PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation of undesirable incident on Troll C on 24 October 2021 – revised	Activity number 001085030

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

Involved	
Team T-1 (Equinor offshore)	Approved by/date Kjell M Auflem, by authority, head of supervision/13.5.2022
Members of the investigation team Bente Hallan, Thom Fosselie	Investigation leader Morten A Langøy

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1 Summary

During an inspection round in the process facilities, a substance was discovered which later proved to be asphaltene. It had leaked from a second-stage gas cooler on Equinor's Troll C facility. This investigation has set 24 October 2021 as the date of the actual incident, since that was when cracks in the second-stage gas compressor coolers were identified. These cracks developed over time, and dating the start of the process is difficult. The consequence was weakened integrity of the gas coolers, which contain hydrocarbon gas under a pressure of 60 bar.

The Petroleum Safety Authority Norway (PSA) decided on 5 November 2021 to investigate the incident.

The actual consequence is that no harm to people or the environment has been identified as a result of the incident, but substantial costs were incurred from material damage and lost production.

In the PSA's view, the incident could have developed under slightly altered circumstances into a major gas leak through brittle fracturing in the outer shell of one of the gas coolers.

Its main finding is that technical and operational solutions were not chosen to prevent damage, faults, hazards and accidents related to degradation of stainless steels in a second-stage gas cooler on Troll C. Six nonconformities from the regulations have been identified, involving lack of risk reduction related to material degradation and use of information, deficiencies in governing documents, maintenance and consequence classification, and late notification. Two improvement points are identified concerning the maintenance programme and application of knowledge, and documentation of passive fire protection.

2 Abbreviations

22%Cr duplex	Stainless steel, typically with 22% chrome and 5% nickel as alloys. Duplex microstructure comprising ferrite and austenite
AI	Asset integrity group – assesses technical integrity
CCR	Central control room (on the facility)
COA ACC	Corporate audit accident investigation team
CSCC	Chloride stress corrosion cracking
CUI	Corrosion under insulation
EPC	Engineering, procurement and construction
EPN	Exploration and production Norway
GL	Guideline
HTA	Second-stage export compressor A KA-23-0012A
HTB	Second-stage export compressor B KA-23-0012B

HTA cooler	Second-stage cooler for export compressor A HA-23-0012A
HTB cooler	Second-stage cooler for export compressor B HA-23-0012B
IOC	Integrated operations centre, monitoring of operating parameters
LBB	Leak-before-break – fracture mechanics method for assessing whether pressure equipment with cracks will result in a leak which might be discovered or a fracture/breakdown
M40	Fram module
NDT	Non-destructive testing
OIM	Offshore installation manager
OM	Operation and maintenance
PM	Preventive maintenance
SCC	Stress corrosion cracking
System 23	System for gas compression and injection
To	Time to degradation of surface coating
Timp	Technical integrity management portal
TR	Technical requirement

3 The PSA's investigation

3.1 Mandate and composition of the investigation team

The mandate is tailored to the circumstances and covers the following points.

a) Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes time lines and incidents).
b) Assess the actual and potential consequences:
   1) harm caused to people, material assets and the environment
   2) potential to harm people, material assets and the environment.
c) Assess direct and underlying causes (barriers which have failed to function).
d) Identify nonconformities and improvement points related to the regulations (and internal requirements).
e) Discuss and describe possible uncertainties/unclear points.
f) Discuss barriers which have functioned (in other words, those which have contributed to preventing a hazard from developing into an accident or reduced the consequences of an accident).
g) Assess the player's own investigation report.
h) Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.
i) Recommend – and normally contribute to – further follow-up.

The investigation team comprised:

- Morten A Langøy: discipline – structural integrity, investigation leader
- Bente Hallan: discipline – process integrity
- Thom Fosselie: discipline – HSE management

3.2 Procedure

The investigation was conducted through interviews and verifications on Troll C during 10-12 November, and in the relevant part of the land organisation, including reviews of the maintenance system, investigation reports and governing documents, on 22-23 November. Parts of this work were done as virtual meetings on 25-30 November. Questions were otherwise put to Equinor by e-mail and answered in the same way.

Attention in the investigation concentrated on technical and operational conditions as shown in figure 1. The full version is presented in appendix C.

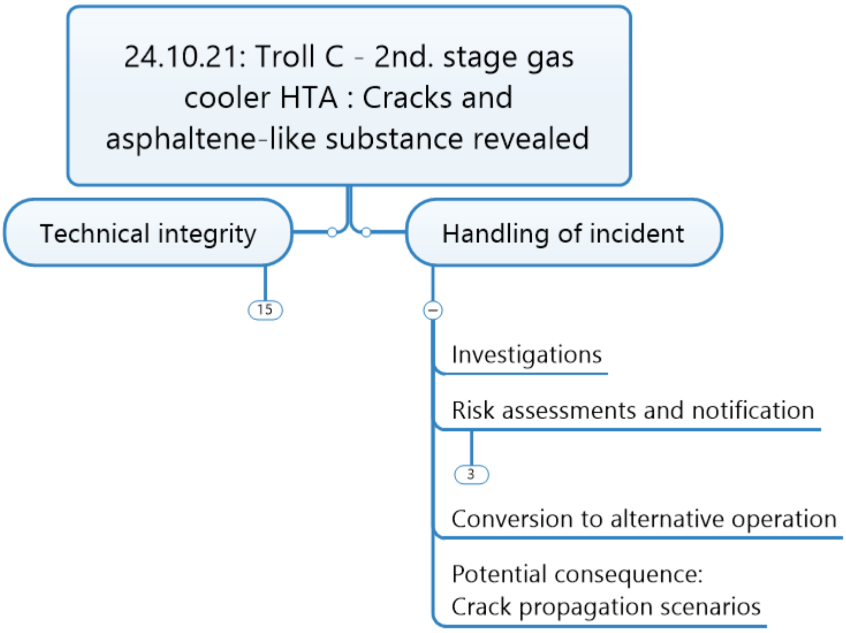

Figure 1: Main aspects covered by the investigation.

The investigation covers the period from the cooler's design and construction until the leak was discovered, as well as internal assessments by Equinor, conversion to alternative operation and a safety alert issued internally, to the authorities and to other relevant stakeholders.

Ztrong was engaged to review technical material requirements and general knowledge in the industry, and TWI to perform fracture mechanics calculations and sensitivity assessments of possible fracture scenarios for assessing the potential consequence of the incident.

4 Background information and system description

During an inspection round in the process facilities, a substance was discovered which later proved to be asphaltene. It had leaked from a second-stage gas cooler on

Equinor's Troll C facility. This investigation has set 24 October 2021 as the date of the actual incident, since that was when cracks in the second-stage gas compressor coolers were identified. These cracks developed over time, and dating the start of the process is difficult. The consequence was weakened integrity of the gas coolers, which contain hydrocarbon gas under a pressure of 60 bar, and this could have led to a major gas leak.

4.1 Description of facility and organisation

The Troll field lies in the northern North Sea, about 65 kilometres west of Kollsnes. Troll C is part of Troll phase II and is a steel semi-submersible quarters and production facility. Norsk Hydro was responsible for the Troll C development, which was approved by the Storting (parliament) in March 1997. Umoe had an EPC contract for the facility, with the topsides built at Umoe Haugesund and the support structure at Hyundai in South Korea.

Fram is also produced via Troll C. The oil is piped to Mongstad, while the gas travels via Troll A in a multiphase flow pipeline to Kollsnes where condensate is separated out and piped to Mongstad. Water depth in the area is about 340 metres.

Figure 2: The Troll C platform in the North Sea. (Photo: Øyvind Hagen/Equinor ASA)

Troll C became part of Equinor through the StatoilHydro merger i 2007. Troll has been part of the operations west entity since 2014, and its organisation is presented in figure 3 and 4.

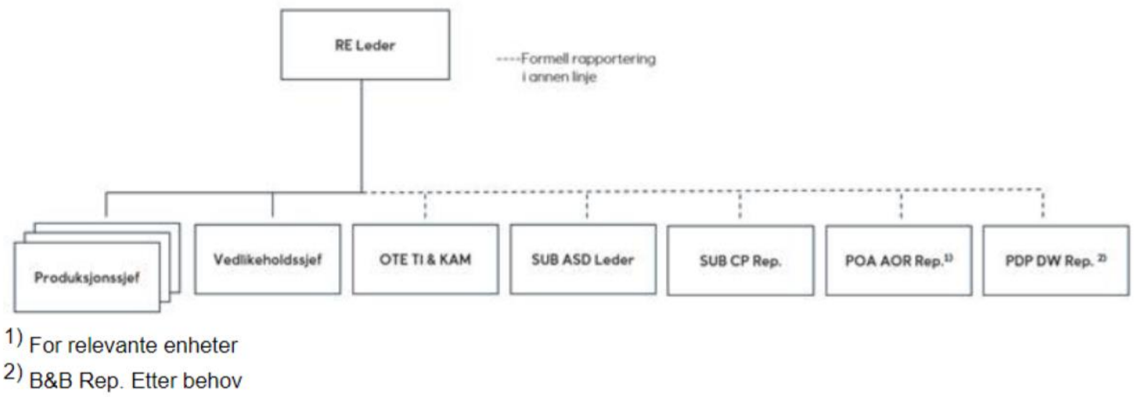

Figure 3: The production units in the Troll profit unit (EPN EPW TRO).

