PETROLEUMSTILSYNET

# Investigation report

| Report | |
|---|---|
| Report title<br>Report of the investigation of a fire in the air intake of GTG4 at Hammerfest LNG, Melkøya | Activity number<br>001901043 |

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

| Involved | |
|---|---|
| Team<br>T-L | Approved by/date<br>Kjell Arild Anfinsen/20 April 2021 |
| Members of the investigation team<br>Liv Ranveig Rundell<br>Arne Johan Thorsen<br>Arnt-Heikki Steinbakk<br>Trond Sundby | Investigation team<br>Bente Hallan |

**Contents**

# 1 Summary

A fire broke out on 28 September 2020 in the air intake for gas turbine generator 4 (GTG4) at Equinor's Hammerfest LNG (HLNG) plant at Melkøya. This facility was in a running-up phase after a shutdown, and GTG4 had been closed down to correct a fault in an oil filter. The Petroleum Safety Authority Norway (PSA) decided on the same day to investigate the incident.

The fire caused material damage to the GTG4 air intake and filter housing and consequential damage from extinguishing work to electrical, instrumentation and mechanical equipment. The plant has been shut down since the fire and is due to resume operation on 1 October 2021.

Had external assistance not been available, the fire would have burnt for longer since firewater monitors at the plant do not cover the turbine air intake. The probability that the fire might have spread to neighbouring areas is considered to be small, but it could have caused more extensive damage to the filter and generator housings.

Equinor has commissioned technical fire tests and KFX simulations of temperature development in the GTG4 filter housing. These support the likelihood that the fire broke out because pre-filters in the air intake auto-ignited. The control valve for hot-oil supply to the anti-icing panels had been opened manually while the turbine was shut down, causing the temperature in the filter housing to rise sufficiently over time to auto-ignite the pre-filters. The valve was opened to dissipate excess heat in the hot-oil circuit. This method was still being practised despite earlier incidents at HLNG where pre-filter cassettes had melted/deformed and filters had dropped after the control valve was opened with the turbine out of operation.

The filters on GTG4 were last replaced in 2015. According to the technical fire test, biomass buildups (primarily insects) in the pre-filters may have lowered their auto-ignition temperature. That could have affected auto-ignition opportunities if enough hot oil was circulated in the weather conditions prevailing on the day of the incident.

Five nonconformities have been identified by the investigation, relating to:

- management and control
- manning in the organisation
- risk analyses
- filter maintenance
- overview of external emergency response resources.

Three improvement points have also been identified, related to:

- log-keeping/whiteboarding
- overview of performance requirements in the emergency preparedness plan
- follow-up of leaks from anti-icing panels.

## 2 Abbreviations

| | |
|---|---|
| CCR | Central control room |
| CFD | Computational fluid dynamics |
| DPN | Development and production Norway |
| DSHA | Defined situation of hazards and accidents |
| ESD | Emergency shutdown |
| FI-FI | Firefighting system |
| GTG | Gas turbine generator |
| HLNG | Hammerfest LNG |
| KFX | Kameleon FireEx |
| Kripos | National Criminal Investigation Service |
| LNG | Liquefied natural gas |
| LOS | Line of sight |
| LPG | Liquefied petroleum gases |
| MMP OPL | Marketing, midstream and processing - onshore plants |
| MMP PM | Marketing, midstream and processing - processing and manufacturing |
| PSA | Petroleum Safety Authority Norway |
| QRA | Quantified risk assessment |
| TPO | Technical and plant optimisation |

## 3 The PSA investigation

The PSA was phoned by Equinor at 16.21 on 28 September 2020 to notify a fire in the HLNG turbine area. Continuous contact was maintained with HLNG through the evening. The PSA decided to investigate the incident, and an investigation team was established on the morning of 29 September. A video meeting was held with Equinor later that day where the company provided information on the incident.

Inspections and interviews were conducted by the investigation team at Melkøya from 30 September to 7 October 2020. The investigation was well organised by Equinor, so that the PSA was able to conduct conversations and inspections within the prevailing restrictions and infection control measures for HLNG. Supplementary interviews were conducted virtually on 26 October and 2, 6, 10 and 17 November 2020. A virtual meeting was also conducted with HLNG on 15 January 2021.

The team has based its investigation on Equinor’s technical fire tests and CFD KFX simulations of temperature developments in the filter housing. Two members of the team were present during the first of the tests, which were conducted by Rise Fire Research in Trondheim. Subsequent tests were witnessed virtually.

Attention in the investigation has concentrated primarily on clarifying the course of events, the direct and indirect causes of the fire, and the response once the fire had been discovered, and on assessing barriers in the plant area where the fire occurred.

Finnmark police district requested support from the PSA for its investigation into the fire. During its stay in Hammerfest, the PSA provided support during questioning at Melkøya and Hammerfest police station. Assistance has also been given subsequently – including dialogue with the National Criminal Investigation Service (Kripos).

### 3.1 Composition of the investigation team

The PSA's investigation team has comprised:

| | |
|---|---|
| Liv Ranveig Rundell | process integrity |
| Arne Johan Thorsen | process integrity |
| Arnt-Heikki Steinbakk | logistics and emergency preparedness |
| Trond Sundby | structural integrity |
| Bente Hallan | process integrity (investigation leader) |

### 3.2 Mandate for the investigation

The PSA's mandate for the investigation was as follows.

a. Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes time lines and incidents).
b. Assess the actual and potential consequences
    1. harm caused to people, material assets and the environment
    2. the potential of the incident to harm people, material assets and the environment.
c. Assess direct and underlying causes.
d. Identify nonconformities and improvement points related to the regulations (and internal requirements).
e. Discuss and describe possible uncertainties/unclear points.
f. Assess the player's own investigation report (which may become available after the PSA's own report).
g. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.
h. Recommend – and normally contribute to – further follow-up.
i. Support the police on request in its investigation of the incident.

## 4 Background information and system descriptions

### 4.1 Description of plant and organisation

Hammerfest LNG is a plant for receiving and processing natural gas and condensate from the Snøhvit field (Snøhvit, Askeladd and Albatross) in the Barents Sea. It became operational in 2007. Equinor (then Statoil) was responsible for its construction and is now operations operator for the plant.

This facility is located on Melkøya island outside Hammerfest, and accessed by an undersea road tunnel. A reception/security gate at Meland, at the landward end of the tunnel, provides access control of personnel and vehicles.

Production from Snøhvit is piped for 143 kilometres from seabed installations to Melkøya. The plant is equipped for processing the wellstream as well as for storage and loading. End products are liquefied natural gas (LNG), liquefied petroleum gases (LPG) and condensate. These are held in storage tanks before being loaded into ships or road tankers for onward transport.

From its startup until 31 December 2015, HLNG was grouped with Equinor's offshore facilities in DPN. From 1 January 2016, it was transferred to MMP OPL (then MMP PM) with the company's other onshore plants.

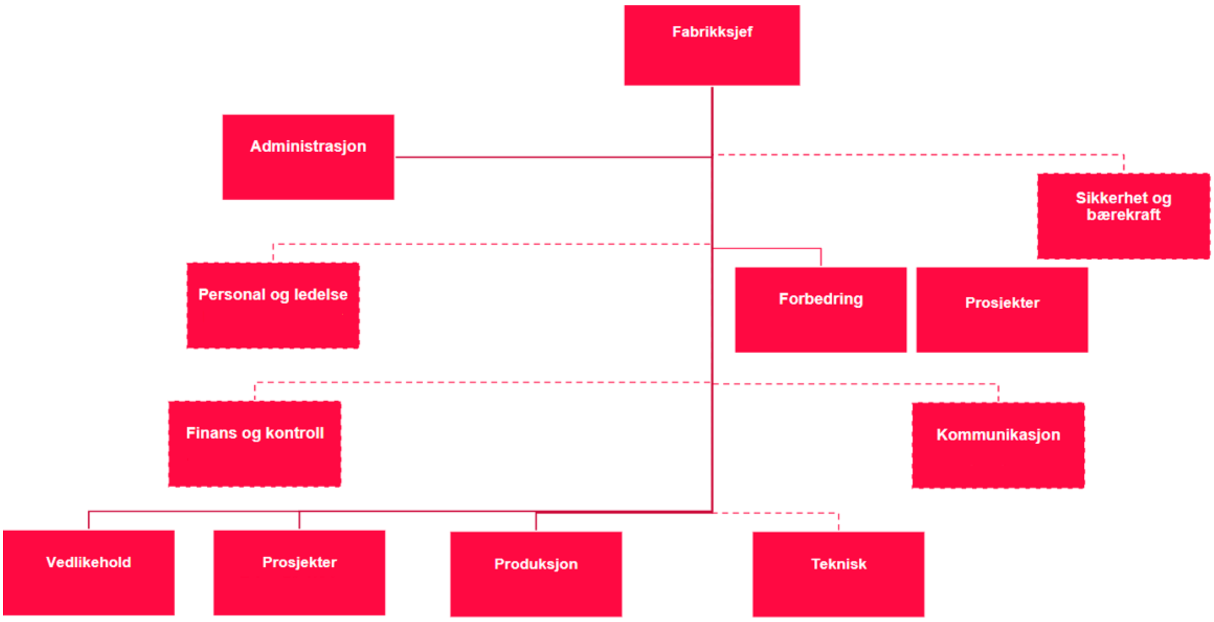


*Figure 1 Organisation of HLNG at 28 September 2020. (Source: Equinor)*

## 4.2 Position before the incident

When the fire broke out, HLNG was in a running-up phase after an unplanned shutdown on 10 September 2020. The latter was caused by frequency disruptions in the national grid during turbine maintenance. This shutdown followed a long-planned maintenance turnaround. In connection with restarting after the unplanned shutdown, gas leaks occurred from heat exchangers 20HA101 and 54HA101A on 10 and 13 September 2020 respectively. Equinor does not consider that the fire of 28 September 2020 had any direct connection with these gas leaks.

At the time of the incident, GTG4 was shut down to correct a fault in an oil filter and was therefore not in operation when the fire broke out.

The air temperature was about 10-12°C, with a wind speed of one-two metres per second from the south-east.

## 4.3 Area at HLNG where the incident occurred

The fire broke out in the air intake to GTG4, which is located in the turbine area south-east of the process areas. Five turbines stand in a row between the process area and the sea, with GTG4 closest to the process area.

