PETROLEUMSTILSYNET

Investigation report

Report	
Report title Report of the investigation into a naphtha leak at Slagentangen on 24 August 2020. Rev 2	Activity number 007931030

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

Involved	
Team T-Land-based plants	Approved by/date Kjell Arild Anfinsen/24 November 2020
Members of the investigation team Elin S Witsø, Jan Erik Jensen, Morten Langøy	Investigation leader Ove Hundseid

Contents

1 Summary

In connection with normal operation of the plant, a naphtha leak occurred on 24 August 2020 in Esso's refinery at Slagentangen. The Petroleum Safety Authority Norway (PSA) decided on 25 August 2020 to investigate the incident.

The naphtha leak occurred in a section of the process plant known as the pipestill. It was caused by corrosion under the insulation in a pipe for heavy naphtha. This pipe had been removed by mistake from the SAP maintenance programme in 2008, and had therefore not been inspected since then. The pipe was last inspected in 2004. Its removal from SAP was discovered in 2013, but it was excluded from the equipment strategy rather than being restored to the maintenance programme.

The leak rate has not been calculated, but is estimated to have been about 10 litres per minute. Total leakage is put at 4 400 litres. The leak was collected by the refinery's open drain system, and did not escape to the natural environment.

The following barriers helped to limit the incident:

- observation and notification of the leak
- activation of the gas alarm for evacuation of the plant
- such emergency response actions as
  - mobilising of the emergency response organisation
  - spreading foam to limit gas dispersion and fire
  - positioning gas detectors
  - installing a system of water curtains in the event of gas dispersion
- shutting down the plant to stop the leak
- the drain system limited spreading and collected the naphtha.

Potentially, the leak could have ignited and caused a fire in the pipestill. The absence of fire and gas detectors means that the detection of any ignition would have depended on its discovery by refinery personnel. A fire could potentially have spread and escalated as a consequence of fracturing in other equipment or structural failure of process facilities in the area. Had the leak been ignited after the establishment of fire-extinguishing resources, the investigation team has concluded that this would probably have hindered an escalation.

The investigation observed nonconformities and improvement points in the following areas:

- risk assessment of the need for fire and gas detection in the pipestill
- maintenance and inspection
- ensuring the safety of the operations and maintenance personnel involved
- performance requirements related to emergency response
- overview of impairments in the plant
- marking in the plant
- shutdown procedures for the plant
- investigation mandate.

2 Abbreviations and definitions

ICP – incident command post/coordination point
CFWT – causal factor why tree – Esso's investigation method
Circuit – corrosion circuit
COD – control of defeat (disconnection of safety system)
Company – Slagen refinery, Esso Norge AS
CUI – corrosion under insulation
DNMI – Norwegian Meteorological Institute
DSHA – defined situations of hazards and accidents for the plant
HC – hydrocarbons
H_2S – hydrogen sulphide
HVN – heavy virgin naphtha
HVO – chief safety delegate
LPG – liquefied petroleum gas
LPS – loss prevention system
MOC – management of change
OIMP – operations integrity management procedure
OIMS – operations integrity management system
P&ID – piping and instrumentation diagram
PIP – pipe segment
PPE – personal protective equipment
RBI – risk-based inspection
SAP – maintenance management system at Slagentangen
SHE&QA –safety, health, the environment and quality assurance
SO_2 – sulphur dioxide
PS – pipestill, area around the main distillation column T-109
PSA – Petroleum Safety Authority Norway
VB – visbreaker, process unit reducing the quantity of remaining oil produced from distillation of crude oil and increasing the output of more valuable middle distillates
WP – work permit

3 The PSA investigation

The PSA was notified of a naphtha leak at Slagentangen by phone at about 12.50 on 24 August 2020. It received status updates in phone meetings during the afternoon, with the duty officer informed at 19.55 that the plant was depressurised and the leak stopped. A brief phone meeting at 09.30 on 25 August gave an updated status report on the incident. The PSA decided on the same day to investigate it.

The investigation team conducted an inspection and interviews at Slagentangen on 2-3 September. Skype interviews also took place on 7 and 16 September. The investigation was well organised by Esso to ensure that conversations and inspections could take place while observing Covid-19 infection controls at Slagentangen.

Attention in the investigation has been concentrated on clarifying the course of events, the underlying causes of the leak, the response to its discovery, an assessment of the barriers in the part of the process plant where the incident occurred, and Esso's own investigation.

3.1 Composition of the investigation team

Jan Erik Jensen	F-Logistics and emergency preparedness
Morten A Langøy	F-Structural integrity
Elin S Witsø	F-Process integrity
Ove Hundseid	F-Process integrity (investigation leader)

3.2 The investigation team's mandate

The mandate for the investigation team has been as follows.

a. Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes timelines 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. Assess the emergency response to the incident, including relevant decision processes
e. Identify nonconformities and improvement points related to the regulations (and the company's own requirements)
f. Discuss and describe possible uncertainties/unclear points
g. Consider barriers which have functioned (in other words, barriers which have helped to prevent a hazard from developing into an accident, or reduced the consequences of an accident)
h. Assess the player's own investigation report
i. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template
j. Recommend – and normally contribute to – further follow-up

4 Background information

4.1 Organisation and management system

The Slagen refinery is owned and operated by Esso Norge AS, a subsidiary of ExxonMobil. Operational since 1961, it currently has about 220 Esso employees. Of these, roughly 80 work shifts (figures from the refinery's safety report). The process department works continuous shifts. Eight people, including the shift leader, are employed in the control room/process area, and four process technicians will normally be present in the actual process plant. In addition come a varying number of inspectors, maintenance technicians, supervisors and engineers working normal daytime hours in the process areas and the tank farm/quay.

The operational management comprise the refinery manager and the technical, maintenance, process and SHE&QA managers.

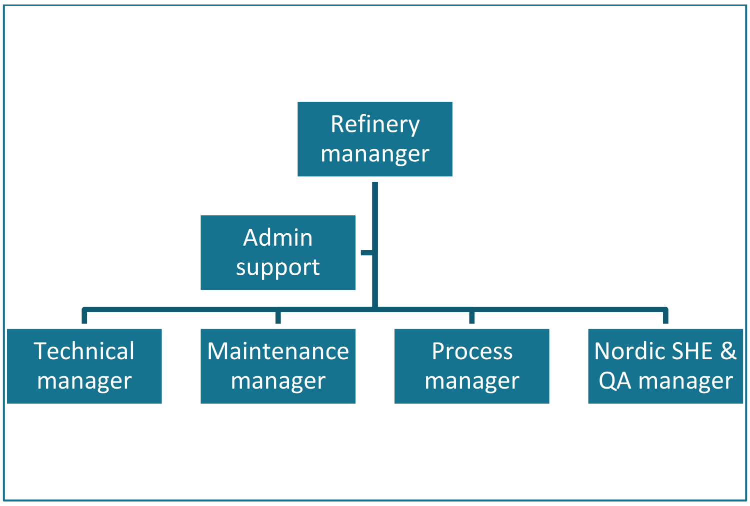

Figure 1: Operational management.

While the process department "owns" the risk of operating the refinery's facilities and allocates money for necessary improvements, the technical department documents condition and identifies improvement requirements – in part by preparing equipment strategies and conducting inspections. The maintenance department carries out maintenance and improvement work in the plant, while the SHE&QA department has an advisory role for risk management, technical and operational safety, security, the working environment, the natural environment and quality assurance.

The company's HSE management system is the operations integrity management system (OIMS). This comprises 11 elements which describe detailed expectations for how refineries should be run. It applies to all ExxonMobil refineries, but each establishes its own procedures and instructions to fulfil the OIMS requirements.

4.2 Description of the plant

Located outside Tønsberg on the Oslo Fjord, Esso's refinery at Slagentangen refines crude oil components. It embraces activities and facilities for feedstock reception, storage and refining as well as testing and delivering products. The refinery processes crude oil and distillates to produce heating oil and motor fuel for vehicles and ships. In addition come such by-products as H_2S, SO_2 and sulphur. The refinery comprises a process plant (onsite) and a tank farm (offsite). The naphtha leak occurred onsite in the section of the process plant known as the pipestill.