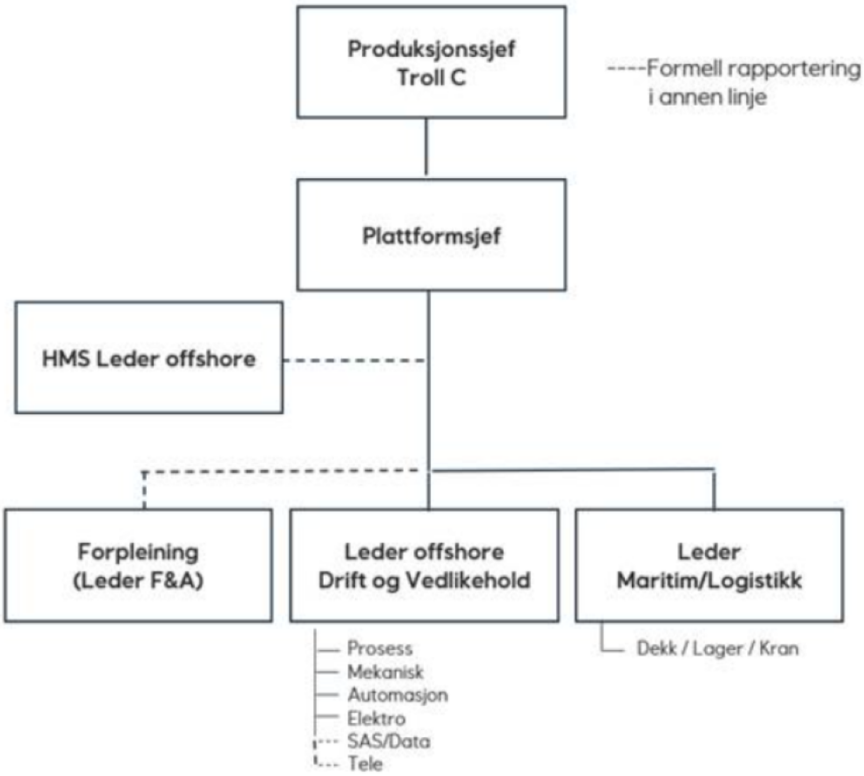

Figure 4: The production organisation on Troll C.

4.2 Description of the process equipment when the incident occurred

The wellstream from the various production wells is conducted to the inlet or test separators via the respective manifolds. The separation train separates gas, oil and produced water from the wellstream and stabilises the oil in accordance with the requirements for export to Mongstad.

After separation, the gas is dewatered to the export specification. The gas export compressor raises the gas pressure from the processing system to the level necessary for export before fiscal metering and onward transport by pipeline to Troll A. Processed gas is also used for injection in Fram and for gas lift.

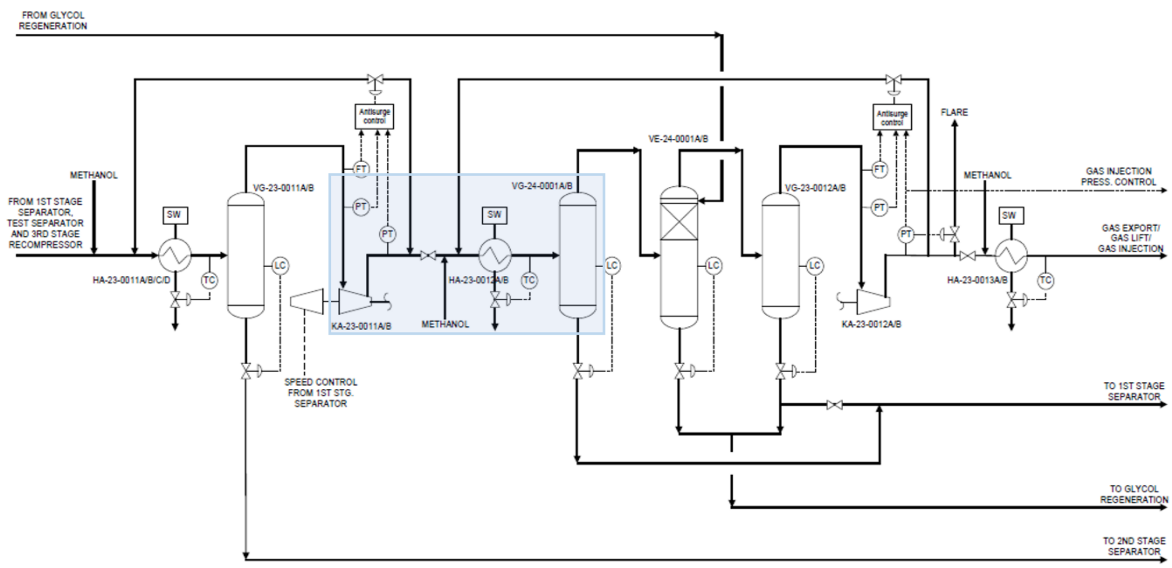

Figure 5 System for gas export compression, Troll C. Source: Equinor

The gas export compression system comprises a three-stage recompression train and three parallel two-stage export compression trains. In addition comes the gas injection train to Fram West. The system also includes equipment for gas dewatering.

Gas from the first-stage export compressors (KA-23-00011A/B) is routed to the second-stage export compressor coolers (HA-23-0012A/B). It enters these coolers with a pressure of about 60 barg and a temperature of roughly 148°C. The gas is cooled down to some 25°C before continuing via the gas dewatering system to the second-stage export compressors (KA-23-0012A/B).

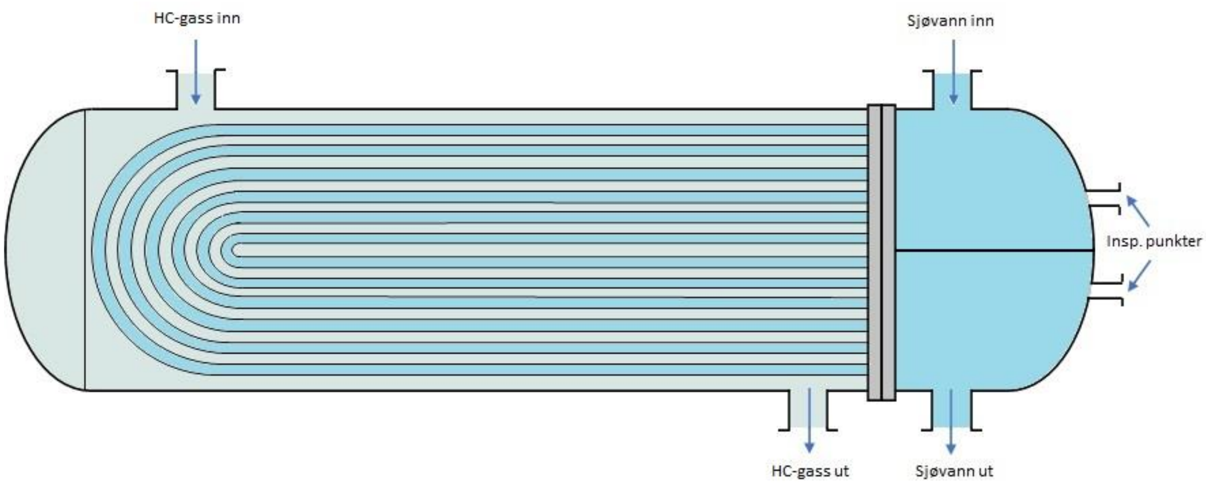

Figure 6 Simplified diagram of the gas coolers.
Key: HC gas in Seawater in Inspection points HC gas out Seawater out

These shell and tube coolers comprise an outer shell in 22%Cr duplex steel and an inner tubing bundle in titanium filled with coolant (seawater). The outer shell has a specified thickness of 36 millimetres. Towards the spherical shell at the end of the cooler, the wall thickness is specified as a minimum of 29 millimetres. The coolers are protected by fire insulation on tanks and flanges.

4.3 CUI and crack propagation caused by stress corrosion cracking (SCC)

4.3.1 Corrosion under insulation (CUI)

The gas coolers on Troll C are insulated to protect them and reduce the temperature in the event of a fire. Other grounds also exist for insulating in the process plant on a facility, as specified in Norsok M-004, for example. Generally speaking, an insulation system comprises the actual insulating material with external weather protection. The latter, or jacketing, is normally in metal. Within the insulation is the actual equipment which, on mature facilities, has an external surface protection coating. See figure 7.

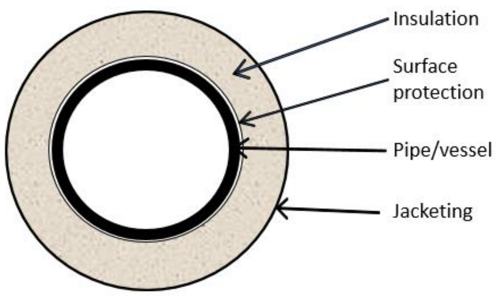

Figure 7: Schematic of the insulation system for the process equipment, illustrated here by a pipe. Not to scale.

CUI is generally associated with low-alloy steels, and involves faster corrosion with insulation than without it when exposed to same environment. The main reason for accelerated corrosion is water intrusion beneath the insulation. Modern systems make greater use other methods, such as surface treatment of piping, pipes in corrosion-resistant materials, hydrophobic (water-repellent) materials in the insulation and watertight external jackets, and in some cases with drainage. Pursuant to DNVGL-RP-G109 (DNVGL, 2019), two barriers to CUI are significant for discussion – coating (surface treatment) and protection against moisture (metal jacket, properties of the insulating material, exposure to water). Both must be taken into account in design, but perhaps even more importantly followed up during operation with the right maintenance, including inspection activities.

The PSA has previously investigated piping leaks related to CUI, including a steam leak in 2012 (PSA, 2013), a hydrogen leak in 2016 (PSA, 2017) and a naphtha leak in 2020 (PSA, 2020).

