PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation of an oil spill from Gullfaks C on 26 April 2021	Activity number 001050081

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

Involved	
Team T-1	Approved by/date Kjell M Auflem 2 July 2021
Members of the investigation team Jorun Bjørvik, Ove Hundseid, Ingvill Røsland	Investigation leader Elin S Witsø

Contents

1 Summary

When starting up production from the Tordis subsea facility after a four-day planned shutdown, an oil spill occurred on 26 April 2021 via the produced-water plant on the Gullfaks C facility operated by Equinor. The latter estimated that 17.5 m^3 escaped, and a slick measuring 3 500 by 500 metres formed on the north side of the platform. The Petroleum Safety Authority Norway (PSA) decided on 29 April 2021 to investigate the incident.

The direct cause of the spill was that the water outlet from the Tordis inlet separator had been opened too early. Combined with emulsion problems, this allowed oil to flow out with the water, through the water treatment plant and from there to the sea. Underlying causes identified by the PSA team include:

- impairments to level and oil-in-water (OiW) meters
- lack of risk assessment of equipment impairments and the impact of corrosion inhibitors on produced-water quality during a start-up
- deficiencies in the system and operating documentation
- a lot for control room operators to deal with overall during a start-up.

Conditions identified by the investigation which could be important for safe operation but which were not directly significant for the incident include impairments and inappropriate design resulting from much overriding of process safety functions. The PSA has identified three nonconformities related to:

- overriding the process safety system
- deficiencies in system and operating documentation
- lack of risk assessment when starting up Tordis production.

Furthermore, two improvement points have been identified in relation to:
- control of the process plant
- use of information envelopes on displays in the control room.

2 Background information

2.1 Description of facility and organisation

2.1.1 Gullfaks field

Gullfaks is an oil and gas producer located in block 34/10 in the northern North Sea. The main field has been developed with three large concrete production platforms – Gullfaks A, B and C – and came on stream in 1986. Produced oil passes via storage cells in the concrete structure for buoy-loading into tankers, while the gas is piped for processing to the Kårstø plant north of Stavanger. Oil and gas from Gullfaks B are transferred to A and C for treatment, storage and export. Gullfaks C has received and processed oil from the Tordis subsea field 10 kilometres away since June 1994.

In addition to its main structure, Tordis comprises the Tordis East (1998), Borg (1999) and Tordis South-East (2001) structures. It has been developed with subsea installations in about 200 metres of water.

Figure 1 The Gullfaks C platform. Photo: Øyvind Hagen/Statoil

2.1.2 Gullfaks C organisation

Operations West includes the Gullfaks profit centre (PC), which comprises the production, maintenance and PC operations groups. The organisation at the time of the incident is presented below.

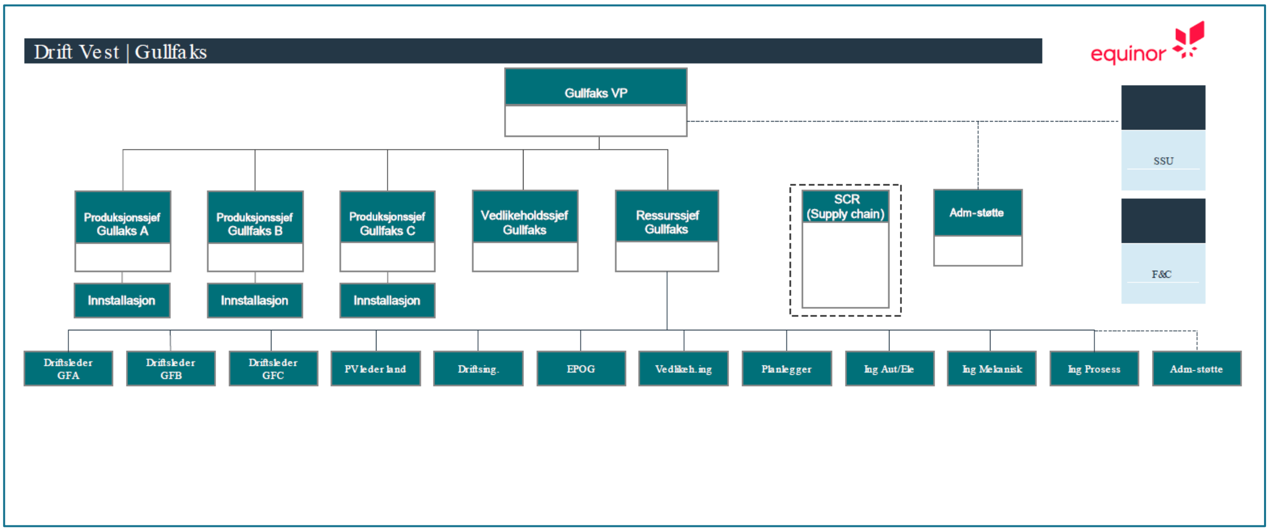

Figure 2 Gullfaks organisation chart – land. Source: Equinor

The organisation chart for Gullfaks C is presented below.

