PETROLEUMSTILSYNET

Investigation report

Report	
Report title Gas leak at Statoil Mongstad on 25 October 2016	Activity number 001902037

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

Summary

The gas leak at the Statoil Mongstad refinery on 25 October 2016 occurred when an operator, after gas had been detected in the area, attempted to operate a valve. Corrosion under insulation (CUI) meant that the pipe end which the valve was mounted on had rusted through. The end plus valve broke off , allowing the gas to escape. Emergency shutdown and manual blowdown were initiated immediately, and activation of the factory alarm meant that the personnel evacuated the whole facility.

Under slightly different circumstances, the gas leak could have caused loss of human life. The actual consequences were the emission of hydrogen and hydrocarbon gases to the natural environment and a halt to production at the affected sub-plant.

Another serious incident caused by CUI, involving a steam leak, occurred at Mongstad in 2012. This incident was investigated by both Statoil and the PSA. Other leaks come in addition, so CUI is a known problem at Mongstad.

The investigation has identified four nonconformities: the plant was not maintained to an acceptable standard, risk assessment was inadequate, information was not provided about the risks associated with the work, and personnel control was inadequate during the evacuation.

Four improvement points were also identified: inadequate system for emergency blowdown, inadequate gas detection, factory alarm which does not have the intended effect throughout the whole facility, and inadequate walkie-talkie communication.

Involved	
Main group T-Onshore plants	Approved by/date Kjell Arild Anfinsen/6 March 2017
Members of the investigation team Bryn Aril Kalberg, Jorunn Bjørvik	Investigation leader Morten Andre Langøy

Contents

1 Summary

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2 Introduction

The gas leak at Mongstad occurred in connection with surface maintenance. The gas consisted primarily of hydrogen (85 per cent), with hydrocarbons accounting for the remainder. The decision to investigate the incident was taken by the PSA on 31 October.

<u>Composition of the investigation team</u>

Morten Andre Langøy	- structural safety discipline, investigation leader
Jorun Bjørvik	- process integrity discipline
Bryn Aril Kalberg	- logistics and emergency response discipline

The investigation was conducted through interviews, site inspections, document reviews and investigations, and conducted by external consultants and Statoil's materials laboratory.

<u>Mandate for the investigation</u>

1. Clarify the incident's scope and course of events
    a. identify and assess safety and emergency preparedness aspects
    b. identify assessments made ahead of the incident.
2. Describe the actual and potential consequences.
3. Assess direct and underlying causes, with an emphasis on human, technological, organisational (HTO) and operational aspects
    a. observed nonconformities from requirements, processes and procedures
    b. improvement points.
4. Discuss and describe possible uncertainties/unclear aspects.
5. Assess the incident in relation to the earlier investigation of a steam leak in 2012 and possible relevant audit activities at Mongstad.

6. Identify regulatory breaches, recommend further follow-up and propose the use of reactions.
7. Assess the operator's own investigation of the incident.
8. Prepare a report and a covering letter in accordance with the template.

3 Abbreviations and explanations

A-1200	Isomerisation sub-plant
CUI	Corrosion under insulation
Alarp	As low as reasonably practicable
DAL	Dimensioning accident load
H_2	Hydrogen gas
ISS	Insulation, scaffolding and surface treatment trades
PS	Performance standard
PS1	Performance standard – containment (barriers against leaks)
SPP	Surface protection project
Synergi	System for registration, analysis, processing and following up accidents, near misses and undesirable incidents
Timp	Technical integrity management programme
TR	Technical requirement – internal Statoil standard
TTS	Condition monitoring of technical safety
WP	Work permit

4 Background

4.1 Brief description of the A-1200 sub-plant

The first stage of Statoil Mongstad was built in 1974. The facility was expanded and upgraded in 1989, including a cracker. The isomerisation sub-plant (A-1200) is a catalytic process unit for upgrading light naphtha to high-value petrol components. This plant became operational in 1982. An overview of Statoil Mongstad and the location of A-1200 are shown in Figure 1 and 2 (source: Statoil).

Figure 1: Aerial view of Statoil Mongstad with a red arrow marking the A-1200 plant.

Figure 2: Aerial view of Statoil Mongstad with a red arrow marking the A-1200 plant.

The A-1200 sub-plant comprises the following components:
- adsorption
- reactor
- stabiliser.

Figure 3 presents a simplified process diagram of A-1200. The leak occurred at a low-point drainage pipe on the recirculation line with hydrogen-rich gas in the reactor part of the plant, on the line into furnace H-1202. The leak point is marked with a star in the figure.