4.3.2 CUI and SCC

SCC is a generally accepted characterisation of sub-critical cracking of normally ductile materials under constant load in an environment with liquids and gas atmospheres (V S Raja, 2011). API RP 583 associates CUI in stainless materials, such as 22%Cr duplex, with external CSCC (ECSCC). This is relevant for the Troll C incident, since the cracking began externally and the environment there is affected by the insulation on the coolers. The presence of water and chlorine, a marine atmosphere and seawater from deluge, as well as the fact that insulation retains moisture, the metal jacket cannot be assumed to be completely watertight and the surface protection is not intact, mean that the probability of CUI/SCC is increased. As a rule, the stress corrosion cracks grow stably until they reach a size which may cause unstable/rapid crack propagation leading to a possible break. Alternatively, the cracks can grow stably through the outer shell and cause leakage, which may be discovered, before a break. This is known as leak-before-break considerations and is covered in a separate report (TWI, 2022).

Operating temperature often sets limits for using stainless steel materials in order to avoid CUI/SCC. API RP 583 puts the critical operating temperature for 22%Cr duplex at 140°C, while Norsok M-001 *Materials Selection* has a maximum limit of 100°C without surface protection. Operating conditions are described in more detail in section 4.2.

5 Course of events

This investigation sets 24 October 2021 as the date of the actual incident because cracks in the second-stage gas compressor coolers were detected then. These cracks developed over time, and dating the start of the process is difficult. In addition come underlying causes related to the way the coolers were designed and followed up in the operating phase. Times and developments in the course of events are described below.

5.1 Chronological sequence for development and handling of the incident

5.1.1 Technical integrity

2nd quarter 1995	Predesign/front-end engineering for the facility by Hydro
11 Apr 1996	Plan for development and operation (PDO) for Troll C submitted
1996	Design assumptions, process and technical safety
1996	Norsok M-501 1996 “General note - When coating stainless steel with operating temperature above 120°C, 30 my (NDFT) of high temperature modified silicone paint suitable for the operating temperatures shall be used”
3 Mar 1997	PDO for Troll C approved, Storting proposition 38 (1996-97)
1997	Material choices, surface protection and insulation solutions
1998	Fabrication at Officine Luigi Resta
1998	The coolers were fabricated to Norsok M-501. The silicon coating chosen

	for the Troll C coolers was Sølvalitt from Jotun Hydro specification called for 25 µm modified high-temperature silicon coating, compared with 30 µm in Norsok
1998-99	Installation and inspection at Umoe
1999	No PM activities, including inspection activities, for the coolers delivered by the project
4th quarter 1999	On stream
2004	Frame programme 43 "Inspection of cooler replaced by activity on equipment which is not in use" Report *Frame programme system 23 TRC*. This document considered the probability of stress corrosion to be minimal. No inspection necessary. Document not revised since 2004
2007	Statoil and Hydro become StatoilHydro Risk related to degrading of coolers not assessed in relation to the change of company Surface maintenance programme (Solve) excludes insulated surfaces
2009	Maintenance concept 43010: generic for tubular heat exchanges and not specifically for HTA/HTB coolers No specific maintenance or inspection strategy for HTA/HTB coolers
2009	24M FV-INP GVI System 23 (established 1 April 2009) General visual inspection without using access aids
2009	TR0042 *Surface preparation and protective coating*, version 2, recommends phenol epoxy up to 150°C for stainless steel
7 Jan 2009	Common operating model – work initiated for integrating a common management system
4th quarter 2009	Troll organised in operations North Sea East
2010	TR1987 Requirements for programme activity to maintain the integrity of static process equipment, pipeline systems and supporting structures: "Where static process equipment in 316 steel (coated) or more corrosion-resistant materials is concerned, no preventive activity is necessary with regard to CUI …" No guidance is given on preventive activity for insulated and coated duplex stainless steel. TR documents are superior to GL documents in Equinor's governing document hierarchy
2012	Rev 6 of Norsok M-501 in February 2012 replaced the system with 30 µm silicon paint for hot insulated surfaces with a thicker coating
2012-17	CUI programme with the emphasis on low alloy steel bolts in stainless steel lines in hydrocarbon systems
3rd quarter 2014	Troll organised in operations west Neither M5 nor M6 notifications registered in SAP against the relevant

	coolers in the period up to the incident
2017	Inspection of fire insulation on piping and vessels in system 23 to check that such insulation is in place where required. Solely an external check, with insulation only removed on an indication. Most recently conducted in 2016-17, interval changed from 24 to 48 months after 2016. The inspection does not assess conditions related to CUI, insulation opened only on suspicion of weakened fire resistance
2017	TR3102 *Material selection*, version 4.01. Added: "Included that insulation systems and pipe penetrations shall be described in inspection philosophy" No specific inspection philosophy established for Troll C which covers the HTA/HTB coolers Added to 4.01: "Added reference to OM (Aris) 104.702"
23-26 Nov 2019	Notification M2 – Black substance observed under HTA. Closed with the conclusion that it derives from the insulation material
2020	GL0560 *Prioritisation of maintenance for static process equipment subject to CUI*, version 2.0. Document updated with reference to table for deterioration of coatings from DNV RP-109 (2019). Chapter 5.1: "Where all corrosion-resistant piping is concerned with an operating temperature above the temperature limit for CSCC and where surface protection is used to deal with the risk of SCC, rehabilitation must be planned when the surface protection has deteriorated in relation to To, specified in section 4.1.2 (in GL05060)"
2020	96M FV-INP Revi system 23 (established 26 November 2020), Revi – new maintenance routine introduced at system level CSCC not specifically identified as an issue in the Revi maintenance routine for coolers
2021	Timp - CSCC not identified as a risk for coolers

5.1.2 Leak handling

Relevant activities and status before October 2021 are covered in the section above.

Date, time	Activity/condition
23 Oct 2021	
Abt 16.30	Inspection round in the process facilities after 16.30 to investigate the status of a valve job. When the OIM lay down to inspect, a black substance was observed on the grating under the second-stage HTA cooler – HA-23-0012A – located adjacent to the valve. A closer look found traces of a black substance on the underside of the jacket. The process operator was contacted to examine in more detail. Sniffing and measuring for gas gave no indications
Abt 17.00	Insulators remove insulation from end of tank, OM leader inspects – more insulation has to be removed
17.30	Evening meeting – the OM leader reports that a substance appears to have accumulated at the bottom of the jacket. More insulation must be removed to

	see whether it comes from the flange over the tank. Scaffolding must be erected during the evening to remove insulation from the flange. Operations department follows up during the night
19.00-23.00	Scaffolding erected for further inspection
24 Oct	
07.30	Insulation over the flange is removed
11.00-	Inspection activity continues without any sign of the substance on the outside of the insulation on the HTB cooler
16.00	Meeting OIM and OM leader. Visual inspection has identified indications of cracks in the tank. OIM decides to run HTA cooler down for further inspection
16.46	OIM notifies production manager of decision to run down and the need for a "blue-light" (emergency) meeting on Monday 25 October
17.00	HTA cooler run down. It must be cooled down before removing insulation
18.48/22.26	The production manager informs the production vice president that the HTA cooler is being run down to check the observation
20.09	Production manager notifies the operations manager land and the technical platform manager to be ready for a blue light process on Monday morning to support the facility with technical expertise/resources
22.26	The production manager updates the report to the production vice president with information that the HTA cooler will remain shut down and link to established Synergi case with more information
22.55	The production VP informs area VP for operations west
25 Oct	
07.30	Tank accessible for inspection and NDT
09.30	First blue-light meeting with land - Decides to inspect HTB cooler, HA-23-0012B, to see if it has the same damage, general visual inspection (GVI) - Remove all HTA cooler insulation for more inspection (takes all day)
14.00	Second blue-light meeting with specialists on inspection, material technology, static mechanics – possible CSCC, requires remedial welding
16.00	Risk workshop on M40 (Fram module) operation without HTA and HTB: CCR, operations, IOC, AI
17.00	Production VP and manager report to area VP operations west on the damage identified so far and initial views on the damage mechanism (CSCC)
20.00	Toolbox talk, check and review M40 operation alone: CCR, operations, IOC, AI
21.00	HTB cooler run down
26 Oct	
All day	Removal of all insulation from HTB cooler
All day	Inspection of HTA cooler under way
All day	Land: started study of possible repair methods: clamps, wrapping, welding, etc
10.15	Third blue-light meeting Possible CSCC makes it necessary to conduct close visual inspection of each cooler and possible penetrant testing around the whole cooler shell. Need to assess whether phased array ultrasonics could be quicker at giving a more detailed condition picture
Unknown	Synergi case 1746821 established – observed asphaltene-like material from