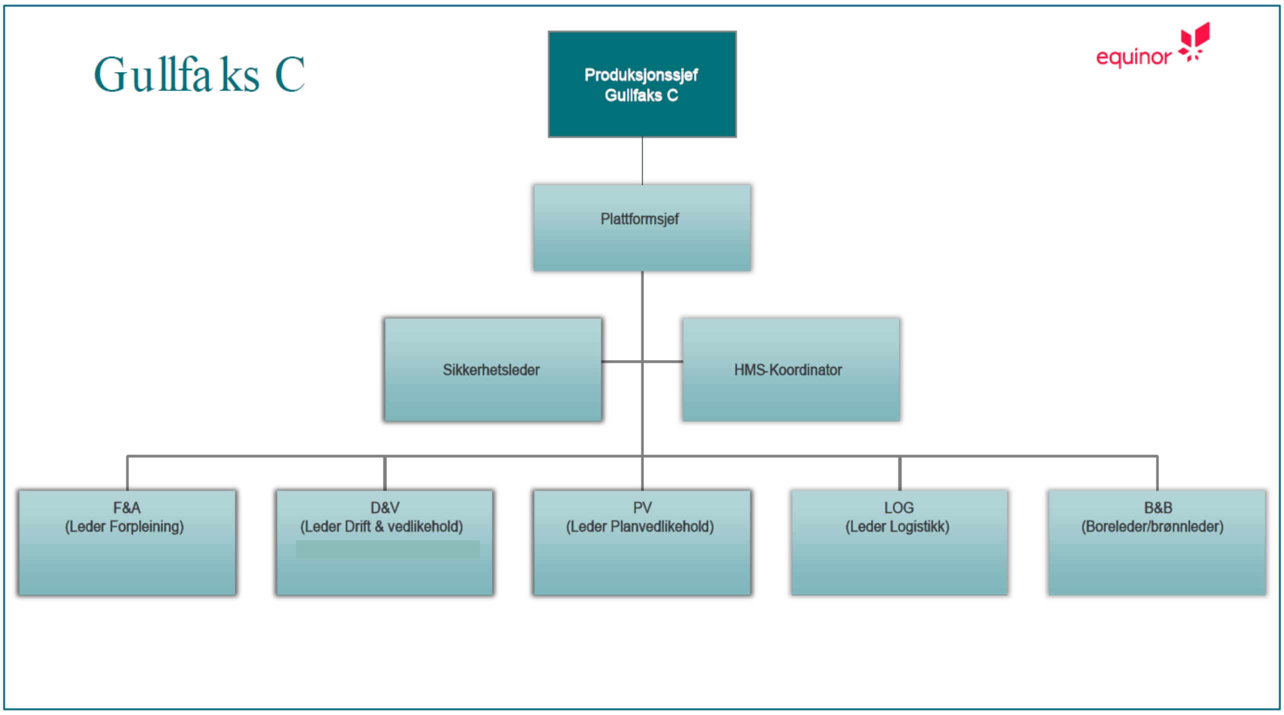

Figure 3 Gullfaks C organisation chart – offshore. Source: Equinor

2.2 Position before the incident

Production from Tordis had been shut down for four days before the incident to carry out a planned IMR operation on the field's subsea installations. That included tie-in of a new well, I-10, to the Tordis central manifold (TCM).

Because of the IMR operation, the Tordis flowlines on the seabed were filled with stabilised oil to avoid hydrate formation. During the shutdown, corrosion inhibitor was continuously injected at a minimum rate in order to prevent hydrate formation in the injection line, since its non-return valve had an internal leak.

Production on Gullfaks C from other fields/wells was stable ahead of the incident and the weather was good, with good visibility, little wind and low waves.

The incident occurred when starting up Tordis production after the IMR operation.

2.3 Abbreviations

AI – asset integrity
Aris – Equinor's process-based management system
CCR – central control room
Epog – energy and production optimisation
ESV – emergency shutdown valve
IMR – inspection, maintenance and repair
LCI – life cycle information
LT – level transmitter
LV – level valve
MEG – monoethylene glycol
O&M – operation and maintenance
OiW – oil in water
OPS – operational support group on land
PCS – process control system
PDO – plan for development and operation
PSA – Petroleum Safety Authority Norway
PSD – process shutdown
PSV – pressure safety valve
Ptek - petroleum technology
SAP – maintenance management tool in Equinor
SO – system and operating documents
SSBI – subsea separation, boosting and injection
TCM – Tordis central manifold
WiO – water in oil
WP – work permit

3 The PSA's investigation

The PSA was notified by Equinor of an acute pollution incident via the Gullfaks C produced-water plant on 26 April 2021 at 06.15 on the same day. More information about the incident was received in a meeting with Equinor on 28 April, and the PSA decided thereafter to conduct an investigation.

3.1 Mandate

Mandate for the PSA investigation.

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 within the PSA's area of responsibility.
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. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.
h. Recommend – and normally contribute to – further follow-up.

When the investigation mandate was established, Equinor had not decided to investigate the incident. The mandate accordingly does not include an assessment of Equinor's own investigation.

Equinor has subsequently decided to conduct a level 3 investigation.

3.2 Composition of the investigation team

Ingvill Røsland – HSE management discipline
Jorun Bjørvik – process integrity discipline
Ove Hundseid – process integrity discipline
Elin S Witsø – process integrity discipline (investigation leader).

3.3 Methodology

The investigation was pursued digitally because of the Covid-19 position. Interviews were conducted with personnel in the Gullfaks C operations organisation, while certain verifications of the maintenance management and process monitoring systems were carried out via Teams. Governing documents and other documentation relevant to the incident have also been reviewed. No inspection was carried out on Gullfaks C.

4 Description and operation of equipment involved

4.1 Description of equipment involved

4.1.1 Description of the Tordis inlet and produced-water system

The facilities on Tordis comprise subsea wells, a manifold and a subsea separation, boosting and injection system (SSBI). A system for injecting produced water below the seabed is non-operational and disconnected from the other installations. Water is separated from the wellstream on the seabed, with production sent to Gullfaks C via two 10-inch flowlines – lines A and B. Water travels primarily in A because material qualities differ between the two lines. B is in carbon steel, and inhibitor is injected in this line to prevent corrosion.

Flow in the two lines is routed to dedicated inlet separators on Gullfaks C, designated Tordis separators A/B (20-VA06 A/B). Operating pressure in the three-phase (oil, gas and water) separators is 18 bar. Tordis production is metered at the separator outlets before entering the process plant on Gullfaks C for processing together with other production.

The water-treatment system on Gullfaks C comprises hydrocyclones, produced-water separators (44-VA01A/B) and flotation cells (44-CV01A/B). Water from the flotation cells is routed to the sea.

With the hydrocyclones currently out of operation, produced water from the inlet separators is sent directly to the produced-water separators. Water is distributed between the latter by two parallel level-control valves located on the water outlet on both Tordis separators.

Operating pressure in the produced-water separators is reduced to about 1.5 barg, with gas liberated by this reduction sent to the low-pressure flare system where opportunities are available for recovery. The separators are operated mainly as two-phase (gas/ liquid) systems but with automatic skimming every six hours to remove the oil layer which builds up over time on top of the water. During skimming, the water level in the tank is raised and the upper layer overflows into “collectors” for return to the process via the reclaimed oil sump tank. No further measurement or regulation of the oil level in the tanks is conducted.

Produced water is then sent on to the flotation cells for further separation of oil droplets before being routed overboard.

Water quality is regularly sampled (routinely three times a day) at the flotation cell outlets. An automatic OiW meter on the outlet from one cell also alerts the central control room (CCR) if values are high.

The system is illustrated in the diagram below.