Operating conditions in the line were 20 barg and about 170°C. The gas comprised 85 per cent hydrogen with the rest hydrocarbons. The plant does not have a system for automatic or remote-operated blowdown. Opportunities for manual blowdown are marked by a broken line in the diagram below. The blowdown valves are located at ground level.

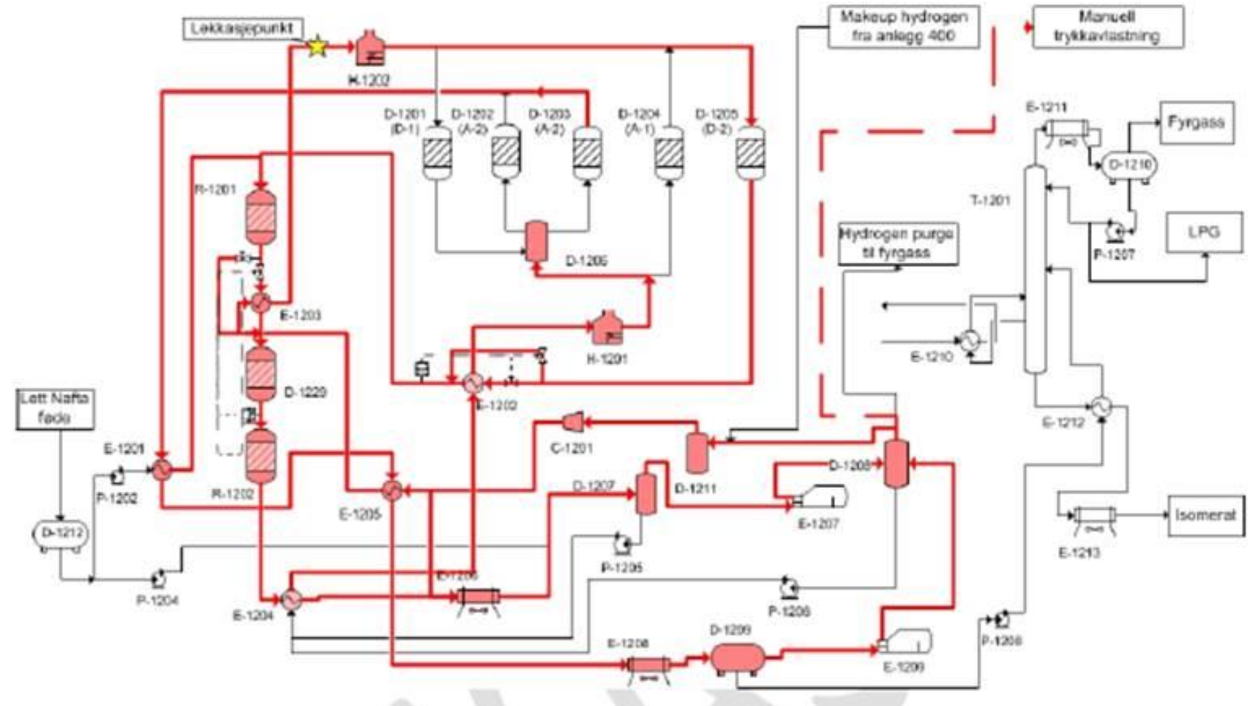

Figure 3: Simplified diagram of the A-1200 process. The leak point is marked by a star at top left.

4.2 Corrosion under insulation (CUI)

CUI is one of the biggest challenges faced by the petroleum industry in older facilities (Næss, 2016). Insulation is very extensive because of the need to preserve thermal energy and control heat flows. The main reason for insulation at Mongstad is to retain energy in piping and equipment in order to achieve efficient refinery processes. Other reasons for insulating also exist, as outlined in Norsok R-004, for example (Norsok, 2006). Generally speaking, an insulation system comprises the actual insulating material and external weather protection. The latter can be a metal mantling (sheath) or tar paper. The actual pipe or equipment is inside the insulation, with or without a protective coating. See Figure 4 for an illustration.

With CUI, corrosion speeds in steel exposed to the same environment are higher with insulation than without. The main reason for the accelerated corrosion is water which has intruded into the insulation. Modern systems make greater use of other methods, such as surface treatment of the piping, pipes in corrosion-resistant materials, hydrophobic (water-repellent) insulation materials and watertight external mantling – in some cases with drainage.