	insulation on HTA cooler. OIM wants to classify the incident, informs safety and sustainability officer (SSU) Troll
27 Oct	
08.00	Synergi 1746821: first classification meeting: OIM, HSE leader, chief safety delegate, OM leaders 1 and 2. Decides to call on assistance from land because of insufficient competence in the team
13.15	Fourth blue-light meeting HTA cooler: a new network of cracks found on rear of first support, one through-wall crack, while a black substance and wet insulation are observed. Clear signs of CSCC. Pitting and corrosion on 316 insulation spacer bands found. Inspection continuing. Other coolers and equipment identified with the same combination of material/temperature on recompressors, which must also be checked
28 Oct	
12.00	Land: review of preliminary findings with discipline leads in Equinor (static mechanics, materials, inspection), recommends no further operation with damaged cooler shell
13.15	Fifth blue-light meeting Sandblasting and penetrant testing conducted on HTA cooler. Status for the day shows complex crack network at welds on the end cap and by first support. HTB cooler has not revealed more visible cracks since previous report. HTB cooler has less extensive damage, further inspection and repair prioritised
29 Oct	
14.00	Sixth blue-light meeting New assessment by discipline lead static mechanics of opportunities for welding repairs on the HTB cooler because scope of damage is limited – acceptable pursuant to ASME PCC-2 (replace area with cracks). Continued inspection and repair is directed at HTB cooler Land: decided to establish a task force for further operational follow-up, inspection and repair. Established mandate and mobilised resources. Blue-light concluded when task force established on Friday evening
16.00 (abt)	OIM conversation with SSU leader operations west concerning classification in Synergi. Planned classification over the weekend
01 Nov	
08.15	OIM meeting with SSU leader operations west and SSU lead engineer on how to understand WR9592
17.00	PSA informed verbally through head of supervision T-1 (Equinor offshore) by head of operations west
13.15	AI sends alert to facilities to check for similar issues to those experienced on Troll C
02 Nov	
11.00	SSU leader called in for classification. Participants: adviser materials technology, lead engineer SSU, adviser safety, chief safety delegate, OM leaders 1 and 2, HSE leader – discussed and decided pursuant to WR9592 that this involves serious corrosion with a serious weakening of barrier PS1 containment. Discussion also on the potential for gas leaks. At this time, the assessment was that more than slightly altered circumstances were needed for

	a gas leak given the time aspect and the knowledge available about the corrosion at that point
12.55	Report form on the incident sent to the PSA
08 Nov	
07.30	Meeting on the subject of the gas leak potential. The conclusion was that the material must be inspected further before anything can be said about the consequences under slightly altered circumstances. In addition to participants at the 2 November meeting, attended by lead adviser materials technology and welding, adviser static mechanics, adviser materials technology inspection, and lead adviser and lead engineer technical management
10 Nov->	
	Equinor sends safety alert on the incident to Norwegian Oil and Gas

5.2 Handling the incident

The chronological sequence of activities associated with Equinor's own investigations, risk assessments (with establishment of Synergi case) and internal notification and externally is largely provided in the section above. Some of these activities will be reviewed in more detail here.

5.2.1 Inspections, NDT, technical material and chemical investigations

Possible leak sites on Troll C were inspected visually and cracking was later identified by penetrant testing on the outside of the cooler shell after the surface had been cleaned – first on the HTA cooler, where the leak was initially discovered, see figures 8 and 9, and then on the HTB cooler where the cracking was not as extensive.

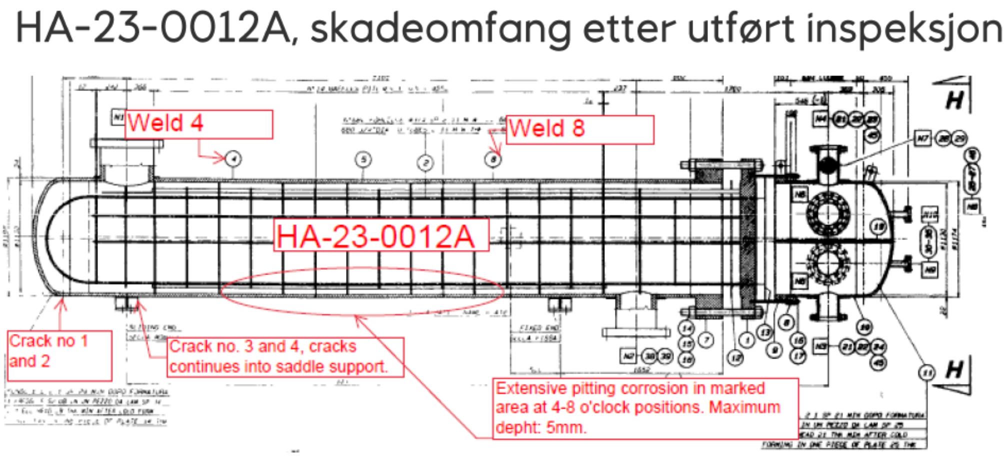

Figure 8: Areas with crack indications and corrosion. (Equinor)

Figure 9: Visual images of crack 1 (left) and penetrant indications of cracks 3 and 4 (right). (Photos: Equinor)

A disc 18 centimetres in diameter in full wall thickness was cut from the HTB cooler at the point where cracks were identified and subjected to technical investigations in Equinor's materials lab at Rotvoll. The microstructure (with ferrite dark and austenite light) and crack morphology are shown in the figure below.

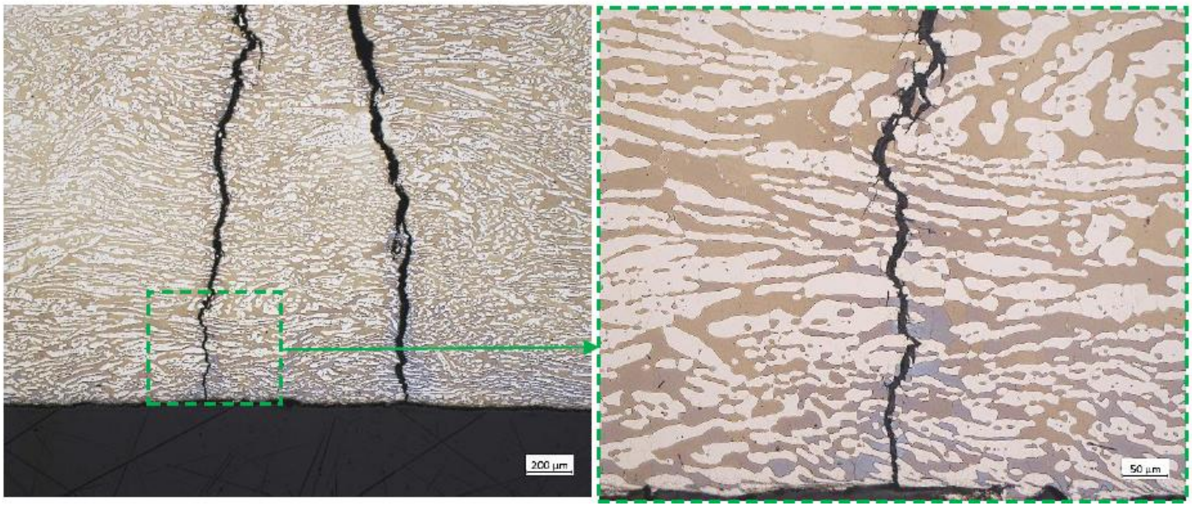

Figure 10: The sample is taken in parallel with a weld, and the crack in the relevant cross-section therefore runs first through weld metal and then base material towards the inner surface. (Photos: Equinor)

It was concluded that the cracks were through-wall and caused by CSCC, which had begun externally. The material had a normal duplex microstructure in both weld and base material. No damaging intermetallic phases or welding faults were identified. The chemical composition, hardness and impact resistance accorded with Norsok M-630, data sheet D45.

The analyses for the HTB cooler also apply to the HTA cooler for crack mechanism and the cracks being through wall, and from NDT over a wider area.

Equinor has commissioned an analysis and composition comparisons of the black substance found on the deck and in cracks on both coolers, and of a similar substance collected from inside the HTB cooler. The analyses of samples from outside the HTA and inside the HTB coolers establish that they are not identical, but that their organic composition shows great similarities. Seven per cent asphaltenes were identified in the HTA samples, but no asphaltenes were present in the HTB case. The inorganic components in the two samples were very different. In the PSA team's view, the analysis results point towards the black substance observed under the HTA cooler originating inside it, and strengthens the assumption that the cracks on this cooler are also through wall.

5.2.2 Synergi and risk assessment

The incident was reported as Synergi case 1746821 – observed asphaltene-like material from insulation on HTA cooler. The OIM wanted to classify the incident, but decided later to obtain assistance from land because the team lacked expertise. From 26 October to 8 November, a number of technical specialists were involved in classification, including the author of WR9592 – register safety and security incidents. Figure 11 presents the classification at 8 November, which concentrated on the potential for gas leaks and concluded that more analyses were needed.

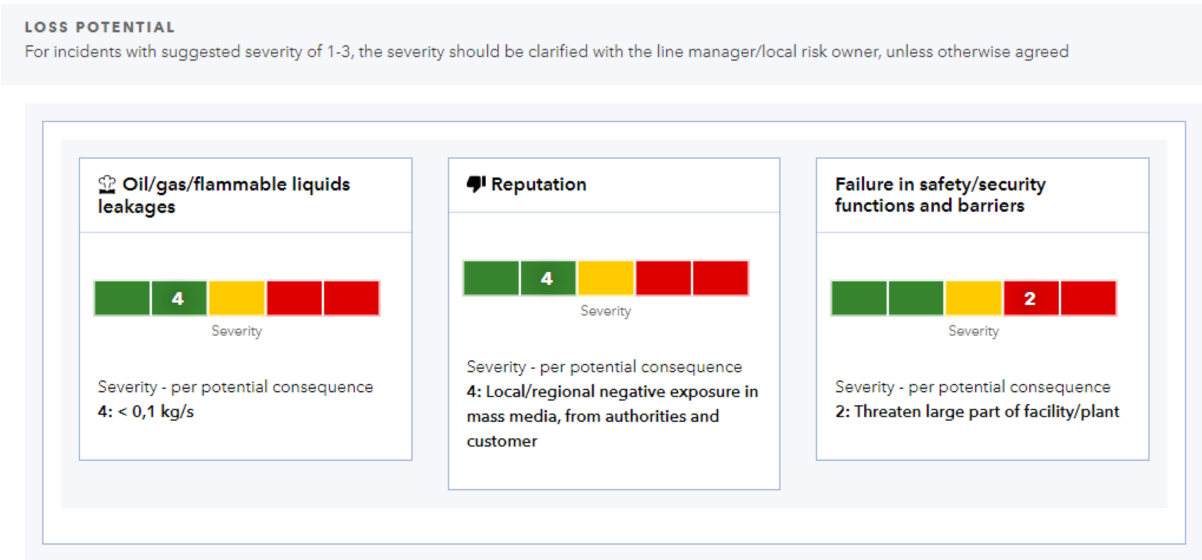

Figure 11: Classification of the incident according to Synergi case 1746821 at 8 November 2021.