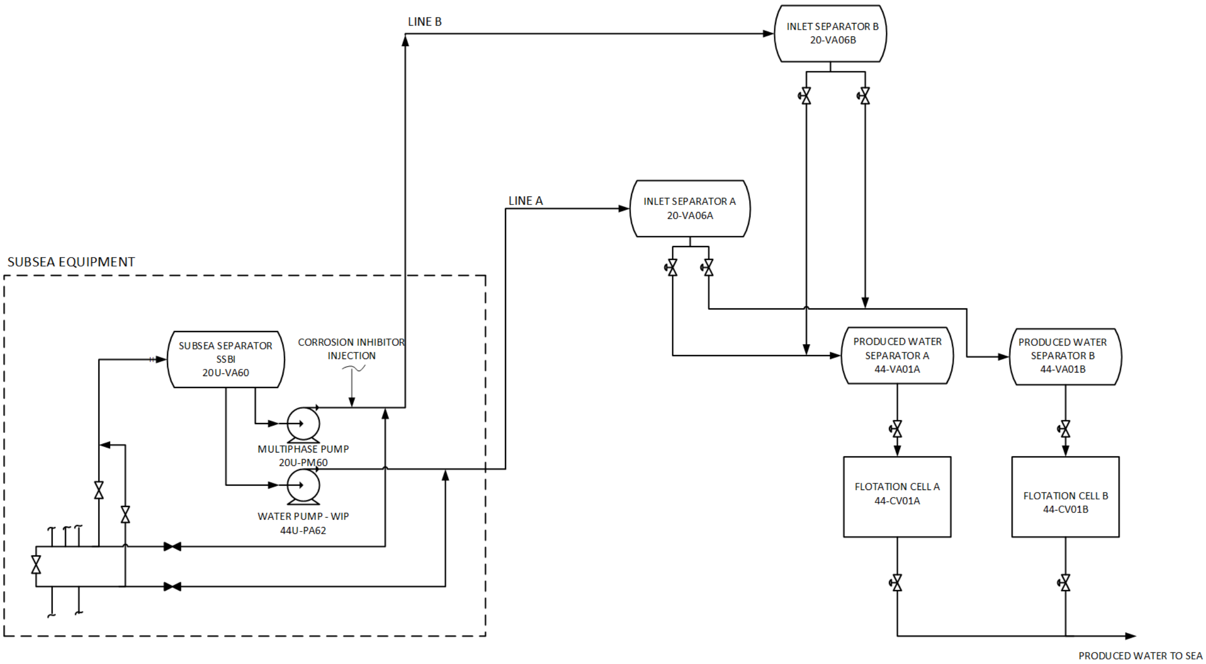

Figure 4 Simplified diagram of the Tordis subsea facility, separation and produced water treatment.

4.1.2 Description of process safety functions

The process control system (PCS) controls water and oil levels in a separator within specified values. If levels move outside these parameters, the process shutdown (PSD) system will engage automatically to place the plant in a safe condition. Automatic shutdown initiated by the PSD will hereafter be termed the PSD function. Its roles in the Tordis separators include preventing oil carry-over in the water outlet, gas blowby in the water outlet or liquid carry-over in the gas outlet. As a safety system, the PSD is independent of the PCS. When overriding the PSD function, CCR operators continue to receive audible alarms but actual shutdown does not occur. This must be done manually by the CCR operators if necessary.

A simplified diagram of Tordis separators A and B, including level control (white) and PSD functions (yellow) is presented below. The tag numbers in the diagram refer to separator B. Liquid levels for oil (orange) and water (blue) are regulated by level transmitters (LT), which control the level valves (LV). LT 853 regulates the water level by controlling LV 853 A/B, while LT 859 regulates the oil level by controlling LV 562 on the oil outlet. Oil and water are separated on the water side of the weir plate. Density differences between oil and produced water mean that the former – which is the lighter component – will rise to the top and flow over the weir plate to the oil side of the separator.

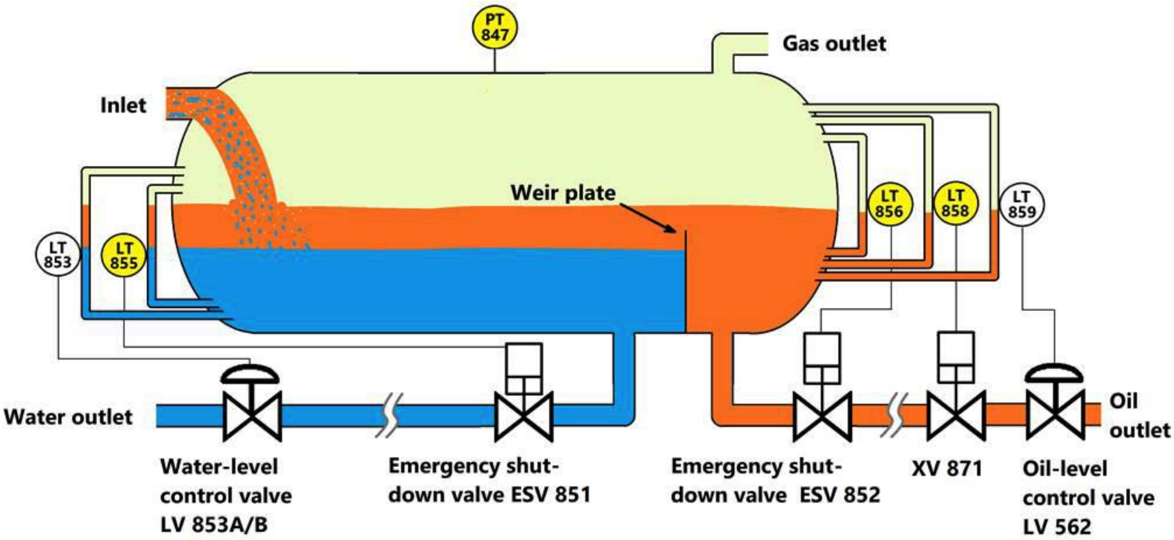

Figure 5 Simplified diagram of Tordis separators A & B (tag numbers in the diagram refer to separator B).

The PSD transmitters, yellow in the diagram, have the following functions.

LT 855	Closes the water outlet when the water level is too low to prevent oil escaping through the outlet.
LT 856/ LT858	Closes the oil outlet at oil level alarm low low (LALL) to prevent gas entering. Only one PSD function is normally available for this, which was adopted as an extra because pressure safety valve (PSV) capacity on downstream equipment was inadequate. Closes supply at oil level alarm high high (LAHH) to prevent liquid entering the gas outlet.
PT 847	Closes supply at pressure alarm high high (PAHH) in the separator. Closes supply to and outlet from the separator at pressure alarm low low (PALL) in the separator (indication of leakage).

When starting up, it may be necessary to override safety functions because process conditions would otherwise cause an immediate shutdown. When starting up a pump, for example, a PSD signal for low pressure on the pump outlet must be overridden until the pump has been started up and normal operating pressure has built up at the outlet.

4.2 Description of the override system

Equinor's management system specifies that overriding PSD functions requires an approved work permit (WP), with the following exception in Aris requirement R-19515 *Documenting/logging safety system impairment*:

> Blocking input signals in the PSD system when running the process up or down, for example, if these are non-critical and last such a short time that they can be activated and reinstated by the same person without leaving the CCR.

When starting up, the following PSD functions were overridden:
- low oil level for A/B separators
- high oil level for A/B separators
- low water level for B separator
- low pressure in A/B separators
- low oil level in collector for produced-water separator B.

4.3 Injection of corrosion inhibitor

Tordis production was shut down for the IMR activity on its subsea facility, and the A and B lines from the wells and the seabed separator were circulated out with stabilised oil to prevent hydrate formation during the shutdown. Inhibitor is normally injected at the template in the B line, which is in carbon steel, to protect it from corrosion. The PSA team was told that a leak in a non-return valve has previously caused production backflow in the inhibitor line, causing hydrate formation and plugging of the line. To prevent this happening again, inhibitor is therefore injected at a minimum rate to prevent backflow during a production shutdown. On this occasion, about 400 litres of inhibitor were injected in the B line.

4.4 System and operating documents

Requirements for the content of system and operating (SO) documents are described in Equinor's governing documentation on life cycle information (LCI).