Historically, mineral wool was much used for insulation. This is also used at Mongstad. Obtaining a good overview of the CUI-related workload is difficult. Identification work is time- and resource-intensive. Scaffolding must often be erected for access, and all insulation must be stripped off. Methods for inspecting and detecting CUI without removing the insulation are in constant development, but visual inspection after removal remains the commonest solution. A risk-based approach is normally taken to this identification and repair work. With heavily corroded piping and vessels, actually removing insulation and inspecting can cause leaks. This risk must also be managed.

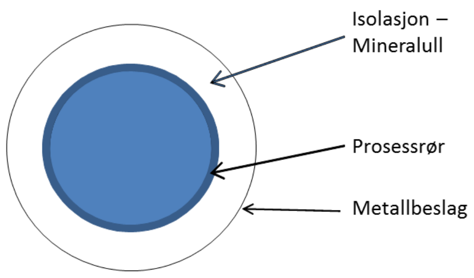

Figure 4: Cross-section of insulated pipe.
Key: insulation – mineral wool, process pipe, metal mantling.

For normal steel under high temperatures (80-90°C), a general corrosion rate could be 0.5mm/y, more than 10 times faster than the assumptions usually applied in calculations. At chemical facilities, annual corrosion could be twice as fast. Other challenges related to insulation and CUI repairs could include chlorides in the environment and corrosive water condensation on steel surfaces, sub-optimum inspection methods, inadequate surface treatment of pipes and equipment, process design, poor mantling of the insulation, access, costs and investment considerations (Næss, 2016).

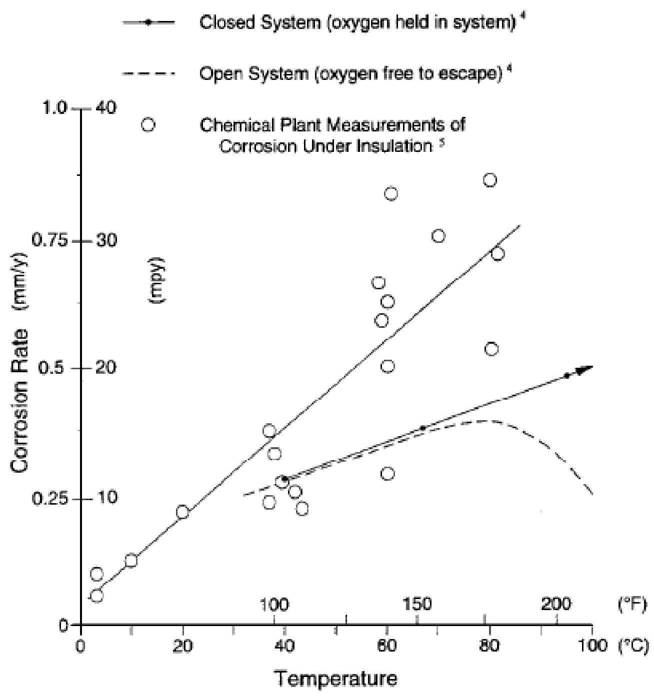

Figure 5: CUI for carbon steel, corrosion rate as function of temperature and system, (Nace , 2010).

Where temperatures exceed 100°C, the increase in corrosion speed could reverse outside the curve in Figure 5 with a further temperature rise. This is plant-specific knowledge.

A serious incident involving a steam leak occurred at Mongstad because of CUI in 2012. The summary from the PSA's investigation report (PSA, 2013) stated: "A powerful steam leak occurred at the Mongstad refinery during normal operation on 8 November 2012. Nobody was seriously injured in the incident, and material damage was limited. However, it had a major damage potential with the threat of several fatalities … [A two-inch] steam line ruptured completely and large volumes of steam, estimated at 16.9 kilograms per second, flowed out at great speed to form a large steam cloud … Extensive corrosion under the insulation was the cause of the leak."

4.3 Surface protection project

The PSA conducted a CUI audit at Mongstad in 2016. (PSA, 2016) During the audit, Statoil Mongstad reported that it worked purposefully on surface maintenance and CUI. A dedicated surface protection project (SPP) began in 2006, when many leaks were experienced. Resources devoted to surface maintenance were increased in 2015 and the budget was further enlarged for 2016. TR 1987 *Preventive Activities for Static Process Equipment and Load-Bearing Structures* is used for developing strategies and conducting the work. According to Statoil, surface maintenance has been intensified and made more efficient by introducing more area priorities in addition to risk-based priorities. Although this is coordinated with notification jobs, improving safety-critical systems speedily enough was described as a challenge during the audit.