At this point, both gas coolers were shut down. Interviewees have reported that the classification of "failure in safety/security functions and barriers" has been Red 2 since 2 November. This calls for a level-2 COA ACC investigation pursuant to the requirements in the supplement to WR9592 – register safety and security incidents (EPN). The task force considered seeking an exemption from this. At a meeting between the PSA and Equinor on 5 November, the PSA inquired whether Equinor intended to investigate, and if so at what level. The PSA reported that it had not yet decided whether to conduct an investigation. Equinor resolved on 8 November to initiate its own investigation at COA level 2.

Category Severity level	Injury		Work related illness (WRI)		Uncontrolled discharge/emissions		Oil/gas/flammable liquids leakages		Fire/explosion		Failure in safety/security functions and barriers	Reputation	
	Actual	Potential	Actual	Potential	Actual	Potential	Actual	Potential	Actual	Potential	Potential	Actual	Potential
1	Fatality		Work related illness that result in death		Single spill with long term effect on the environment, or Discharge/emissions of component > yearly expectancies		>10 kg/sec. or brief leakages >100 kg		Whole facility/plant exposed		Threaten whole facility/plant	Great international negative exposure in mass media and among organisations	
2	Serious lost time injury/serious injury		Serious work-related illness		Single spill with medium term effect on the environment, or Discharge/emissions of component > monthly expectancies		1-10 kg/sec. or brief leakages >10 kg		Large part of facility/plant exposed		Threaten large part of facility/plant	Medium international negative exposure in mass media and among organisations	
3	Other lost time injury or Injury involving substitute work		Work related illness that results in short-term absence or restricted/ alternative work		Single spill with short term effect on the environment, or Discharge/emissions of component > weekly expectancies		0,1-1 kg/sec. or brief leakages >1 kg		Parts of facility/plant exposed		Threaten parts of facility/plant	National negative exposure in mass media, from authorities on national level	
4	Medical treatment injury		Work related illness that results in treatment from authorised health care personnel		Single spill with minor effect on the environment, or Discharge/emissions of component < weekly expectancies		< 0,1 kg/s		Local area of facility/plant exposed		Threaten local area	Local/regional negative exposure in mass media, from authorities and customers	
5	First aid injury		Other work-related illnesses		Single spill or discharge/ emission with negligible effect on the environment		<<0,1 kg/sec. (significantly less than 0,1 kg/sec.)		Negligible risk for facility/plant		Negligible risk for facility/plant	Limited to a few persons or a single customer	

Figure 12: WR9592 – table 1 matrix for categorising and classifying the seriousness of incidents.

5.2.3 Notifying the PSA and other stakeholders

Section 29, paragraph 1, litera d) of the management regulations on immediate notification of the PSA in the event of hazard and accident situations which have, or under slightly altered circumstances could have led to serious impairment or discontinuance of safety-related functions or barriers, so that the integrity of the offshore or onshore facility is threatened. In the event of incidents of a less serious or acute nature, the operator must submit written notification to the PSA on the first working day after the incident took place or was discovered. See section 29, final paragraph.

Where incidents have consequences for oil or gas production, the PSA notifies the Norwegian Petroleum Directorate.

In governing document WR2563 on notifying and reporting hazards and accidents to the Norwegian authorities (EPN), Equinor has specified that incidents classified as Red 2 – failure in safety/security functions and barriers – must be notified immediately. The PSA was not notified for more than a week after the incident/position was identified. The investigation has found that the weakening in integrity and the degree of seriousness were known at an early stage. When earlier versions of documentation concerning the knowledge basis and developments in assessing seriousness were requested, the response was: “Differing (historical) versions of Synergi 1746821 – the conclusion is that extracting historical versions of the Synergi case is not possible. A log is available which shows when it was amended, but we are unable to print out how it looked at that time”.

The conclusion is that those involved were aware of the seriousness for a time before the PSA was informed. At the classification meeting on 8 November, Equinor decided to conduct an internal investigation.

Facilities with similar solutions
AI took the initiative on alerting other Equinor facilities about the incident involving equipment in 22%Cr duplex steel. A response was also requested, with a deadline, on the overview of relevant equipment. Possible follow-up of this falls outside the mandate of this investigation.

Equinor has prepared a safety alert based on the incident and submitted it to Norwegian Oil and Gas in order to inform the industry of the hazard. See appendix E.

6 Potential of the incident

Actual consequence
No harm to people or the environment from this incident has been identified.

Estimate of costs by Equinor at 18 March 2022.
Material damage (repair costs): about NOK 24 000 000.
Lost production: An overall loss corresponding to 25 days of lost oil production has been estimated. Production from Troll C was not shut down completely, but it operated with reduced output over a lengthy period.
Lost gas production from Troll C was compensated for by Troll A and will probably not be included in the classification of lost production.

Potential consequences
The PSA team's assessment is that, under slightly altered circumstances, the incident could have developed into a major gas leak owing to a brittle fracture in the outer shell of one of the gas coolers.

7 Direct and underlying causes

The incident resulted from a condition which had developed over time. In the following, the PSA team will concentrate on the technical and operational aspects. It has transpired that information available on degrading mechanisms was not taken into account in design and operation. This is dealt with in the Ztrong report (2022).

7.1 Materials choice and technical specifications

When the PDO was approved in 1997, the regulations on process and support facilities in the petroleum industry were in force. No nonconformity in material choices related to these have been identified. The PSA team has assessed materials choices, surface protection and the insulation system against recognised standards, such as Norsok, and established knowledge in the industry.

The choice of material for the cooler tank shell, exposed to hydrocarbons on the inside and the maritime environment on the outside, was based on operating conditions from the *System Engineering Manual* (17-1B-UH-C85-23000), as shown in table 1. Based on the *Material selection report* (ENG17-1B-UH-R15-0000207000_1A0479588), the cooler shell was built in 22%Cr duplex steel with a 25 µm silicon coating. Even with the requirement for insulation, this choice accorded with Norsok M-501 *Surface preparation and protective coating*.

Table 1: Key equipment information from table 5.2.1 in the System Engineering Manual.

Tag no	Description	Flow rate duty size	Design T (°C) Design P (barg)	Top (°C) Pop (barg)	Area El (m)	Case	PO order
HA-23-0012A/B	2nd stage export compressor cooler	12 008 kW	shell = -46 and 195 tube = -10 and 195 shell = 86 barg tube = 19 barg	shell = 148 and 30 tube = 12 and 30 shell = 49-65 barg tube = 7.5-8.5 barg	C15C 559	2AA	21 201

In December 1991, operator BP found that a separator on Gyda had been destroyed by SCC. As a result, the company decided that all insulated duplex surfaces under pressure were to be coated, regardless of operating temperature. Other operators also took action and prescribed thermally sprayed aluminium (TSA) for 22%Cr duplex (and other stainless steels) under insulation.

The system with 30 µm[1] high-temperature silicon coating for hot insulated surfaces was not removed from Norsok M-501 until revision 6 of the standard in 2012, and epoxy phenolic coatings could be used up to 150°C (Ztrong, 2022).

Where Troll C is concerned, version 2 of TR0042 *Surface preparation and protective coating* was in force from 31 July 2009 This lists supplementary requirements for M-501: "Coating system no 6 shall be applied on all insulated stainless steel piping and vessels regardless of the location. Coating system no 6 shall in addition be applied on all uninsulated stainless steel piping and vessels located in outdoor marine environments. For stainless steel piping and vessels, 2x125 µm epoxy phenolic can be used at operating temperatures up to 150°C".

[1] The requirement was 30 µm, but Hydro opted for 25 µm as the minimum coating thickness.

Equinor has no systematic process for identifying the gap between knowledge and guidance in applicable governing documents and established practice for maintenance of the relevant coolers.

7.2 Material degradation and technical specifications

As noted above, CUI/SCC for 22%Cr duplex steel is to be countered with a protective surface coating. Depending on system and operating conditions, its effective life can range from zero to 30 years (Ztrong, 2022, DNV GL-RP-G109). To safeguard integrity, the condition of the surface treatment must be inspected as part of maintenance.

Equinor documents TR0007 *Functional specification for surface maintenance* and TR1660 *Piping and equipment insulation* specify that a plan must be produced for maintaining coating and insulation (Ztrong, 2022). This has not been done for the coolers concerned. The investigation was informed that the background on Troll C is that using TR1987 *Preventive activities for static process equipment and supporting structures* does not give support for risk assessment of CSCC with equipment in 22%Cr duplex. It permits the use of 22%Cr duplex beyond the limits established in TR3102 *Material selection for development and modification projects* and Norsok M-001, regardless of the preconditions in GL0560 *Prioritising maintenance for static process equipment exposed to CUI*, which from 2021 also specifies that insulated 22%Cr duplex must always be coated. This is a new internal requirement, but Equinor has not presented any gap analysis.

7.3 PM and inspection activities

Generally speaking, little attention has been paid to the HTA and HTB gas coolers by Equinor's organisation on land or offshore during the operating period. Several interviewees said that the coolers have been "off the radar", and the risk of CUI and CSCC has not been actively assessed by the company.