Containing system descriptions and operating procedures, such documents are drawn up on a system basis – for example, system 20 for separation and stabilisation/ crude oil treatment, and system 44 for produced water.

The system descriptions cover processes, mode of operation, design basis, system protection and so forth.

Operating procedures normally cover operations, startup, shutdown and special operations.

The PSA team has received descriptions for systems 20 (oil separation) and 44 (produced water) as well as selected procedures.

Where system 20 is concerned, the description received was updated in 2021.

The system description part in the SO documentation for system 44 system refers to several different documents whose structure does not conform to that described in TR2381 (LCI requirements master). Reference is made to the following documents:
- system design and operation summary
- system description manual (published in 2010)
- system handbook (published in 2013).

No cross-referencing occurs between the system description manual and the system handbook, and the information partly overlaps. In some areas, conformity is lacking between the documents or with today's operating conditions. For example:

- the description of the produced-water separators differs between the documents – one describes them as identical, while the other gives them different functionalities and capacities
- requirements for water purity do not accord with current discharge requirements
- the method for skimming the produced-water separators does not accord with today's practice
- the description specifies that two 100 per cent level control valves are installed on the water outlet from the Tordis separators, but both are now in use.

Where operational procedures are concerned, the documentation is built up with a main document which primarily references underlying procedures for the individual operations. The underlying procedures are intended to cover:

- normal operation
- normal startup
- normal shutdown
- special operations
- operating routines.

The PSA has received overall operating documents for systems 18, 20 and 44 as well as selected procedures.

Procedures for startup of the Tordis subsea facility (system 18) have been prepared. These contain limited information on necessary actions related to equipment on the platform when starting up Tordis.

Where system 20 is concerned, procedures have been established for pigging and circulating out Tordis flowlines. However, detailed procedures describing normal startup of Tordis do not appear to have been drawn up. The PSA team has been informed that starting up after a long shutdown corresponds to startup after a pigging operation, but that the pigging procedures also fail to provide startup details.

5 Course of events

5.1 Outline of the incident

The CCR restarted Tordis production in the early morning of 26 April 2021 after a four-day shutdown. Flowlines from the field were filled with stabilised oil, which was to be produced out through the Tordis separators before wellstream from Tordis began to arrive. The inlet separators were filled with seawater before startup. Lines B and A were opened at 02.00 and 02.35 respectively, with water outlets on the Tordis separators closed. When indications were received at 05.30 of water in oil (WiO) from separator A, its water outlet was opened. The water outlet from separator B was opened about 15 minutes later. At 06.05, the CCR observed that the flare valve on a produced-water separator opened, and interpreted this to mean that pressure in the separator had become too high – most probably because of degassing from oil in it. The CCR asked a plant operator to check the produced-water system. He detected irregularities in a produced-water separator tank downstream from the Tordis separator, and oil was immediately afterwards observed on the sea to the north of the platform. The CCR closed the produced-water outlets on the separators to stop oil being discharged to the sea via the produced-water system. This prompted automatic shutdown of most satellite and platform wells on Gullfaks C because of a high liquid level in second-stage separator B. The liquid level valves in the flotation cells were closed at 06.39. and the produced-water flow to the sea ceased. The spill lasted about 39 minutes.

5.2 Timeline

A timeline for the incident is presented below. Including conditions considered relevant by the PSA team before and after the event, it is based on documentation received and conversations with personnel involved. Unlogged times will be rather uncertain, but the timeline provides a good description of the course of events.

	Conditions and information before the incident relevant to the accidental spill	**Comments**
5 Nov 2020	Synergi 1628727 *High OiW out of flotation cell B.*	High OiW values from flotation cell B (seriousness level 4, green) were encountered for a brief period when running up Tordis. Commented that online measurement of OiW was inadequate and that personnel should have been more hands-on in the field when running up. It transpires that OiW problems have occurred before with Tordis startup. Measures focused on handling high OiW, but not on identifying the causes of the spills.

15 Dec 2020	Oil-level control valve 21-LV561 in 20-VA06A was defective.	Notification 46422500 *Tordis line A level valve leaking*. Report of "large internal leak (20 m^3/h) in the valve in closed position. Calls for continuous supervision and use of XV870 as on/off valve". Reported replacement and back in operation on 20 January 2021 without removing the envelope on the PCDA display. Although not significant for the spill, this was an unnecessary extra element to monitor for the CCR operators during startup and also gave inaccurate information. Probably why PSD signals were overridden during startup.
23 Jan 2021	Oil-level control valve 21-LV562 valve in 20-VA06B was defective.	Notification 46465981 *Tordis line B level valve leaking*. Report of "large internal leak (20 m^3/h) in the valve in closed position. Challenging for testing and running up/down". Due for replacement in June 2021. Envelope with leak information posted by the valve on the PCDA display. Although not significant for the spill, this was an unnecessary extra element to monitor for the CCR operators during startup. Probably why PSD signals were overridden during startup.
31 Jan 2021	Water-level control valve 20-LT853 in 20-VA06B was defective.	Notification 46476468 *Level measurement water side Tordis B not functioning.* Also notified on 23 January 2020 and closed. Last comment on the issue was on 6 February 2021: "Transmitter works fine for measurements when the level is falling, but when the level rises it lags behind and catches up with a big jump. New Vega metering principle ordered, delivery 16 July 2021". The trend plot showed that this level transmitter "chased" during startup on 26 April, and it looks as if the fault condition remained real.
14 Feb 2021	PSD transmitter 20-LT855 in 20-VA06B was defective.	Closes water outlet from 20-VA06B when water level too low in order to prevent oil escaping this way. Notification 46494972: *Level measurement water side Tordis B not functioning*. The PSD transmitter was overridden during startup, without this directly affecting the incident. Could be an indication that the operator did not trust it.
12 Apr 2021	Marine field operations can begin. Work programme IMR 20-137 for installation and hook-up of new I-10	Included description and risk assessment of the IMR operation, but not the subsequent startup.

	flowline and installation of new pipe section published	
21 Apr 2021	Online OiW meter from the flotation cells ceased to function.	Notification 46588832 *Produced water analyser not functioning*. Not the cause of the spill, but will generally ensure rapid detection and could have helped to detect OiW earlier in this case. No measures to compensate for it being out of operation.
22 Apr 2021	Controlled shutdown of Tordis production because of IMR activities.	The flowlines were filled with stabilised oil. A minimum rate of corrosion inhibitor, totalling 400 litres, was injected continuously in the B line to avoid hydrate formation in the chemical injection line because of an internal leak in a non-return valve. This was known to pose possible emulsion challenges in the event of backflow.
23 Apr 2021	Energy and production optimisation (Epog) meeting held.	Attended by the offshore operations department, operations leader land, operations engineer, operations O&M engineer, Ptek and others. No discussion of special challenges related to Tordis startup. One purpose of an Epog meeting is to ensure learning and improvement following challenges with produced-water separation. Backflow of corrosion inhibitor, challenges with level control valves and transmitters in 20-VA06B, and the lack of an online OiW meter could have been highlighted here when starting up.
25 Apr 2021	IMR operation completed. Ready for Tordis production startup.	
25 Apr 2021	Operations department meeting dedicated to startup.	Before O&M manager 2 went off duty, a meeting on startup was held with plant operators and CCR personnel. Attention centred on giving the two CCR operators the space to concentrate on Tordis startup. Special startup challenges or barrier impairments were not discussed.
26 Apr 2021	Operations department meeting dedicated to startup.	Immediately before startup, after night-shift lunch, the work team – a plant operator and two CCR operators – were brought together for a pep talk to ensure that everyone's attention was on running up being under way. No discussion took place on the startup or on whether any special factors indicated that they could not begin. The CCR operators had not received a startup plan from Petek onshore, so they "flipped" the shutdown plan received earlier

		and conducted it in reverse order for startup. It was assessed as a normal run-up.

