PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation of inadequate barriers at Hammerfest LNG	Activity number 001901039

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

Involved	
Team T-L	Approved by/date Kjell Arild Anfinsen/9 July 2019
Members of the investigation team Arne Johan Thorsen, Knut Ivar Hjellestad, Espen Landro	Investigation leader Ove Hundseid

1 Contents

2 Summary

Hammerfest LNG (HLNG) shut down its plant on 11 March 2019 in order to correct weaknesses in a number of pressure safety valves (PSVs). The reason was the absence of heat trace (HT) cables and insulation on 190 of these devices, which posed a threat of hydrate formation in or upstream from them. That in turn could block the PSVs or reduce their capacity. After more detailed consultation with Equinor's professional ladder for process safety on 6 March 2019, the overall position was considered so serious and uncertain that a shutdown and correction were required.

HLNG was informed of the risk posed by inadequate HT cables/insulation on the PSVs through a report from the professional ladder in 2013 and a self-assessment of the plant as input to that report. The latter focused in part on the importance of heat conservation for PSVs and on misunderstandings and lack of clarity about hydrates and how these can form. In addition, the lack of heat conservation was identified through internal verification of the safety systems (TTS) in 2010 and reopened 2015.

Hydrate was discovered in a PSV during December 2017. This was not registered in Equinor's HSE systems, but became known in the organisation during early 2018.

Equinor first informed the Petroleum Safety Authority Norway (PSA) about the position on 7 March 2019. After a number of meetings and information acquisition, the PSA decided on 22 March 2019 to investigate the incident given the potential of the impairments and the long time taken between their discovery and the decision to shut down in order to correct them.

Hydrates have formed in the plant's PSVs, and have been discovered in some cases to be extensive enough to disable the valves. The actual consequence is that barriers against overpressure were reduced or absent in parts of the process plant.

Had a fault or instability arisen in the plant which called for the PSVs to be activated, this could have led in the worst case to fracturing of the process equipment the valves were supposed to protect. A fracture in a pressure vessel as a result of overpressure is a very serious incident, which can result in an explosion and a big escape of hydrocarbons with an associated increase in the probability of ignition. This is an incident with major accident potential, which could have resulted in several facilities and substantial damage to the plant.

The direct cause of a potential for the PSVs to become blocked was that HT cables/insulation had not been installed to ensure that the temperature in the valves remained above the level for hydrate formation.

The most important underlying cause for operating the plant over a long period with these impairments was that the risk had been underestimated. One reason was that the hydrates discovered in December 2017 were not considered sufficient to block the PSV. A survey by Equinor in 2013 showed that the lack of HT cables/insulation on PSVs and associated piping systems was a design weakness at several of its plants. Unlike a number of other plants, HLNG has heat conservation installed on associated piping systems, and it was therefore felt to be less likely that hydrates could form and block the PSVs. Nor did the management have adequate knowledge about the scope of the impairments to process safety at the plant.

HLNG's system for following up and correcting barrier impairments within a reasonable time has not been good enough.

3 Background information

HLNG shut down its plant on 11 March 2019 in order to correct weaknesses in a number of PSVs. The reason was the absence of HT cables/insulation on 190 of these, which posed a threat of hydrate formation in or upstream from them. That in turn could block the PSVs or reduce their capacity. After more detailed consultation with Equinor's central professional ladder for process safety on 6 March 2019, the overall position was considered so serious and uncertain that a shutdown and correction were required. The condition of these valves had been known for some time, and a specific plan was established as recently as the summer and autumn of 2018 to correct the most critical PSVs. However, this was not initiated because the activity was redefined as a modification project, which resulted in a bigger scope of work.

3.1 Description of plant and organisation

The HLNG plant is located on Melkøya island outside Hammerfest. It receives gas and condensate transported by pipeline from the Snøhvit, Askeladd and Albatross fields. The plant stabilises the condensate and processes the gas into liquefied petroleum gas (LPG) and liquefied natural gas (LNG) through a series of fractionation stages and cooling cycles. These products are stored in large tanks before being loaded into ships or road tankers for onward transport.

From its start-up until 31 December 2015, HLNG was organised with Equinor's offshore facilities in the DPN business area. On 1 January 2016, it was transferred to the MMP PM business area which organises Equinor's other land plants.

3.2 Abbreviations

API	American Petroleum Institute
DMP	Decision meeting projects
Disp	Exemption application in Equinor
DPN	Development and production Norway business area
HLNG	Hammerfest LNG
HSE	Health, safety and the environment
HT	Heat trace (cable)
ISO	Isometric piping drawings
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MMP PM	Processing and marketing, marketing midstream and processing business area
M1	Maintenance request
M2	Malfunction report
P&ID	Piping and instrument diagram
PDO	Plan for development and operation
PM	Preventive maintenance
PSV	Pressure safety valve
PS12	Performance standard 12 (process safety)
Timp	Technical integrity management portal
TPO	Technical and plant optimisation
TTS	Technical condition safety (condition monitoring of technical safety)

4 PSA investigation

Composition of the investigation team:

Ove Hundseid	process integrity (investigation leader)
Arne Johan Thorsen	process integrity
Espen Landro	process integrity
Knut Ivar Hjellestad	occupational health and safety

5 Procedure

The investigation team travelled to Hammerfest on Monday 8 April 2019.

It kicked off its work on Tuesday with a meeting where Equinor reviewed the status and history of hydrate-related incidents in PSVs. This was followed by a tour of the plant.

A number of conversations were conducted over the next two days with relevant personnel in the HLNG organisation, along with a review of documentation received.

Further conversations were held on Friday 3 May with Equinor's professional ladder for process safety at Forus, former HLNG managers involved in dealing with hydrate discoveries, and personnel from the Kårstø plant who have provided relevant support to HLNG.

The team has concentrated on identifying why considerable time passed between discovering the hydrates in the PSVs and shutting down the plant to correct the impairments.