The PSA report identified an improvement point related to a marked increase in the number of leaks the year before. In its response, Statoil Mongstad stated (Statoil, 2016): "We see an increase in leaks in both categories, but the biggest is in category 2 [category 1: hydrocarbons/ toxic gases/high pressure and temperature; category 2: other media (steam, water, air, nitrogen)]. This is a consequence of the decision taken to prioritise areas with the largest number of high-criticality pipes in the surface protection programme during the mid-2000s, which means in turn that maintenance intervals for less critical pipes and areas become too long. We still regard that decision as correct.

"When the surface protection project [SPP] was launched, areas with the largest number of high-criticality pipes were given priority. That could have led to maintenance intervals for other areas with mostly low-criticality pipes becoming too long. This has been a conscious decision in order to get control of the riskiest areas. The leak trend referred to[1], together with other baskets in our portfolio of corrective surface treatment and corrosion jobs, give us a continuous basis for assessing how condition and risk are developing. Developments in condition and risk are documented and followed up through PS1 in Timp. Timp forms the basis for continuous assessment of ongoing measures and the need to take new action."

A concern emerged at Statoil Mongstad during the investigation that surface maintenance is not keeping pace with expected corrosion. Uncertainty also exists over knowledge of the condition of A-1200. In its response to the PSA's CUI audit, Statoil writes (Statoil, 2016): "Attention in PS1 in Timp is focused on describing the condition of the barrier and what is needed to improve its condition and character to get the position under control. Underlying causes are not fully identified in Timp."

Plans call for the SPP in A-1200 to be carried out through six work packages, with three done during 2016 and the remainder in 2017. The incident occurred in connection with inspection activity for the first work package. Insulation had been removed in the area, which was partly covered with tarpaulins. The plant remained fully operational while the SPP was under way.

[1] in the PSA's audit report

During the PSA's CUI audit (PSA, 2016), Statoil Mongstad explained that it uses a pre-inspection "vanguard" team in areas with expected corrosion based on possible degradation mechanisms. The vanguard devotes special attention to reducing risk associated with insulation removal. The PSA has asked Statoil about risk assessments and measures for operator safety related to the work on A-1200, without this being documentable.

4.4 Plant condition

The refinery was built under a different regulatory regime and to other standards than apply today. A-1200 is governed by requirements from 1982, when it came on line. A local safety strategy has been developed for Mongstad, where gaps in relation to current regulations have been identified. An upgrading strategy is in place.

Regular condition assessments are conducted to identify both nonconformities from today's standards and deteriorations in physical plant condition. Condition assessments cover both the individual barrier elements (PSs) and each part of the facility. Results for the individual PSs form the basis for specifying the condition of each sub-plant. Timp reviews are supplemented by independent TTS reviews, inspections and notifications of condition assessment. At the time of the incident, A-1200 was rated D on a scale from B – where all significant system performance requirements are met – to an F rating where the equipment has such serious faults or deficiencies that critical safety functions would not operate in a relevant accident. A D rating indicates faults or deficiencies in the system which could lead over time to failures in certain safety functions or reduced reliability, or uncertainty about the actual condition owing to inadequate maintenance or documentation.

Statoil Mongstad's condition assessments for A-1200 before the incident show that a major problem has been an inadequate overview of the condition for CUI. The need to include the sub-plant in the surface protection programme has long been pointed out, including in Timp.

In addition to uncertainty about the actual condition, weaknesses in important barrier elements for handling a possible gas leak are identified in Timp. These include inadequate gas-detector coverage and no opportunity for remote operation of blowdown in A-1200. An opportunity for manual blowdown is available in the field. This system is not identified by tag, and thereby not classified as safety-critical equipment.

A number of studies related to gas detection and blowdown have been conducted in A-1200 and the rest of Mongstad. Proposals for A-1200 in this area have not been implemented.

CUI has been a known challenge at Mongstad over time. The surface protection programme at the facility requires substantial personal and financial resources. According to Statoil's investigation report (Statoil, 2017A), substantial cuts were made to the programme in 2011-12 to reduce costs at Mongstad. This meant that the programme came to lag several years behind the requirement. Statoil's investigation finds it is not clear that decisions relating to programme progress are taken on the basis of the technical condition of the sub-plants, risk assessments, or established strategies for the programme. That was also confirmed by the investigation team's conversations at the facility, where several people pointed to the problem of constantly lagging behind with surface maintenance.

Inspection of the refinery after the 25 October incident made 19 findings which had to be repaired before start-up.

5 Gas leak 25 October 2016

Scaffolding was erected for the first SPP package and the area screened with a temporary solution comprising a tarpaulin roof and side walls. Ventilation was provided top and bottom of these screens. The pipe track was stripped of insulation and ready for inspection.