26 April	Tordis startup – course of events	Comments
		A number of PSD functions were overridden for the startup activity.
02.00	Tordis B flowline started up.	The line was filled with 550 m^3 of stabilised oil to be produced out before the wellstream entered the Tordis separator.
02.35	Tordis A flowline started up.	The line was filled with 550 m^3 of stabilised oil to be produced out before the wellstream entered the inlet separator. Volume flow during startup was greater in the A line than in B because the SSIB (water) pump supplied the former with feed.
05.30	Water outlet from the Tordis separator A was opened after the WiO meter detected water in the oil flow from the separator.	This means that the stabilised oil had been produced out of the flowline and the wellstream with both oil and water was now flowing into the separator.
05.46	Water outlet from the Tordis separator B was opened.	Little or no water was measured in the oil outlet when the water outlet was opened.
06.05	The CCR operators observed that the flare valve on the produced-water separator opened.	This indicates that pressure in the separator had become too high, most probably because of oil degassing in the separator. The CCR contacted and informed the plant operator by radio and asked him to check the produced-water system.
06.15	Personnel out in the plant observed oil on the sea.	
06.17	The CCR was told to close the produced-water outlets on the separators to halt the discharge of oil to the sea via produced-water system.	
06.20	Water samples were taken from flotation cells A and B.	Final treatment stage before produced water goes to the sea. The samples showed large quantities of oil in both cells, in the order of 3.5 per cent (maximum permitted oil is a daily average of 0.003 per cent).
06.26	Automatic shutdown of most satellite and platform wells on Gullfaks C.	Because of a high liquid level in second-stage separator B. That was because more liquid had been produced into the process plant than it could handle when no water was entering the produced-water system.

06.39	Liquid-level valves in the flotation cells closed and halted the produced water flow to the sea.	

26 April	Conditions and information after the incident relevant to the accidental spill	Comments
	An oil slick measuring 3 500 by 500 metres formed on the north side of the platform.	Mechanical dispersal of the slick was initiated by standby ship *Stril Merkur*. The search and rescue helicopter overflew. A gradual reduction of the slick was observed. The emergency response was not part of the mandate for this investigation.
Abt 08.00	Time-out in the operations department.	A plan for cleaning the produced-water plant was established. This involved emptying oily water from the produced-water separator and flotation cells by raising the level of the produced-water separator with flushing (jetting) water in order to move the oil layer on top of the level over to oil collectors and from there to the reclaimed oil sump tank. The water was then carefully released to the flotation cells with outlets closed, and the level lifted over to the froth separator and on to the sludge cell.
Abt 10.45	New time-out in the operations department.	To plan startup. Start up Tordis with water outlets closed until a stable water level was established in the separators.
Rest of the day, 26 Apr 2021	Produced for many hours with extra attention devoted to water production, and the water outlet from 20-VA06B was eventually opened slowly and carefully. This was viewed as demanding because little reliance could be placed on the LT meters. Water valves were operated manually, very conservatively, and it was agreed to require a WP1 for operating these valves automatically. An A standard for Tordis startup was established and reviewed, which concluded that the water outlet on Tordis 20-VA06B would not be opened	

	until 20-LT855, which sends the closure signal to the ESV, was completely reliable. This meant the water outlet was closed.	

6 Assessment of the incident and operation of the process plant

6.1 Tordis startup

When starting up Tordis, the first step is to produce the stabilised oil out of the flowline before the wellstream comprising oil, water and gas arrives. The water outlets on the Tordis separators are kept closed during start-up, and are to be opened when wellstream with both oil and water flows into the separator. If the outlet is opened before water production begins, the water level in the separator can be lost should the valve controlling it be leaking. Until the outlet is opened, water flowing into the separator accompanies the oil through the oil outlet. Water can be sent together with oil on Gullfaks C because the stabilised oil is held in storage cells before transfer to shuttle tankers. This means the water separates out in the storage cells before transfer. The diagram below illustrates flow through the Tordis separators before the water outlet is opened and water flows over the weir plate together with oil.

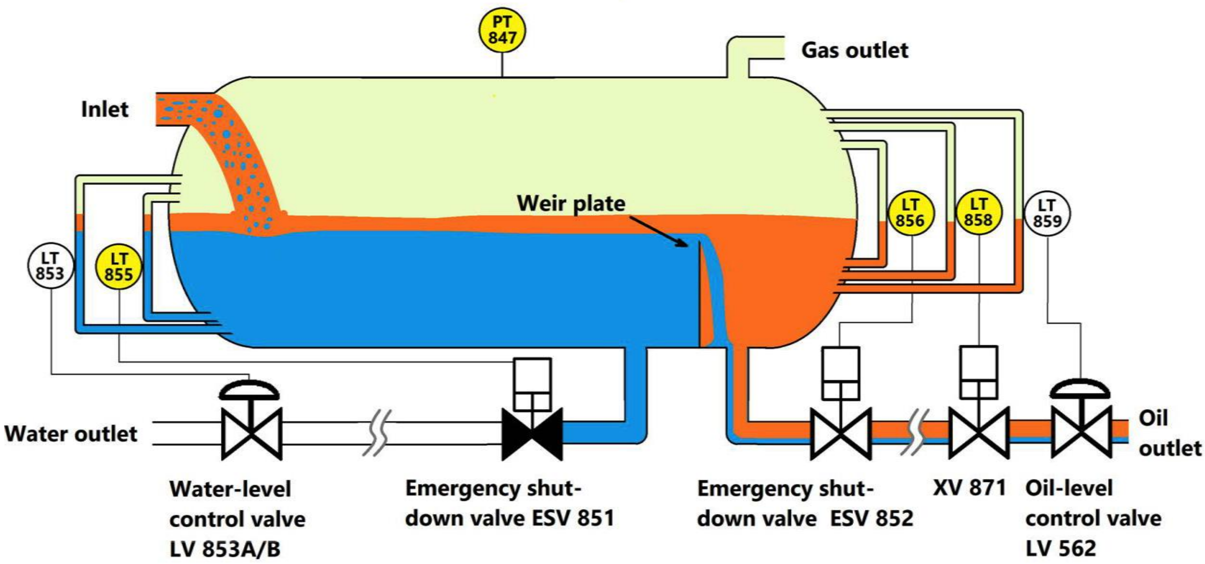

Figure 6 Tordis separators A and B (illustrated by 20-VA06B) at startup.