6 Timeline

Based on conversations, presentations and documentation received, the team has established the timeline outlined below.

2002
March: The PDO for HLNG was approved. Relevant regulations and standards are referenced in chapter 11 of this report.

2007
The plant came on line. Documentation handed over from the development project relating to the operation of process safety functions varied in quality: "generally thin and to some extent inconsistent documentation of process safety functions makes it difficult to understand", see Timp assessment Q1-19. Installed HT cables were not related to tags and were inconsistently identified between P&IDs and ISOs with respect to information on where such cables should be found. The P&IDs largely related such cables to PSV flanges, while the ISO drawings at times also showed them on flange and valve.

2008
P&IDs were reviewed to identify missing links between HT cables and tags. Two notifications were established following this exercise.

1. One dealt with the nonconformity between ISOs and P&IDs for HT cables and which of these document types was determinative. The response to this enquiry was that the information in the P&IDs should be followed.

2. The other concerned whether it would be possible to modify the HT cables to reduce the scope of work by reducing cable numbers to accord with the P&ID information.

Registered job activity in preventive maintenance (PM) following the notifications showed that the number of cables was cut so that they accorded with the P&ID. Subsequent PM jobs did not include insulation on PSVs any more, which suggests that the latter no longer had HT cables.

2010

A TTS was conducted at the plant. Its report included the following observations.

- No maintenance programme was in place for safety-critical HT cables on PSVs (PS12 finding F9.2.1). This finding was assessed as criticality level Yellow-1.
- Random sampling revealed missing HT cables on PSVs in the wet gas system, with examples given of valves involved (PS12 finding F3.1.2). Requirements in API 520 were also referenced. The finding was assessed as criticality level Yellow-2.
- A risk of blocking pressure transmitters existed because the design was sub-optimal with regard to temperature monitoring (PS12 finding I3.4). Such monitoring was installed on the impulse line, but this was placed in a heated cabinet. The finding was assessed as criticality level Yellow-2.

2013

February

Valves SV-22-103A and SV-22-103C opened unintentionally on 3 February because HT cable coverage of the PSV pilot lines was inadequate. This was reported via M2 notifications, but not registered in Synergi – Equinor's system for reporting undesirable incidents.

March-November

A memo from Equinor's professional ladder for process safety in March recommended that all the company's plants should conduct a verification of their safety-critical heat conservation, insulation and HT cables. The reason given was a growing number of incidents being reported to Equinor's corporate technical team for process safety related to the issue of heat conservation, combined with the criticality of this subject.

Results from this survey in DPN were compiled in a report completed during November 2013. These findings revealed a considerable amount of safety-critical equipment with inadequate heat conservation. Given the extensive work required to correct the deficiencies, the report provided guidance on how to prioritise findings, identify possible compensatory measures and apply for exemption (Disp) as well as guidance on possible design solutions.

HLNG notified in the report that it had reviewed 10 033 components and conducted criticality assessments for these. It only reviewed systems where HT cables were installed, and accordingly failed to assess where such cables were required. PSVs with no cables were not assessed even though this was one of the items in the memo from the professional ladder centrally.

2014

Valve SV-22-108D opened unintentionally on 23 June because the HT cable was turned off. Recertification was carried out for this valve on 2 June and for valve SV-22-108A on 22 June. That might indicate that the HT cable was turned off in connection with these jobs. No registered notification or Synergi case can be found for these incidents.

2015
A TTS was conducted at the plant. Its report reopened finding F9.2.1 from the 2010 TTS and observed that:

- a test and maintenance programme for safety-critical HT cables on PSVs was lacking
- PSVs were observed, both in the field and on diagrams, to have HT cables upstream and, where relevant, downstream but to lack insulation on the actual valve, and no assessments were found which indicated that there was no risk of the valve being exposed to freezing/hydrate formation.

The TTS report noted that finding F.9.2.1 from 2010 was reopened and could not be closed until, among other things, the need for HT cables on PSVs had been assessed.

2017
Ice/hydrates were discovered in SV-11-104 on 9 December when the valve was disassembled for testing/recertification. A notification (45077384) was created in SAP, where the discovery was described as ice, but no registration was made in Synergy until February 2018 (1534350).

Whether the HT cable on SV-11-104 was hot has not been documented, but HLNG personnel interviewed by the team assumed it was turned on.

2018
Late January/early February
In connection with an internal course, the person responsible for the process safety performance standard (PS12) in Equinor became aware of the SV-11-104 discovery made the previous December.

February
An e-mail was sent to relevant technical personnel at HLNG on 8 February with information on/notification of the discovery.

A team was established on 9 February to go into the plant and identify PSVs without HT cables.

March
Survey completed. It identified that ice/hydrate formed in PSVs owing to the absence of HT cables, and that 190 PSVs needed upgrading with HT cable/insulation.

April
Work began on reviewing various cases with a view to establishing the criticality of the 190 identified PSVs. These were split into three categories – high (H), medium (M) and low (L). The team was told that PSVs which exclusively covered fire scenarios were considered to be less critical and placed in L, and that an overall group assessment was made of these valves rather than an individual evaluation on the grounds that the areas would be evacuated in the event of fire and personnel removed from the plant.

Equinor’s research centre at Rotvoll was brought into the assessment of opportunities for hydrate formation in the monoethylene-glycol (MEG) facility. This concluded that hydrates were also possible there.

May
The Timp review in May 2018 flagged the PSVs as an area for attention. The Timp score for PS12 was D, and a modification proposal was produced for correcting the identified valves.

June
Work begun in April to establish the criticality of the 190 PSVs was reported to be completed in late June. Fifty-five valves were identified in category H and 49 in category M.

August
The modification proposal was considered by the preparatory plant board (FAR) on 2 August, and continuing the work under way was recommended.

September
A decision meeting for projects (DMP) was held on 24 September at decision gate 2 (DG2), which decided to establish a supplier study (IMX324). This aimed to detail the work of insulating and installing HT cables on the PSVs and installing temperature monitoring to thereby close TTS finding F9.2.1.