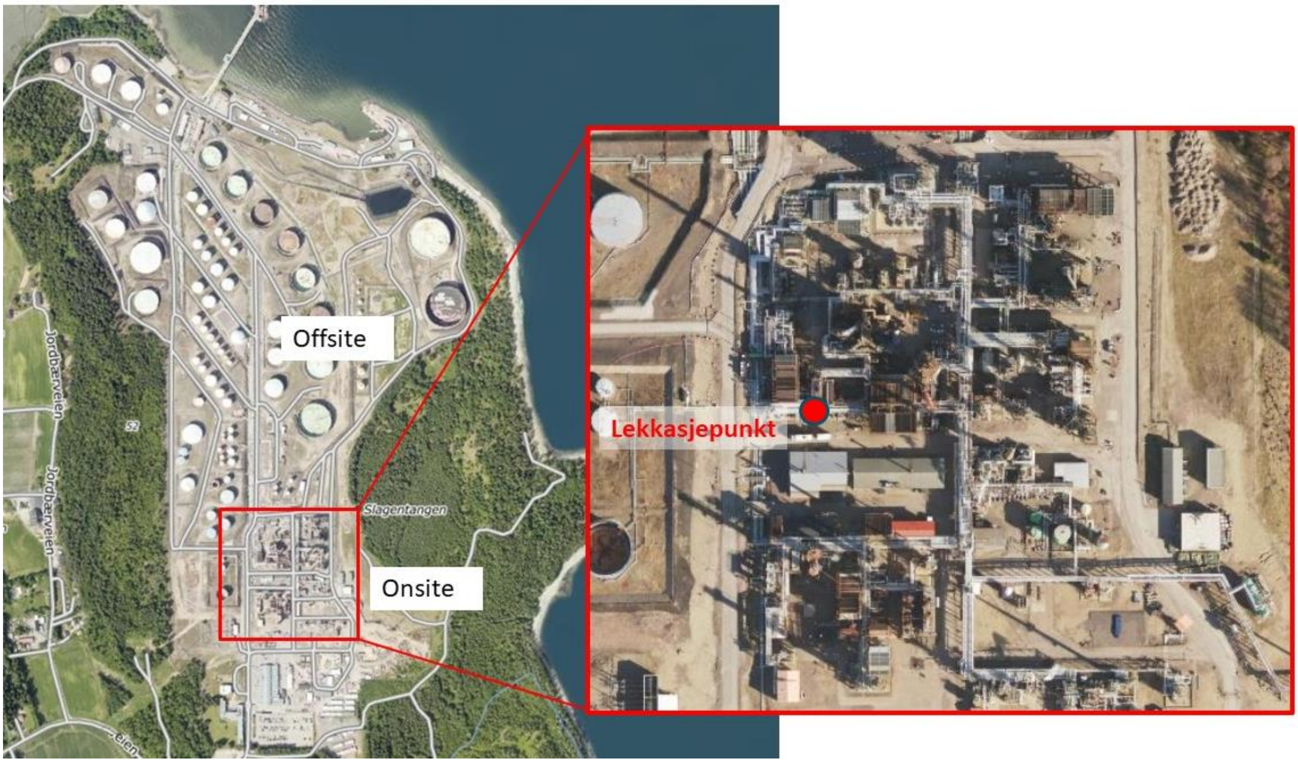

Figure 2 Overview of the Slagentangen refinery and the leak site. Photos: kart.finn.no
Key: Lekkasjepunkt: Leak point.

The pipestill distils crude oil in an atmospheric distillation tower. Figure 3 presents a simplified diagram of a distilling process. As this shows, naphtha is one of the lighter fractions taken off, and is comparable with petrol.

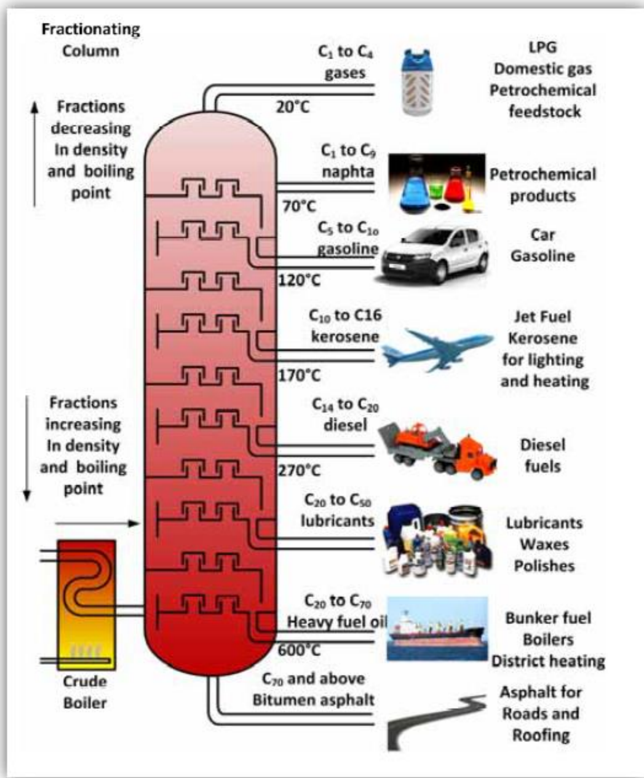

Figure 3 Simplified diagram of crude oil distillation. Source: https://no.pinterest.com

Oil distilled in the pipestill at Slagentangen is heated by a gas-fired furnace located approximately in the centre of the plant. See Figure 11. It is then led into a distillation column (designated T-109), where the various oil fractions are distilled out.

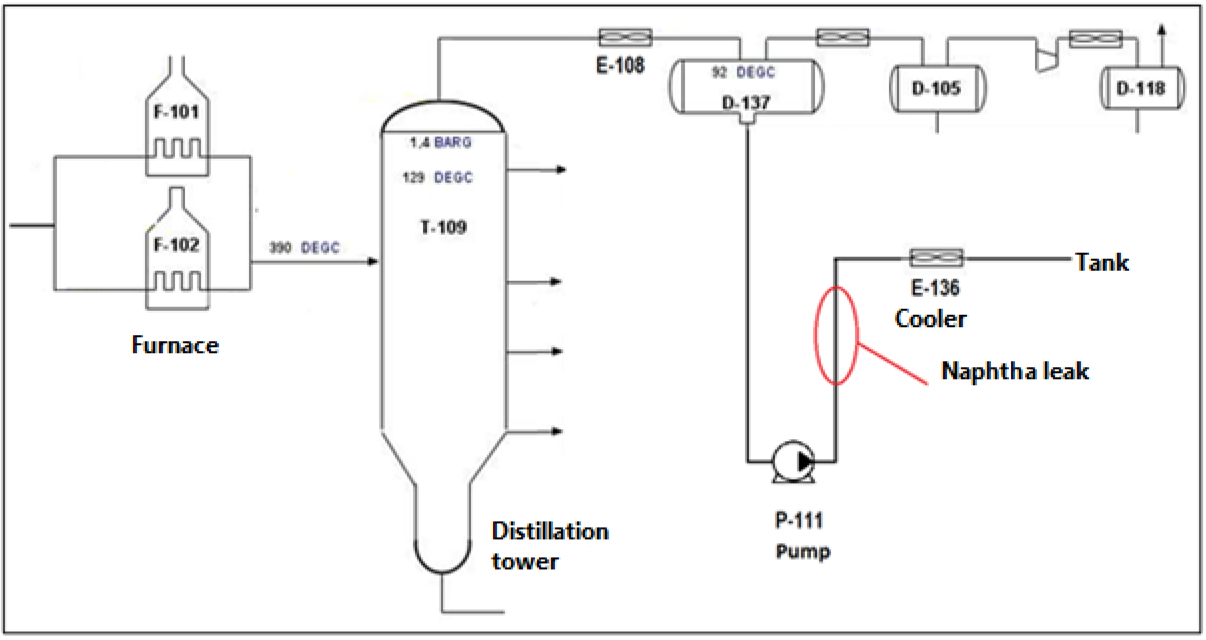

Figure 4: Simplified diagram of a pipestill.

