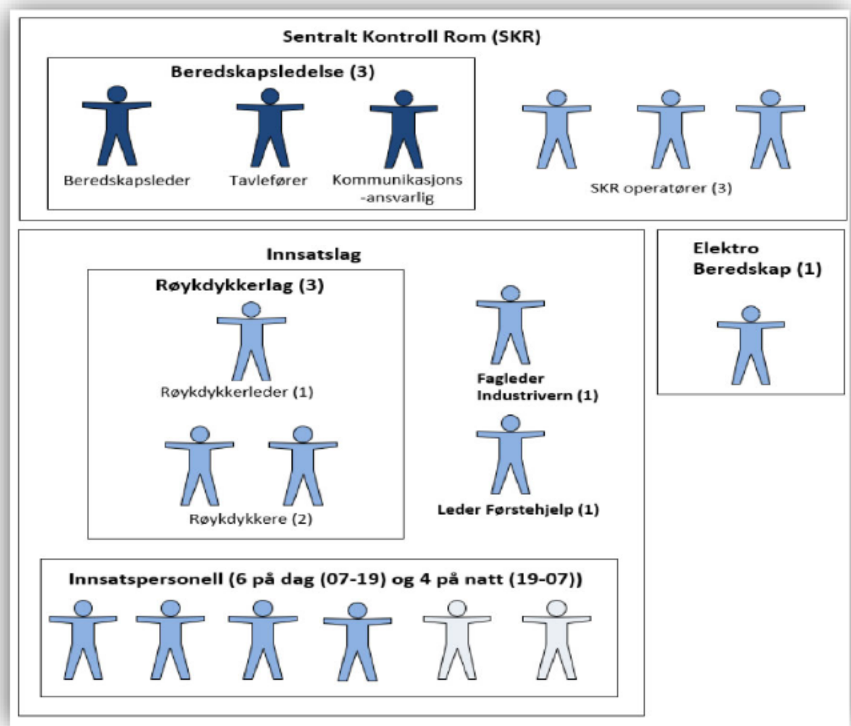


Figure 12 Organogram showing the ERT first-line response organisation. (Source: Equinor)

8.2 Emergency response during the incident

As noted initially, the emergency response effort during the incident is described at an overall level on the basis of the response measures initiated during alarm/

notification, response and rescue phases and personnel evacuation until the position was normalised and the gas leak halted. See section 64 of the technical and operational regulations.

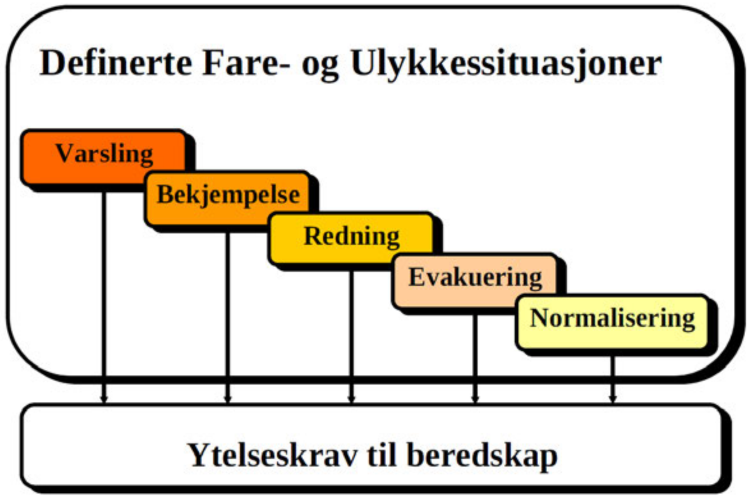


Figure 13 The phases in an emergency response. (Source DNV GL- emergency response analysis HLNG)
Key: Defined situations of hazards and accidents. Notification; Combating; Rescue; Evacuation; Normalisation. Emergency response performance requirements.

The description here is based on information obtained through interviews and logs from the ERT and IMT, and the response effort is basically meant to be based on HLNG's own emergency plans and other requirements which apply to onshore plants in Equinor – such as WR-1920 (performance standards).