October
Seven M2 notifications were established on 1 October for reinstalling HT cables in order to accelerate implementation for the most critical PSVs. Work related to the M2 notifications was coordinated with the IMX324 study which was decided on in September.

On 23 October, a DMP for DG3 decided to establish a project for 34 of the PSVs. These were identified as those where HT cables/insulation in the field had been reduced in relation to the original design (P&ID info) in order to cut the workload for maintenance-related disassembly and assembly. Designated “HT and insulation back to design”, the project was intended to return insulation and HT cables to the state shown in the P&IDs.

December
A meeting on 18 December decided to merge the IMX324 study from September and the DG3 project for 34 PSVs from October. This was because the project team for the 34 valves had found that documentation was inadequate and that more design was needed to clarify and detail the work.

A meeting on 21 December discussed the scope of work required for temporary and permanent measures. The decision was taken that installing temporary HT cables was undesirable because of ignition source control. Impairments in such control had already been identified at the plant, so there was no desire to introduce additional risk by using temporary extensions to HT cables. The time required for installing temporary and permanent cables was considered to be virtually the same. It was also decided that the technical and plant optimisation (TPO) unit for process needed to look at whether other compensatory measures could be used, and to group the 55 PSVs in category H by priority.

In connection with the 21 December meeting, it was also decided to apply for Disp for missing HT cables/insulation on the PSVs.

2019
January/February
A Disp proposal was prepared locally. Technical specialists at Kårstø supported HLNG in

administering the application, and contacted the professional ladder centrally. The Disp proposal was ready on 28 February.

March
A meeting was held on 6 March with the professional ladder for process safety, which responded that providing its support for the Disp was not desirable.

Given that response from the professional ladder centrally, a meeting was held in HLNG TPO on 7 March to identify possible solutions.

The HLNG management decided on 9 March to run down and close the plant in order to install temporary compensatory measures.

The plant was shut down on 11-14 March and temporary compensatory measures installed. All PSVs considered critical were covered either by temporary HT cables or other measures regarded as eliminating possibilities for overpressure.

After the shutdown
Work to replace temporary HT cables with permanent ones began in the last half of March and will reportedly continue until early autumn 2019.

7 Hydrates in process plants

Hydrates are a form of ice which can occur in a hydrocarbon/water mix under high pressure and low temperature. The water molecules create a lattice structure which encases small hydrocarbon molecules. Hydrates primarily form with light hydrocarbons such as methane, ethane and propane. The gas crystallises in solid form as ice. At higher pressures, hydrates can form under warmer temperatures but not normally above 30°C. See Figure 1.

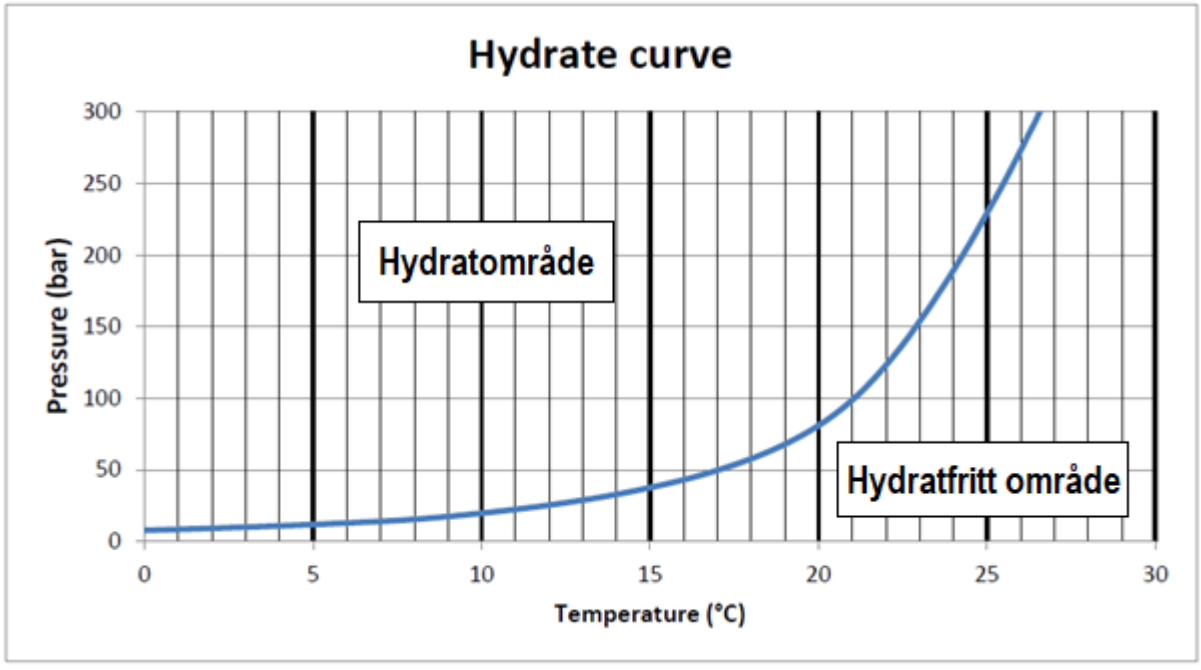

Figure 1: Hydrate curve. Source: Safety Critical Heat Conservation - Work Group Report 2013.

Key: Hydratområde = Hydrate area; Hydratfritt område = Hydrate-free area.

LNG primarily comprises methane and some ethane. Early in the process, the gas is also saturated with water and under varying pressures. Hydrates can form in deadlegs and parts of the process where the medium is normally stationary – such as pipes leading to PSVs and blowdown valves. If ambient temperatures fall and piping/valves lack heat conservation, these hydrates can grow and eventually cause blockages. A blocked pipe can prevent gas flow. In the event of a pressure blowdown, for example, gas will not flow past the hydrate plug to a safe area. The result could be overpressure in the process equipment which the PSV is intended to protect. Hydrates can also form in vertical piping.