Remaining gas is led away from the top of the distillation tower at about 130°C, and then passes through a series of coolers. Liquid (naphtha) is separated out in each cooling stage. In the first cooler, E-108, the gas is cooled to about 92°C. Naphtha removed in separator D-137 is led on to pump P-111, where its pressure is increased to about 10 bar before it is piped to cooler E-136 for the naphtha to be cooled further and then led to a storage tank. The naphtha leak occurred in the pipe between pump P-111 and cooler E-136. See Figure 4 above. Because this liquid has condensed out at the highest temperature, it is the heaviest naphtha taken out of the process stream and is known as heavy virgin naphtha (HVN).

5 Course of events

Figure 5: The pipestill, with the arrow pointing to the leak site.

The plant was in normal operation when the incident occurred.

Table 1 *Timeline for the course of events.*

Date/time	Description of event
1997	CUI inspection of the pipe (designated PIP-171)
2004	Final CUI inspection of PIP-171
2004	Equipment strategy approved for Circuit-04, which PIP-171 belongs to.
2008	PIP-171 was removed when rationalising SAP. This meant work orders for inspecting the pipe were no longer generated.
2013	The equipment strategy for Circuit-04 was updated, and PIP-171 was found to have been removed from SAP. Instead of being restored to SAP in order to ensure CUI inspection of this section, PIP-171 was left out of the equipment strategy.
2018	Circuit-04 was inspected, but PIP-171 was excluded.
24 August 2020	The day the naphtha leak occurred in PIP-171. Relevant timings for sub-events are specified below.
About 12.05	The contractor working to insulate piping in the pipestill discovered a leak on returning from lunch. He waited a few minutes until his colleague arrived, because he knew the latter had a walkie-talkie. On his arrival, the colleague notified one of Esso's process operators about the leak over the walkie-talkie. He had worked in the same place before lunch, but saw no sign of leakage then. The work site was about six-seven metres from the leak site. The contractor was wearing both H_2S and HC gas monitors, but the latter did not register any gas.

Date/time	**Description of event**
About 12.15	The process operator arrived, investigated the leak and reported a distillate leak to the control room. He climbed a ladder to a platform closer to the leak point in order to determine which pipe was leaking. He saw that this was a naphtha pipe leading to cooler E-136. The shift supervisor and foreman arrived soon after the process operator. They inspected the leak from the same platform over the leak site, and discussed with the control room whether it could be isolated by closing valves in the plant.
About 12.25	After discussion with the foreman and process operator, the shift supervisor decided to activate the gas alarm for evacuating the plant.
12.30	The gas alarm was activated. The emergency response organisation mobilised and the plant was evacuated. Mustering of personnel with and without response duties accorded with the alarm instructions. The fire-fighting team mustered and was ready for action from the ICP close to the pipestill, where the leak was located. The production rate in the plant was reduced and the shutdown level was discussed in the ICP.
About 12.50	The emergency services were alerted. They mobilised, but Esso decided these resources were not required for dealing with this incident,
12.59	Evacuation of the pipestill was confirmed on the action board.
About 13.00	The mechanical support team laid out fire hoses and connected them to nearby fire hydrants.
13.06	The area was foam-covered, and preparations were made for water curtains between the pipestill and the furnaces, which represented a potential ignition source (refilling of fire-extinguishing foam took place during the incident because foam ran off to the drain system).
13.09	Overview of evacuated personnel established. This took longer than normal because coronavirus measures prevented automated personnel registration at the muster stations (not everyone had access to the room with the card-reader). Registration was done manually.

Date/time	Description of event
13.26	Discussion over how much of the plant had to be shut down continued from activation of the alarm at 12.30 until 13.26. The process manager came down to the ICP to learn what the status was. The inability to isolate the leak point meant that the whole pipestill had to be shut down. The manager ordered the plant to be run down, returned to the control room and instructed that it had to be run down within four hours – faster than a normal shutdown. It was decided at 13.26 to shut down the pipestill – in other words, the largest section of the onsite process plant. The plant was shut down in accordance with the normal procedure but over a shorter period.
About 18.30	All energy input to the pipestill was stopped.
About 19.45	The pipestill was shut down.
About 23.30	The leak was stopped.
Early on 25 Sep 2020	The night shift isolated the pipe so that it could be inspected.

6 Corrosion and risk-based inspection

Piping equipment in the process part of a refinery is vulnerable to both external and internal corrosion. The American Petroleum Institute (API 571) has identified more than 30 corrosion mechanisms which can occur in such a facility.

Piping and equipment subject to internal corrosion are inspected at specified intervals for monitoring and repair. These intervals are based on the risk of leaks – a method known as risk-based inspection (RBI). The risk is calculated as the product of the probability of a leak and its consequences. An important precondition for RBI is accurate information in order to support decisions on probability and consequence for all equipment and piping. This is obtained by dividing the plant into corrosion circuits, where possible corrosion and damage mechanisms are identified. Slagentangen draws up an equipment plan/strategy (Strategy SLR-APS-Circuit-04), where the plant is divided into circuits, and specified pipes into smaller units called PIPs. The pipe which leaked is tagged: SLR-APS-Circuit-04, PIP-171.

6.1 Corrosion under insulation (CUI)

A refinery contains a lot of insulation because of the need to preserve thermal energy and control heat flow. Insulation at Slagentangen is used mainly to retain energy in piping and equipment and thereby to achieve efficient refining processes. Other reasons are spelt out in the Norsok M-004 standard, for example. Generally speaking, an insulation system comprises the actually insulating material plus external weather protection, which could be anything from a metal jacket to tarpaper. Inside the insulation is the actual pipe or equipment, with or without a protective coating. See Figure 6.

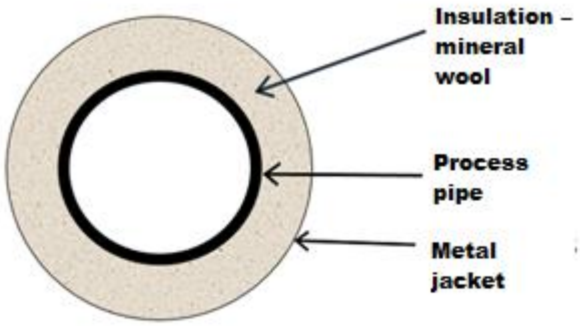

Figure 6: Illustrative cross-section of an insulated pipe.

CUI finds expression through faster corrosion in carbon steel with insulation than without it, assuming the same environment and temperature. The main reason for accelerated corrosion is water intrusion into the insulation. Modern systems make greater use of other methods, such as surface treatment of pipes, pipes in corrosion-resistant materials, hydrophobic (water-repellent) materials in the insulation, a water-tight jacket and, in some cases, drainage. The leak occurred in a four-inch carbon steel (ASTM A106 gr B) pipe with a six millimetre wall thickness, insulated with mineral wool and jacketed in aluzinc. The surface treatment is not known but, given that the pipe was installed in 1971, any treatment was probably confined to possible transport protection from the pipe mill. Given an operating temperature of 90°C, probably unsuitable surface protection, damaged jacket[1] and mineral wool, the probability of failure is very high. See DNV GL-RP-G109 (DNV GL, 2019) and chapter 12 Discussion of uncertainties.

The PSA has previously investigated leaks in pipes associated with CUI at other land plants, such as a steam leak in 2012 (PSA, 2013) and a hydrocarbon leak in 2016 (PSA, 2017).

6.2 Inspections and maintenance

The inspection department at Slagentangen, which reports to the technical manager, is responsible for preparing a programme whose name has been changed from inspection strategy to equipment strategy. This is in order to underline that it is not the department's strategy alone, but something owned by several departments. The strategy is subject to several approval levels and QA activities.

[1] Based on the condition of the jackets on surrounding pipes.

Staffing of the inspection department has reportedly been doubled since 2013 because the review of equipment strategies had fallen behind schedule, and this work is still ongoing. Both the process and the technical process support departments are now also involved in updating the strategies. This ensures that personnel who are well acquainted with the plant participate in the work.