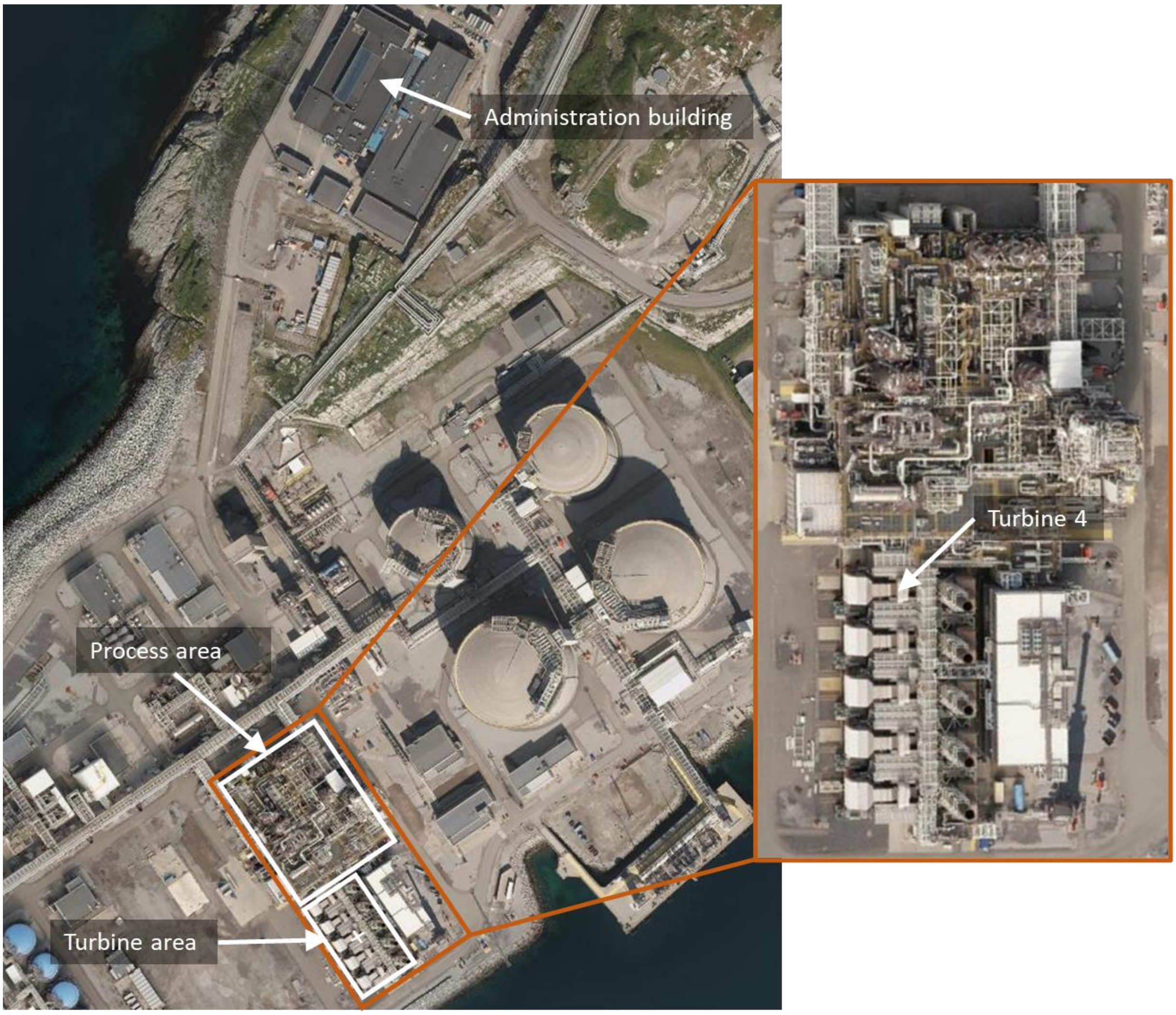


*Illustration 1 Overview of the area where the fire occurred. (Background photo: kart.finn.no)*

*Illustration 2 The turbine area. (Photo: PSA/AHS)*

## 4.4 Filter housing and filters

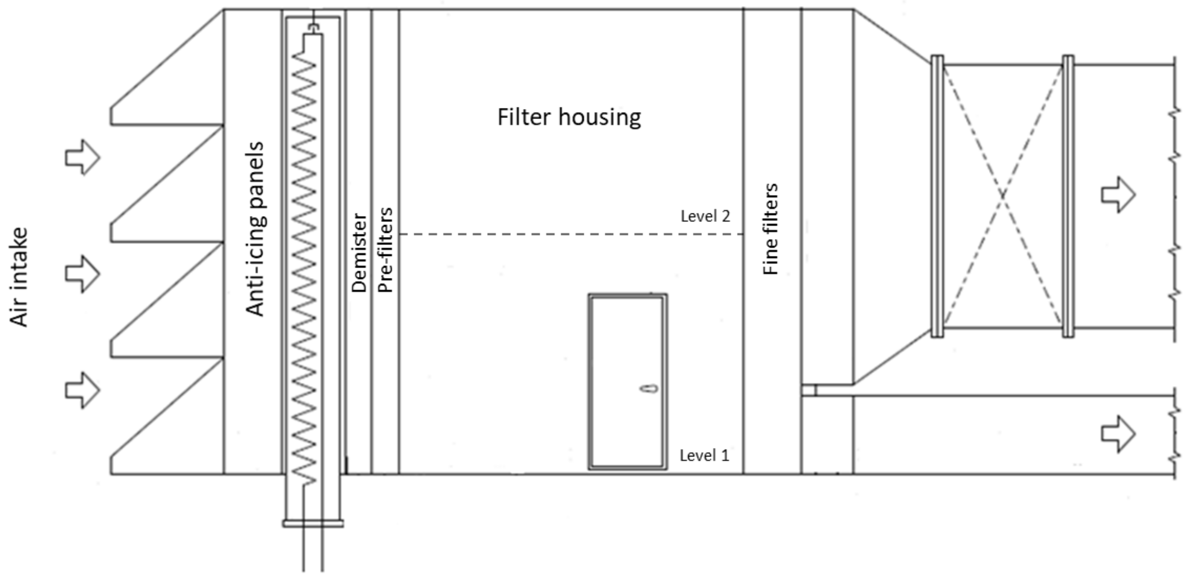


*Figure 2 Diagram of the air intake and filter housing*

The fire was located in the filter housing for GTG4. This is an enclosed room for filters and their inspection/maintenance, with access doors at each end. Made of steel, the housing comprises two levels separated by a steel divider. Access to the upper level is by means of a ladder through a hatch between the levels. Each housing contains two sets of filters – pre-filters located just inside the air intake and the anti-icing panels, and the fine filters opposite. The pre-filters are a bag type, while the fine filters are installed in cassettes. Both types are positioned in plastic frames which each contain several filters held in place by steel clips/attachment brackets. Manufactured by Camfil, these filter types are widely used for different applications in the oil industry. According to the data sheet, their maximum design temperature – in other words, the maximum temperature where the manufacturer/supplier guarantees performance – is 70°C. Other equipment in the room primarily comprises light fittings, drainage pipes and gas detectors.

Two line-of-sight (LOS) gas detectors are installed on the upper level and one on the lower. They are positioned just inwards of the pre-filters from end to end of the room at heights of about 0.5 and 1.5 metres. The detectors are part of the protection for the turbines, and intended to shut them down if gas enters the air intake.

*Illustration 3 Camfil HI-FLO XLT pre-filter. (Source: manufacturer)*

*Illustration 4 GTG5 filter housing, second level. Pre-filters right and fine filters left (Photo: Kripos)*

## 4.5 System 81 power generation

HLNG is supplied with electricity from a power station with five identical units (GTG1/2/3/4/5). Each comprises gearbox, turbine, generator and step-up transformer, and has an electricity output of about 45 MW at an ambient (design) temperature of 4°C and optimal humidity. GTG4 has recently been run at somewhat reduced output because of earlier vibration problems.

The power generation system interfaces with four systems – 80, which receives the electricity output (80-EH-110) from the generators, 50, used to heat the anti-icing facility for the turbines, 57, for fuel gas to supplement feed gas to the turbines, and 85, which handles control and management functions.

To achieve flexible and stable power output, electricity can also be imported from the 132 kV regional grid. Since the national grid has limited delivery capacity, this import is limited to a ceiling of 115 MW.

The safety report for HLNG describes five different operating modes.

- Normal operation: own power station plus national grid available (synchronised)
- Island operation: output from own power station alone
- Essential operation: only essential power generation and UPS
- Emergency operation: only UPS battery banks
- National grid operation at 132 kV or a lower voltage (can supply the plant with power, but not sufficiently to maintain production)

## 4.6 System 50 hot oil

Statoil Thermoil 30 has been chosen as the heating medium for those parts of the plant which must be heated. This hot oil has a flash point of 236°C and an auto-ignition temperature of 348°C. Its data sheet states that the cracking temperature is 358°C – in other words, the hot oil decomposes into both simple/light and complex molecular hydrocarbon structures at this temperature. That will cause the oil to coke inside the hot oil circuit and restrict heat transfer for the whole system. Samples of the hot oil are taken weekly to check its quality. The operating documentation specifies that the hot oil should not exceed 300°C, and a high-temperature alarm is accordingly incorporated at 280°C.

The hot oil flows in a closed circuit with the aid of two circulation pumps (50-PA-101 A/B). A reserve pump is also available for alternation or back-up (50-PA-101 C). These units each have a capacity of 1 600 tonnes per hour – 3 200 tonnes per hour in total. Each pump is driven by a dedicated electric motor.

Hot oil is distributed to three different consumer groups with the necessary thermal energy:

- high-temperature-level (HTL) consumers – 260°C
- medium-temperature-level (MTL) consumers – 192°C
- low-temperature-level (LTL) consumers – 148°C (varies somewhat, depending on total heat requirement).

The system contains three hot-oil tanks, which are pressurised with nitrogen to prevent air intrusion and to maintain a minimum pressure in order to prevent negative pressure and cavitation in the pumps.

Since the complete hot-oil circuit is regarded as a single segment, it does not contain sectioning valves to isolate parts of the circuit.