Timings received from Statoil (Statoil, 2016A) accord with information given in interviews.

Just after 13.00 on Tuesday 25 October 2016, operator 1 was called to A-1200 by an inspector seeking clarification after his gas meter gave a reading[2] beside a drainage valve on a local low point on the line into furnace H-1202. The valve appeared to be standing a little open, and it was thought the packing box valve could be leaking. Operator 1 descended to fetch a valve key and lubricating spray. The inspector remained on the scaffolding but withdrew some metres from the valve.

Operator 1 returned, looked around, oriented himself and sought exits and escape routes.

At 13.10.29, operator 1 took the valve key and gave the valve a light rap. He suddenly found the valve and pipe end in his hand, hanging by the key. The gas flow from the one-inch pipe end hit the scaffolding floor half a metre from the fracture site. Those standing nearby describe a “infernal noise” from the gas flow.

Operator 1 descended, and signalled to personnel he met to leave the area. He tried to tell the control room by walkie-talkie to initiate ESD and a factory alarm, but the control room was unable to understand the message from operator 1 clearly.

Operator 2, who was by the compressor building, grasped that operator 1 was trying to give the control room a message and repeated by walkie-talkie that the control room had to initiate ESD and a factory alarm

ESD was initiated by the control room at 13.11.38, the compressor was stopped at 13.11.39 and zero flow through the H-1202 feed pipe was indicated at 13.11.42. The factory alarm was activated at the same time.

The inspector had descended from the scaffolding, heard the factory alarm and evacuated.

The acting assistant operations supervisor (plant supervisor) for area B was working on new signs on a pump north of A-1200. He heard a loud noise and perceived mumbling over the walkie-talkie: A-1200 – ESD – serious. He went directly to the blowdown valves and started opening them on his own initiative.

Operator 1 saw that an operator was opening the blowdown valves and ran to help him.

Operator 2 ran to A-1200 and saw two people working on blowdown. He heard the factory alarm and saw many people (20-30 of them) emerging from the A-800 Revamp sub-plant just north of A-1200. He drove them away from the area and helped with blowdown.

[2] Material technology investigations have subsequently confirmed that an actual leak existed since the pipe wall was corroded through.

At 13.11.43, the incident log in the control room registered a big pressure reduction in the H-1202 feed pipe. That meant blowdown had commenced.

The operators at the blowdown valves start connecting for nitrogen flushing of H-1202.

At 13.16.36, four minutes and 53 seconds after blowdown started, pressure in H-1202 was down to 1.37 barg.

The system was virtually fully depressurised about 10 min after blowdown started.

After the incident and before work was resumed on the SPP, Statoil Mongstad was ordered by Statoil's corporate investigation to empty the sub-plant of process gas ahead of further inspection.

5.1 Handling of the incident by response personnel

The B shift was at work on the day. The A shift was also present for an emergency response exercise, and out the refinery ready for action when the incident occurred.

The emergency response organisation was mobilised at the same time as the factory alarm was activated at 13.11. Response personnel assembled east of A-1200. The response team/ smoke divers were ready to act once the sub-plant was depressurised.

The on-scene commander asked the control room whether the fixed detectors showed any gas readings in the area. But coverage of fixed detectors in the area was poor, so response personnel had to rely on their own gas meters. A fire curtain (water spray) was established around the area.

Smoke divers entered the area to check it was clear. They were told by the control room that a total of 17 people on two written WPs and two on one verbal WP were associated with the area. None were present when the smoke divers went through it. They checked up to the pipe end – no readings on their gas meters. To ensure airing, the smoke divers cut up the tarpaulin covers.

Response terminated.

5.2 Factory alarm – evacuation

Several people in the area and the adjacent A-800 Revamp have said that they did not hear the factory alarm. That contradicts operator 2, who says that he heard the alarm at the same time as he ran into A-1200 where the noise from the leak was coming from.

According to interviews, two people were observed to emerge from a work tent in A-800 after the factory alarm had ended. The PSA asked about this, and Statoil undertook a review of personnel lists. It confirmed that two people from a supplier had not mustered at the muster site and accordingly had not left the refinery. This was not known when "danger over" was activated and personnel were readmitted to the refinery.

5.3 Radio communication

In interviews, several of the people directly involved in the incident raised problems with new digital walkie-talkies and their allegedly poor coverage – particularly inside large steel structures. High noise levels can also cause radio communication to fail.