Esso registers sweating and leaks caused by CUI. Based on information from the company, these findings and observations are presented in Figure 7. This shows that the annual number of incidents has declined since 2011.

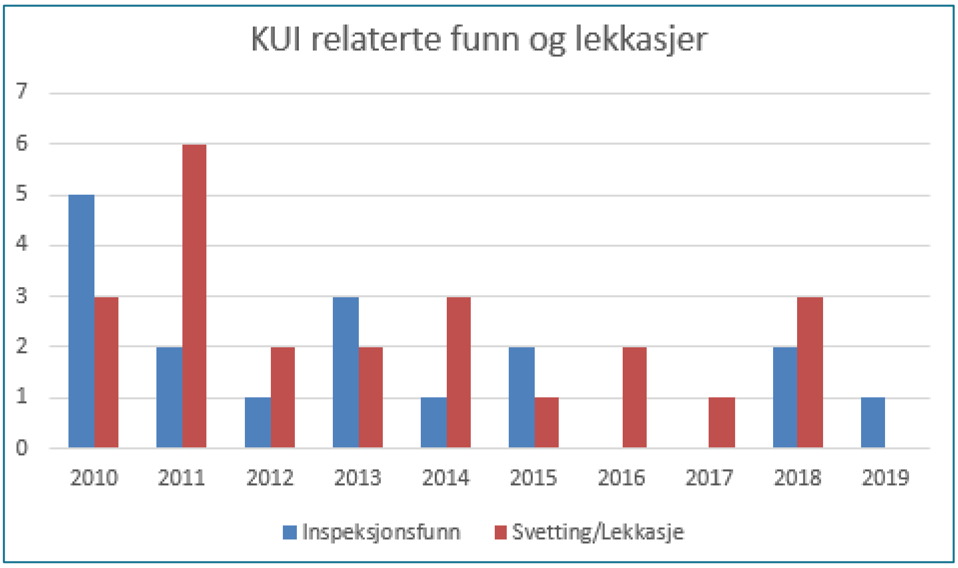

Figure 7: Number of findings and observations during operation and inspections. Key: CUI-related discoveries and leaks; Inspection findings; Sweating/leaks.

Esso has reported that the relevant pipe in SAP was removed by mistake in 2008, and that documentation shows it was identified in 2013 during a comparison with the P&ID. The PIP was thereby found to have been removed from SAP but, instead of then being reinstated there, it was left out of the strategy. The pipe has therefore not been inspected since then. It was inspected in 1997 and 2004, and was due for inspection in 2018 if it had not been removed. The normal method for CUI inspection is to remove the insulation and inspect the pipe visually, which is resource-intensive. Since the leak occurred relatively soon after the planned PIP inspection date in terms of the inspection interval, the robustness of the programme might be questionable. A less resource-intensive inspection method, which can be done more frequently, is to inspect the jacket visually to check that it remains watertight. However, this has not been done here.

The most recent developments in process technology have demonstrated that the need to insulate piping is smaller than assumed in earlier designs. In such cases, it is appropriate to remove the insulation in order to avoid CUI. When conducting inspections, the inspection department at Slagentangen investigates whether insulation is necessary and removes it if not. The investigation has been told that several hundred metres of insulation has been removed both offsite and onsite. After the leak, the relevant pipe has been assessed and found to be among those which do not need to be insulated.

6.3 The pipe leak

The leak has occurred after substantial external corrosion owing to CUI. See Figure 8 and Figure 9. Whether internal corrosion has also contributed to wall thinning has not been investigated. This is considered unlikely, given that virgin naphtha is not corrosive and there was no sign of internal corrosion when the pipe was cut and blinded after the leak. The pipe rests directly on a small plate on the steel beam which provides its support, and the insulation has not covered it entirely. That has given easy access for water. The insulation jacket has not been inspected for leakage, but it has been reported that jacket condition is the same on surrounding pipes. See Figure 10. Together with the pipe's condition, this indicates that CUI is likely.

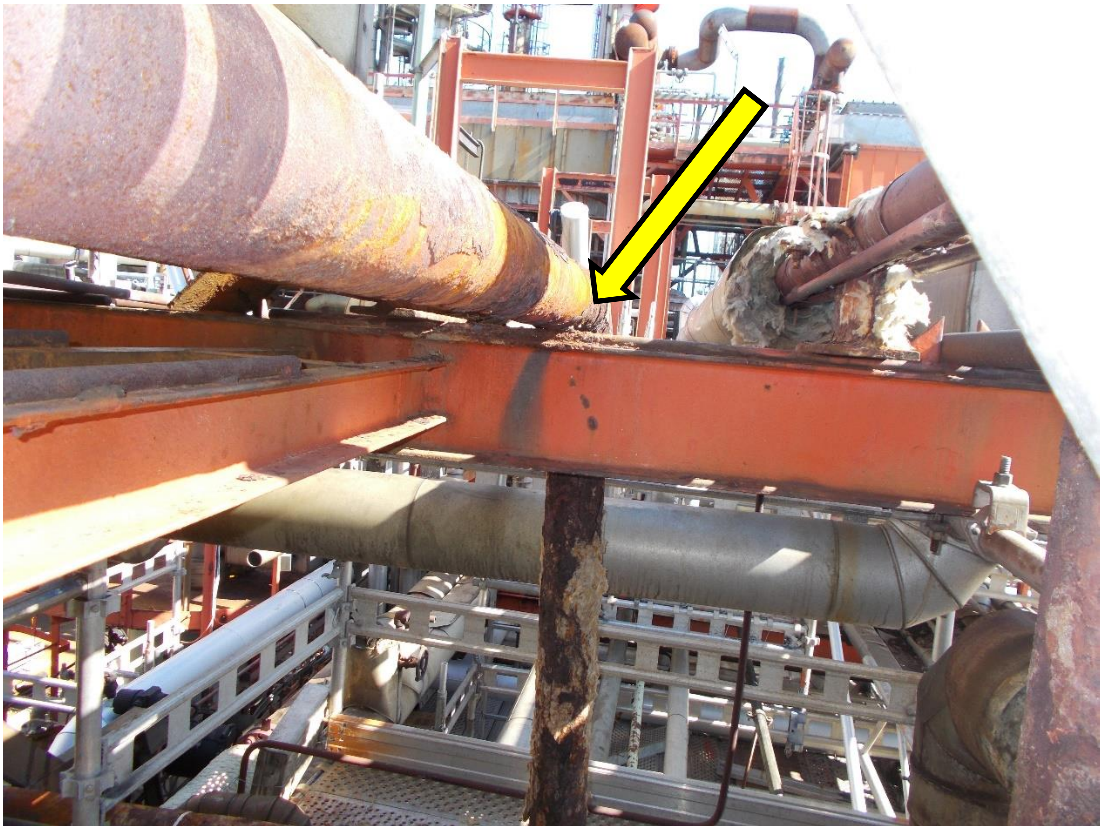

Figure 8: The naphtha pipe after removal of its insulation. The assumed leak point is at the end of the horizontal stretch indicated by the arrow.