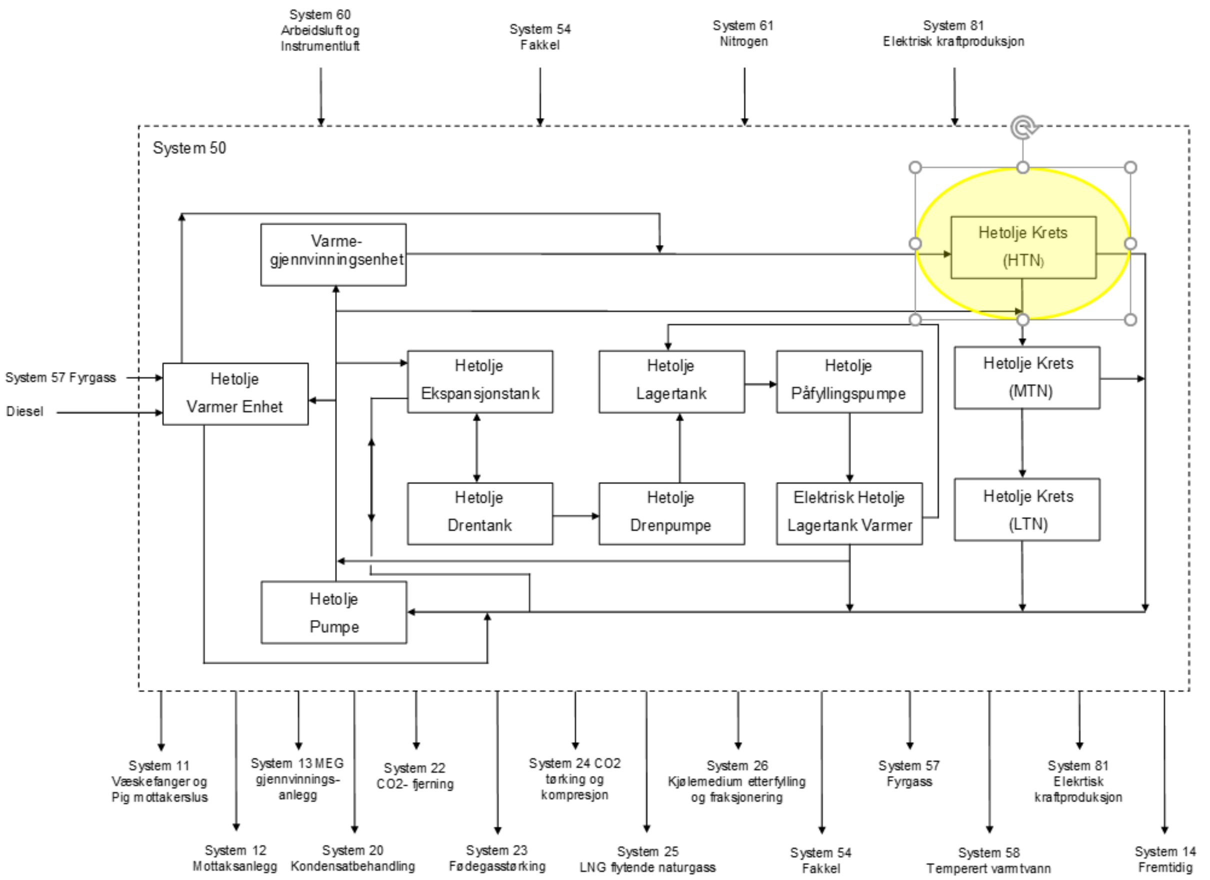


*Figure 3 Block diagram of system 50. (Source: Equinor)*

An overview of HTL consumers in the hot-oil system is presented below.

| | |
|---|---|
| Stabilisation column boiler (20-HA-101) | 9 000 kW |
| Regeneration gas heater (23-HA-101) | 8 900 kW |
| $CO_2$ dewatering regeneration gas heater (24-HA-105) | 600 kW |
| Methane column boiler (26-HA-101) | 6 150 kW |
| Ethane column boiler (26-HA-102) | 7 500 kW |
| Propane column boiler (26-HA-104) | 8 900 kW |
| Methane additive absorber regeneration heater (26-HA-107) | 50 kW |
| Anti-icing heaters for gas turbines (81-HE-101/201/301/401/ 501) | 2 100 kW (seasonal use) |

*Table 1 High temperature level (HTL) consumers in the hot-oil system.*

### 4.7 Anti-icing system (part of system 81)

Each of the five gas turbines has its own anti-icing system to prevent ice build-up in its air intake when operating and starting up in cold weather. This is done by heating the intake air sufficiently to prevent it falling below the dewpoint temperature. The temperature rises in line with relative humidity. The system is installed in the weather hoods at four levels, with rain/snow louvers fronting each level.

The anti-icing system comprises heat exchangers with associated instrumentation and valves for temperature regulation. Intake air is heated as it passes through the heat exchangers. The latter are built up as panels constructed from horizontal tubes about 15 millimetres in diameter, which is heated by hot-oil system 50. Air passes between these tubes. As an HTL consumer for hot oil, the anti-icing system is supplied with oil heated to 260°C. Each exchanger has a thermal spread of 360-400 kW. In addition to warming up intake air to prevent icing, it continuously melts snow and ice penetrating through the louvers as well as heating the aluminium demister located right next to the anti-icing panels. The system is recommended for use when snow is falling or when humidity is high at temperatures below 5°C.

One control valve for each anti-icing panel controls the quantity of hot oil supplied to it. This normally stands in the automatic position, and regulates the supply in accordance with the external temperature and humidity. Manual shut-off valves are located upstream from the control valve and on the return piping from the anti-icing panel.

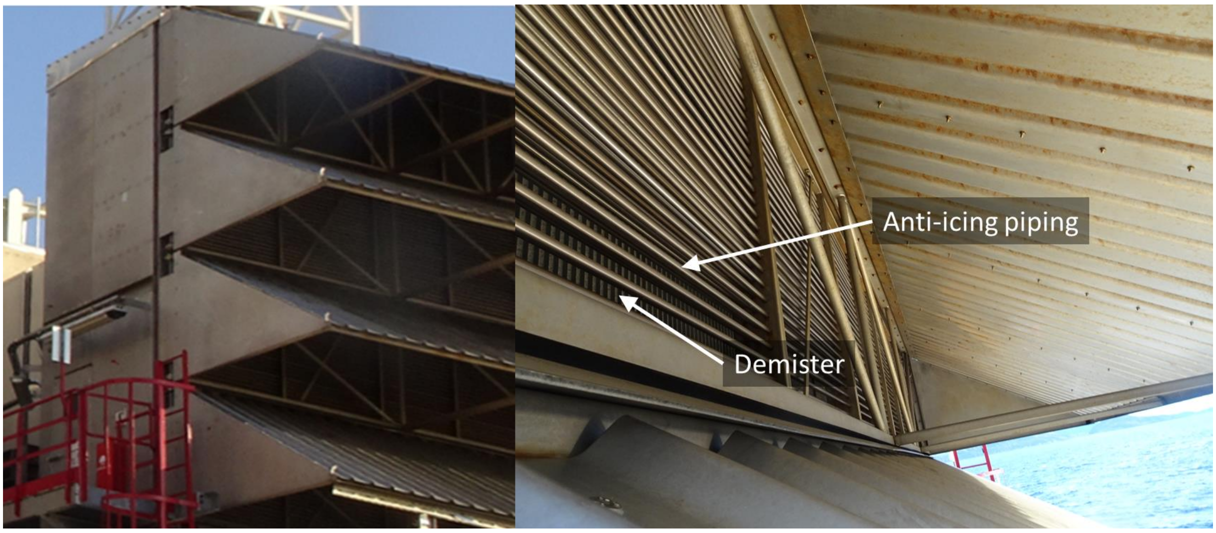


*Illustration 5 Location of the anti-icing panel. (Photo: PSA/AHS)*

## 4.8 Fire and explosion strategy

The fire and explosion strategy for HLNG specifies that fixed firewater and possible foam systems must be installed "where escalation can occur" and which "cannot be reached by firewater monitors".

The risk map for the turbine/generator package (CAH1) area specifies that firewater coverage there is based on firewater monitors started up from the CCR with programmed oscillation. Only the nearest filter housings are partly covered by firewater monitors from the top deck of the process area. The turbine packages with filter housings are positioned in a row, where GTG4 stands closest to the process area with distance and obstacles increasing for GTG3, GTG2, GTG1 and GTG5 (outermost). Firewater coverage reflects probability assessments of whether incidents with the potential to escalate could occur in this area. The actual turbine houses are protected by internal water-mist systems.

Active fire-extinguishing systems are manually activated, apart from the water-mist system in the turbine, emergency generator and firepump houses where activation is automatic on fire detection.

Gas detection – 10% LEL/1 LELm on one detector (single detection) – activates an alarm in the CCR and the whole production area. Manual alarm points in the area can also be used to notify the CCR of a hydrocarbon leak or other incidents. Generally speaking, gas detection does not automatically shut down the process except in certain very specific cases, including:

- gas turbine shutdown, ventilation halt and closure of ventilation butterfly valve for the gas turbine on detection by two out of six gas detectors in the turbine air intake

- shutdown of gas turbine, ventilation on standby on detection by two out of six gas detectors in the turbine house.

Furthermore, the operators are reported to have an important job in identifying the causes of a gas detection so that further manual action can be taken quickly and safely. The operators must decide as rapidly as possible whether they should manually disconnect possible ignition sources (turbines, burners, ventilation intakes for substations), even if they are automatically isolated on confirmed local gas detection (two out of N).

### 4.9 Earlier nonconformities related to firewater coverage in the process area

The PSA conducted an audit in 2012 on the use of risk analyses and requirements for fire resistance at HLNG. Among other findings, this identified a nonconformity related to lack of documentation for firewater coverage at lower levels in the process area (areas CAG1/CAF1). Equinor conducted further tests and assessments of firewater coverage for these areas. That was followed up by a new PSA audit in 2013, which concluded that the nonconformity from 2012 had been handled in line with Equinor's feedback, and follow-up of the nonconformity was terminated. The nonconformity did not address firewater coverage in the turbine/generator area (CAH1).

## 5 Equinor's analyses

Equinor has commissioned CFD KFX-simulations, technical fire tests and investigations of the ignition properties of the hot oil. This report draws on the results from these simulations, tests and investigations.

### 5.1 CFD KFX simulation

CFD KFX simulations were conducted to investigate possible temperature developments in the filter housing. Three were carried out with following initial parameters: no wind, air temperature 14°C and hot-oil temperature 260°C.

Results from the three simulations show that, when exposed to 260°C from the heat exchangers over a long period, the temperature in the pre-filter cells could reach 175-199°C (448-472 Kelvin). In the tests, the anti-icing panels were modelled as a continuous wall of cells with a constant temperature of 260°C. In reality, the system is not a continuous wall, so this simplification represents a rather conservative approach. Based on these results, it can be said that the temperature might have been in the 175-199°C range. No account has been taken of the possibility that the plastic pre-filter cassettes might have melted and dropped, and the simulation assumes that the cassettes remain in the same position throughout the run. The temperature at the fine filters at the rear rose significantly less than for the pre-filters.

## 5.2 Technical fire tests

Technical fire tests were conducted to determine which conditions would permit auto-ignition of the filters. Full-scale tests were made with both new and used pre-filter cassettes as well as with new fine-filter cassettes. Small-scale tests were also conducted with new and used cassette pieces.