Equinor has adopted a generic maintenance concept for the HTA/HTB coolers which does not specify process-medium leaks from the cooler shell as a critical fault, and no maintenance has been carried out with a view to preventing or identifying CUI.

The PSA's investigation has shown that Equinor failed to maintain or inspect the actual tank shell of the coolers during the operational period from 1999 until the incident occurred in 2021. It did not maintain or inspect the surface coating on the cooler tank shells. No maintenance nor inspection was conducted on the jacket around the actual cooler shell with an eye to possible moisture intrusion in the insulation and the threat of chloride accumulation on the cooler shell.

On the basis of its own experience, Equinor has installed insulation around gas inlet flanges on both coolers with an eye to bolt corrosion – but without reporting the condition of the actual cooler shell. The company conducted a general visual inspection (GVI) of the whole system 23 without using access aids.

8 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.

8.1 Nonconformity: Lack of risk reduction related to material degradation

Technical or operational solutions were not chosen to reduce the probability of damage, faults, hazards or accidents related to material degradation of stainless steels in the HTA and HTB coolers.

Grounds
The investigation has shown that technical and operational solutions were not chosen to address and reduce risk related to material degradation in the form of CUI and CSCC for the relevant coolers on Troll C.

Equinor has not assessed uncertainty related to degradation of the material in the tank shell, the effect of the surface coating's condition, and access for moisture containing chlorides. These were known issues, discussed in the industry at the time when both design work and material choice were carried out. Nor was the problem addressed in the operational phase.

Requirement
Section 4, paragraph 1 of the management regulations on risk reduction

8.2 Nonconformity: Maintenance deficiencies

The company's maintenance programme did not prevent CSCC under insulation in the HTA and HTB coolers on Troll C, and did not ensure that it was identified and corrected. The HTA and HTB coolers were not maintained so that they were capable of performing their required function in all phases of their working life.

Grounds
Equinor has not had a systematic process for establishing a maintenance regime which could prevent and identify CSCC on the relevant Troll C coolers.

The investigation has shown that maintenance related to preventing or identifying material degradation was not performed for the relevant coolers on Troll C.

Among other considerations, Equinor could not demonstrate that it had established:

- maintenance to ensure that chloride-containing water did not penetrate the jacket
- inspection to check the possible presence of moisture on the tank shells
- inspection to identify damage to or degradation of the surface coating
- maintenance of the surface coating on the tank shells to ensure it was intact
- a maintenance programme tailored to the Troll C coolers
- a risk-based inspection (RBI) analysis of the coolers was conducted with an eye to external degradation under the insulation and the need for inspection
- a maintenance strategy for the surface coating.

Requirement
Section 47 of the activities regulations on maintenance programme, see section 45 on maintenance

8.3 Nonconformity: Deficiencies in consequence classification

The consequence classification does not describe the threat of external leaks of process medium from the coolers.

Grounds
The generic maintenance concept and information in SAP specifies internal leakage as “unsafe failure”, but not external leakage of the process medium.

Criticality assessments of the main and subsidiary functions of the coolers do not describe the effect on the system or the facility.

The consequence classification specifies “low consequence” for HSE and the threat of fire in the classified area. Nor is a potential specified for big environmental discharges/emissions.

No clear description is given in the consequence classification of the consequence of corrosion, in this case CSCC, and the failure mode “external leakage” of process medium.

Requirement
Section 46 of the activities regulations on classification

8.4 Nonconformity: Failure to use information

Equinor has failed to ensure that the necessary information about the threat of CSCC and the need for maintenance was processed and communicated to personnel responsible for following up the HTA and HTB coolers.

Grounds

The investigation has found that the company possessed knowledge and information which was not applied in following up the risk of CSCC for the relevant coolers on Troll C. Knowledge of surface-coating durability and maintenance requirements was incorporated in version 2.0 of the company's GL0560 but not applied. Equinor has known about the overriding threat of moisture intrusion in the insulation system and thereby the possibility of a combination of moisture and chlorides on the steel surface. Version 8 of governing document TR0042 requires coating system 2A for insulated equipment in duplex with operating temperatures above 100°C.

Information about the threat of CSCC as a result of coating degradation, moisture intrusion in insulation, and chlorides on metal surfaces with a temperature above 100°C has not been utilised in the company.

Equinor has lacked a systematic process for identifying the gap between knowledge and guidance in applicable government documents and established maintenance practice for the relevant coolers.

Requirement
Section 15, paragraph 2 of the management regulations on information

8.5 Nonconformity: Deficiencies in governing documents

Efforts have not been made to ensure that Equinor governing document TR1987 on preventive activities for static process equipment and supporting structures is formulated and used in a way which fulfils its intended functions.

Grounds
Governing document TR1987 on preventive activities for static process equipment and supporting structures does not provide support for assessing the risk of CSCC for equipment in 22%Cr duplex steel.

The applicable version of the document, TR1987 section 3.4.15, states: "Where static process equipment in 316 steel (coated) or more corrosion-resistant materials is concerned, no preventive activity is necessary with regard to CUI ...". This does not accord with knowledge in the area relating to 22%Cr duplex steel under insulation in maritime environments.

Requirement
Section 24, paragraph 2 of the activities regulations on procedures

8.6 Nonconformity: Late notification

The PSA was not notified immediately.

Grounds

More than a week passed between identifying indications of through-wall cracks in second-stage gas compressor coolers and notifying the PSA of the incident by phone. A written notification was received the following day.

The investigation has found that the reduction in integrity and its seriousness were known at an early stage, and for some time before the PSA was notified.

Requirement
Section 29, paragraph 1, litera d of the management regulations on notification and reporting of hazard and accident situations to the supervisory authorities

9 Improvement points

9.1 Improvement point: Maintenance programme

The Revi and Moni maintenance programmes do not appear to address the risk of CSCC under insulation to an adequate extent.

Grounds
Equinor introduced Revi in 2019 in order to check preconditions and underlying information for risk assessments and inspections. It was explained in the investigation that this routine is primarily used for internal degradation. The 96M FV-INSP Revi system 23 routine for PM includes the HTA and HTB gas coolers but, as formulated today, does not identify the risk of CUI on the surface of the cooler shells. The Revi routine refers to an RBI analysis which the company does not have for the relevant coolers.

The company is introducing Moni in 2022 to identify parameters relevant for follow-up. It was explained in the investigation that this routine will primarily be used for internal degradation. The 12M FV-INSP Moni SYS 23 routine for PM includes the HTA and HTB gas coolers but, as formulated today, would not be able to identify the risk of such degradation mechanisms as CUI on the surface of the cooler shells.

Nor would the Revi and Moni maintenance programme, as presented today, be unable to address risk related to external pitting on the gas cooler cells.

Requirement
Section 47 of the activities regulations on maintenance programme

9.2 Improvement point: Documentation of passive fire protection

Passive fire protection on the HTA and HTB coolers with associated flanges and valves does not appear to provide sufficient fire resistance.

Grounds
Where passive fire protection is used, it must be designed to provide sufficient fire resistance for relevant structures and equipment.

The company has been unable to specify with certainty what type of fire insulation has actually been used on the coolers and the associated flanges and valves.

Documents 17-1B-UH-F02-00005 *Passive fire protection philosophy* and 17-1B-UH-R52-00010 *Specification for insulation of equipment and piping* both specify that Firemaster 607 is to be used on the HTA and HTB coolers and equipment connected to them (such as inlet and outlet flanges). According to the data sheet provided, this material is suitable for use under high operating temperatures and is reported to begin transforming to a crystalline phase on exposure to temperatures above 900°C over long periods.

During inspection in the process facilities, however, it was observed that fire insulation in demounted insulation boxes for valves/ flanges connected to the HTA cooler appeared to be crystallised/degraded.

Furthermore, a notification (M2 45473729) dated 18 November 2018 on damaged fire insulation as a result of exposure to high temperature was found during verification in SAP. The notification expressed uncertainty over whether the insulation used was foam rubber or Pitt-Char, with the comment that neither of these can be used above 80ºC. The PSA team has been provided with the specification for Energy FireBoard – Pitt-Char XP, which specifies an application range from -30ºC to 80ºC.

Requirement
Section 82, sub-section 2 of the facilities regulations, see section 19, paragraph 1 of the regulations on explosion and fire protection of facilities in the petroleum sector (adopted by the Norwegian Petroleum Directorate on 7 February 1992) on general requirements for passive fire protection.

10 Discussion of uncertainties

Interviews and document reviews have provided an unambiguous picture of the course of events. Technical material investigations are based on samples from the HTB cooler, while NDT shows that cracking is greater in the HTA coolers.

To assess the potential consequences, TWI (2022) conducted an LBB analysis in order to evaluate the sensitivity (uncertainty) related to possible breaks in the outer shell of one of the gas coolers, which would have caused a major gas leak. Based on recognised standards and methods, this analysis shows that the outer shell could behave in a ductile manner and have through-wall cracks without breaking. At the same time, many variables could have resulted in a break under slightly altered circumstances. In this context, the PSA team would emphasise the asphaltene which seems to have sealed the crack and prevented a gas leak detectable by the fixed detectors. In addition comes a lack of planned inspection. Where this incident is concerned, a chance observation in connection with the follow-up of nearby equipment led to investigations which identified the cracks in the outer shell of the HTA cooler. The asphaltene and the lack of inspection could have caused the SCC to propagate unobserved until reaching a critical size which would have caused a break.

11 Assessment of the player's own investigation report

The PSA's investigation report has been completed before the player's report is available, and this has therefore not been assessed here.

12 References

The following documents have been drawn on it the investigation.