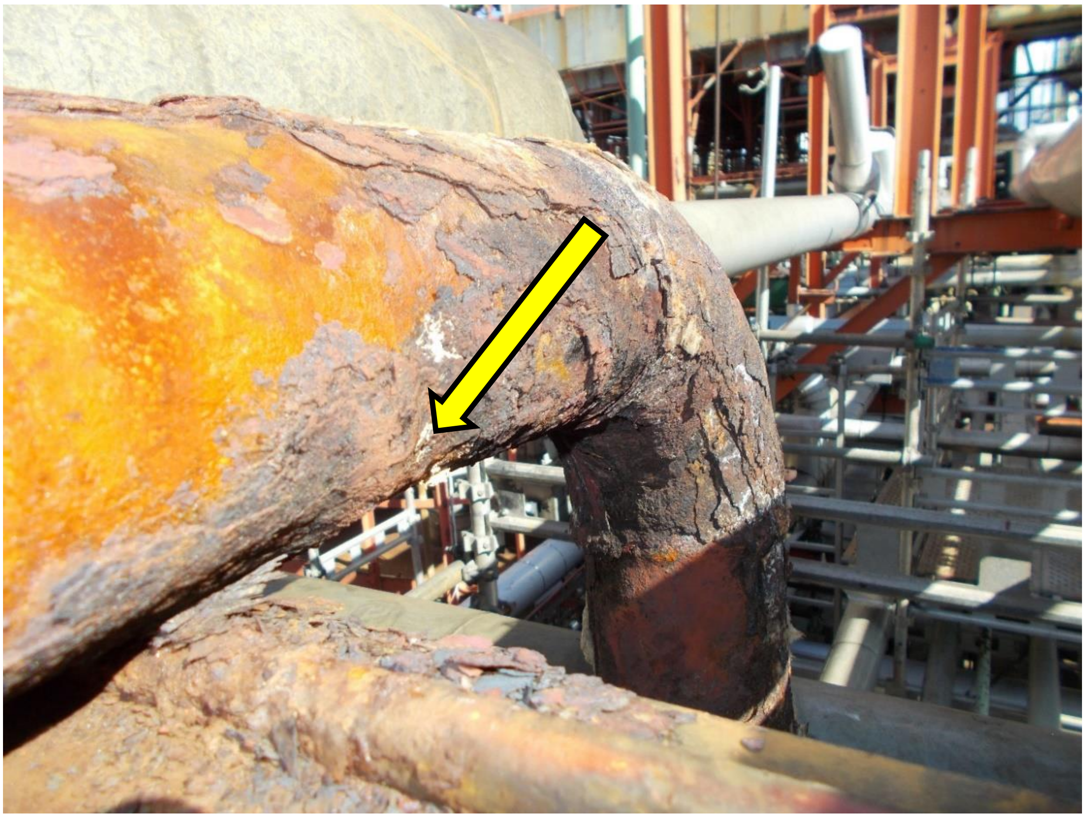

Figure 9: The naphtha pipe after removal of its insulation. Arrow indicates the assumed leak point.

Figure 10: Condition of insulation jackets on surrounding pipes close to the leak.

7 Potential of the incident

7.1 Actual consequences

The naphtha leak occurred because of CUI in a pipe for heavy virgin naphtha from the distillation column. This pipe was still installed in the plant when the investigation was conducted. Because sufficient capacity was available to handle the naphtha without the leaking pipe, the plant could restart after valves had been installed to isolate the pipe section. The size of the hole in the pipe has not been investigated nor the leak rate calculated. According to the personnel who saw the leak, it was in the order of 10 litres per minute. The naphtha which leaked was collected by the plant's open drain system and accordingly caused no discharge or damage to the environment. Based on the assumed leak rate, Esso has estimated that 4 400 litres of naphtha leaked out.

No HC gas detectors are installed in the pipestill. Operating personnel who initially investigated the leak did not have portable HC monitors with them, only H_2S monitors, and were not wearing respirators. The operators were a few metres from the leak point. The contractors who found the leak wore personal HC gas monitors because they were doing hot work in the plant, and these devices registered nothing when the leak was discovered. HC gas detectors deployed at a distance from the leak as part of the emergency response showed no readings either. The naphtha which leaked was nevertheless close to its boiling point and must have given off vapour, but it is not possible to determine how much. Exposure of the operators to benzene while they investigated the leak cannot be excluded.

7.2 Potential consequences

Potentially, the leak could have ignited and caused a fire in the pipestill. The absence of fire and gas detectors means that the detection of any ignition would have depended on its discovery by refinery personnel. A fire could potentially have spread and escalated as a consequence of fracturing in other equipment or structural failure of process facilities in the area. It could also have increased the leak rate from the pipe which was already undermined by corrosion. The investigation team lacks sufficient information to make a detailed assessment of the incident's potential. Had the leak been ignited after the establishment of fire-extinguishing resources, the team has concluded that this would probably have hindered an escalation.

The probability of a leak igniting in a process plant where explosion-proof equipment remains intact is low. Had it ignited while being investigated by operations personnel, however, they could have been exposed to a fire. They were particularly vulnerable when close to the leak point on a platform which could only be accessed via a ladder.

8 Direct and underlying causes

The direct cause of the leak was external corrosion of a four-inch pipe taking naphtha from pump P-111 to cooler E-136. Lack of inspection and repair meant that the corrosion had continued long enough for a hole to form in the pipe.

Esso has investigated why the pipe was not inspected. As noted in the timeline above, this was because PIP-171 had been removed from the SAP maintenance programme in 2008, even though it was still in use. Nor had PIP-171 been restored to SAP when a new equipment strategy covering the relevant pipe was established in 2013. Instead, PIP-171 was left out of the equipment strategy in this review. The latter checked the inspection drawings against the P&ID to ensure that all pipes were included. Esso has been unable to establish why PIP-171 was not included in the equipment strategy and SAP in connection with this review.

Since 2013, Esso has reinforced its inspection department by recruiting more engineers, and the investigation team has been told by the company that its organisation is more robust today in terms of preventing similar errors. Soon after the incident, Esso initiated a review of piping in the pipestill to check whether other pipes were not covered by the inspection programme. No further errors have been found, which indicates that this was a one-off case rather than a systematic fault.

9 Handling of the incident

9.1 Emergency response

The response to an incident is described in OIMP 10.1, the emergency response plan for the Slagen refinery. This contains the alarm instruction for the plant, which has the following main elements:

- halt work and secure the workplace
- notify by phone or walkie-talkie
- activate alarms
- evacuation across the wind direction (in the event of a gas alarm)
- muster at specified stations.

The instructions in the alarm instruction and the emergency response plan were observed, with the following exceptions.

1. It was decided to inspect the leak point without personal protective equipment (PPE) being used (reference OIMP 10.1, chapter 1 – alarm instruction). The leak point was several metres above ground level. Personnel inspecting the leak could have been exposed to volatile components from the naphtha, and evacuating the site in the event of possible ignition would have been demanding.

2. Establishing an overview of non-essential personnel evacuated to muster stations in the area took longer than normal. Not everyone had access to the room with a card reader owing to coronavirus measures. Registration was manual, which took longer than normal. Esso has not established performance criteria for mustering.

Considerations related to the failure to use PPE are discussed in section 10.1.3 of this report.

The alarm instructions and emergency response plan were otherwise observed in connection with notifying the incident (the contractor to Esso's plant operator, and on to the control room), assessing the incident (in this case shift supervisor and foreman), activating the alarm, mustering of essential (emergency response) and non-essential personnel, and other measures specified in the emergency response plan for DSHA fire.

Where activating the alarm as mentioned above is concerned, the leak was verified by the process operator 15 minutes before the plant alarm was sounded. In other circumstances where an incident had escalated, it would have been important to activate evacuation by sounding an alarm immediately after the incident was discovered.

Measures included

- notification of the incident
- check of the leak point (see also section 10.1.3)
- gas alarm with associated mustering of emergency response and non-essential personnel (see also section 10.1.4)
- mobilisation of fire-fighting personnel at the fire station, and laying foam in the area below and around the leak point
- technical support team mobilised to carry out the following activities
    - connecting fire hoses to nearby hydrants, mobile and oscillating water monitors
    - establishing the water curtain system against potential ignition sources (including furnaces) and HC gas detectors between the leak site and potential ignition sources.