No permanent personal injuries were registered as a result of the incident, but one person was checked by health personnel immediately afterwards because they were thought for a time to have received a gas spray in their eye. This was not categorised as a personal injury.

On the orders of the police, the incident site was secured and cordoned off.

The PSA was notified about the incident by phone on the same day within an hour after the event, about 11.40, and later the same day in writing.

8.2.1 Managing the incident

8.2.1.1 Notification, alarm and evacuation

The CCR was notified of the gas leak at 11.06 on Wednesday 31 May 2023 via radio by a plant operator from the insulation, scaffolding and surface treatment (ISS) contractor working at the incident site. A general alarm was initiated immediately by the CCR, followed by an evacuation alarm and soon afterwards by an announcement over the PA system that all personnel should evacuate the inner industrial area at

HLNG. Audible and alarm signals for evacuation were also sounded across the whole plant. In addition, an immediate halt to all WPs and hot work was announced. The Havtil team has not had access to actions from the time of the alarm until the first log entry at around 11.20, and these are assumed to have been whiteboarded or solely oral.

The first-line (shift) leader was in the CCR when the incident was reported, and the second line was informed immediately. Notification was given in parallel to the health and safety supervisor, who was out in the plant. The smoke-diving/emergency response team mobilised in the fire-engine garage and prepared for intervention.

Immediately after the incident was notified, at 11.07 and 11.15 respectively, the first- and second-line response organisation mustered and established themselves. The first log entry was made by the first line/ERT at 11.20.

The response effort was based on **DSHA 1: oil and gas leak**.

The civilian emergency services received a joint alert through the use of triple notification at about 11.15, and arrived one after another at HLNG soon afterwards. According to the log, the first emergency service reached the administration block immediately alongside the fire station at about 11.30, logged at 11.32.

According to interviews, a command post was established in the shift leader’s office alongside the CCR soon after the arrival of representatives from all the emergency services. However, this does not emerge from logs or other documentation which the Havtil team has had access to.

An overview of personnel inside the HLNG plant (POB) was reported about 20 minutes after the incident was notified, logged at 11.27. A total of 98 people were on site when the incident occurred.

A 300-metre safety zone was established around the leak site in an early phase for safety reasons and with regard to a possible escalation of the incident. Receiving and expediting vessels for HLNG was halted during the response and while the gas leak continued.

The training plan for HLNG covers general handling of gas leaks, but has no scenario which specifically covers a leak in the relevant module. Response personnel had not practised or trained with this type of escape at the specific leak site.

8.2.1.1.1 Weather data

It was determined that the weather was favourable for a possible response at the leak site, with some wind to ensure good dispersal of the gas at the leak site (reported as

10 metres per second when the incident occurred). YR.no provided the following weather data for 31 May 2023 at Melkøya: average temperature 3.7°C, with lowest 2.3°C and highest 5.8°C, precipitation 0.4 millimetres measured at 07.00, and wind varying from 5.1 to 15.6 m/s as the strongest for the day. The variation in wind measurements could reflect several factors, including different meter locations.

8.2.1.2 Planning for and intervention by the smoke-diving team

According to the log (ID:68), a risk assessment was carried out in a separate meeting with the smoke divers ahead of their intervention at the leak site. The log also states that “the risk will be dealt with in parallel in the response team”. Logging of this meeting is confined to points entered in the log without more detailed descriptions. It is therefore unclear which specific conditions and measures were discussed in this assessment, and whether the use of a Flir camera, for example, was considered. According to the response team, a Flir camera was not used.

Furthermore, the second-line log shows that the emergency services participated with the first line/ERT in the risk assessment and preparation of tactical plans A, B and C for intervention at the leak site. Interviews also confirmed that fire service, police and HLNG response personnel were involved in these assessments ahead of the intervention at the leak site. The Havtil team has not found documentation concerning which risk conditions were assessed ahead of this action.

Plans A, B and C are described in more detail in section 5.1.

The smoke-diving team was transported into the module near the incident site via the north door in the health and safety department’s rescue vehicle and, according to the log, parked beside L-05 at about 12.20. The health and safety supervisor arrived at the same position in their own rescue vehicle. It is considered reasonable to view this as establishing a command centre out in the field where the health and safety supervisor was positioned to lead the response.