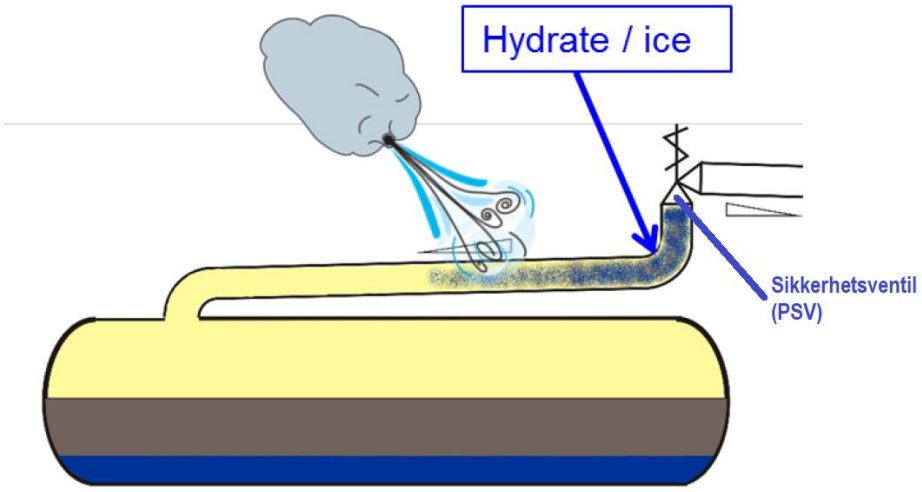

Figure 2: Hydrate formation in a PSV. Source: Safety Critical Heat Conservation - Work Group Report 2013

8 Potential of the impairment

This case has not concerned an incident or a near-miss, but a barrier impairment. What the condition of the PSVs in the plant has been is unclear, and the actual and potential consequences must be viewed in that context.

8.1 Actual consequences

Hydrates have formed in an unknown number of PSVs, and sufficiently extensive hydrates have been discovered in some PSVs to prevent them functioning. The actual consequences is reduced or missing barriers against overpressure in parts of the process plant.

8.2 Potential consequences

Had a fault or instability arisen in the plant which called for the PSVs to be activated, and had the PSV been blocked by hydrates, this could have led in the worst case to fracturing of the process equipment it was supposed to protect. A fracture in a pressure vessel as a result of overpressure is a very serious incident, which can result in an explosion and a big escape of hydrocarbons with an associated increase in the probability of ignition. This is an incident with major accident potential, which could have resulted in several facilities and substantial damage to the plant.

9 Direct and underlying causes

9.1 Direct causes

The direct cause of a potential for the PSVs to become blocked was that HT cables/insulation had not been installed to ensure that the temperature in the valves remained above the level for hydrate formation. The Melkøya plant is particularly exposed in this respect during the winter, when it faces a combination of low air temperature and wind. This combination had prevailed for a period when hydrate plugs were discovered in December 2018. See Figure 3 below.

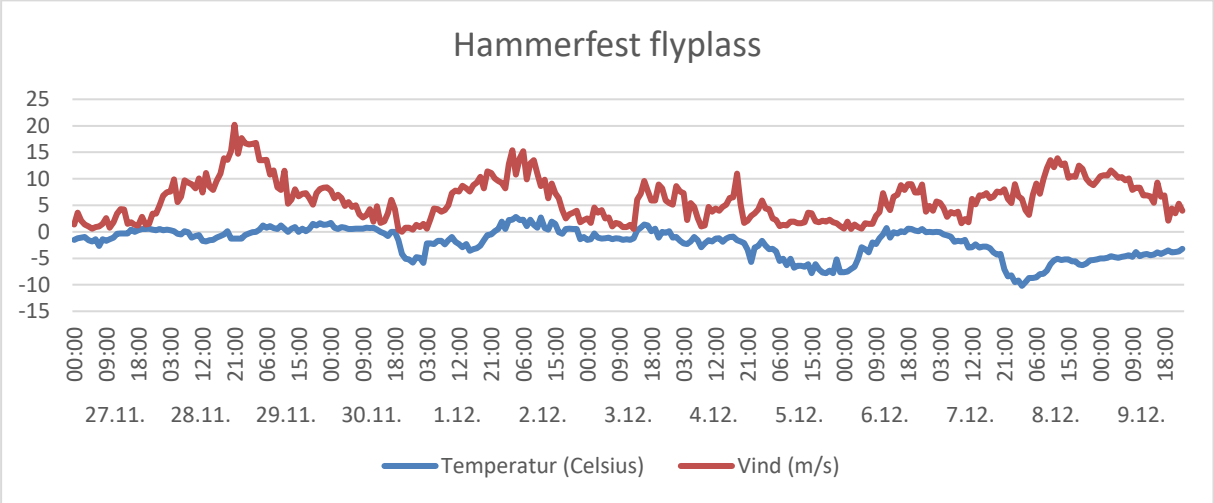

Figure 3: Measured temperature and wind in Nov/Dec 2017 – Hammerfest airport observation station

9.2 Underlying causes

Considerable time elapsed between the discovery of the hydrates in December 2017 until the HLNG plant was shut down in March 2019. Via TTS, HLNG was also made aware in 2015 that the PSVs would lack heat conservation unless necessary action was initiated.

9.2.1 Lack of heat conservation on the PSVs

9.2.1.1 Plant design

The PDO for HLNG was approved in 2002 and built on the regulations in force at the time. API STD 520 and 521 were used in designing overpressure safeguards and the flare system. API STD 520 has included requirements for installing adequate HT cables/insulation to prevent hydrates in PSVs ever since 1994. However, the EN 1473 standard on installation and equipment for liquefied natural gas – design of onshore installations, which was also applied, specifies that the PSVs are not normally insulated.

The plant was largely designed without insulation and HT cables on the PSVs. However, the piping leading to the PSVs does have this protection. See the photograph below.