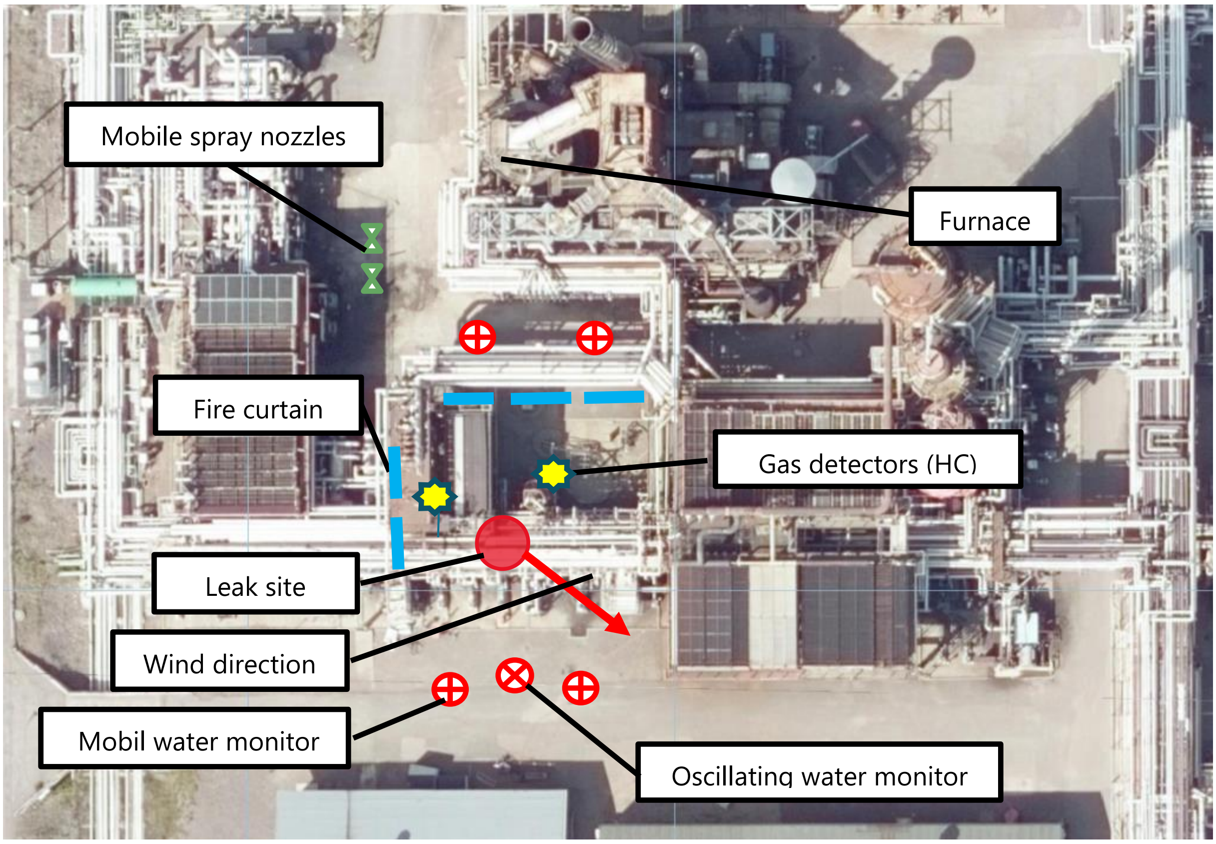

Figure 11: Overview of the process plant with equipment and wind direction. North at the top. Photo: kart.finn.no

9.2 Plant shutdown

While a naphtha leak was confirmed at about 12.15, shutdown of the plant first began just over an hour later. This was because the process department took time to assess opportunities for isolating the leak without a full shutdown. Two principal methods exist for shutting down the plant – normal and emergency. The first, carried out for such purposes as a turnaround, is a lengthy business. Much heat is supplied in the plant, and time is taken when running down in order to avoid undesirable effects such as reducing the operational life of the catalysts used. An emergency shutdown takes a matter of minutes. It can impose a heavy burden on the plant and, in the worst case, damage equipment. Avoiding this unless it is necessary will therefore be desirable.

In this case, Esso believed it had the leak under control. Foam was laid over the area where the naphtha leaked out to prevent vaporisation/ignition, and gas detectors were positioned which showed that the leak was not producing gas in the plant. Since the naphtha was collected in the plant's drain system, no discharge occurred to the natural environment. Overall, Esso therefore assessed that the lowest risk would be to follow the procedure for normal shutdown with technically supported adjustments to accelerate implementation. If the company saw things take a negative turn, it still had the option to activate emergency shutdown.

The leak stopped at 23.30, when the system had been drained down. In this case, the investigation team considers that Esso handled the leak in an appropriate manner.

While the normal shutdown procedure was followed, its implementation was faster than prescribed. The technical department gave advice to the process department on how quickly it could shut down without overburdening the plant. Apart from emergency shutdown, no procedures exist for shutting down faster than normal. See improvement point 10.2.3.

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 Lack of risk assessment of the need for fire and gas detection in the pipestill

Nonconformity
No risk assessment of the need for fire and gas detection in the pipestill has been carried out.

Grounds
Fire or gas detectors have not been installed in the pipestill. When the naphtha leak was discovered, mobile gas detectors were positioned between the leak point and the gas-fired furnace, an ignition source in the centre of the pipestill. Firewater curtains were also installed to lead away possible gas.

The absence of fire or gas detectors means that the refinery depends on personnel in the plant to discover leaks, as in this case. The gas-fired furnace is an ignition source which could potentially ignite gas from a leak in the plant. Rapid gas detection could therefore be crucial in preventing ignition from the gas-fired furnace.

An extract from the general guidelines for assessing gas detection has been received by the investigation team. This states that installation of gas detectors can be assessed if leaks have a potential to reach ignition sources – in this case the gas-fired furnace. The team has not received a specific assessment of the need for fire and gas detection in the pipestill. The regulations require barriers to be established which are able at any given time to identify conditions which could lead to faults, hazards or accidents, and which reduced the opportunities for faults, hazards or accidents to occur and develop.

Requirements
Section 17, paragraph 3, litera d and paragraph 4, litera a of the management regulations on risk analyses and emergency preparedness assessments

10.1.2 Deficiencies in maintenance and inspection

Nonconformity
Inspection and maintenance of the pipe which leaked was deficient.

Grounds
The leak was caused by CUI in a pipe which has not been inspected or covered by a maintenance programme.

Requirement
Section 58 of the technical and operational regulations on maintenance

10.1.3 Failure to ensure the safety of the operations and maintenance personnel involved

Nonconformity
Inadequate care was taken of the safety of the operations and maintenance personnel in connection with the incident.

Grounds
After a naphtha leak had been confirmed, a total of three people from the process department were in the plant close to the leak point to establish where it was coming from. This accorded with Esso's procedures, which say that the scope of the incident must be assessed. These people had no HC gas monitors or protection against benzene exposure, and could therefore have been exposed to the latter. Had the leak ignited, they would also have been at risk of exposure to the fire.

During normalisation, the pipe insulation at the leak point was removed. Pursuant to Exxon's guidelines, benzene checks must be made at leaks and spills from product flows containing this substance. Based on the results of these measurements, PPE must be used in accordance with the guidelines to ensure that personnel are not exposed to benzene. No benzene measurements were carried out to ensure that personnel involved in insulation removal used the correct PPE.

Interviews and document reviews, combined with the failure of Esso's own review of the incident to identify conditions related to the safety of the personnel involved, show that protection of the individual's own safety is not sufficiently operationalised.

Requirements
Section 4 of the management regulations on risk reduction

Section 48, paragraph 3 of the technical and operational regulations on the physical and chemical working environment
Section 67, litera b of the technical and operational regulations on handling hazard and accident situations

10.1.4 Lack of performance requirements related to emergency response

Nonconformity
No performance requirements had been defined for measuring the functionality of key measures for responding to hazards and accidents.

Grounds
Through interviews and the document review, it was observed that no performance requirements had been defined for measuring the quality of organisational and operational barriers in the emergency response organisation. No requirements were set, for example, on the time to be taken in evacuating the plant and registering personnel, or between observing an incident and activating alarms for evacuating the plant and mobilising the emergency response organisations.

The alarm was not immediately activated on observation of the incident, and it took a long time before the operational management had registered the mustered personnel.

It emerged from the documentation review and interviews that about 15 minutes passed between observing the incident and activating the gas alarm to initiate evacuation. In addition, 40 minutes passed from activation of the gas alarm until an overview was secured of non-essential personnel at the muster stations. Interviews revealed that this was because the room with the automated registration machine had been locked because of the coronavirus position. Logs from the muster stations are routinely deleted, and it has not been possible to verify the number mustered and timings from the muster log.