Manual intervention was then initiated by a smoke-diving team comprising a leader and two other members from the HLNG health and safety department, logged at 12.25 (ID:86), commencing with plan A. This is described in the log as the smoke-diving team entering towards the leak site and manually placing specified valve 25-LD-0250 in the fully open position in order to reduce the enclosed gas volume. The team decided shortly after its arrival in the area immediately adjacent to the leak site, and in communication with the health and safety supervisor, not to go closer to the leak point to operate the specified valve because the CCR observed and believed that the gas escape was starting to increase.

The log states that the wind direction was favourable for intervention at the leak site.

According to the log, the fire service at this point had its own smoke divers in reserve and ready to intervene as required from the muster point in front of the administration building.

Shortly after the smoke-diving team had withdrawn from the leak site without implementing Plan A, the decision was taken to execute Plan B as described in the log at 12.33 (ID:67). This plan involved, if the desired effect was not achieved with Plan A, halting the supply of feed gas to the plant, isolating parts of the cooling circuit and manually reducing pressure in the latter by moving and draining liquid.

It also emerged from interviews with the response personnel in the smoke-diving team that, shortly after arriving at the leak site, they considered it safe not to use the bottled gas they were carrying but to breath the open air. The team members were equipped with personal gas meters.

Plan B included manual opening of 12 drainage valves to the flare. These valves are located on the level below the leak site. That job also had to be done by the smoke-diving team, which the log placed in the relevant area at 13.05. Its assignment was now to locate 12 valve wheels and turn them manually into the open position for pressure blowdown and drainage. According to the response personnel, this was a heavy and demanding job which took about 30 minutes to complete. The CCR subsequently registered that the pressure sank and the leak was reduced.

See more details about the plans in section 5.1 Timeline.

While preparing to carry out the job at the leak site, the smoke-diving team registered and reported that radio communication between its members was not functioning and was also poor with the health and safety supervisor. The team nevertheless opted to continue the work.

The Havtil team has been unable to establish whether consideration was given at this time to sending in the fire service’s smoke divers, either as support or to replace the team experiencing radio communication problems.

Creating a water curtain with two-three stationary fire-water monitors in the area was considered by the health and safety supervisor, but they eventually decided that activating this was unnecessary.

The log shows tank pressure below was reduced to about two bar around 14.08, but full shutdown was first established almost three hours later – logged at 17.21.

Several reasons are given for this delay, including a shift change at about 15.00 and the police cordoning off the leak site and leaving HLNG at roughly the same time, before the gas leak had been halted.

After the whole smoke-diving team had completed Plan B, it left the module and returned to the safe area.

8.3 Normalisation

The normalisation phase is not described in more detail other than that the gas leak was halted. What specific measures were implemented until this part of the plant was ready for continued operation are not covered.

Confirmation has been received by the Havtil team that the personnel involved were offered further follow-up and that a debriefing took place the day after the incident for response personnel and others wishing to attend.

8.4 Collaboration with civilian emergency services

After the triple notification was sent to the emergency services at about 11.15, units arrived from the police and the fire and rescue service as well as ambulances with personnel from the emergency medical communication centre (AMK)/health trust during the subsequent 15-20 minutes. Logs show that the first services were present at about 11.30. According to interviews, as mentioned above, a command post was created in the shift leader’s office once representatives of all the services had arrived.

Following the fire at HLNG in 2020, the issue of collaboration with the emergency services was reviewed in detail by Equinor’s own investigation, with a number of observations forming a basis for improvements. The main message was that a need was seen for closer and better cooperation, including training and exercises, and clarification of the division of responsibilities in the event of emergencies.

Assessing collaboration between HLNG, the police and the AMK beyond what emerged from interviews and conversations with response personnel linked to Equinor and its subcontractors fell outside the PSA’s mandate. Furthermore, as noted above, a number of important decisions were discussed jointly – including managing response to the gas leak – but not documented in more detail in HLNG’s logs.