Figure 4: PSV layout with insulation and HT cable. Source: Safety alert HLNG, 11 March 2019.
Key: Isolation/HT terminated upstream of the PSV inlet flange.

Greater attention has been paid in Equinor to the hydrate problem with PSVs after HLNG was built, and internal documents currently set explicit requirements for heat conservation. However, the use of insulation and HT cables on piping up to the PSV suggests that the hydrate problem was also an issue in the design phase, and that this could then have been considered sufficient to prevent hydrates from plugging PSVs.

The team has been informed through conversations during its investigation that PSVs have also been installed with insulation and HT cables. PSVs must be regularly removed for testing and certification, and insulation/HT cables have in some cases been removed to ease this work. P&IDs have then been used to determine if such protection is needed. HT cables/ insulation are not shown on the at the plant. See Figure 4 above.

9.2.1.2 Historical development of the hydrate problem in PSVs

Attention paid to hydrate-related issues with PSVs has varied over time. Many plants were earlier designed without HT cables/insulation on either upstream piping or the PSV. The perception has been that hydrate would not form in pipes leading to PSVs, probably because these do not normally flow or contain standing liquid since a fall is incorporated from the PSV to the process equipment it protects. See Figure 2. Even without flow in the piping, however, gas replacement will occur with the addition of moist gas so that hydrates can build up over time. As hydrate incidents have occurred, Equinor has paid more attention to them.

Incidents experienced by Equinor with hydrates related to PSVs include:

- **2008 Kalundborg**: Overpressure in equipment caused by hydrates in PSVs because HT cables/insulation were not installed.
- **2009 Oseberg East**: Pilot-operated PSV opened because of hydrates in the pilot line.
- **2010 Grane**: Bleed valve immediately upstream from a PSV was blocked by freezing because of low temperature and removal of insulation before operating the valve.

- **2011 Oseberg South**: Incident with hydrates in a PSV as a result of inadequate insulation and lack of HT cable (failed to maintain sufficiently high temperature).
- **2013 Kollsnes**: Overpressure in equipment because of hydrates in a PSV.

A memorandum on *Verification of Safety Critical Heat Conservation*, dated 20 March 2013, was issued to the various production areas in Equinor, including HLNG, in the spring of 2013. The purpose was to inform all plants about the requirements for and criticality of safety-critical heat conservation in ensuring necessary overpressure protection and blowdown (preventing hydrates in the system for PSVs and blowdown valves). The memorandum makes recommendations on how to apply for exemption in those cases where heat conservation is lacking, which state in part that exemptions must be accompanied by sufficient compensatory measures to ensure hydrate-free operation. The professional ladder for process safety would conduct the necessary verifications to ensure the integrity of the safety barriers, and expected the plant to draw up the necessary plans for permanent heat protection. It also stated that absence of safety-critical heat conservation was regarded as a TTS Yellow-1 because it could disable the safety system completely in breach of the regulatory requirements. A Yellow-1 finding requires involvement by management.

The memorandum was followed by the internal *Safety Critical Heat Conservation - Work Group Report 2013*. This described the position in the company with regard to safety-critical heat conservation, and included recommendations on classification and on preparing an exemption application. The report makes it clear that requirements exist for heat conservation of PSVs, including possible pilot lines and upstream piping.

9.2.1.3 Handling of heat conservation at HLNG

The memorandum sent to HLNG in the spring of 2013 included a warning against hydrate formation in piping up to a PSV which could disable the valve.

The memorandum provided the following recommendations:

- identify the need for safety-critical heat protection for uninsulated systems
- check the performance of existing heat conservation (ie, temperature) to ensure reliability
- initiate and handle identified nonconformities, including risk-reducing measures (eg HT cables, insulation and temperature monitoring)
- ensure proper and reliable safety-critical heat treatment for all operating conditions – ie, temperature ranges which prevent hydrates and avoid corrosion in stainless steel.

It has not been possible for the team to determine whether these recommendations resulted in any action at HLNG. The 2015 TTS review reopened findings from 2010 on the lack of a test and maintenance programme for safety-critical HT cables on PSVs. Its report also commented that the possible need to install heat conservation on the actual valves had to be assessed before closing the finding, which was categorised as Yellow-1. No heat conservation was installed on the PSVs before the discovery of hydrates and the decision to shut down the plant for upgrading in 2019.

9.2.2 Dealing with the December 2017 discovery of hydrates in a PSV

Considerable time passed after hydrates in a PSV were discovered by a PSV mechanic in December 2017 before the plant was shut down for upgrading in April 2019. The mechanic who removed the PSV for testing did not report the hydrates in the Synergi reporting system. The TPO technical condition unit became aware of the discovery during a process safety

course. It established a case in Synergi itself and a process to handle the discovery. Chapter 6 lists the incidents and processes implemented up to the shutdown.

The plant already had a Yellow-1 TTS finding from 2015 which addressed the lack of heat conservation. Discovering hydrates therefore represented a confirmation that this was actually a problem at the plant, and should had led to a rapid response and upgrading. Identifying and determining the reason why this took a long time has been challenging.