Oil from the Tordis separators flows through a WiO meter. When this detects WiO, CCR operators know that the stabilised oil has been produced out of the flowline, and that the wellstream has reached the separator. The water outlet can then be opened.

Where separator A was concerned, a clear indication of water production had been received when the water outlet was opened. However, very little or no water had been measured from separator B when opening its outlet. The diagram below presents water measurements for separators A and B and the time when the outlets were opened.

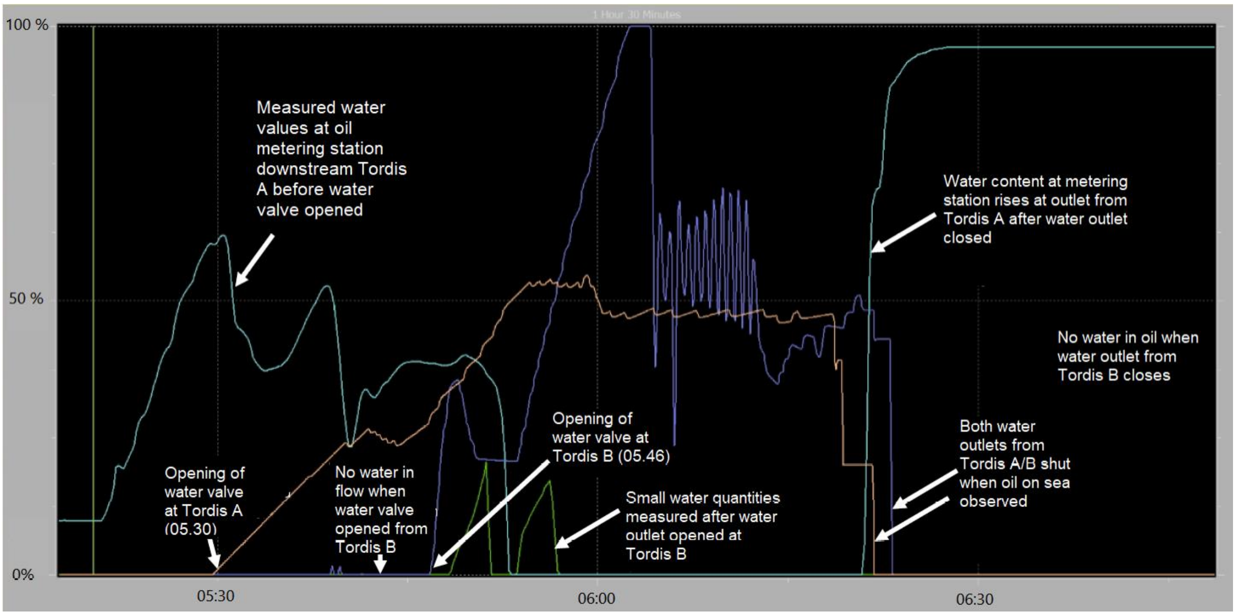

Figure 7 Trend curves for WiO from Tordis separators A & B. Source: Equinor

The figure shows that water content in the oil from separator A rose to about 90 per cent after the water outlet was closed, but that no WiO was detected from separator B after its water outlet was closed. This could indicate that water was still not being produced to the latter.

A known problem on Gullfaks C is that injecting corrosion inhibitor in the B flowline can create emulsion problems between oil and water, which may prevent them being adequately separated in the separator. During this startup, the water outlet was probably opened immediately before or after the inhibitor injected during the shutdown entered the separator, followed by the wellstream.

In conversations, the PSA team has been told that the oil most probably accompanied the water as a result of emulsions which prevented good separation. Inhibitor was changed to the type used today a few years ago because the previous product created emulsion problems. The latter were reduced with the new inhibitor, but the large quantity of about 400 litres which entered the separator in a relatively short time has most probably created emulsion problems which affected level control and oil content in the water from separator B. Problems have also arisen with the level transmitters earlier, and it is difficult to say whether these also played a role during the incident.

If the water outlet valve had been opened some time after water was measured in the oil outlet from separator B, the inhibitor could have been displaced by the produced water from the wells – thereby reducing the separation problems with associated oil spill to the sea. Opening the water outlet early ought not to have resulted in oil escaping through the outlet. The water control valve should have remained closed when the water level fell low enough, and automatically reopened when water began flowing into the separator. However, the separator B control valves have substantial internal leaks. Had they been closed without water being produced in, the water might have drained to the produced-water system followed by oil. Nor would inhibitor have been injected during the shutdown if the non-return valve on the inhibitor line had functioned as it should, and the associated emulsion problem could perhaps have been avoided.

When oil was introduced to the produced-water system, the OiW meter – the only device able to provide an automatic alarm to the CCR operators – was out of operation. However, the operators detected that something abnormal was happening in the system because a control valve on the produced-water separator opened to the flare in order to reduce pressure in the separator. If oil accompanies the water from the Tordis separators, gas flashing will occur in the produced-water separators. This increases pressure, which is bled off to the flare system. That also indicates the stabilised oil had been produced out of the system, because this would not degas. The liquid level sank in both Tordis separators when the water outlet was opened. Figure 8 below presents the position in separator B during the incident.

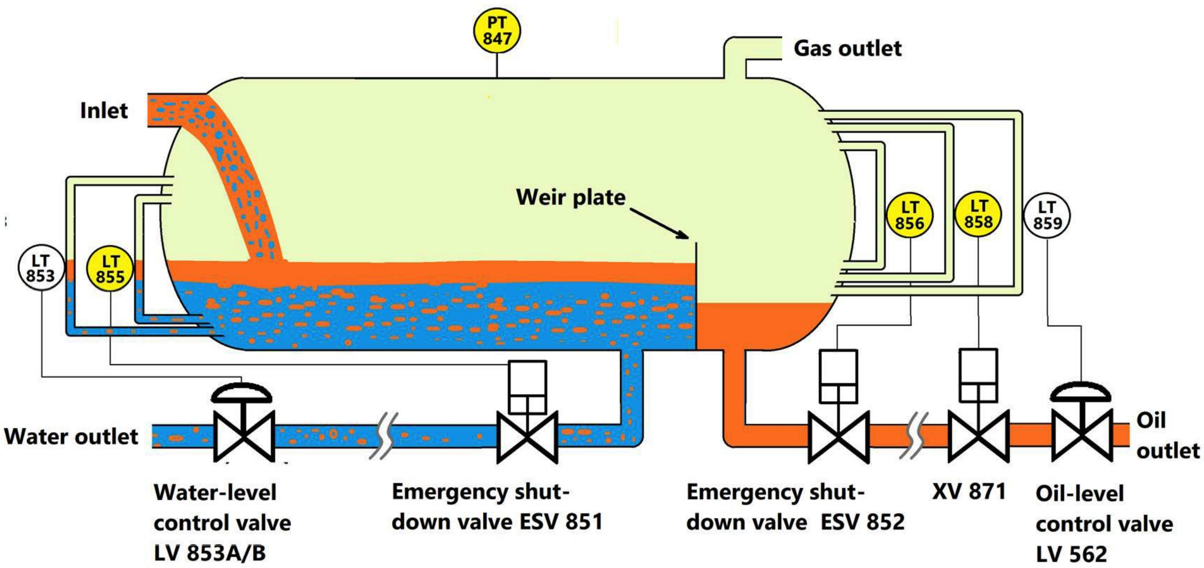

Figure 8 The position in Tordis inlet separator 20-VA06B during the incident.