HLNG collaborates closely with the Hammerfest fire and rescue service, which will in part contribute crews, equipment and mobile extinguishing systems, fire engines and ladder trucks in the event of actual incidents. The plant does not have its own fire engine or ladder truck for spraying water or foam/chemicals.

Based on interviews and logs, the Havtil team's main impression is that collaboration in handling the incident between the HLNG response organisation and the emergency services functioned well.

Furthermore, the logs show that tactical plans were prepared for handling the incident in collaboration with the emergency services and HLNG's first-line response organisation, including risk assessment ahead of the commitment. This is logged with a description as (tactical) plans A, B and C (ID:67).

Apart from keywords in the ERT/IMT logs and interviews with personnel involved, the Havtil team has obtained no detailed insight into how the risk assessment and tactical plans were prepared and executed, and which subjects they covered ahead of the health and safety department's intervention at the leak site.

The team has not requested insight into the fire service's logs (emergency number 110) for its response to the incident since this does not fall within Havtil's area of responsibility.

HLNG has presented the team with an RACI responsibility assignment matrix which gives an overview of how the division of responsibility and interaction between the emergency services is allocated for managing an incident here. Main responsibility rests with the police and the formal incident command, with the fire and rescue service taking over if the police are not present. These are issues which the joint exercises between HLNG and the emergency services will emphasise.

The Havtil team would emphasis the importance of documenting which safety and tactical assessments are made jointly by HLNG, the police, the fire service and other emergency services before the response is decided and implemented. This case involved a substantial gas leak at an initially unknown rate and a potential threat of fire and explosion.

It is therefore important that high priority is given to taking care of response personnel through risk assessments ahead of action, and that these are based on thorough risk assessments followed by tactical plans derived from these, as emerges partly from incident logs. This is also a key requirement for follow-up and possible investigations after an incident. The Havtil team assumes that this was done in a prudent manner, but sees these assessments could have been explained and documented more fully in logs or in another traceable manner.

It emerged from interviews with response personnel that they feel collaboration with the civilian emergency services has developed positively following earlier incidents at HLNG, particularly the 2020 fire and this 2023 leak, and it is now described as very good.

9 Observations

Havtil'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 Knowledge about and documentation of equipment components

Nonconformity
Knowledge about and training on installed equipment components were inadequate.

Grounds
The bleed plug involved in the incident was installed in 2017. It is a different type from the plugs normally installed at HLNG. The investigation observed the following.

- Operators involved were unfamiliar with the bleed plug installed.
- No special training was provided when introducing a new plug type. The Havtil team has been informed that training and/or participation in mechanical completion or system testing on project delivery varies by its type and scope.
- Drawings of the valve arrangement were unclear about what type of plug this was.
- Ignorance about the way equipment components function could result in consequential errors during use. The component concerned is involved in the activity for verifying that the system is depressurised before opening, and a verification error could mean the system is opened while still pressurised.

Requirements
Section 40, litera b of the technical and operational regulations on start-up and operation of onshore facilities
Section 15 of the management regulations on information

9.1.2 Procedures and training

Deficiencies existed in procedures and established training scenarios.

Grounds
Three different patterns of behaviour are described in the guidelines for managing gas leaks. The philosophy document and system descriptions largely cover the option related to initiating ESD. Where a controlled running down is concerned, plans must be established as the incident unfolds.

Concerning the system where the leak occurred, the Havtil team saw that:

- no procedure was established for dealing with leaks in parts of the system which would remain pressurised after ESD and blowdown were completed
- no training scenarios were established for managing leaks in this segment.

Requirements
Section 45 of the technical and operational regulations on procedures
Section 52 of the technical and operational regulations on practice and exercises

9.1.3 Gas detection

Nonconformity
Positioning of gas detectors was not based on relevant scenarios and simulations so that the consequences of the gas leak could be limited.

Grounds
The scope and positioning of gas detection in the CAG1 level 4 area was assessed during the HLNG design phase and implemented before the plant became operational. A project for improving gas detection in the area has also been executed with three further line gas detectors installed on level 4 in CAG1.