Several considerations could have influenced the response to the hydrates discovered in a PSV during December 2017.

a) Providing heat conservation for PSVs has not been established practice earlier, and the perception prevailed that hydrates were not a problem for such valves.
b) HLNG received a Yellow-1 finding after a TTS review in 2015 because it lacked a test and maintenance system for safety-critical HT cables. The lack of heat conservation on the actual PSV was not a finding in itself, but the report commented that it had to be checked out before the item was closed. Yellow-1 does not basically require a plant shutdown.
c) The hydrates discovered in the PSV were not considered enough to disable it.
d) Reviewing DPN's plants with regard to heat conservation of PSVs, among other equipment, showed that this was a deficiency at many Equinor facilities. The report opened for seeking exemption from the requirement, and provided a template for such applications. Although the report made it clear that an exemption application must specify compensatory measures which prevent hydrate formation in the PSVs, this could have contributed to an acceptance of seeking exemption until the deficiency had been corrected. Nor did the report provide guidelines for when the plant should be shut down to correct the absence of heat conservation. The professional ladder centrally was made aware of the lack of heat conservation on the HLNG PSVs as early as the spring of 2018. This did not result in any response which indicated to HLNG that the impairment was unacceptable. The scope of the problem was the main reason the exemption application could not be supported, and that first became known after work on the application had begun.
e) The Melkøya plant is designed with heat conservation up to the PSV flange. In other words, it does not totally lack heat conservation as has been case at many other facilities. Conversations have revealed that the plant was viewed as being in a grey area, where the risk of hydrates sufficient to block a PSV was lower than if no heat conservation had been installed.
f) The risk of PSV formation in the PSVs was underestimated. The Melkøya plant has been operated without overpressure incidents resulting from hydrates in PSVs since it came on line in 2007, and this may have contributed to an underassessment of the risk. Management was invited to participate in the risk assessment of the barrier impairment in July 2018, but did not do so.
g) As recently as 2013, a serious incident involving overpressure in process equipment at the Kollsnes plant was found to be most probably caused by hydrates in a PSV. This incident confirmed the seriousness of hydrates in PSVs, but HLNG personnel told the team they had not heard of it. A lesson pack distributed by central management after the Kollsnes incident asked the plants to conduct more checks. Hydrates in PSVs were not included in the pack, probably because the incident included other serious learning points.

h) During its investigation, the team was told that the Melkøya plant does not always have two barriers against overpressure as today's regulations require. HLNG is therefore more vulnerable to blocking of PSVs. This was not known to several of the relevant managers the team talked with.
i) Weaknesses had already been identified in ignition source control at the plant, and management accordingly wished to avoid introducing new risks through the use of temporary HT cables. The latter were also considered to take as long to install as a permanent solution. A plant shutdown until the impairments were corrected would be of long duration.
j) Several managers were replaced during the period concerned. New ones arrived after the hydrates were discovered and their seriousness assessed. This could have reduced ownership of the impairment. Such personnel will also face many other matters which are new and demand attention, leading them to accept decisions already taken.
k) It emerged from conversations that the TPO unit has limited capacity, with few people available to interact with in several disciplines. HLNG therefore has an agreement to borrow resources from other onshore plants. This solution can contribute to good learning across the company, but may also mean less hands-on for following up the plant. Personnel responsible for performance standards (PS) had more of these to deal with than before. Giving people too many duties on a day-to-day basis could affect the follow-up of discoveries like those involved in the present case. This has emerged as a concern in several conversations.
l) The Timp assessment of the plant gave the overpressure protection system at the plant a D rating. When serious E and F ratings are given, the Timp guidelines require them to be highlighted in relevant risk management tools (typically Pims/New MiS). An F rating requires shutdown, which was the final outcome in this case. The D rating does not basically indicate shutdown of a plant. The Timp guidelines provide the following guidance for determining ratings: "If uncertainty exists that an item of equipment/system might have defects or deficiencies, a worst-case philosophy should be applied whereby a poor rating (D) is awarded until a check/assessment of whether defects/deficiencies actually exist has been made. Once the evaluation has been made, the rating is set on the basis of the actual conditions." Given that hydrates thought likely to block the PSVs had not been identified here, it could be argued on the basis of the recommendations in the guidelines that D was the correct rating. The problem with the guidelines is that a D rating does not necessarily reflect a worst-case philosophy, as exemplified by the incident here. This could suggest that too much emphasis is placed on maintaining production when assessing ratings in Timp. See also item d), where the report provides guidelines for a Disp application but not recommendations for when the plant should be shut down.
m) Differences in reporting practice for incidents have emerged. HSE incidents must be registered in Synergi. This was not done with the hydrates discovered in December 2017. Hydrates were also discovered in PSVs in 2012 and 2014 without being recorded in Synergi. However, these were registered as M2 notifications in the SAP maintenance system. M2 is used to report faults (indication of a fault or failure) and to requisition, prioritise and describe work which should be done. If the incidents are not registered in Synergy, they will not be picked in the same way as with registration in SAP. Equinor's central professional ladder reported that it picks up incidents through Synergi and would not do so if they are only recorded in SAP. Conversations have also revealed that PSV mechanics have discovered hydrates in other cases without registering them in Synergi. Lack of registration in Synergi may have prevented a full overview of impairments related to hydrates in the plant.

10 Other considerations related to hydrates in PSVs

10.1 Scope

Melkøya lies in the far north and is thereby exposed to low temperatures. That makes the plant particularly vulnerable to hydrates. The combination of low temperature and strong winds means that, even when the PSVs have HT cables/insulation, monitoring is important for ensuring that the temperature exceeds the level when hydrates form.

The PSVs are not normally used actively in a process plant. They must open to prevent overpressure if all other barriers have failed. As a results, hydrates in them will not be noticed in normal operation. The exception is when the valves are removed for recertification or testing. HLNG's practice has been that the PSV mechanic removes them after they have been isolated and blown down by the process operators. Since hydrates melt at low pressure, they could have been present in the PSVs without this being noticed because they melted before the PSV mechanics got around to removing the valves.

HLNG has now changed its practice so that the process operators themselves remove PSVs weighing less than 25 kilograms. The time between isolation/blowdown of the valves and their removal will therefore generally be shorter. The team was informed that hydrates were twice discovered in PSVs by the process operators, on 9 March and 2 April 2018 respectively. In the first instance, the operators asked for a camera to be sent down to photograph the hydrates, but these melted quickly before it could arrive. With the second case, the hydrates were so extensive that they blocked the whole PSV inlet. Hydrates in PSVs can therefore have been an extensive problem at HLNG for a number of years without being identified. Those discovered in a PSV in December 2017 could have been more extensive and partly melted before the PSV was removed.

The photograph below shows hydrate/ice discovered in a PSV at HLNG.