Among other findings, these tests showed that used pre-filter cassettes ignited after about 160 minutes when the oven was set to 170°C. New cassettes did not ignite in the oven at this temperature in either full- or small-scale tests. Nor did they ignite in tests where pieces of new cassettes were sprayed with hot oil (to simulate hot-oil intrusion after a possible leak).

The discovery of biomass buildups (primarily insects) in the used pre-filters compared with the results from tests with new pre-filters may indicate that the biomass has lowered the auto-ignition temperature in the used filters.

Tests with heating of light fittings similar to those in the filter housing were also conducted in order to check whether the plastic in these could have auto-ignited. This trial showed that these fittings are unlikely to have been an ignition source.

## 5.3 Testing of hot-oil ignition properties

The hot oil was investigated to determine some of its ignition properties. Tests were conducted with the hot oil both as received from HLNG and after heating to 260°C for one hour. The properties investigated are the flash point, fire point and auto-ignition temperatures.

> The *flash point* is the lowest point at which a flammable liquid under a given pressure (atmospheric, for example) releases enough vapour to begin burning. At this temperature, contact with an ignition source (such as a spark or flame) is required for ignition. If the energy source is removed, the flame dies out.
>
> The *fire point* is the lowest temperature at which vapour from the burning liquid will remain continuously alight.
>
> The *auto-ignition* temperature is the lowest temperature which the liquid must be heated to before it ignites without exposure to an ignition source.

These investigations showed that the hot oil, as received from HLNG, had an auto-ignition temperature of 351-354°C. This was 352-355°C after pre-heating the oil.

The methodology used to investigate the flash and fire points was unable to determine flash-point temperatures above 100°C in liquids. It was therefore only possible to establish that the flash-point, and thereby also the fire-point, temperature was above 100°C for the hot oil, both as received and after heating.

## 6 Course of events

A brief overview of earlier incidents related to the anti-icing panels in the generator air intakes has been included in order to show that the system has a history of leaks.

The description below of what happened immediately before the incident is provided with limited detailing, in chronological order and including emergency response.

This information is based on various logs, documentation and conversations. Some timings from different sources may differ. The main points in the course of events have also been reviewed with Equinor's corporate investigation department.

At a point after the auto-ignition of filters in the air intake, heat build-up from the fire caused tubing in the anti-icing panels to fracture. The fire was subsequently fed by hot oil contained in the hot-oil system upstream from GTG4.

**Overview of leaks and incidents with generators**

| **Date** | **Incident** |
|---|---|
| **2007** | |
| 21 July | Leak from vent plug in anti-icing panel for GTG4 |
| 1 August | Leak from vent plug in anti-icing panel for GTG2 |
| 5 August | Leak in anti-icing panel for GTG1 |
| 7 August | Leak in anti-icing panel for GTG3 |
| 7 August | Leak in anti-icing panel for GTG5 |
| 13 September | Startup of HLNG |
| 5 October | Small leak/sweating from vent plug in GTG4 |
| **2008** | |
| 14 March | Leak in anti-icing panel for GTG2 |
| **2011** | |
| 16 May | Leak in anti-icing panel for GTG5 |
| **2012** | |
| 1 March | Leak in anti-icing panel for GTG2 |
| 1 March | Leak in anti-icing panel for GTG4 |
| 2 December | Problem with anti-icing panel for GTG5 |
| **2013** | |
| 5 April | Leak in anti-icing panel for GTG4 |
| 5 December | Pressure test recommended for anti-icing panel for GTG4 |
| **2014** | |
| 30 June | Leak of hot oil from GTG3 manifold |
| **2015** | |
| 2 January | Leak in anti-icing panel for GTG2 |
| 5 March | Leak in anti-icing panel for GTG2 and corroded piping |
| **2016** | |

| | |
|---|---|
| 11 August | Leak in anti-icing panel for GTG4 |
| 2016 | Replacement of anti-icing panel in GTG4 |
| 20 October | Leak in anti-icing panel for GTG3 |
| **2017** | |
| 22 April | Leak in anti-icing panel for GTG2 |
| 29 August | Fretting corrosion found in anti-icing panel for GTG1 |
| 29 August | Leak in anti-icing panel for GTG1 |
| **2019** | |
| 15 October | Leak in anti-icing panel for GTG4 |

**September 2020, activities related to GTG4 and the incident**

| **Date/time** | **Incident** |
|---|---|
| 23 Sep | Attempted start of GTG4 failed to increase its rpm, starter motor unable to raise it from about 1 800-1 900 rpm to achieve further increase. Machine halted and troubleshooting initiated with the hydraulic starter for GTG4 |
| 24 Sep, 00.00 | Hot-oil valve (81TC4293) for GTG4 had been closed for several days – ongoing work to prepare plant startup after shutdown. Starting up the whole plant can potentially generate much heat in the hot-oil system, depending on how it is run up |
| 24 Sep, 02.13 | Hot-oil valve (81TC4293) for GTG4 opened manually from 0% to 20.8% opened in three steps over two minutes |
| 24 Sep, 02.26 | Hot-oil valve manually changed from 20.8% to 30.8% open |
| 24 Sep, 02.30 | Hot-oil valve manually changed from 30.8% to 50.8% open |
| 24 Sep, 02.44 | Hot-oil valve manually changed from 50.8% to 0% open |
| 24 Sep, 03.33 | Hot-oil valve manually changed from 0% to 20% open and altered in stages over five minutes to 51.7% open |
| 24 Sep, abt 06.00 | Hot-oil valve manually changed from 51.7% to about 41% open. Remained at about 41% open 26 September |
| 25 Sep, abt 09.00-14.30 | Troubleshooting with the GTG4 hydraulic starter under way. A notification was established to replace oil filters |
| 26 Sep, abt 00.47 | Hot-oil valve manually changed from 41% to 0% open |
| 27 Sep, 02.07 | Hot-oil valve manually changed from 0% to 30.7% open |
| 27 Sep, abt 19.00 | Hot-oil valve manually changed from 30.7% to about 20% open |
| 27 Sep, abt 20.00 | Hot-oil valve manually changed from about 20% to 0% open |
| 27 Sep, 23.30 | Hot-oil valve manually changed from 0% to 50% open |
| 28 Sep, 00.00 | Hot-oil valve adjusted manually up and down over the next five-six hours – between 0% and 50% open |
| 28 Sep, abt | Hot-oil valve manually changed from 0% to about 40% open |

| | |
|---|---|
| 05.35 | |
| 28 Sep, abt 05.38 | Hot-oil valve manually changed from about 40% to 60% open |
| 28 Sep, 09.50 | Troubleshooting with GTG4 hydraulic starter, operator/technician locked off starter |
| 28 Sep, 10.03 | LOS gas detector (74ARH1094227) in the GTG4 filter housing registered line block at 10.03 and 10.04. The filter housing has three LOS detectors, 4228 and 4227 in the upper level and 4226 in the lower level |
| 28 Sep, 10.41 | LOS gas detector (74ARH1094228) gave alarm message (assumed to be because the glass was dirty) |
| 28 Sep, 10.44 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 10.55 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 10.59 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 11.03 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 11.20 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 11.20 | LOS gas detector (74ARH1094228) registered line block |
| 28 Sep, 11.46 | LOS gas detector (74ARH1094228) gave alarm message |
| 28 Sep, 12.00 | Hot-oil valve was still 60% open and had been so since about 05.38 |
| 28 Sep, 15.39 | Manual observation of smoke from turbine area/GTG4, and notification by radio to CCR |
| 28 Sep, 15.39 | ESD and activation of firewater (time from whiteboard in emergency response room) |
| 28 Sep, 15.43 | Evacuation of production area on Melkøya (from image of CCR whiteboard – can vary somewhat from timing in event logs) |
| 28 Sep, 15.43 | ESD 2 for process area (time from control system log) |
| 28 Sep, 15.43 | Emergency response team mustered |
| 28 Sep, 15.48 | Notification of second-line emergency response for mobilisation, plus emergency services and other relevant responders, check of all personnel in production area |
| 28 Sep, 15.50 | ESD 2 System 57 |
| 28 Sep, 15.53 | Suspended ESD 2 for process area – resumed 15.56 |
| 28 Sep, 15.55 | ESD 2 System 57 completed – 0 bar |
| 28 Sep, 15.56 | Shutdown hot oil, sectioning WHRU |
| 28 Sep, 15.59 | Sluice for firewater opened |
| 28 Sep, 16.05 | S7 blown down/scrubber empty |
| 28 Sep, 16.20 | Mobilised vessels for firewater support |
| 28 Sep, 16.23 | Public authorities notified |
| 28 Sep, 16.24 | Internal management at plant notified, need for technical support assessed |
| 28 Sep, 16.39 | Activated water mist for GTG4 and GTG3 manually |

| | |
|---|---|
| 28 Sep, 16.56 | Water spraying from support vessels, *Esvagt Aurora, Pax* and *Audax. Esvagt Auror*a was in position and began spraying at 17.05 |
| 28 Sep, 17.29 | Fire continued in GTG4 air intake. Hot oil and filter intake burning. Naked flame confirmed. Status: personnel checked, nobody injured, response personnel and acute medical communication mobilised, area 2 blown down, pressure remained in CB and 25-VD-103 |
| 28 Sep, 18.37 | Drone requisitioned to get closer to GTG4, expected arrival about 19.40 |
| 28 Sep, 18.40 | Fire-appliance garage manned by two people |
| 28 Sep, 18.56 | *Esvagt Aurora* standby for fire-fighting (withdrew a little so that water spray did not enter the filter housing) |
| 28 Sep, 18.57 | Last flames observed in GTG4 |
| 28 Sep, 18.58 | Extinguisher robot assessed, mobile crane requisitioned |
| 28 Sep, 19.04 | *Esvagt Aurora* continued fire-extinguishing and spraying |
| 28 Sep, 20.30 | Drone launched |
| 28 Sep, 20.55 | Fi-Fi system on *Esvagt Aurora* set to idle – drone flight under way in this period – water removed from GTG4 air intake in that *Esvagt Aurora* pulls back a little and directs the spray in a slightly different direction |
| 28 Sep, 21.15 | Completed drone flight – estimated 30 minutes until film ready |
| 28 Sep, 21.22 | *Esvagt Aurora* re-establishes full water pressure and continues cooling of GTG4 |
| 28 Sep, 21.38 | Decided not to accept offer of assistance with fire-extinguishing robot from Oslo fire service |
| 28 Sep, 21.39 | Assessed manual effort to reach GTG4 air intake with hoses |
| 28 Sep, 21.52 | Drone video showed no sign of flames. Cooling of damage site continued with own system and *Esvagt Aurora*. Fire service went in with appliance and laid foam. Dialogue with area operator. Return for hot oil closed manually. |
| 28 Sep, 23.27 | Foam carpet on GTG4. Surface temperature at 7°C. Fire service and police confirmed fire extinguished and demobilised. Focus: damage site – first line acted to cordon it off |
| 28 Sep, 23.28 | Debriefed personnel leaving work |
| 28 Sep, 23.40 | *Esvagt Aurora* completed spraying and withdrew somewhat |
| 28 Sep, 23.50 | Status meeting emergency response |
| 29 Sep, 00.20 | Planned and initiated flushing of firewater system, cleaned salt water from process area and conducted technical recheck of system |
| 29 Sep, 00.20 | Second-line emergency response debriefed |
| 29 Sep, 00.25 | Second-line emergency response demobilised |
| 29 Sep, 00.40 | *Esvagt Aurora* demobilised |

# 7 Emergency response

Pursuant to the regulations, licensees and other participants in petroleum activities on the NCS and on land must maintain an effective emergency preparedness at all times in order to be able to handle hazards and accidents which could cause loss of human life or personal injury, environmental pollution or major material damage.