Requirements
Section 5, paragraph 4 of the management regulations on barriers
Section 67, litera c and d of the technical and operational regulations on handling hazard and accident situations

10.2 Improvement points

10.2.1 Inadequate overview of impairments in the plant

It is unclear how barrier impairments in the plant are communicated to relevant personnel.

Grounds
Inspection of the leak site revealed that passive fire protection was lacking on the structure for process equipment, including coolers. The team was informed that Esso was aware of this, and that work had started to correct it. In the event of fire, the lack of such passive protection could cause a faster collapse and escalation of the blaze. The investigation could not clearly establish what system was in place to make this known to the fire-fighting personnel or whether measures had been taken to compensate for the lack of passive fire protection.

Requirement
Section 5, paragraph 5 of the management regulations on barriers

10.2.2 Lack of marking in the plant

Improvement point
Inspection of the plant revealed a lack of marking.

Grounds
The investigation team observed that most of the pipes it checked lacked marking which identified the medium carried or the direction of flow. Conversations with personnel confirmed that deficiencies exist in marking equipment in the plant, and that this is something being worked on. Esso reports that responsibility for marking when requirements are identified rests with the process department, and that no managed process exists for this.

Requirement
Section 7, paragraph 2 of the technical and operational regulations on installations, systems and equipment

10.2.3 Shutdown procedures for the plant

Improvement point
Apart from emergency shutdown, no procedures have been established for shutting down the plant as quickly as possible in the event of a leak.

Grounds
When shutting down the plant, the procedure for normal shutdown was used but without observing points which were not relevant, and implementing it faster than was specified in the procedure. In this case, the process department received support from the technical department on how fast it was possible to shut down. Based on the information received by the team, it would seem appropriate to establish a procedure for fast shutdown so that the process department does not have to depend on the technical department or have to make this type of assessment in the

event of a leak. That applies particularly if the incident occurs at a time when personnel from the technical department are not immediately available.

Requirement
Section 45 of the technical and operational regulations on procedures

10.2.4 Inadequate investigation mandate

Improvement point
The scope of the company's own investigation has been inadequate for investigating conditions which could have resulted in damage.

Grounds
The responsible party must ensure that hazards or accidents which have occurred and which might have, or have, resulted in acute pollution or other damage are registered and investigated to prevent recurrence. The mandate for a CFWT investigation is general, and says nothing about its scope. It emerged from interviews that the investigation group has viewed its job as purely technical. The investigation report describes the course of events and causes related to the PIP where the leak occurred, but devotes less attention to assessing the inspection programme, the estimated leak rate, the potential of the incident, how the leak was discovered or how it was handled. The safety of those who discovered/investigated the leak is not assessed.

Emergency response aspects are not covered by the investigation, but were assessed in the debriefing conducted after the incident.

Requirements
Sections 20 and 23 of the management regulations on registration, review and investigation of hazard and accident situations, and on continuous improvement respectively

11 Barriers which have functioned

In this cases, the plant had no automatic safety systems which activated. The barriers were manual actions by personnel in the plant and the emergency response team.

Barriers which have functioned

- observation and notification of the leak
- activation of the gas alarm for evacuation of the plant
- such emergency response actions as
  - mobilising the emergency response organisation
  - spreading foam to limit gas dispersion and fire
  - positioning gas detectors
  - installing a system for water curtains in the event of gas dispersion

- shutting down the plant to stop the leak
- the drain system limited spreading and collected the naphtha.

12 Discussion of uncertainties

When the investigation was being conducted, the pipe which leaked had not been removed from the plant for inspection of the hole. A leak rate has therefore not been calculated. Those who saw the leak estimated it at about 10 litres per minute. The rate is therefore uncertain and could have been both higher and lower without this having substantial significance for the actual investigation. Had the leak been ignited, the investigation team's assessment is that this would probably have been manageable in terms of fire-extinguishing.

The PIP-171 pipe was inspected in 1997 and 2004, and the investigation team has failed to obtain clarification of why the inspection activity for it was removed from SAP. As a result, the pipe has not been inspected since. Changes have been made to work processes and organisation in the inspection department after the errors made in 2008 and 2014. Attention in the investigation has therefore concentrated on clarifying how today's system ensures that similar errors are picked up and corrected.

The team has been informed that intervals of more than 20 years can occur in the inspection programmes. It is unclear whether PIP-171 would have been assigned an interval of 14 or 21 years. Based on the method in DNV GL-RP-G109, that does not seem robust and the leak in this case occurred 16 years after the last inspection. DNV GL-RP-G109 uses four parameters (barriers) to assess the probability of CUI. These are as follows (with examples).

1. Material
    a. Surface temperature
2. Coating
    a. Type
    b. Age
3. Water wetting
    a. Condition of mantling
4. Design
    a. Inspection interval

A high probability score is achieved here for all the parameters.

Where the first three are concerned, the material has a surface temperature of 90°C, no and/or old surface treatment, and the protection against water intrusion is in poor condition (damage to the jacket). This should have been compensated for by frequent inspection. CUI inspections at Slagentangen are conducted by removing the jacket and insulation for a visual check of the metal surface. This is a resource-intensive process, and efforts are therefore made to avoid doing it too frequently. The team has been informed that the refinery uses TMEE-062, ExxonMobil (2014), to develop equipment strategies. This takes a similar approach to DNV GL-RP-G109. The team has not reviewed this on the pipe which leaked in order to assess probabilities and the calculation of inspection intervals. Alternatively, frequent visual inspections can be made of the jacket to check that it is watertight. However, this was not done here.

Little documentation was available on sub-events, such as logs from the incident command, muster stations and damage sites, which could be used to establish a timeline. Several of the timings in the timeline have therefore been determined from interviews.

13 Assessment of the player's investigation report

Slagentangen's requirements for following up incidents and near-misses are described in the SLR-OIMP-9.1 procedure on incident reporting and investigation. The Impact tool is used to register incidents and near-misses. Their seriousness is assessed on reporting, and the results of this assessment determine the type of investigation.

The incident risk analysis tool (Irat) was used to assess the seriousness of the naphtha leak on 24 August. According to OIMS 9.1, Irat provides a good understanding of the actual consequences, the possible consequences with various scenarios relevant to the incident/near-miss, and which barriers were in place, failed or were missing. Irat is based on an impact classification from I to IV, with I as the most serious.

<u>Irat score</u>
The Irat score is based on an assessment of

- actual consequences (level I-IV, value 20/10/5/2)
- potential consequences (level I-IV, value 20/10/5/2)
- barriers (none=20, 1=10, 2=5, 3+=2)

Where the relevant incident is concerned, the investigation team made the following assessment.

- Actual consequence: 2, with the comment: Tier 2 process safety event, all the naphtha was recovered, no personal injury, no environmental impact.
- Potential comment: 10, with the comment: Leak could have been ignited and caused equipment damage of USD 1-30 million in direct costs.
- Barriers: 10, with the comment: Personnel rigged up gas detectors, fire water monitors and water curtains. The area was foam covered and the process department was ready for emergency shutdown of the plant.

This gave an Irat score of 2 x 10 x 10 = 200

Choice of investigation method
Esso requires that incidents and near-misses with an Irat score > 400 are investigated, using the causal factor why tree (CFWT) method. The team was informed that it was not unusual to initiate a CFWT investigation even with an Irat score of < 400, as is the case with this incident.

Assessment of the investigation report
The mandate for the CFWT investigation is general, and says nothing about its scope. While the investigation report describes the course of events and the causes associated with the PIP where the leak occurred, it devotes less attention to assessing the inspection programme, the estimated leak rate, the potential of the incident, how the leak was discovered and how it was handled. The safety of those who discovered/ investigated the leak is not assessed.

The following comment is entered in the barrier assessment chapter of the report:
Because of the low Irat, it has been decided not to make a bow-tie.