Figure 5: Example 1: Hydrate/ice in a PSV inlet. Source: HLNG

10.2 Leaks

It emerged from conversations that the most frequent reason for PSVs failing tests was that they began leaking at a lower pressure than they should. Because pressure in the flare system is low, which thereby means that no hydrates form, insulation or HT cables are not normally installed downstream from the PSVs. If a PSV leaks, however, water from the process gas could condense and freeze downstream from the valve. Should cold weather prevail for a time, the worst-case result could be ice plugs forming downstream from a PSV which block or restrict the outlet. HLNG could be vulnerable to this because it can be exposed in winter to winds and long periods of sub-zero temperatures.

11 Regulations

Regulations which apply in the design phase

- Regulations on flammable goods, (FOR-2002-06-26-744)
- Regulations on pressure equipment, 9 June 1999

Standards used in the design phase

- API STD 521, 4th edn (1997) Pressure-relieving and depressurising systems
- API STD 520 I, 7th edn (2000) Sizing, selection, and installation of pressure-relieving devices, part I – sizing and selection
- API STD 520 II, 4th edn (1994) Sizing, selection, and installation of pressure-relieving devices – part II, installation

- IEC 61508 (several parts) Functional safety of electrical/electronic/programmable electronic safety-related systems
- IEC 61511 (several parts) Functional safety – Safety instrumented systems for the process industry sector
- EN 1473 (1997) installation and equipment for liquefied natural gas – design of onshore installations

12 Observations

The PSA's observations fall generally into two categories.

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

Four nonconformities and an improvement point were identified by the investigation.

12.1 Nonconformities

12.1.1 Management follow-up of safety at HLNG

Nonconformity
Management has failed to ensure an acceptable level of safety at HLNG.

Grounds
HLNG has operated over a long period with serious impairments to process safety barriers. Management has not made itself sufficiently acquainted with these impairments and ensured that they are corrected within a reasonable time.

- The TTS findings in 2010 and 2015 related to HT cables/insulation were not corrected until March 2019, following the discovery of hydrates in late 2017.
- The TTS finding was closed without being adequately corrected and was reopened following a new TTS review.
- The *Safety Critical Heat Conservation - Work Group Report 2013*, which noted the seriousness of the missing HT cables/insulation on the PSVs, did not lead to action to correct these impairments at HLNG.
- Management did not take part in the hydrate risk assessment in the summer of 2018.
- Management has not informed itself adequately about other process safety (primary barrier) impairments which were relevant for dealing with the absence of HT cables/insulation on the PSVs.

Requirements
Section 10 of the framework regulations on prudent activities
Section 6 of the management regulations on management of health, safety and the environment
Section 5, paragraph 3 of the management regulations on barriers
Section 21, paragraph 1 of the management regulations on follow-up

12.1.2 Deficiencies in risk assessment of discoveries

Nonconformity

No adequate risk assessment was made when hydrates were discovered in a PSV in order to provide the necessary decision base to take care of safety at the plant.

Grounds

- A risk assessment was not made quickly enough after discovering hydrates in a PSV in December 2017, with no assessment made until the summer of 2018.
- Management was invited to take part in the assessment, but did not do so.
- The assessed risk posed by a potential incident was set too low.
- Relevant managers were not aware of the impairment presented by the absence of primary barriers to overpressure, which was important for assessing the risk related to the discovery of hydrates in the PSV.
- The discovery was rated D in Timp, which did not reflect the level of seriousness represented by the hydrates.

Requirement
Section 16 of the management regulations on general requirements for analyses

12.1.3 Inadequate correction following a hydrate discovery in a PSV

Nonconformity
Impairments related to the discovery of hydrates were dealt with inadequately.

Grounds
Too much time passed between discovering the hydrates and shutting down the plant to correct the lack of heat conservation. The discovery was made in 2017, and the TPO was made aware of it in January/February 2018. This confirmed that the finding in TTS reports concerning missing HT cables/insulation on the PSVs represented a serious impairment. The lack of heat conservation was not corrected until 20 March 2019. Nor was any action taken in this period to check the actual scope of hydrates or to implement compensatory measures.

Requirements
Section 5 of the management regulations on barriers

12.1.4 Deficiencies in registering HSE incidents

Nonconformity
HSE incidents have not been registered in accordance with Equinor's management system.

Grounds
Pursuant to Equinor's management system, HSE incidents must be registered in Synergi. The hydrate discovery in 2017 was not registered when it was made. The person responsible for PS12 learnt of it by chance, and the incident was thereafter registered in Synergi.

The discovery of hydrates in PSV pilot lines during 2012 and 2014 was not registered in Synergi either. It emerged from conversations that hydrates had been discovered in PSVs on several occasions without being registered.

Requirement
Section 19 of the management regulations on collection, processing and use of data

12.2 Improvement point

12.2.1 Inadequate capacity in the organisation

Improvement point
The organisation lacked sufficient capacity in all phases of its activities.

Grounds
It emerged from conversations that the TPO unit has limited capacity, with few people available to interact with in several disciplines. HLNG therefore has an agreement to borrow resources from other onshore plants. This solution can contribute to good learning across the company, but may also mean less hands-on for following up the plant.

The team was told that TPO staffing has been reduced in recent years and that it faced challenges in dealing with the number of notifications generated in day-to-day operation. This made it necessary to prioritise, and meant that some notifications could be passed over for lengthy periods on the basis of criticality assessments.

Staffing cutbacks meant that personnel responsible for performance standards (PS) had more of these to deal with than before. Insufficient capacity in relation to day-to-day operational duties could affect follow-up of discoveries even if the organisation has the expertise for such action.

Requirement
Section 14 of the management regulations on manning and competence

13 Barriers which have functioned

The plant was operated for a long period with potentially serious impairments, but once a Disp application failed to secure support and the impairments became properly understood in the organisation, necessary action was taken to return the plant to a safe condition.