5.4 Notification of the authorities

Statoil alerted the police, fire and ambulance emergency services (triple alert).

The PSA's records show that it was notified by phone at 13.39 – in other words, less than 30 minutes after the incident began.

5.5 Investigation of the incident

5.5.1 Inspection, interviews, review of documents and system

Interviews were conducted with 16 people during the investigation. These took place in Statoil's operations office at Mongstad on 2-4 and 17 November. Statoil had an observer present who also organised the interviews in line with an established timetable.

The investigation team had free access to documents, and separate investigations were conducted in Timp and Synergi on 17 November.

Explosion analyses were conducted by Gexcon on behalf of Statoil, while material technology investigations took place at Statoil's materials department in Trondheim.

5.5.2 Investigations of pipe and fracture

Material technology investigations were carried out by Statoil's materials department in Trondheim (Statoil, 2016), which concluded that the leak and fracture were caused by CUI. The pipe had suffered substantial external corrosion, reducing its wall thickness to zero in parts of the circumference. Internal corrosion was insignificant. Figures 6 and Figure 7 show the main pipe and the pipe end with the fracture to illustrate the configuration. They also gives an impression of the extent of the corrosion. All the photographs in this section are from Statoil.

Figure 6: Main pipe with pipe end where the fracture occurred. The pipe end was later removed for material technology investigations. The scale of external CUI can be seen.

Figure 7: Configuration of the branch pipe with the end to the main pipe on top, the packing box valve and the blind flange. The arrow points to the fracture site. Scale in millimetres.

Figure 8: Section of the fracture site. Scale in millimetres.

Visual and macrofractographic investigations (Statoil, 2016) showed that the wall thickness had thinned almost to zero around roughly half the pipe circumference in the fracture area. The fracture site appeared to have corroded right through before the incident. See Figure 9. The remainder of the circumference showed a morphology compatible with a pure overload fracture. Internally, the pipe components had a thick oxidised layer but were not significantly corroded. The original wall thickness is unknown, and corrosion rates have not been calculated.

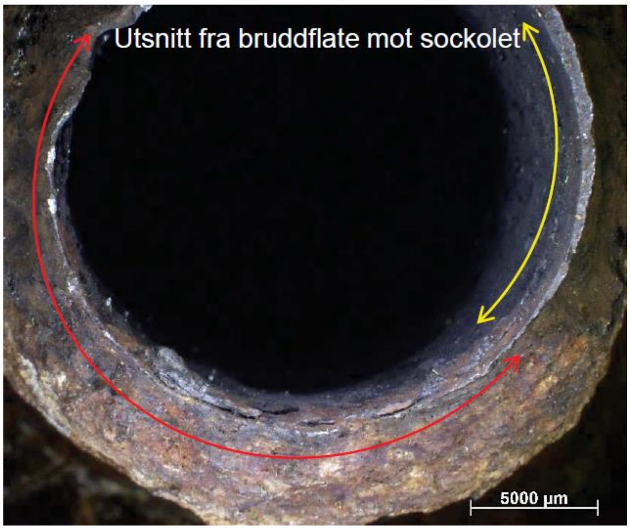

Figure 9: Photographs of the opposing fracture sites. Red arrows show areas where the wall thickness has been reduced to zero. The yellow arrow to the right shows where the fracture has a 45-degree propagation and appears as an overload fracture.

Some rough calculations have been made of residual strength in the pipe cross-section at the fracture and the probability of the pipe end failing with no external load. This corresponds with “exerting a little force” when operating the valve. The possibility that the end could have broken off after “some time” (Statoil, 2017) is not excluded.

5.5.3 Explosion analyses

Gexcon has been commissioned by Statoil to produce a report on possible consequences of the incident (Gexcon, 2016). This covers the following scenarios:

- gas diffusion from the actual incident site
- explosion loads from delayed ignition of the incident
- fire loads from early ignition of the incident
- gas diffusion if the leak had occurred during normal operation
- explosion loads from delayed ignition if the leak occurred during normal operation.

The team has no comments on the assumptions made for simulations or the selected case. The initial gas leak is calculated at 0.51kg/s.

Simulations of gas diffusion for the incident indicate the maximum size of the flammable cloud to be $120m^3$. They show that much of the northern part of A-1200 would have been encapsulated in combustion products had the gas cloud ignited. The simulated maximum pressure for this scenario is 0.6 barg. This exceeds explosion loads for the sub-plant identified in the total risk analysis (TRA). Simulated explosion loads are lower if the leak had occurred during normal operation. Enclosing for the inspection job meant that simulated explosion loads exceed the explosion loads defined in the TRA.