- GL0604 Potensiell alvorlighetsgrad for HMS-hendelser unde.pdf
- Notat - Økt kapasitet ved drift av M40 alene.pdf
- Piping insulation procedure for Troll C project 8cd1a21a-.pdf
- Mail kommentar passiv brann beskyttelse.pdf
- Anleggsvurdering Troll C JUNI 2021 Utdrag for informasjon til Ptil.pdf
- TDS Solvalitt_2000.pdf
- Liste over korrigerende arbeidsordre i SAP på 1 trinn_2.pdf
- 17-1B-UH-X56-18003_03L_fire and gas layout coolers.PDF
- 17-1B-UH-X56-18011_fire_gas_layout coolers.PDF
- 17-1B-HM-C72-23201_01L_2_process_flow_m40.PDF
- RISIKOVURDERING_AV_SEGMENTER_MED_MANGLENDE_ BRANNINTERGITET.PDF
- Isolajsons spec firemaster_434878303707d2_article_ 1495614797689_en_msdss.pdf
- 17-1B-AOP-C15-00048 Troll C Depressurisation and Time to Rupture Calculations.PDF
- Vedlegg 1 Synergi 1746821.pdf
- Vedlegg 2 Synergi 1746821.pdf
- Vedlegg 3 Synergi 1746821.pdf
- System Engineering Manual 17-1B-UH-C85-23000.PDF
- Timp juni 2021_.pdf
- WR9592 - Registrer sikkerhets og sikringshendelser.pdf
- Isolasjons strategi Troll C 17-1B-EQ-X02-00001.PDF
- Surface Protection Specification 17-1B-UH-R52-00009__06L_1.pdf
- Inspeksjonsrapport fra M2 45473729 skadet brannisolasjon.pdf
- PS 1 innspill fra FAK Timp juni 2021_.pdf
- TR0042 Surface preparation and protective coating filename_1001674348.pdf

- Inspeksjonsrapport fra Axess HA-23-0012B.pdf
- Analyseresultater_bek_ RITM2303101.pdf
- 17-1B-HM-C72-23201_01L_4_process_flow M40_sheet2.PDF
- Materiale i 1 & 2 trinn kjøler (1).pdf
- Detaljert inspeksjonsplan for system 23 20255-2007-101-01-Sys23 rev1.pdf
- Material selection report ENG17-1B-UH-R15-0000207000_1A0479588.pdf
- 17-1B-UH-C72-23002 Process flow HTA compressor.pdf
- Utdrag fra brannisolasjon spec, (1).pdf
- OM101.05.04 - Håndtere driftsavvik – Upstream offshore.pdf
- TR1987 Forebyggende aktiviteter for statisk prosessutstyr .pdf
- TDS Solvalitt_MIdtherm_2005.pdf
- Voided Flare Report 17-1B-UH-C15-00002-05V.pdf
- Inspeksjonsrapport fra Axess HA-23-0012A.pdf
- 17-1B-UH-C72-23003 Process flow HTBcompressor.PDF
- Vedlikeholdskonsept varmevekslere SAP.pdf
- Tillegg til WR9592 Registrer sikkerhets og sikringshendelser (EPN).pdf
- 17-1B-UH-X56-18004_fire_gas_layout_coolers.PDF
- M2 45961491 fra 2019 - funn av bek på A kjøler (1).pdf
- Rammeprogram system 23 TRC.pdf
- Utdrag fra Surface Protection Spec 1 (1).pdf
- Driftsparameter.xlsx
- Materiale gass eksport kjøler (1).pdf
- Specification for insulation of equipment and piping. 2070.pdf
- Anleggsvurdering Troll C JUNI 2021 Utdrag for informasjon til Ptil_.pdf
- Timp inspeksjon (1).pdf
- 1746821 • Observerte asfalten lignende matriale ut av is.pdf
- M2 45473729 skadet brannisolasjon (1).pdf
- TR1660 Piping and equipment insulation filename_1001693001.pdf
- Inspeksjonsprogram fra SAP.pdf
- 17-1B-UH-C72-00001_process_flow_overwiev.pdf
- 17-1B-UH-X56-18012_fire_gas_layout_coolers.PDF
- Passive fire protection philosophy 17-1B-UH-F02-00005.pdf
- TR3102 Material selection for development and modification.pdf
- TR0007 Requirements for coating maintenance filename_1146314.pdf
- GL0560 Norsk Prioritering av vedlikehold for statisk prosessutstyr utsatt for korrosjon under isolasjon
- Troll C – Tidslinje HTA HTB hendelse
- Epost fra Equinor, Utestående per 8.12.21, datert 10.12.2021
- Epost fra Equinor, Gransking Troll C - Hendelse 24.10.2021 - anslag på materielle skader med angivelse av kostnad, tapt produksjon, datert 18.3.2022
- Troll C - Kamfer consequence analysis information - Delfunksjonfunksjon kritikalitetsvurdering – Funksjonslokasjon

- Troll C - Kamfer consequence analysis information - Hovedfunksjon kritikalitetsvurdering
- Troll C – Klassifikasjonskriterier
- Troll C - Vedlikeholdskonsept - 1776-HA-23-0012B - Konsept 43010 - Varmeveksler rør

Other references

- API Recommended Practice 583, Corrosion Under Insulation and Fireproofing, Second Edition, March 2021
- DNV GL-RP-G109 «Risk based management of corrosion under insulation"
- Norsok M-001 "Material selection"
- Norsok M-501 "Surface preparation and protective coating"
- Norsok M-630 "Material data sheets and element data sheets for piping», D45
- PSA (2013). Investigation report on a steam leak at Mongstad on 8 November 2012
- PSA. (2017). Investigation report, gas leak at Statoil Mongstad on 25 October 2016
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- TWI, Assessment of Cracking of a 22% Cr Duplex Stainless Heat Exchanger, Report No: 34746/1v2/22, March 2022
- V S Raja, T. S. (2011). Stress Corrosion Cracking: Theory and Practice. Cambridge: Woodhead Publishing Ltd.

13 Appendices

A. Overview of personnel interviewed

B. Notification form received by the PSA from Equinor

C. Schematic overview (MindManager) of the course of events

D. Table 1 matrix for categorising and classifying the seriousness of incidents from the WR9592 register of safety and security incidents

E. Safety alert from Norwegian Oil and Gas

13.1 Appendix A

Available separately.

13.2 Appendix B

Petroleum Safety Authority Norway

Notification and report of hazard and accident situations

Submitted:	2021-11-02 12:55:58
Time of incident:	2021-10-24 17:41:00
Incident type:	Report
Operator:	EQUINOR ENERGY AS
Field:	Troll
Facility type:	FIXED
Facility/land plant:	TROLL C

Description incident/near miss

Drops of “pitch” were discovered on 24 October from the second-stage gas compressor cooler on the A train. The cooler had its insulation removed and visual inspection found cracks in the steel. It was then decided to run down the compressor and gain an overview of the seriousness of the cracks. There was no indication or measurement of gas by the cracks. On 25 October, the cooler on the B train was considered to have the same operating conditions, it was then also decided to run down, remove the insulation and inspect the cooler on B. After extensive inspection, chloride stress corrosion is suspected. Work is underway to repair and replace the coolers. The Fram compressor train is still in operation.

DSHA

DSHA22D Other incidents-OTHER

Other information

Response organisation activated:	No
Personnel mustered:	No
Production/operation shutdown:	No
Drilling operation halted:	No
Area cordoned off and evidence secured:	No