The investigation team has chosen to summarise the emergency response in four main phases, which cover alarm, notification and mobilisation, fire-fighting – including rescue and evacuation – and final normalisation.

When the incident occurred, HLNG's emergency response organisation – including its own first and second lines – was immediately alerted and a number of measures were continuously implemented pursuant to the response plan for the plant. These included notifying local civilian emergency and response resources, such as the West Finnmark police district, the Hammerfest fire and rescue service and Hammerfest Hospital. Support was requested from *Audax* and *Pax*, two tugs belonging to the Østensjø shipping company, in order to deploy their fire-fighting (Fi-Fi) monitors. These vessels are normally under contract to HLNG. *Esvagt Aurora*, which usually serves as the standby ship on the Goliat field (Vår Energi), was also notified and asked to support extinguishing efforts with its Fi-Fi system.

The team's overall impression is that the emergency response organisation and the establishment of measures largely functioned as planned, but that there was one condition it would characterise as a nonconformity and two with a potential for improvement. These will be described in more detail under the various phases as described below and later in the report.

The emergency response plan for HLNG Melkøya (WR-2181) provides a detailed description of how the predefined dimensioning incidents (DSHAs) are to be handled in the various phases which normally succeed each other in time. Response duties as well as descriptions of roles and teams are defined through preparedness analyses together with roles related to a standard emergency response organisation based on internal company standards and designations, and on enterprises required to maintain an industrial safety capability.

## 7.1 Alarm phase

The fire in GTG4 was discovered at about 15.40 by plant operators who were in the vicinity in connection with work under way. They immediately notified the CCR of their observations by radio. The CCR responded by activating the fire and gas alarm for the production area, including the evacuation alarm for the whole of HLNG.

Smoke from the fire could soon afterwards be observed from the CCR in the administration building on Melkøya.

The alarm signals were audible throughout the plant and also beyond it, and mobilisation of HLNG's own emergency response personnel began immediately. The latter were operational soon after the alarm was sounded, at about 15.43.

In an emergency, the CCR functions as the first line and response centre, and dedicated personnel now took their places and roles there in accordance with the emergency response plan for Melkøya. The second line was also quickly established in a room adjacent to the CCR, and was operational from about 16.05. From there, communication was established with the third line at the corporate head office in Forus. The relevant DSHA in the HLNG's emergency response plan applied during the response was DSHA no 3 fire/explosion.

As far as the PSA team has been able to establish through interviews and by reviewing logs, no technical alarm systems, gas, heat or fire detectors, or other warning systems sent alarm signals to the CCR about the fire which had occurred.

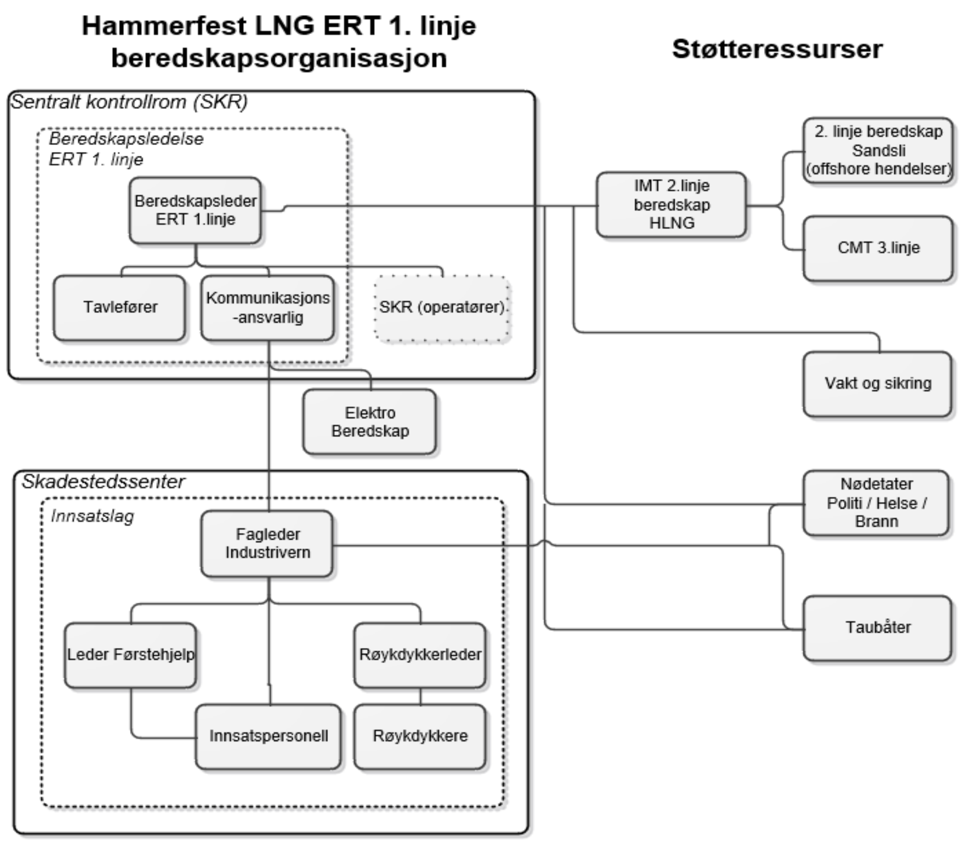


*Illustration 6 HLNG Melkøya's emergency response organisation, first line (Source: Equinor)*

## 7.2 Notification and mobilisation phase

The CCR was led by the shift supervisor who now converted to the role of emergency response duty officer. Notification of the internal emergency response organisation and external agencies was initiated immediately, and preparations began in parallel to evacuate everyone except response personnel and key workers.

Notification was given to the PSA at 6.21 on the same day.

Response personnel from Equinor mustered after a few minutes – logged at 15.43 – at their specified muster point immediately outside the administration building in what is known as the fire-appliance garage. The external emergency services also arrived shortly at Melkøya and the administration building.

The Hammerfest fire and rescue service turned out with response personnel (11 in all) divided between a crew car (H.1-1) and two water tenders (H.1-4 and H.2-4). A command car (H.0-1) and a smoke diving tender (H.2-7) were also dispatched to Melkøya. In addition, Hammerfest fire station was manned to contribute logistics, support services and other back-up related to the response.

Hammerfest Hospital sent two ambulances with medical personnel, and an ambulance was also placed in readiness at the hospital. According to the CCR response log, these resources – including police units – were in place at about 15.45.

Leading personnel from the emergency services mustered at the emergency response centre to stay updated on the position and to maintain a close dialogue with the response command.

To ensure the fastest possible access to Melkøya from the land side, the undersea tunnel to Meland was closed by traffic lights (red from the Melkøya end) for a time immediately after the alarm was given. Traffic from Melkøya was therefore halted for a short period and queues of cars and other vehicles periodically formed because of the evacuation. Infection control considerations (Covid-19) meant that many people drove from Melkøya alone and a number were therefore left to wait for bus transport.

Østensjø has three tugs stationed on behalf of HLNG at Polarbase in Rypefjorden outside central Hammerfest. These were notified and asked to assist from the sea side with their firewater monitors.

The *Esvagt Aurora* standby ship, on its way out of Polarbase when the fire broke out, was notified by Goliat operator Vår Energi of the fire and asked to render assistance.

*Esvagt Aurora*'s master decided immediately to make for Melkøya in order to provide possible extinguishing help. The port captain at Melkøya, who knew the vessel was at Polarbase, had also recommended that the CCR contact *Esvagt Aurora* to request assistance.

No tankers were berthed at Melkøya when the incident occurred.

### 7.3 Fire-fighting – rescue and evacuation

The emergency response command initiated predefined shutdown procedures with the production plant in the specified order. This is described in more detail in chapter 6 above. Furthermore, it decided in accordance with the response plan not to send response personnel to the scene of the fire but to seek as far as possible to use the stationary extinguishing systems to cool the fire area. In parallel, ESD 2 (blowdown) was initiated in the process area.

Personnel on site (POB) at Melkøya, including in the process area where GTG4 is located, was reported to the CCR relatively quickly. The CCR log/whiteboard shows that the POB overview was ready at 15.48 (about seven minutes after the alarm) and that all personnel were then evacuated from the production area and everyone was accounted for. The performance requirement for POB is specified in Equinor's own governing documents (WR 1920 and the emergency response analysis for HLNG).

Meland (the security checkpoint on the mainland) has its own entry and access control system (boom for vehicles and turnstile for personnel), which is intended to ensure a complete overview of who is in HLNG at any given time. The team has been told that the personnel overview was maintained throughout the incident. There were 309 people in HLNG at 13.00, including 50 in the production area. The final registration before the alarm sounded was 267 people on Melkøya at 15.00. After evacuation had been initiated, 68 people were registered on the island at 16.00 and none in the production area.

Internal response personnel, including fire and smoke divers belonging to Melkøya, mustered first at the specified muster point in the fire-appliance garage by the administration building. They remained in and beside the administration building ready for action, and were in continuous dialogue with Equinor's response command and the other response agencies – including the police and the Hammerfest fire and rescue service. After arrival on Melkøya, the latter stayed outside the administration building ready to intervene with vehicles and crews. The same applied to the police and the ambulance service. Leading personnel from these agencies also contributed advice to the leadership in the CCR. At one point after the response personnel had mustered, it was decided to bring everyone inside the building because thick smoke from the fire was drifting over the administration building and the open space in front of it.