- Until the plant had been shut down, all activity there which was not necessary for stable operation was halted and the number of people in the plant minimised.
- The PSVs were assessed and prioritised in relation to the potential.
- Where possible, overpressure scenarios were eliminated.
- Heat conservation was installed on the remaining PSVs when the plant was shut down.
- Since restarting, priority has been given to heat conservation of fire PSVs which only have an overpressure function in the event of fire in the process plant.

14 Discussion of uncertainties

The investigation on this occasion has not concerned an incident in the traditional sense, such as emission/discharge, fire or personal injury, but an impairment of the barriers in the plant. It is uncertain how extensive the hydrate problem has been, in terms both of the number of PSVs which have been affected and the extent to which they might have been blocked. This could have been extensive, particularly in periods of cold weather, and have resulted in an unacceptably high risk to personnel at the plant.

Hydrates in PSVs have a clear major accident potential, but the seriousness of the potential consequences will depend on where in the plant they occur.

It is also uncertain how far the PSVs were originally installed with HT cables/insulation. The team was informed that work orders were registered in SAP for removing insulation and HT cables in connection with valve recertification, but was also told in conversations that their installation was limited in the original design.

15 Assessment of the player's investigation report

HLNG commissioned Equinor's corporate investigation department to investigate the incident. The team considers it positive that the plant opted to carry out a corporate investigation to learn from this, even though it was not an incident in the traditional sense with the release of energy. Completed on 16 May 2019, the report describes the course of events, the investigation team's assessment of direct and underlying causes, and nonconformities from governing documents. It also lists learning points and recommendations to prevent similar circumstances recurring at Equinor's plants.

The PSA team's impression is that the Equinor investigators have made a thorough assessment of the incident in relation to the company's internal requirements and work processes, and that the report provides important learning points to improve these.

In the team's view, observations in this report coincide by and large with the PSA's report. It concludes that HT cables/insulation were originally installed on the PSVs and have been removed during operation of the plant. Based on conversations in its own investigation, however, the PSA team has concluded that uncertainty prevails about the extent that HT cables/insulation were installed. See chapter 14. Equinor's report concluded that removal of the HT cables/insulation was not adequately assessed and subject to formal consideration.

16 Other comments

It has emerged from the investigation that managing follow-up of TTS findings at HLNG has not been good enough. Findings with varying degrees of seriousness from the TTS reviews in 2007, 2010 and 2015 were still open. Certain nonconformities have also been closed on the basis of plans. These plans have not always been implemented, and findings have therefore been reopened in the next TTS review. HLNG has now commissioned the Kårstø organisation to manage this process, and wants to adopt Kårstø's procedures for it.

The team also learnt that no central guidance exists on how TTS findings are to be followed up, but that this is left up to the individual plant.

17 Appendices

A: Documents utilised in the investigation
B: Overview of personnel interviewed

Appendix A Documents utilised in the investigation

1. 19/437-4-3 Memo Safety Critical Heat Conservation – Appendix B – TEX MEMO to DPN Ox OMT
2. 19/437-4-4 Extract from Sams – open PS12 findings
3. 19/437-4-5 Extract from Sams – discoveries related to PSVs
4. 19/437-7-2 Tr0052 Hammerfest LNG_kapittel 3.3 System codes
5. 19/437-7-3 M2 documentation 14122017
6. 19/437-7-4 Synergi 1576024
7. 19/437-7-5 Synergi 1576024 – SV-13-115_1 (photo)
8. 19/437-7-6 Synergi 1576024 – SV-13-115_2 (photo)
9. 19/437-7-7 Safety alert – Sevkket barriere mot overtrykking p# HLNG (1)
10. 19/437-8-2 TR3001 Process safety_version 4.01
11. 19/437-9-2 List of temporary HT_ISO
12. 19/437-9-3 Appendix Synergi 1534350 Experience report
13. 19/437-9-4 RUH 1534350 Hydrate_ice formation in PSV due to insufficient HT isolation
14. 19/437-9-5 Organisation chart Hammerfest LNG
15. 19/437-9-6 Disp 1934257 Midlertidig unntak fra krav om sikkerhetskritisk varmekabel – not approved
16. 19/437-11-2 *Safety Critical Heat Conservation – Work Group Report 2013*
17. 19/437-11-3 Experience report - MMP HLNG- Utilstrekkelig HT_Isolasjon av sikkerhetsventiler (1-4)
18. 19/437-11-4 Incident Kollsnes_ Synergi case 1460808
19. 19/437-11-5 Sustainable learning from Kollsnes_ Synergi case 14488423
20. 19/437-11-6 Exemption 169958 – with actions
21. 19/437-11-7 Exemption 169958 – case log for actions
22. 19/437-11-8 Drawings with/without HT cable
23. 19/437-11-9 E066-VL-E-KB-5004 Installation procedure
24. 19/437-11-10 E066-VL-E-KB-5003 Installation procedure
25. 19/437-11-11 E066-VL-E-KB-5002 Installation procedure
26. 19/437-11-12 E066-VL-E-KB-5001 Installation procedure
27. 19/437-11-13 E066-AB-S-RE-0052_Final Hazop follow-up report
28. 19/437-13-2 Learning package Kollsnes
29. 19/437-16-3 TTS report 2010 HLNG (sections relevant for PSA investigation April 2019 marked)
30. 19/437-15-2 Technical and plant optimisation (MMP PM TPO)_OMC 442597
31. 19/437-15-3 Technical and plant optimisation (MMP PM TPO) Appendix A
32. 19/437-14-2 OMC04 Roller og ansvar teknisk HLNG – lokalt tillegg til OMC04 TPO
33. 19/427-17 A 2019-7 MMP L2 *Granskingsrapport etter hendelse svekket sikkerhetsbarriere mot overtrykking på HLNG Hammerfest LNG Melkøya*
34. 19/427-18 Photographs and Synergi report related to the incident at Melkøya – information on safety assessment missing heat conservation, Equinor