The fire and gas detection engineering report for the design phase states:

> To meet Statoil's performance standard (informal reference) with regards to detection of a continuous HC gas leakage of 0.5 kg/s in open naturally ventilated areas in 95 per cent of the cases with an alarm from one detector (ref PS 03, F1), simulations have been made to determine the size of such clouds for various areas and gases in the HLNG plant.
>
> The gas cloud simulations were made with the Phast Professional 6.1 programme. Detectable cloud sizes were simulated for methane, ethane, propane, LNG and LPG in open naturally ventilated areas.

Equinor has been unable to present the decision basis for the positioning and scope of gas detectors in the design phase.

The Havtil team has been informed that installation of line gas detectors in the above-mentioned project is based on TR2237. This specifies that the properties of the gas (light/heavy) which might leak out must be assessed when positioning detectors.

The leak involved cooling medium, which is a heavy gas. No detectors were installed at a low level over the grating in the area where the leak occurred.

Requirements
Section 5 of the management regulations on barriers
Section 8 of the management regulations on internal requirements
Section 16 of the management regulations on general requirements for analyses

9.1.4 Dealing with barrier impairment

Nonconformity
Compensating measures for barrier impairment were not implemented as quickly as possible. The status of the safety system was not known.

Grounds
When inspecting the incident site, the Havtil team observed that scaffolding was installed between transmitter and receiver of the line gas detector with tag number 74-AR-CAG1-01-0235. Since the detector measured gas during the incident, its line of sight was not completely blocked. The trend report for readings by the detector show that its measurement range started at -0.319 LELm, corresponding to dirty optics. According to the trend report, the faulty condition occurred on 10 May 2023.

In addition, the detector with tag number 74-AR-CAG1-01-0209 was faulty and therefore out of operation. The trend report for this detector showed that the fault arose around 11 May 2023

Requirements
Section 5 of the management regulations on barriers
Section 42 of the technical and operational regulations on safety systems

9.1.5 Documentation

Nonconformity
Technical operating documentation is inconsistent and inadequately updated.

Grounds
Updating of technical operating documents was inadequate. During its investigation, the Havtil team observed the following.

- The investigation clarified that the philosophy described for confirmed gas detection in open areas at HLNG is an alarm from a single point or line gas detector. The alarm limits are 10% LEL for point gas detectors and one LELm for line detectors. The documentation received contained inconsistencies

related to alarm limits and philosophy for confirmed gas detection. Examples include:
    - the safety strategy stated: "In general gas alarm is triggered at 10% LEL. Confirmed gas alarm is triggered at 20% LEL detected by 1 detector or 10% LEL detected by more than one detector in same area"
    - section 2.2 on confirmed HC leaks in GLO744 – *Guidelines for managing HC leaks* states: "When one or two HC detectors, point or line, measure 20% LEL (or 0.2 LELm) or more and/or visual gas/liquid leak.
- Lack of consistency between memorandum (E066-AN-P-RE-0019) and the C&E diagram (E066-SD-75-JE-0001-007) concerning what remains pressurised after ESD 05 with subsequent blowdown.
- Studies carried out have identified segments which will remain pressurised after ESD/blowdown. System descriptions and P&IDs have not been updated to reflect this.
- The status of the C&E diagram received is "for approval".

Requirements
Section 40, litera b of the technical and operational regulations on start-up and operation of onshore facilities

9.1.6 Inadequate radio communication in the response/smoke-diving team

Nonconformity
The smoke-diving team continued its intervention and moved into the leak area without adequate and necessary radio communication.

Grounds
It emerged from interviews and logs that the smoke-diving team lost radio contact between its members and with the health and safety supervisor at an early stage during its intervention at the leak site.

Requirements
Section 22 of the technical and operational regulations on communication systems and equipment
Section 67, litera a and b of the technical and operational regulations on handling hazard and accident situations

9.1.7 Inadequate warning system – PA system in Oddasit building

Nonconformity
No PA loudspeaker system is installed in the Oddasit building and the area around it so that announcements about hazards and accidents which have arisen can be conveyed to personnel present there at any given time.

Grounds
No loudspeaker system has been installed to communicate announcements to personnel in the Oddasit building and the surrounding area so that they can be notified of hazards and accident or other important information from the CCR.