Two of the three Østensjø tugs on fixed contract, *Audax* and *Pax*, were also contacted and asked to come to Melkøya, as close as possible to the fire scene on the south side facing central Hammerfest. The intention was to see whether they could be used for extinguishing or cooling with their monitors. Both were in position at 16.25, and *Audax* was asked at 16.45 to start water-spraying with both its monitors.

While en route to Melkøya, *Audax* 's master heard over the radio from Polarbase that standby ship *Esvagt Aurora* was also called in around 16.00. It was asked to prepare to use its monitors, which had much greater capacity than the tug systems (1 450 $m^3$ of seawater per monitor for *Audax* compared with 3 600 $m^3$ for *Esvagt Aurora*).

Before the incident, *Esvagt Aurora* had been in Hammerfest/Polarbase on a Nofo verification exercise and was on its way back to Goliat when the alarm sounded. It was in position and began spraying with its monitors around 17.00. According to its master, the ship hit the fire scene fairly precisely with its two monitors. That was confirmed several times by the CCR, which also confirmed that the water had a good effect on fire-extinguishing and cooling of the fire scene. The power of the monitors meant that some time was taken to manoeuvre-in the ship and the sprays and to try to avoid damaging other parts of the plant.

At around 19.00, the response command asked *Esvagt Aurora* to suspend spraying (for about six minutes) in order to check whether the fire was under control. The ship's master was then informed that the fire appeared to be out but that spraying towards the site should continue. This continued until about 22.30.

In one case, according to the log around 17.54, two smoke divers and then two electricians were sent into an equipment room in L-111 in the evacuated production area to turn a bend and take other manual action in order to permit the startup of associated seawater pumps and compressors which had then run out of emergency air. That was considered safe by the response command because this building was well away from the actual fire scene. Everyone was out of the area by about 19.00.

Furthermore, with assistance from a local company, a drone was deployed at about 20.30 to examine the fire scene from the air. According to the response leader, the images/ video provided good information directly from the site without having to send in personnel for such observations. The images/video confirmed that the fire was under control and appeared to be extinguished. For safety's sake, however, the response command decided to continue spraying seawater from *Esvagt Aurora* until about 21.20 to prevent a resurgence of the fire and ensure good cooling of the fire scene.

Immediately after 22.30, a fire appliance from the Hammerfest fire and rescue service and an internal response team were deployed to the fire scene to carry out a visual check and to initiate foam spraying of the actual GTG4 air intake. According to the response log, foam spraying from the appliance began at 22.59.

The vessels were released from their assignment at that time. *Esvagt Aurora* left HLNG around 00.40 on 29 September to return to Goliat, while *Audax* remained on standby at Melkøya until the following day. The police and fire service demobilised their response forces at Melkøya around 23.30.

According to the CCR log/whiteboard, the fire was formally declared extinguished at 23.20.


*Illustration 7* Esvagt Aurora. *(Photo: Esvagt)*

### 7.3.1 Comments on fire-fighting, rescuing and evacuating

Using vessels and their fire monitors is not included in the Melkøya/HLNG emergency response plan for handling DSHA 3 incidents in the production area, but the tugs are mentioned as an emergency response resource when loading/ discharging ships and as a supplementary resource to add capacity to seawater/ firewater pumps. Vår Energi and Equinor have also entered into a collaboration agreement on use of standby ships in the Barents region. *Esvagt Aurora* had not participated previously in training or drills directed at Melkøya and, according to its leadership, this response was its first assignment at the plant.

Some people found the evacuation from Melkøya confused in its initial phase. Reportedly, perceptions differed over whether the evacuation alarm applied only to the inner production area or to the whole island. The response command believed it had good control and that it activated the evacuation alarm which means that everyone had to go to their specified muster point. The public address announcement was also interpreted differently over whether it meant "evacuate the production area" or "evacuate the island". Reportedly, the first PA announcement made should mean "evacuate the production area".

As smoke from the fire blew over the administration building, many people also moved further in towards the emergency response centre/CCR corridor, where they perceived the HVAC system to be providing better air conditioning.

Response personnel noted that they lacked opportunities to see the response log and images/video monitors from the production area at their muster point (the fire-appliance garage).

HLNG/Melkøya is a member of Resource Companies for Mutual Assistance (RFGA). This collaboration allows Melkøya to draw on greater material resources in the event of a major accident, such as large quantities of foam liquid, transportable/portable firewater monitors and portable fire pumps as well as advice/special expertise on large, long-lasting incidents or accidents of a unique character. The investigation team has been told that HLNG took advantage of this agreement immediately after the fire to secure foam liquid from other Norwegian production plants in order to refill its foam system.

Oslo's fire and rescue service (OBRE) offered in an early phase to provide special remote-controlled fire-fighting robots. That was considered by the response command, which decided against requisitioning this since no need was seen for it.

The times specified above are based on interviews, documentation received, second-line logs and images of the whiteboard maintained manually in the CCR during the incident. Some of the timings have been clarified in retrospect through consultation with Equinor, in part because no whiteboard images are available between about 17.00 and 21.00. In the team's view, minor adjustments to some timings have no significance for the response or the outcome of the incident but have created more work for the investigation in reconstructing parts of the response and commitment.

Although the incident was handled in accordance with DSHA 3, fire/explosion, the duties of the communication officer in the response plan do not include whiteboarding – only log-keeping. Whiteboarding is listed among the communication officer's duties under other DSHAs in the same plan. Furthermore, it emerged from interviews that the response command had trained/drilled on the same DSHA 3 in the previous shift before the incident occurred.

The quality of other logging, including weather data, is not assessed further in this report.

Performance requirements for the various measures in the response plan, such as evacuation of personnel from the production area and time taken to mobilise the internal response team, are not directly described in the plan or in a separate attachment/ appendix to it. That makes it more complicated to locate the various requirements specified in the company's governing document WR-1920 *Emergency preparedness in MMP PM*. To locate certain requirements, it is also necessary to be familiar with or look up HLNG's emergency preparedness analysis to locate the requirement.

### 7.4 Responsibility and safety zones at HLNG

HLNG is responsible for safety within its own security zone, and a security field has been established around Melkøya. See the illustration below. Vessels are not allowed to remain within or pass through this field at any time without permission from Equinor or possibly the Hammerfest port authority. At no time during the fire-fighting was any illegal intrusion reported into the security zone around the plant.

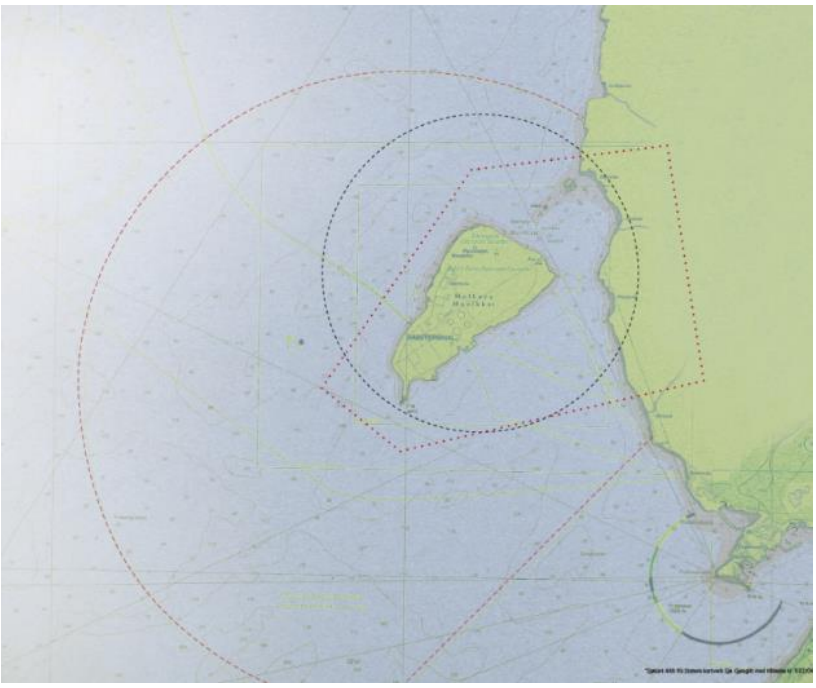

*Illustration 8 HLNG/Melkøya security field. (From the HLNG emergency response plan/WR-2181)*

## 7.5 Normalisation

The main purpose of the normalisation phase is to return the plant with associated personnel resources to a safe and normal condition.

This work is still under way, and Equinor plans to start up on 1 October 2021.

The investigation team has been told that a number of debriefings and conversations were conducted immediately after the incident and on subsequent days for personnel involved who are associated with Melkøya, and assumes that this was also the case for external responders. Professional health care was also offered, including from psychiatrists/psychologists, for people who wanted this. The team has not investigated this subject any further. But it noted during interviews that a number of people felt that too little attention was paid to personnel involved, who were asked to report for work as normal the day after the incident. Some also felt that insufficient information about the incident was provided on the following working day.

The fire scene was cordoned off and preserved after the incident, so that investigation work could be conducted in the best possible way.

Information provided to the civilian population in Hammerfest does not fall within the PSA investigation’s mandate, but is assumed to have been taken care of by the company in collaboration with the local authorities.

No acute personal injuries were reported at any time during or after the incident.

# 8 Potential of the incident

## 8.1 Actual consequences

The fire has had the following consequences:

- the structure of the GTG4 filter housing is damaged
- the demister has been destroyed
- extensive deformation to and fractures of tubing in the anti-icing panels
- pre-filters and fine filters have burnt up.

Consequential damage from extinguishing work:

- damage to electrical equipment and instruments from seawater spraying
- damage to mechanical equipment from seawater spraying.

Production shutdown

- The plant has been shut down since the fire. Equinor plans to start it up again on 1 October 2021.

*Illustration 9 Interior of the GTG4 filter housing, level 1, after the fire (Photo: Kripos)*

*Illustration 10 Interior of the GTG4 filter housing, level 2, after the fire (Photo: Kripos)*

*Illustration 11 External view of the damage to the GTG4 air intake (Photo: PSA/AHS)*

## 8.2 Potential consequences

Air intakes to the turbines have no fixed extinguishing system. The filter housings located closest to the process area are only partly covered by firewater monitors in the uppermost level of the process area, but the actual air intakes and equipment in the filter housing are screened by weather protection and structures.

If external extinguishing assistance had not been available, the fire would have continued for longer. This creates a potential for greater damage in the filter housing and turbine house, but the team considers that the probability of the fire spreading to neighbouring areas was small.

# 9 Direct and underlying causes

## 9.1 Direct cause

The technical fire tests and KFX simulation of temperature development in the GTG4 filter housing support the likelihood that the fire broke out because the pre-filters in the air intake auto-ignited. A high surface temperature on the anti-icing panels caused a temperature rise over time in the filter housing, which was sufficient for the pre-filters to auto-ignite.