A fire simulation shows that, in the event of ignition, the operator closest to the leak and potentially also the inspector would have been exposed to fatal heat radiation.

5.6 Assessment of Statoil's incident investigation

The report has been reviewed (Statoil, 2017A), and Statoil's description of the incident and the run up is considered to coincide by and large with the investigation team's findings. Statoil's investigators regard the incident as a possible Red 1 level of seriousness – fatality.

6 Potential of the incident

<u>Actual consequence</u>

- Emission of H_2 and hydrocarbon gas to the natural environment.
- Production shutdown for the A-1200 sub-plant.

<u>Potential consequences</u>

The following could have happened under slightly different circumstances.

- Gas ignition, either immediately after the leak began or somewhat later, might have caused one or more fatalities.
- The pipe end fell off on a later occasion during normal operation, and gas could have been ignited by the heating furnace. This would have caused damage to the sub-plant. Harm to people would have depended on how many were in the vicinity. Larger quantities of H_2 and hydrocarbon gas could also have escaped to the natural environment.

7 Observations

The PSA's observations fall generally into two categories.

- Nonconformities: this category embraces observations which the PSA believes to be a breach of the regulations.
- Improvement points: these relate to observations where deficiencies are seen, but insufficient information is available to establish a breach of the regulations.

7.1 Nonconformities

7.1.1 The sub-plant has not been maintained to an adequate standard

Nonconformity
Inadequate maintenance meant that CUI on process piping was not discovered and repaired, which led in turn to a gas leak.

Grounds
Short-term plans and budgets exist for annual maintenance. But it emerged from document reviews and interviews that the total long-term requirement for surface maintenance (inspection and repair), based on risk assessments for the refinery as a whole and specific parts of it, has not been sufficiently reflected in concrete plans or budgets.

Long-term planning of and priorities for maintenance work have been inadequate, and do not reflect the extent and risk associated with CUI.

The investigation team was told that no operational or capacity-related restrictions prevent the pace of maintenance work being speeded up.

Requirement
Section 58 of the technical and operational regulations on maintenance require the responsible party (to) ensure that land facilities and parts thereof are maintained, so that the required functions are safeguarded in all phases of the lifetime

7.1.2 Risk assessment before commencing an activity was inadequate

Nonconformity
When planning and starting the SPP in A-1200, insufficient attention was paid to ensuring that important contributors to risk and changes to risk from removing insulation and subsequent work were kept under control.

Grounds
Repeated assessments of A-1200 and PS for containment show that great uncertainty prevails about the actual condition of pipes where CUI is concerned. Stripping insulation in and inspection of A-1200 was conducted with the plant still in operation. In a corrosion-weakened facility, the actual removal of insulation and inspection can cause leaks. Statoil Mongstad has not adequately assessed the need for compensatory measures to handle known weaknesses in the sub-plant combined with new risks arising from planned activities related to stripping insulation and inspection.

- The sub-plant lacks automatic blowdown or opportunities for remote operation of this.
- Parts of the sub-plant have poor or no coverage by gas detectors.
- The Timp report identifies poor control of potential ignition sources (hot surfaces).
- Inadequacies in documentation at the facility. Local drainage pipes, which can typically be particularly vulnerable to corrosion, are not included on drawings.

Requirement
Section 55 of the technical and operational regulations on planning specifies that, when planning activities on the individual onshore facility, the responsible party shall ensure that important risk contributors are kept under control, both individually and overall

7.1.3 Inadequate information about risk

Nonconformity
When planning and starting the SPP in A-1200, the changed risk was not communicated to the operators.

Grounds
It has emerged from interviews that risk related to work on stripping insulation in the sub-plant was not communicated to the operators in A-1200. The operators were not informed, for example, about the precautions they should take because of the plant's weakened condition.

Requirement
Section 53 of the technical and operational regulations on risk information during work operations, which specifies that it shall be ensured that the employees are provided with information on health risk and the risk of accidents during the work to be performed

7.1.4 Inadequate personnel control during evacuation

Nonconformity
The system for personnel control failed to ensure a full overview of personnel during evacuation and when resuming work after the incident.

Grounds
According to interviews, two people were observed to emerge from a work tent in A-800 Revamp after the factory alarm had ended. Statoil has confirmed that two people from a supplier had failed to muster at the muster site and accordingly had not left the refinery. This was not clarified when "danger over" was activated and personnel were readmitted to the refinery.