Today's system is largely based on using radio communication or physical instructions and fetching personnel from Oddasit and the area around it.

Requirements
Section 67, litera a and b of the technical and operational regulations on handling hazard and accident situations
See section 4-1, paragraph one of the design and furnishing of workplaces and premises (the workplace regulations) on alarm and notification equipment

9.2 Improvement points

9.2.1 Inadequate documentation on and description of preparing risk assessments and tactical emergency response plans

Improvement point
Havtil's regulations require that the responsible party ensures that the necessary measures are implemented as quickly as possible to prevent hazards and accidents from developing. The logs fail to provide a more detailed description of how risk assessments and action plans were produced through cooperation between the HLNG response organisation and the Hammerfest fire and rescue service.

Grounds
The first- and second-line (ERT and IMT) logs do not explain which assessments were made jointly with the emergency services before HLNG's smoke-diving team was sent into action at the leak site.

HLNG bases a significant part of its emergency fire preparedness on receiving assistance from the local fire service in Hammerfest, which thereby assumes close collaboration between the two. On the other hand, underlying assessments made before deciding to send in HLNG's smoke-diving team rather than the local fire service's response personnel are not documented in detail.

Requirements
Section 22 of the framework regulations on emergency preparedness at onshore facilities
Section 66, third sentence of the technical and operational regulations on emergency preparedness plans

Section 67, litera b of the technical and operational regulations on handling hazard and accident situations

10 Barriers which have functioned

Personal gas meters for insulation workers and responsible operators for the area.

Establishing and activating the plant's own emergency response organisation and health and safety department, including notification and mobilisation of civilian emergency services, functioned as intended.

In connection with action taken during the incident, personal gas meters for smoke divers functioned as intended.

The CCR initiated manual actions for ignition-source disconnection.

11 Discussion of uncertainties

In connection with inspection after the incident, it was discovered that the bleed valve was not quite closed. The reason for this has not been finally clarified by the investigation, but it is reasonable to assume that it was due to activity related to insulation. As shown in figure 4, the needle valve was tightly enclosed in insulation and conditions were restricted around the box to be removed.

12 Assess Equinor's own learning and experience transfer from earlier incidents

Through searches in its own system for incident follow-up after the incident, Equinor has identified a number of relevant cases. These were recently discovered and have not been reviewed at HLNG.

A safety alert was produced in the wake of the incident at HLNG on 31 May.

13 Other comments

13.1 Hand-held Flir cameras

HLNG's health and safety department possesses hand-held Flir cameras. These were not utilised by the smoke-diving team during its intervention at the leak site. Using these devices are likely to provide a more secure indication of the possible spread of gas in the area entered by the team.

13.2 Equinor's communication with the police

Havtil has subsequently, and through Equinor's own investigation report, been made aware that the company identifies possible poor communication and collaboration with the police on access to the leak site, and challenges with its own shift change at HLNG as reasons why the leak was able to continue for more than three hours longer than is considered necessary.