## 9.2 Underlying causes

The investigation has identified several elements which were or could have been significant for the fire breaking out. These are described below.

### 9.2.1 Manual control of hot-oil supply to the anti-icing panel

The surface temperature of the anti-icing panels was high because the control valve for hot-oil supply to the panels was manually opened while the turbine was shut down. This was done to dissipate excess heat in the hot-oil circuit. The valve was 60 per cent open from about 05.30 on the day of the incident. When the turbine is not running, it draws no air through the intake which cools the anti-icing panels. Weather conditions, with a temperature of 10-12°C and virtually no wind, contributed little to cooling.

### 9.2.2 Follow-up of earlier incidents with melting of filter cassettes and practice with manual operation of control valve

According to their data sheet, the pre-filters in the filter housing have a design temperature of 70°C. Earlier incidents with melting/deformation of pre-filter cassettes and filters dropping as a result of manual opening of the control valve with the turbine out of operation were not made known to all relevant personnel who operate the hot-oil system. At least seven notifications created in the maintenance system (SAP) in 2009-13 documented findings of melting/deformation in filter cassettes. These melting incidents were regarded as operating incidents handled by the operations and maintenance department, without cases being created in the Synergi incident follow-up system.

Opening the control valve to dissipate excess heat was still practised after these incidents. The week before the incident, this valve was opened on several occasions to various extents for shorter or longer periods. Opening the control valve was logged in the CCR, but not mentioned specifically on hand-over to the next shift.

### 9.2.3 Filter replacement

On investigation, used pre-filters from another GTG revealed a buildup of biomass (primarily insects). Results from the technical fire tests indicate that such buildups could have reduced the filter’s auto-ignition temperature. The maintenance programme for filter replacement in the turbine filter housings was previously calendar-based, with a two-year interval between replacements. The programme changed in 2016 to condition-based replacement. Criteria for condition and replacement have not been described in the filter maintenance programme. It emerged from the investigation that the filters in the GTG4 filter housing had not been replaced since 2015. More frequent replacement would probably have reduced biomass buildup in the filters and thereby probably also affected opportunities for auto-ignition under the prevailing conditions on the day of the incident.

### 9.2.4 Manning

Relatively few people are available in certain disciplines and trades to give technical support for day-to-day operation and maintenance of the plant. Manning in TPO has been reported on several occasions to be so reduced that the department has found it challenging to handle the number of notifications generated from day-to-day operation. That has led to changes in priorities, postponement of maintenance and modifications, reclassification of job criticality, and movement of the final date for jobs. Operating disruptions have at times affected the ability to implement planned work and ensure that targets are met. This has meant resources being devoted to operational incidents at the expense of ordinary operational assignments, changes to priorities and plans, and less time to assess the condition of barriers in the plant. A number of such operational disruptions ahead of the fire meant that plant operation was unstable, including mercury challenges and leaks.

## 9.3 Other conditions significant for the course of events

### 9.3.1 Fault alarms from gas detectors in the GTG4 filter housing

Fault alarms received in the morning from the gas detectors in the filter housing were not registered/assessed as critical. Since the turbine was not operational, the alarms were not perceived as relevant and therefore not checked out. A physical check of the filter housing detectors would probably have revealed the temperature increase.

#### 9.3.2 Fire-fighting from vessels

Fi-Fi support from *Esvagt Aurora, Pax* and *Audax* was established. The water spray from *Esvagt Aurora* hit the GTG4 air intake and eventually extinguished the fire.

## 10 Observations

The PSA's observations fall generally into two categories.

- Nonconformities: this category embraces observations where the PSA has identified breaches 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.

### 10.1 Nonconformities

#### 10.1.1 Management and control

**Nonconformity**
Follow-up of compliance with governing documents is inadequate.

**Grounds**
Step-by-step procedures are in place for starting up HLNG after a shutdown. It emerged during the investigation that a method used on several occasions to dissipate excess heat in the hot-oil system involves running hot oil through a turbine's anti-icing panels even when the turbine is out of operation. The valve regulating hot-oil supply to the panels is manually opened from the control room. This method was utilised in the days before the fire and, at the time of the incident, the control valve was about 60 per cent open. With the turbine shut down, no air which cools the panels flows through the intake, and supplying hot oil to the panels will raise the temperature in the filter housing.

The method used to dissipate excess heat through the panels is not described in the governing documentation for HLNG. It emerged from the investigation that several cases had occurred from about 2009 to 2013 which involved pre-filter cassettes melting/being deformed and filters dropping when a mini-flow utilising a 10 per cent opening of the control valve had been run with the turbine shut down. This shows that the method has the potential to build up considerable heat behind the panels and in the filter housing. During this period, at least seven work orders related to notifications in the SAP maintenance system were established which document findings of melting/ deformation of filter cassettes. These experiences were not made known to all relevant personnel.

According to the design assumptions for the anti-icing panels, the recommendation is to use the turbine anti-icing system in conditions when the air has a high humidity and a temperature below 5°C. It must be assumed that the assumption is that the turbine is in operation, so that heat does not accumulate in the filter housing. At the time of the incident, virtually no wind was blowing at the plant and the air temperature was around 10-12°C.

Melting pre-filter cassettes through manual supply of hot oil to anti-icing panels on generators which are not in operation is documented and known in Equinor. The company has not ensured adequate personnel training or initiated the necessary measures to ensure compliance with routines, procedures and governing documentation for relevant personnel when starting up HLNG.

***Requirement***
*Section 21 of the management regulations on follow-up, see sections 40, litera c and 45, paragraph 2 of the technical and operational regulations on startup and operation of onshore facilities and on procedures respectively*

#### 10.1.2 Manning in the organisation

**Nonconformity**
Manning in the organisation was not adequate in all phases of the activities.

**Grounds**
During interviews in the investigation, several people reported inadequate available resources and manning in parts of the organisation. This is an issue which the PSA has followed up and identified in earlier audits and investigations (such as the audit of major accidents and electrical installation, 21-24 September 2020, the audit of operation and maintenance of pipelines, subsea facilities and onshore plants on Snøhvit and at HLNG, 27-29 August 2019, and the investigation of inadequate barriers at HLNG, 11 March 2019).

Earlier PSA audits and investigations have followed up how Equinor manages HLNG's activities, how entities responsible for different parts of the plant interact, and how the company ensures that the organisation has sufficient capacity to do the work required. The engineering support function (TPO) at the plant has a key role in providing technical support for day-to-day operation and maintenance. Relatively few people are available to contribute in certain areas and disciplines at the plant. Agreements have been established on utilising resources from other units and plants, but it is unclear how well this arrangement has functioned compared with having sufficient dedicated personnel at HLNG. The PSA has identified weaknesses and deficiencies on several previous occasions. This has also been raised in various collaboration fora, and has been expressed by employees – including reduced local availability of personnel with relevant expertise, personnel turnover, periods of high sickness absence, recruitment challenges and big workloads for certain functions/ people. These conditions have received further confirmation during the investigation through conversations and verifications of such aspects as the maintenance system.

The PSA investigation has also conducted verifications of various parts of the maintenance system and maintenance data for HLNG. The latter show that the plant has a larger proportion of corrective maintenance compared with preventive maintenance than other onshore facilities. Examples also exist where a number of indicators and measurement parameters have lain and still lie above defined levels, including for corrective maintenance. In addition, examples can be found where preventive maintenance has not been implemented within the company's own deadlines, and a relatively large amount of maintenance has fallen into the "not estimated" category.

Operating disruptions have at times affected the ability to implement planned work and ensure that targets are met. This has meant devoting resources to operational incidents at the expense of ordinary operational assignments, changes in priorities and plans, and less time to assess the condition of barriers in the plant. A number of such operational disruptions ahead of the fire meant that plant operation was unstable, including mercury challenges and leaks.

A number of people have emphasised that HLNG is complex, and that a certain level of local expertise and training is required to work there. Regardless of how the company organises its operation, the personnel resources needed must be available (capacity), they must be able to do their assigned job (expertise) and communication must be clearly defined (organisation). Manning in TPO has been reported on several occasions to be so reduced that the department has found it challenging to handle the number of notifications generated from day-to-day operation. That has led to changes in priorities, postponement of maintenance and modifications, reclassification of job criticality, and movement of the final date for jobs.

HLNG has been operated over time with inadequate capacity in parts of its organisation and has faced challenges managing in accordance with established maintenance criteria. This is supported by earlier observations, interviews and verifications in the management system and in maintenance.

***Requirement***
*Section 14 of the management regulations on manning and competence*

### 10.1.3 Risk analyses

**Nonconformity**
Lack of risk assessments related to the possibility of leaks and fires in the GTGs.

**Grounds**
The quantitative risk analysis (QRA) for HLNG states that minor leaks from the hot-oil system must be expected, but that the risk of leaks there is considered low and should be manageable with the safety system and by emergency preparedness. Key factors for this assessment are a low leak rate, a low probability of ignition/auto-ignition and the effect of safety barriers. The risk contribution from hot-oil leaks is considered negligible from a major accident perspective. No need is therefore seen for specific physical measures, such as better monitoring and sectioning of the hot-oil system or verification of operations and the operating mode. Nor is active fire-extinguishing equipment installed in the turbine area. On the other hand, great trust prevails that human and organisational barriers will help to prevent serious incidents.

The team's impression is that the risk of hot-oil ignition has been assessed as low, assuming that the system is designed, operated and followed up correctly. To ensure that the probability of hot-oil leaks igniting is as low as possible, emphasis is given, for example, to the importance of regular testing to ensure that oil ignition properties are unchanged. The relevant risk of possible incidents related to leaks and fires has not been adequately assessed for this part of the plant, and nor are the strength of knowledge and uncertainty in the assessments addressed in the QRA. Relevant incident scenarios assessed in the turbine area are primarily work accidents and hot-oil leaks with a limited/low potential. The size of discharges and the use of relevant safety barriers are highlighted as reasons why risk from this type of incident is rated so low and thereby not quantified. The QRA nevertheless notes that such incidents can be expected and may cause substantial local damage as well as plant downtime. It identifies the turbine air intake as a possible ignition source and notes that the GTGs, for example, will not shut down automatically without confirmed gas detection. CCR operators must assess the need for manual shutdown of ignition sources.

According to their data sheet, the pre-filters in the filter housing have a design temperature of 70°C. They were identified as flammable, and the door to the housing carried a sign saying this. However, the possibility that the temperature in the housing might exceed the filter limit was not adequately known or appreciated at HLNG. Earlier incidents in the plant where pre-filter cassettes had melted/deformed and filters dropped as a result of manually opening the control valve with the turbine shut down had not been sufficiently followed up or made known to relevant personnel. A fire on the *Petrojarl Knarr* FPSO in 2015 was probably caused by filters in the engine-room filter housing auto-igniting after being heated by the hot-air system. This incident was investigated by the owner as well as the PSA. The filters had the same design temperature and came from the same manufacturer as those in the GTG filter housings, but this incident was unknown to HLNG.