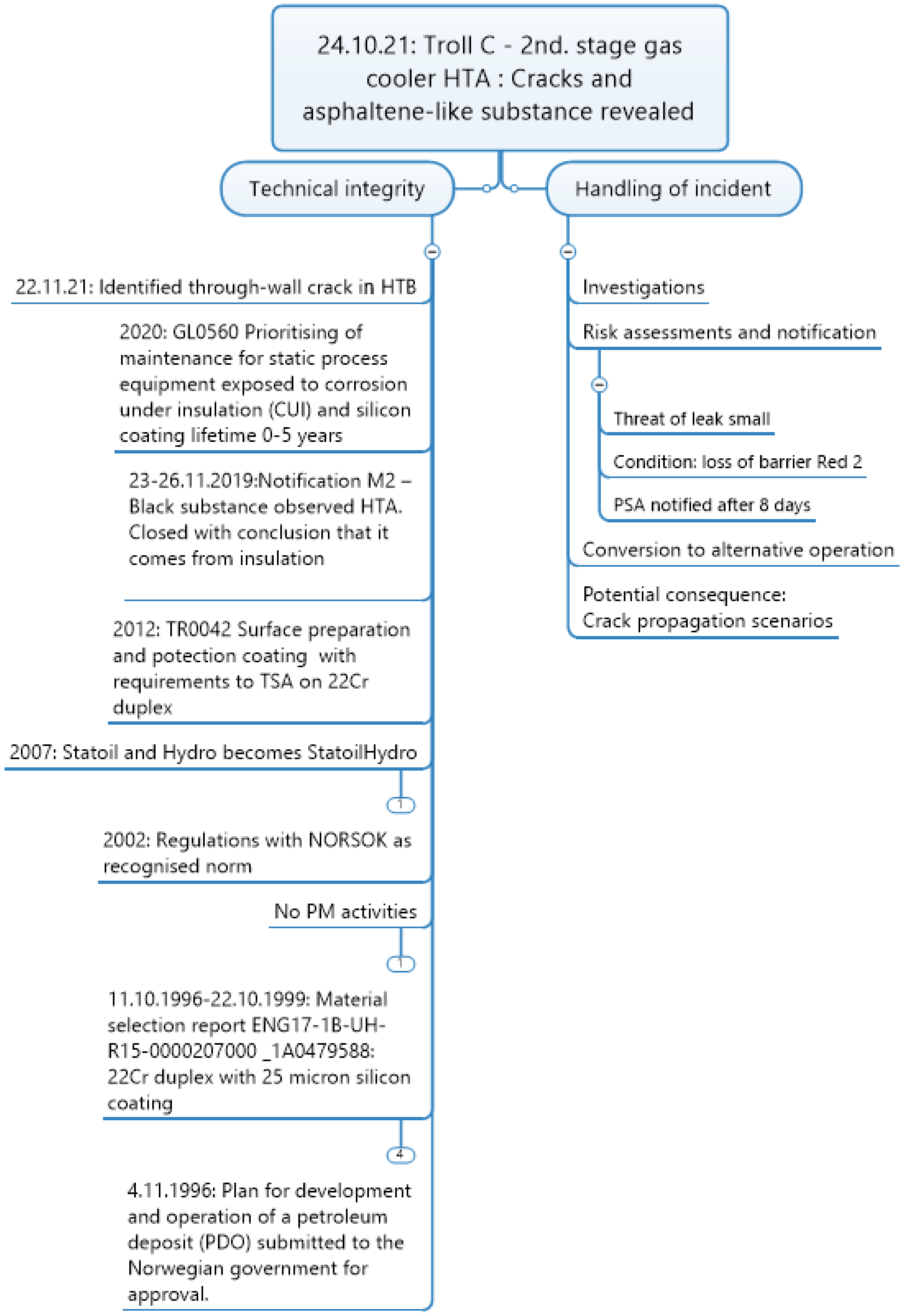
Others informed

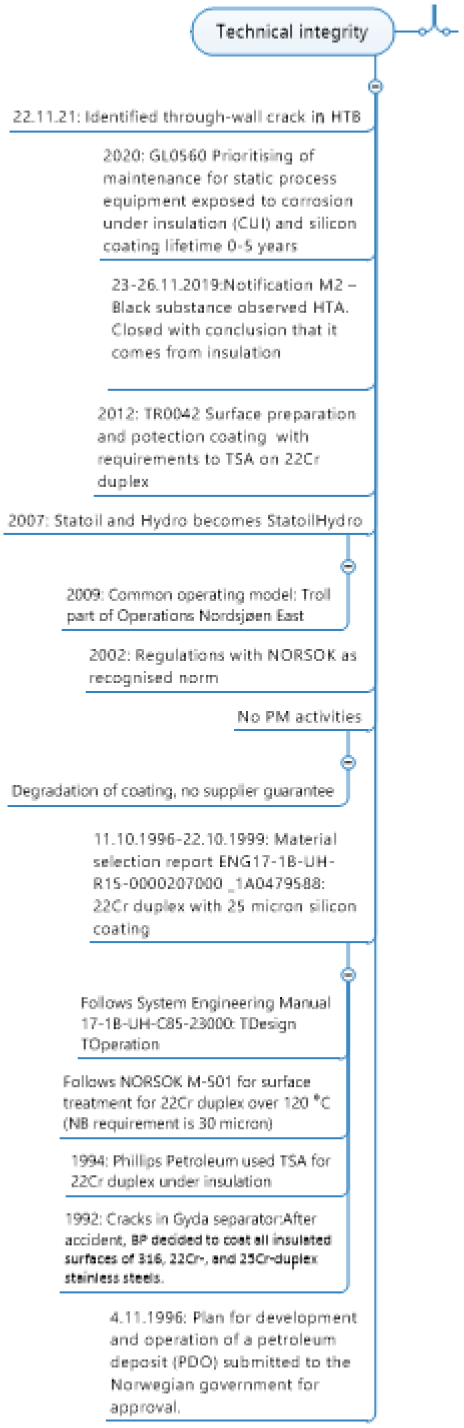
No others notified

Other measures taken

Compressor trains to these coolers is shut down. Repair work initiated.

13.3 Appendix C




Technical integrity
22.11.21: Identified through-wall crack in HTB
2020: GL0560 Prioritising of maintenance for static process equipment exposed to corrosion under insulation (CUI) and silicon coating lifetime 0-5 years
23-26.11.2019:Notification M2 – Black substance observed HTA. Closed with conclusion that it comes from insulation
2012: TR0042 Surface preparation and potection coating with requirements to TSA on 22Cr duplex
2007: Statoil and Hydro becomes StatoilHydro
2009: Common operating model: Troll part of Operations Nordsjøen East
2002: Regulations with NORSOK as recognised norm
No PM activities
Degradation of coating, no supplier guarantee
11.10.1996-22.10.1999: Material selection report ENG17-1B-UH-R15-0000207000 _1A0479588: 22Cr duplex with 25 micron silicon coating
Follows System Engineering Manual 17-1B-UH-C85-23000: TDesign TOperation
Follows NORSOK M-501 for surface treatment for 22Cr duplex over 120 °C (NB requirement is 30 micron)
1994: Phillips Petroleum used TSA for 22Cr duplex under insulation
1992: Cracks in Gyda separator:After accident, BP decided to coat all insulated surfaces of 316, 22Cr-, and 25Cr-duplex stainless steels.
4.11.1996: Plan for development and operation of a petroleum deposit (PDO) submitted to the Norwegian government for approval.

13.4 Appendix D

Tabell 1 Matrise for kategorisering og klassifisering av alvorlighetsgrad for hendelser *

Kategori / Alvorlighets-grad	Personskade		Arbeidsrelatertsykdom (ARS)		Ukontrollerte utslipp		Lekkasjer av olje/gass/brennbare væsker*		Brann/eksplosjon		Feil på sikkerhetsfunksjoner og barrierer	Renommé	
	Faktisk	Mulig	Faktisk	Mulig	Faktisk	Mulig	Faktisk	Mulig	Faktisk	Mulig	Mulig	Faktisk	Mulig
1	Dødsfall		Arbeidsrelatert sykdom som medfører død		Enkeltutslipp med langvarig virkning på miljøet, eller Utslipp av komponent > årlig forventet utslipp		>10 kg/sek. eller kortvarigs >100 kg		Hele innretningen/anlegget eksponert		Truer hele innretningen eller anlegget	Stor internasjonal negativ eksponering i media og mellom organisasjoner	
2	Alvorlig fraværsskade / alvorlig personskade		Alvorlig arbeidsrelatert sykdom		Enkeltutslipp med mellomlang miljøpåvirkning, eller Utslipp til komponent > månedlig forventet		1-10 kg/sek. eller kortvarigs >10 kg		Store deler av innretning/anlegg eksponert		Truer stor del av innretningen eller anlegget	Middels internasjonal negativ eksponering i media og mellom organisasjoner	
3	Øvrig fraværsskade eller personskade med alternativt arbeid		Arbeidsrelatert sykdom som medfører kortvarig fravær eller begrenset/alternativt arbeid		Enkeltutslipp med korttids miljøpåvirkning, eller Utslipp av komponent > ukentlig forventet utslipp		0,1-1 kg/sek. eller kortvarigs >1 kg		Deler av innretning/anlegg eksponert		Truer deler av innretningen eller anlegget	Nasjonal negativ eksponering i media, fra myndigheter på nasjonalt nivå.	
4	Medisinsk behandlingsskade		Arbeidsrelatert sykdom som medfører behandling fra autorisert helsepersonell		Enkeltutslipp med liten miljøpåvirkning, eller Utslipp av komponent < ukentlig forventet utslipp		< 0,1 kg/s		Lokalt område av innretning/anlegg eksponert		Truer lokalt område	Lokal/regional negativ eksponering i media, fra myndigheter og kunder	
5	Førstehjelps-skade		Øvrig arbeidsrelatert sykdom		Enkeltutslipp til omgivelsene med neglisjerbar miljøpåvirkning.		<<0,1 kg/sek. (vesentlig mindre enn 0,1 kg/sek.)		Neglisjerbar risiko for innretning/anlegg		Neglisjerbar fare for innretning/anlegg	Begrenset til få personer eller en kunde	

* In addition, the major accident potential must be assessed by the investigator pursuant to RM100 for the most serious incidents.

13.5 Appendix E

SAFETY ALERT

Chloride stress corrosion cracking (CSCC) on two gas coolers on Troll C (NCS).

equinor

Pic. 1: Gas cooler after partly removal of insulation.

How the damage was unveiled:

During a routine area check asphaltene was observed on the underside of the insulation on the 2nd stage gas cooler.
Upon stripping and inspection cracks and pitting were identified.

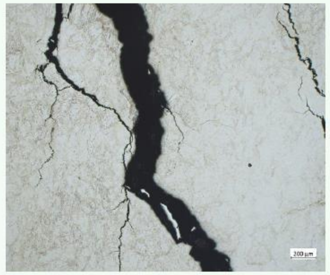
Relevant Information about the equipment:

Service	In service on the Norwegian Continental Shelf since 1999. Shell and tube heat exchanger. Hydrocarbon gas on the shell side.
Pressure/ temperature	60 barg, cooling from 140° to 25° C.
Material	22Cr Duplex UNS S3 1803.
Coating	Modified silicone paint for temperature above 120° C.
Insulation	Firemaster and 316 mantling.
Environmental exposure	Coolers are located in process area outdoors with deluge coverage.

Findings during inspection of coolers:

A test piece of the cracked material was cut out and subject to further examination. Results from the material examination showed chloride stress corrosion cracking. An internal investigation has been commissioned and a report will be published when ready.

Pic. 2: Field observation on gas cooler.



Pic. 3: Metallographic examination shows typical crack propogation pattern for CSCC.

Equipment group:
Heat exchanger, pressure vessels in 22Cr Duplex

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