14 Appendices

Appendix A – Documents utilised in the investigation

The following documents have been drawn on in the investigation

1) Hammerfest LNG Beredskapsanalyse (14.6.2019)
2) Beredskapsplan Hammerfest LNG – linje 1
3) Tegninger av 25-LD-0250
4) C&E (F&G)
    a. 74-AB-CAG1-01-0022
    b. 74-AR-CAG1-01-0209
    c. 74-AR-CAG1-01-0211
    d. 74-AR-CAG1-01-0235
5) E066-AB-S-RE-0003 Fire and gas detection Engineering report, rev 7
6) E066-VV-S-KF-5002 74 F&G System 3.1.4 Installation, Operating and Maintenance Manual for Simrad GD10P Gas detectors
7) GL0744 Retningslinje for håndtering av HC lekkasje, 12.08.2021
8) ICC1734891 Full isolation certificate for å ta ut PSV
9) E066-AN-J-KS-2004 Safety manual (IEC 61511/IEC 61508) (Searchline Excel Open Path Infrared Detector)
10) Skiftplan 1. – 15. juni
11) System 74 Brann og gass – Systembeskrivelse 31.12.2016
12) AT'er for andre jobber i området:
    a. Nivå 1 – 65-TP-101 – Entring av pit
    b. Nivå 2- Kaldt arbeid – Rengjøre/feilsøke på nivåmåler
    c. Nivå 1 – Varmt arbeid kl B – 3D Scanning for future jobber – prosjekt 223328, Overtrykkssikring system 25
    d. Nivå 2 Kaldt arbeid – Fjerne isolasjon 1380-SV-25-253 – aktuell jobb – inkludert også original med signaturer
    e. Nivå 2 Kaldt arbeid – Fjerne isolasjon på ventiler (25-LD-0741 – 25- LD-1045)
13) Prosedyre Nedkjøling og fylling av 25-CT-101 (pågående aktivitet)
14) Safety valve SV-25-253 – kort info om ventil
15) Utvalgsrapport Synergi – hendelser fra 2019 – 2023
16) Øvingsplanverk
17) Eventlog eksport 31.5 0900 – 13:00
18) Liste over involvert personell

19) WR 1920 Beredskap i MMP OPL
20) Liste over systemnummer
21) Tegning av 25-LD-1316 (DBB oppstrøms PSV)
22) Kursplan HMS 24 moduler
23) Timp
24) AO26066557 SV 25-253
25) Synergi etablert for hendelse (2531047) inkludert video av plugg
26) Kort video fra hendelsen (fra CCTV)
27) Beregning av lekkasjemengde
28) E066-AN-P-RE-0019 Segmenter som ikke trykkavlastes ved ESD 2
29) E066-SD-S-RB-0009 Assessment on trapped segments – technical note
30) Bilder detektorer
31) Notifikasjon for den detektoren som var i skitten / stillas
32) Notifikasjon fra 20.3.2022
33) AO på stillas: 24713324
34) Trend på relevant linjegassdetektor – fra 6.5 - 5.6
35) Historikk for siste år – gassdetektorer – alle som har feilet
36) Oversikt M2 notifikasjoner
37) E066-AB-SS-0002-001, ESD & Depressuring System Engineering report
38) Presentasjon oppstartsmøte
39) SO09325 – System 25 – Natural gas liquefaction
40) Material data sheets SF710 – TR 2000
41) E066-SD-75-JE-0001-007 C&E ESD_05 rev 1
42) Mandat for ekstern gransking (COA)
43) OM105.06 Measures for weakend safety system
44) Synergi GFC - Safety alert "Nye bleedplugger som er montert har motsatt funksjon av gammel type»
45) Synergi Troll A – observasjon av åpen bleedplugg ved montering av 35-EV8636 (refererer til erfaringsoverføring fra annen installasjon – dette er samme type bleed plugg)
46) Synergi Snorre A (23.5) – Oppdaget bleedplugg med motsatt funksjon på Flowline P10 300barg gass
47) AT nivå 2 – stillas, Modifikasjon av stillas SV-25-146 G4 (09.05 – 11.05)
48) AT nivå 2 – Build lift stand for valve SV-25-124 (14.05 – 16.05)
49) ERT CIM log
50) IMT CIM log
51) Uttrekk fra 3D modell – plassering av gassdetektorerE066-SA-00-PD-0025-001,
52) Oversiktstegning system 25
53) Plott – utslag på gassdetektorer
54) E066-AB-74-SP-0002 F&G detection layout CAGI level 4
55) Skisse System 25 nedkjøling
56) E066-AB-25-PE-1023-001 – P&ID -lekkasjested
57) E066-AB-S-AE-0002.002 C&E –historisk

58) E066-SD-75-JE-0001-032 rev 1
59) E066-SD-75-JE-0001-036, rev 1
60) E066-AB-75-PQ-1001-001 rev J
61) ICC inkl. P&ID
62) Forenklet spredningsanalyse
63) Equinor sin granskingsrapport
64) Diverse svar på avklaringsspørsmål til mottatt dokumentasjon
65) Sikkerhetsstrategi for HLNG
66) TR2237 inkludert addendum for HLNG

Appendix B – Overview of personnel interviewed – see separate document