No assessment has been made of the probability with associated uncertainties of errors which could lead to conditions where ignition might occur. The team believes this is a weakness in the risk analyses and assessments at the plant. Its impression is that, rather than taking technical steps to handle the risk associated with the hot-oil system, HLNG chose to rely on documentation being correct and updated at all times, on expertise and training being in order, and on procedures and behavioural patterns being correct and complied with. Nor have assessments of filters and changes to the maintenance programme been adequately addressed. The team cannot see that this has been systematically followed up and verified by Equinor.

***Requirement***
*Section 17 of the management regulations on risk analyses and emergency preparedness analyses*

#### 10.1.4 Filter maintenance

**Nonconformity**
Maintenance deficiencies with filters in the turbine air intakes.

**Grounds**
The team was informed that filter replacement in the turbine air intake was changed in 2016 from calendar-based (24 months) to condition based. This was done after consideration of a change proposal (M5 43962253). Equinor has been unable to document specific routines for inspection or unambiguous criteria to be applied when assessing condition and the need to replace filters after this change. It has only defined a limit for differential pressure over the filter which will trigger a change, but interviewees reported that this criterion was not appropriate. Nor can the team see that adequate risk assessments were made for the change which took account of previous experience with melting filter cassettes following manual opening of control valves to supply hot oil to the anti-icing panels.

When verifying the maintenance system, the team saw a recommendation to change filters after a hot-oil leak from the GTG4 anti-icing panels in the autumn of 2019 (M2 notification no 45906039). That was not done. The most recent pre- and fine filter replacement in the GTG4 filter housing was on 6 May 2015.

***Requirement***
*Section 58 of the technical and operational regulations on maintenance*

#### 10.1.5 Overview of external emergency response resources

**Nonconformity**
Failure to include the use of external response resources – vessels with fire monitors – in the emergency response plan.

**Grounds**
Vessels and their fire monitors are not included in the emergency response plan for Melkøya/HLNG for handling this type of incident (DSHA 3) in the production area.

It emerged in connection with this incident that
- both the plant's own permanently chartered tugs and a standby ship were deployed to fight the fire using their monitors
- vessels with fire-extinguishing equipment, either permanently chartered tugs and others (such as *Esvagt Aurora*) with similar and/or greater capacity are not mentioned in the emergency response plan for this type of incident in the GTG area.
- as a result, no training or drills had been conducted in fire-fighting using these resources.

**Requirement**
*Section 66 of the technical and operational regulations on emergency preparedness plans*

### 10.2 Improvement points

#### 10.2.1 Log-keeping/whiteboarding

**Improvement point**
Lack of whiteboarding, log-keeping and documentation of measures taken by the first-line response command for parts of its handling of the incident.

**Grounds**
In the event of hazard or accident situations which can cause or have caused substantial damage, recording all actions and measures is important both to prevent recurrence and to make subsequent investigation easier.

To clarify the actual course of events, it is therefore important to log the best possible timeline for the incident from notification and alarm until normalisation can begin.

Which measures are taken by the first line in the CCR during the incident response is rather incompletely documented and logged for parts of the time. That applies particularly from about 17.00 to 20.49. No updated images/copies of the whiteboard in the emergency response room/CCR are available in this period, when the timing of measures has been based on information from the second line, the *Esvagt Aurora* log and interviews.

The emergency response plan for Melkøya specifies that the first line must use both whiteboarding and logging during an incident for several DSHAs, but whiteboarding has been omitted as a separate point for the communication officer in a DSHA 3.

***Requirement***
*Section 20, paragraph 1 of the management regulations on the registration, review and investigation of hazard and accident situations*

### 10.2.2 Overview of performance requirements in the emergency preparedness plan

**Improvement point**
The emergency response plan does not include an overview of the performance requirements set for the various response measures, such as personnel evacuation from the production area or mobilisation time for the response team.

**Grounds**
Performance requirements are set for the various emergency response measures, and should be known to the response personnel involved. The HLNG emergency response plan does not include these, either in the main body or in attachments/appendices, which complicates finding them in other internal guidelines – WR-1920 and associated emergency preparedness analysis – in order to secure the full overview.

***Requirement***
*Section 64 of the technical and operational regulations on establishment of operational preparedness, see section 67 of the technical and operational regulations on handling hazard and accident situations*

### 10.2.3 Follow-up of leaks from anti-icing panels

**Improvement point**
Deficiencies existed in the follow-up of leaks from anti-icing panels for generators.

**Grounds**
The historical review in the investigation has revealed several incidents involving leaks related to anti-icing panels on GTGs (overview of leaks received from Equinor in chapter 6 of the report). The first reports of such leaks pre-date full operation at the plant. Following these actual or suspected leaks, notifications have been established and improvements made. The team has not gone into detail with all these reported incidents, but the overall impression is that incidents and leaks in the early years may have been viewed as more critical and requiring shorter correction deadlines than in

later years. More recently, it appears that criticality has rated lower and with attention concentrated on the environmental consequences rather than the danger of ignition, and that deadlines for correction appear to have become longer.

***Requirement***
*Section 59, paragraph 3 of the technical and operational regulations on classification*

## 11 Barriers which have functioned

**Fire detection**
The fire in GTG4 was discovered by plant operators who notified the CCR by radio (fire detection was not installed to detect the fire in the air intake/filter housing).

**Alerting and mustering**
The CCR activated the evacuation alarm, which was audible throughout HLNG and also outside the plant. Emergency response personnel were mobilised and operational soon after the alarm sounded. Personnel evacuated rapidly from the hot plant and POB was established after seven minutes.

**Shutdown/emergency shutdown**
The CCR activated emergency shutdown. All sectioning valves closed and all blowdown valves opened. All shutdown functions worked as intended.

**Fire-fighting**
The CCR activated firewater and started fire-fighting. Three firewater monitors – 71-SN-114/115/116 – were directed at the air intake. They provided little coverage of the GTG4 air intake, but had a cooling function for the surrounding equipment.

Pursuant to the emergency response plan, response personnel were not sent into the fire scene until the position was under control.

**Drainage**
The drain system functioned as intended and collected hot-oil residues after the fire had been extinguished.

## 12 Discussion of uncertainties

The technical fire tests and KFX simulation of temperature development in the GTG4 filter housing commissioned by Equinor support the likelihood that the fire broke out because the pre-filters on the air intake auto-ignited. No indications were found that a different course of events occurred before ignition, but it is not possible in retrospect to determine exactly what the course had been.

## 13 Assessment of the player's investigation report

To be updated.

# 14 Appendices

A: The following documents have been utilised in the investigation.

- Analysis plan – hot oil
- Analyses of hot-oil results for density and flash point
- Analyses of density and flash point – hot oil
- Atex approval
- *Auto-ignition of air filter in a heated cabinet* – report RISE F20561:1
- Emergency response plan for MMP PM, WR1920, ver 2.0
- Emergency response plan for MMP PM, WR1920, ver 2.0
- Photographs
- Photograph report – inspection report 81-HE-301, 2014
- Data sheet – product description oil
- *Determination of some flammable liquid referred to as "hot oil" and the behaviour of a light fixture when exposed to high temperatures* – report Gexcon-21-F101214-RA-1
- Equinor memorandum – KFX simulation Hammerfest LNG final
- Event log hot-oil valve
- Full-scale test of firewater monitors, E066-SD-S-RT-0001
- Full-scale test of firewater monitors, E066-SD-S-RT-0001
- Harbour regulations and information handbook, rev 7
- Inspection reports 1380-81-HE-201 and 1380-2-OH-81-1138-BC20A-16 2015 - Leak in anti-ice unit and corroded hot oil
- Inspection report 81-HE-401 2013 Noweco – magnetic powder – penetration test – Hammerfest
- Distance of throw for firewater from the tugs
- Expertise profile for technical manager industrial safety
- Layout drawings
- Log from PCDA
- Notification 45950327
- Notifications related to leaks from or inspection findings on anti-ice panels
- Area classification, drawing
- Area classification, drawing
- Temperature overview for turbine and air intake
- P&ID – system 81
- P&ID – turbine intake filter
- Plant startup procedure, E066-SD-A-KF-0011 rev 46
- Presentation – Fire GTG4 Hammerfest LNG
- Product document HI-FLO XLT
- PS9 U71 test report
- QRA – App A – Assumptions
- QRA – App B – Study basis and methodology
- QRA – App D – HRA

- QRA – App F – Hydrocarbon events
- QRA – App G – Process barge
- QRA – App H – Other accidents
- QRA – App I – Area risk map
- QRA – Appendix C – Hazid report
- QRA – Appendix E – OMT
- QRA Hammerfest LNG
- Minutes – meeting with Equinor concerning its follow-up of the firewater system 15 January 2021
- Minutes – meeting with Equinor concerning its follow-up of the firewater system 15 January 2021
- Risk of unacceptable ruptures – HLNG barge area – report E066-SD-S-RE-0010, rev 01
- Safety report for Hammerfest LNG plant
- Shift log, assistant shift supervisor 29 September 2020
- Screen image – trend – door movements
- Screen images – trends from Aspen Process Explorer – System 50 – hot-oil system
- Screen images from PCDA
- Screen images from verification in SAP
- Study report concerning full-scale test of firewater monitors on process barge
- Synergi case 1629483
- System 50 – hot oil – historical E066-SD-A-YP-1050
- System 50 – hot oil – operational procedure, SO09350
- System 50 – hot oil – system description, SO09350
- System 50 – startup hot-oil node A220-06 – operational procedure, SO09350
- System 81 – electricity generation – historical S066-SD-YP-1081
- System 81 – electricity generation – operational procedure, SO09381
- System 81 – electricity generation – system description, SO09381
- Table covering and comments on POB, e-mail from Equinor 13 October 2020
- Tug specification
- Whiteboard overview 17.00, 28 September 2020
- Drawing – monitor coverage barge
- Temperature trends for surroundings GTG
- Supplement to WR0213, ver 1, Hammerfest LNG, measures with firewater pumps out of action
- Timp PS9
- TTS report audit 2015
- Turbine control and protection system, E066-AV-81-PE-5001-014, rev C
- Printout from Satos
- Printout work order: 25216856
- Vessel sharing contract, ENI and Statoil
- WR 1920 Emergency preparedness in MMP PM, final version 2.0 2019-03-21

B: Overview of personnel interviewed (see separate document)