The oil level sank below the measurement area of the level transmitters on the oil side when the water outlet was opened. At startup, the separators were filled with seawater. When the outlet was opened, the water level stood up to the top of the weir plate and was drained down to the desired level. This lowered the liquid level in the whole separator to the top of the weir plate. A combination of design and control inertia and leaks in the outlet valves caused the oil level to sink below the measurement area of the transmitters on the oil side.

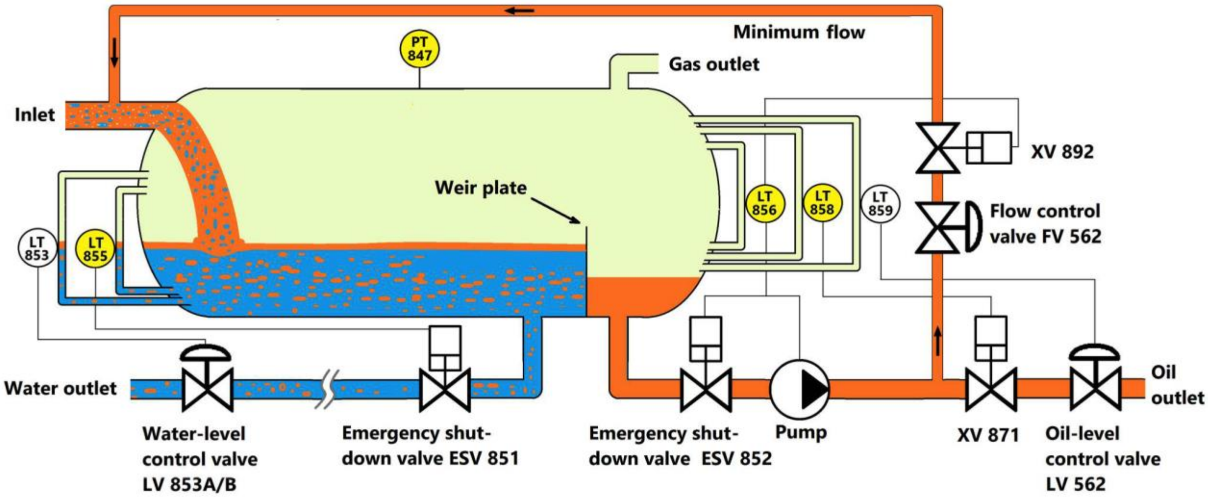

Figure 9 20-VA06B, including the pump installed on the oil outlet.

The diagram above shows the separator including the pump installed at the oil outlet. A return line is installed from the pump outlet to the separator inlet to ensure flow through the pump if the oil-level control valve closes because of a low oil level in the separator. When the water outlet was opened on the separators, the water level was higher than normal (to the top of the weir plate). The PCS thereby reduced the level. More liquid then flowed through the outlet than entered the separator, reducing the overall liquid level below the weir plate and halting oil supply to the oil side of the separator.

Although the oil control valve closed, oil returned to the separator inlet in order to ensure flow through the pump. The oil side has two PSD functions for low level. First, the oil flow is halted downstream of the pump by closing XV 871. If the level sinks further, the pump is stopped, ESV 852 on the outlet closes, and the minimum flow line (XV 892) is closed so that that oil no longer leaves the separator. Both these PSD functions were overridden during startup. At low level, the CCR operator closed the oil outlet by closing XV 871 to increase the oil level in the separator. Despite that, however, the level can fall further because oil then passes through the minimum flow line. This was done for both separators during the startup. Their control valves have suffered substantial leaks. While the one for separator A had been repaired, that for oil on separator B continued to leak heavily. This helped to reduce the level further on the oil side of separator B during startup.

Because the minimum flow line returns to the separator's water side, it reinforces the problem of low level on the oil side. Had this line returned to the oil side, the low-level problem there would have been reduced.

6.2 Known impairments of level and OiW meters

Uncertainty prevailed about level measurements for the oil/water interface in Tordis inlet separator 20-VA06B, for level transmitters LT 853 controlling the water level and for LT 855 providing PSD in the event of low water level. Serious faults with both transmitters have been reported in the maintenance system in 2021. Conversations and SAP reviews show that views on whether the measurements are reliable have differed, and that problems have existed over time with the level measurements.

The automatic 44-AIT-481 OiW meter installed on the outlet of one of the flotation cells was not working during the incident. A notification of this was entered in the maintenance system on 21 April 2021.

Two OiW meters have been requested by the CCR operators, so that they receive an alert for excessive oil in water discharged to the sea from both flotation cells. At present, they have to choose between using the meter on either A or B cells. Only the OiW meter automatically notifies CCR operators if the oil content rises towards the permitted limit. Since the incident, Equinor has decided to install an additional meter so that – once it is in place – the CCR can monitor both cells simultaneously. In this specific instance, had the OiW meter been in operation, it would have detected an excessively high oil level regardless of whether it was connected to cell A or B via the produced-water separators, since produced water from Tordis goes to both A and B cells and the samples taken showed excess oil in both.

6.3 PSD functions overridden during startup

When starting up Tordis production, the following PSD functions were overridden on Tordis separators A and B.

Transmitter	PSD function	Grounds
Separator A: LT 831 LT 832 Separator B: LT 856 LT 858	Low oil level	Substantial control valve leak on the oil outlet meant that the oil level during startup could fall lower than it should have been. The CCR operator was notified of the low level and closed the shutdown valve on the oil outlet until the oil side had built up to a sufficiently high level. The control valve leak on separator A had been repaired, making this override unnecessary. It was done because the information envelope on the CCR operator's display had not been removed.
Separator A LT 832 Separator B LT 858	High oil level	Slugging during startup meant these had been overridden to prevent automatic shutdown if liquid level in the separators was too high. However, two PSD functions are available for high level in the separators, and only the one was disconnected.
Separator B LT 855	Low water level	This should not have been overridden. Equinor has been unable to establish why it was overridden during the startup.

Separator A PT 820 Separator B PT 847	Low pressure	Because stabilised oil was being produced from the flowlines, no gas was supplied to the separator. Pressure can therefore fall too low even without leakage in the system.

The PSD for low oil level in the oil collector, intended to prevent gas in the oil outlet, was overridden on produced-water separator 44-VA01B. It had been overridden for a long time, and was reconnected after this emerged following the incident.