Requirement
Section 67 of the technical and operational regulations on handling hazard and accident situations specifies that the responsible party shall ensure that necessary measures are taken as soon as possible in the event of hazard and accident situations so that (...) the onshore facility's personnel can be evacuated quickly and efficiently at all times

7.2 Improvement points

7.2.1 Inadequate system for emergency blowdown of A-1200

Improvement point
No opportunity for remote control of emergency blowdown in the A-1200 sub-plant.

Grounds
Remote control of emergency blowdown was not a requirement when the facility was built. In dealing with findings from TTS reviews, Alarp assessments have concluded that remote control of emergency blowdown should be implemented for A-1200.

Requirements
Sections 4, 5 and 23 of the management regulations on risk reduction, barriers and continuous improvement respectively

7.2.2 Inadequate gas detection

Improvement point
Inadequate coverage of gas detection in A-1200.

Grounds
It emerged from Timp assessments received and from interviews that parts of the sub-plant are totally without gas detection, while the need for improvement has been identified in other areas.

Requirements
Sections 4, 5 and 23 of the management regulations on risk reduction, barriers and continuous improvement respectively

7.2.3 Factory alarm does not have the desired effect in the whole facility

Improvement point
Mongstad lacks an alarm system which can alert personnel at all times of hazards and accidents.

Grounds
Several people who were in the A-1200 area and the adjacent A-800 Revamp have said they did not hear the factory alarm.

Requirement
Section 22 of the technical and operational regulations on communication systems and equipment

7.2.4 Inadequate walkie-talkie communication

Improvement point
Mongstad lacks a communication system which makes it possible to communicate internally in the onshore facility at all times.

Grounds
In interviews, several of the people directly involved in the incident raised problems with new digital walkie-talkies and their allegedly poor coverage – particularly inside large steel structures. High noise levels can also cause radio communication to fail.

The PSA is aware that Mongstad itself has identified the problem and has prepared an “outline” for optimising the new digital communication system at the facility.

Requirement
Section 22 of the technical and operational regulations on communication systems and equipment

8 Other comments

8.1 Categorisation of the consequences of the incident on first notification

Statoil categorised the incident internally and in its notification to the PSA as a potential hazard for damage to equipment and injury to people. During the investigation, a number of people expressed astonishment that fatality was not a potential consequence. The PSA investigation team was told that this was a result of the group's model for calculating gas leaks. The gas which escaped in this incident is not included as an option in the model and another gas was chosen for the calculation.

8.2 Barriers which have functioned

During the incident, the emergency response organisation was established as a barrier to a possible escalation. In this case, no escalation of the incident occurred.

ESD was initiated from the control room on reported confirmation of a gas leak by the operator.

9 Discussion of uncertainties

During interviews conducted by the investigation team, concurrent descriptions have been given on the incident and the immediately preceding and succeeding events. Statoil has given the investigation all the information it has requested, and the team has not found contradictory information during its investigation

9.1 Explosion loads

The facility was originally designed on the basis of wind loads. Ignition and explosion loads which exceed the values of the dimensioning accident loads (DAL) have been simulated, but their consequences are uncertain.

10 Documents

The following documents have been utilised in the investigation.

Gexcon (2016). *Teknisk notat: Konsekvensmodellerinig av lekkasje Mongstad.* Project number: 100161.

Nace (2010). *SP0198-2010, Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A Systems Approach.* Nace.

Norsok (2006, August). Norsok Standard R-004. *Piping and equipment insulation, Edition 3*. Norsok.

Næss, O J (2016). *Sektoroppgave Korrosjon under isolasjon.* PSA.

PSA (2013). *Investigation report on a steam leak at Mongstad on 8 November 2012*. PSA.

PSA (2016). *Tilsyn med overflatevedlikehold og korrosjon under isolasjon hos Statoil Mongstad.* PSA.

Statoil (2016). *Materialteknisk undersøkelse av havarert rørstuss fra Mongstad.* Statoil materials department.

Statoil. (2016). Reference: AU-MO-02860 - Svar på Ptil rapport etter tilsyn overflatevedlikehold og korrosjon under isolasjon 2016.03.07. Statoil.

Statoil. (2016A). Tidslinje - Hydrogenlekkasje A-1200. E-mail 15 November 2016.
Statoil. (2017). Estimat av kraft til brudd. E-mail 14 January 2017.
Statoil. (2017A). *Granskningsrapport Lekkasje av H2 rikt prosessmedium i område A-1200 på Mongstad.* COA INV Internal accident investigation.

11 Appendix

A: Overview of personnel interviewed