14 References

DNV GL (2019). RP-G109 *Risk based management of corrosion under insulation*.
Norsok (2019). Standard M-004. *Piping and equipment insulation.*
PSA (2013). *Investigation report on a steam leak at Mongstad on 8 November 2012*.
PSA (2017). *Gas leak at Statoil Mongstad on 25 October 2016.*

15 Appendices

A: Relevant diagrams/figures/etc
B: Documents utilised in the investigation
C: Overview of personnel interviewed

Appendix A: Wind conditions 24 August 2020, Slagentangen

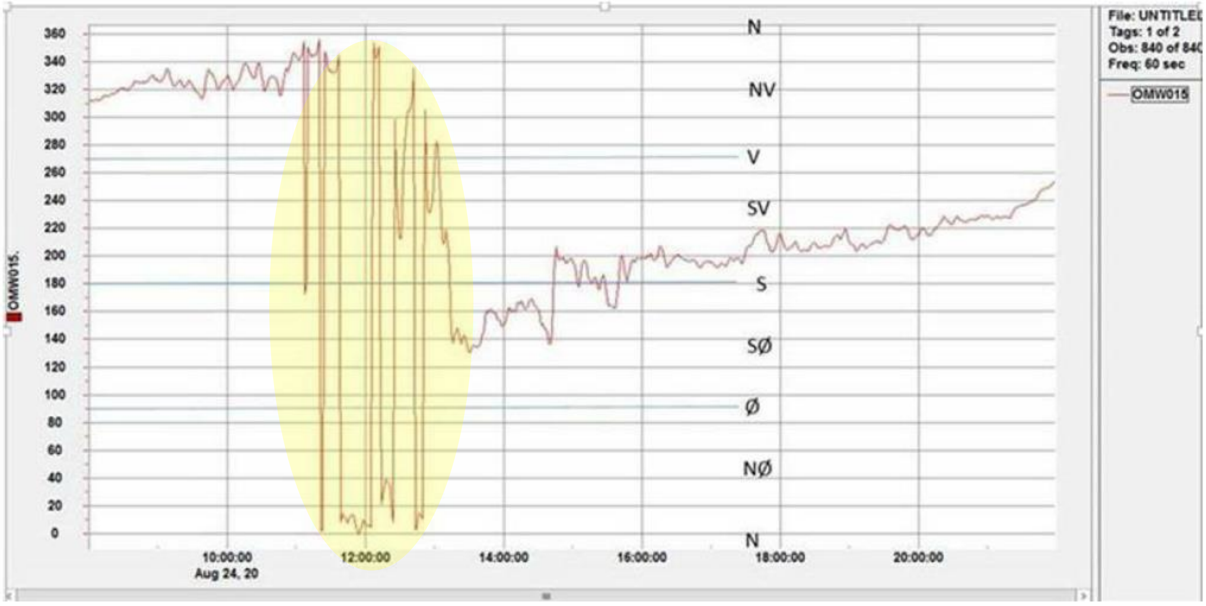

Figure A-1 *Wind direction measured by Esso's anemometer at Slagentangen.*

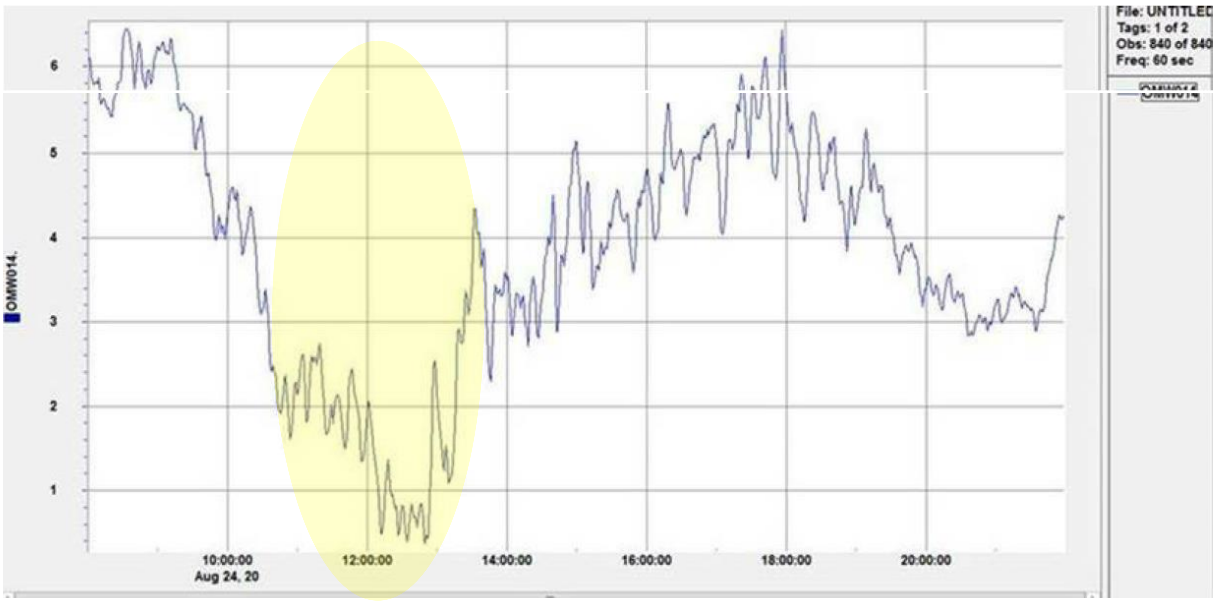

Figure A-2 *Wind speed measured by Esso's anemometer at Slagentangen.*

Appendix B: Documents utilised in the investigation

Archive ref	Document
2020/1680-4	Information to the PSA – naphtha leak 24082020
2020/1680-4	OIMP 10.1 Emergency response plan
2020/1680-4	Log of events – modified
2020/1680-6	EDD 1A
2020/1680-6	Strategy SLR-APS Circuit-04
2020/1680-6	Coating and insulation procedure
2020/1680-6	Roles in relation to section 7.1, on-scene commander plant
2020/1680-6	Action board – modified
2020/1680-6	Log of events – modified abbreviations
2020/1680-6	Organisation chart
2020/1680-6	Pear board form – modified
2020/1680-6	Leak sweating and CUI discoveries 2010-2020
2020/1680-6	Summary of the emergency response organisation's commitment
2020/1680-8	OIMP 6.4
2020/1680-8	OIMP 9.1 Incident reporting and investigation
2020/1680-8	VI-16 Asbestos and other insulating materials
2020/1680-8	VI-28 Use of respirators
2020/1680-9	ISO drawings PIP-171
2020/1680-10	DV screenshots
2020/1680-10	S210-Ua2-2028
2020/1680-10	PS&-P111
2020/1680-10	PS 3 E-136
2020/1680-11	GRP 6C Procedure for equipment strategy, fixed equipment
2020/1680-12	7111719XNO sales product
2020/1680-14	Slagen opening presentation
2020/1680-14	Draft CFWT PIP-171
2020/1680-15	CFWT investigation of liquid filling in flare
2020/1680-16	HPScan 20200907
2020/1680-16	Copy of near-miss PIP-204
2020/1680-17	OIMP 10.1 Fire appendix 3
2020/1680-17	Photographs from inspection in plant
2020/1680-18	Photographs from inspection in plant, part 2
2020/1680-21	Logs from process, part 1
2020/1680-22	Logs from process, part 2
2020/1680-23	Logs from process, part 3
2020/1680-24	OIMP 6.3 SSHE critical equipment Slagentangen
2020/1680-24	OIMS 2.1 Risk management Slagentangen
2020/1680-24	Installing shutdown valves before E-136 Slagentangen
2020/1680-24	Offsite CSOV-747 23 August 2020 – Permit for temporary deactivation of SHE-critical equipment – Slagentangen
2020/1680-24	Drawing – Onsite fire extinguishing extra equipment
2020/1680-25	WP pipestill
2020/1680-26	Fireproofing PSA
2020/1680-29	Investigation of naphtha leak in PS 240820

2020/1680-31	Safety instruction 11: Benzene and PAH
2020/1680-34	CUI report from 2004
2020/1680-36	System for emergency response training – training
2020/1680-40	Response to questions – extracts from documents
2015/20	ExxonMobil (2014). TMEE-062 Corrosion under insulation
	Safety report for Slagentangen