In addition to the overrides, trends show that PSD transmitter LT 830 for low water level in Tordis separator A was not working during startup. Its curve is flat in the figure below, while that for the transmitter controlling water level varies. Both devices measure the same level and should therefore have shown the same trend/variation.

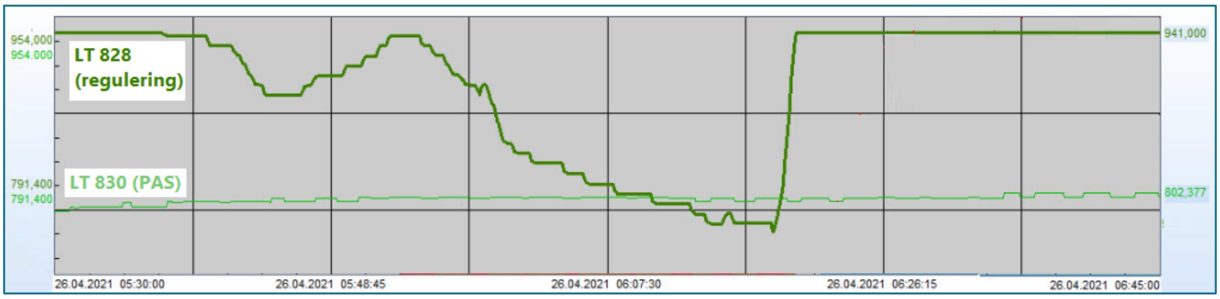

Figure 10 Control and PSD transmitter for water level in Tordis separator 20-VA06A.
Key: (regulering) = control; (PAS) = PSD

A notification (46614911) was established for this transmitter after the incident.

7 Potential of the incident

7.1 Actual consequence

Equinor has estimated that about 17 m^3 oil was discharged to sea during the incident, and considers this figure conservative. A slick of 3 500 by 500 metres was observed north of Gullfaks. The spill corresponds to the normal oil discharge in produced water from about one month’s production on the Gullfaks field. Some uncertainty exists about the quantity of oil spilt, as discussed on chapter 11. The investigation does not include an assessment of harm to the natural environment, since this falls outside the PSA’s area of responsibility. Equinor has told the PSA team that it has classified the incident in risk class yellow 3, short-term environmental impact/spill >weekly expected discharge of component, and as a process safety incident (tier 1). No injury to seabirds or other signs of damage have been observed after the incident.

7.2 Potential consequences

The abnormal position in the produced-water system was detected at an early stage by the CCR operators, and quick action was taken to halt the spill when it was discovered. No alarm notified the CCR operators that produced water being discharged to the sea contained too much oil, and the spill could have continued rather longer if the abnormal position had not been detected by the CCR. However, plant operators are likely to have soon observed the spill since visibility was good and the sea calm, so that oil on the surface was easy to spot. If the spill had not otherwise been detected, it would have been seen when water samples were taken from the flotation cells. This is done every eight hours, but the PSA team considers it unlikely that so much time would have passed. The OiW values might have improved before that, because the emulsions would eventually have been replaced by produced water.

Should large quantities of oil have been spilt to the sea, they are unlikely to have ignited. The oil was stabilised and cools in the sea, which would have meant relatively little degassing. Nor are ignition sources present in the immediate vicinity.

8 Direct and underlying causes

8.1 Direct causes

When starting up Tordis production after a planned shutdown, where the seabed flowlines were circulated out with stabilised oil, the water outlet on Tordis inlet separator 20-VA06B was opened too early. Combined with emulsion problems, this resulted in oil flowing from the outlet, through the produced-water plant and into the sea.

8.2 Underlying causes

The investigation has identified weaknesses in operating Gullfaks C as well as several elements which could have been significant for the oil spill. Along with factors which might be significant for safe operation, these elements are described in the following sub-sections.

8.2.1 Barriers for avoiding accidental spills from produced water

As part of its investigation, the PSA team asked to be provided with Equinor's requirements for barriers to prevent oil spills to the sea via produced water, and was sent an extract from governing document WR1151 *Environmental assessments, discharge curbs and operational follow-up*. This specifies that all facilities must prepare a local best practice for operation and maintenance of treatment plants for produced water discharged to the sea.

This requirement is met on Gullfaks C through operating procedures for the treatment plant under different conditions. Reported OiW values are based on mean values from water samples taken at least three times a day. Equinor also has a requirement for installing online OiW meters, but this applies only to new plants or if major modification projects are to be conducted on existing systems. One online OiW meter is installed on Gullfaks C. Interviews, Synergi reports and SAP notifications show that the online meter is perceived to be useful. It is used to monitor water values and has also been utilised when testing level control.

The 44-AIT-481 online OiW meter was not working during the incident, and has also experienced problems earlier. A notification about this was written on 21 April 2021, but compensatory measures were not discussed. The only comment is a desire to get it working again as quickly as possible since it is used in day-to-day operation. This meter is classified as medium in *Function fail consequence – HSE*.

Uncertainty prevails over whether the oil/water level measurements in the Tordis separators presented actual values or were "polluted" by emulsions during the relevant period when the accidental spill was under way.

In connection with startup after the accidental spill, Equinor developed an internal A standard for level regulation in Tordis separator B. This concluded that the water outlet from this separator cannot be opened until the PSD transmitter for low water level (LT 855) is completely reliable.

8.2.2 Risk assessment of Tordis startup

No systematic assessment of risk associated with the running up was conducted. A detailed work programme and an extensive A standard for the IMR operation were prepared, but these did not cover the subsequent running up.

The PSA team has been told that the operations department held two gatherings in the evening before/early morning of 26 April. Attention there was concentrated on giving the CCR operators space to concentrate on the startup. Based on information obtained from interviews, the team takes the view that other risk conditions associated with the startup were not discussed, and measures to compensate for risks were therefore not assessed either. Nor was there any discussion of known impairments and conditions which could affect produced-water quality during the Epog meeting on the Friday before the startup.

Conditions which could have been significant for risk associated with the Tordis startup include the following.

- It was a known problem on Gullfaks C that corrosion inhibitor injected in the B flowline could create emulsion problems between oil and water, which might prevent their adequate separation in the separator. It was therefore important that the water outlet was not opened too soon. The MEG injected in the subsea facility to inhibit hydrate formation during a shutdown can also pose challenges for level control of OiW. According to the operating procedure, Tordis separator B has previously tripped because the return of MEG caused

level problems. Had this been discussed in advance, it could have concentrated greater attention on not opening the water outlet too early.
- The online OiW meter was not working, with a notification of this written only four days before the startup. Had the meter worked, the CCR would have been alerted to the rise in OiW values so that the incident was detected sooner.
- Level measurement/control for the oil/water interface in Tordis separator B was unstable, with several notifications written on this. Had this been discussed in advance, more attention would have been paid to produced water during startup.
- Big leaks in level valves for Tordis separator B.
- A large number of PSD functions were overridden during startup. See also section 8.2.4.

8.2.3 Updating of and detail in system descriptions and procedures

As described in section 4.4, the level of detail varied between the procedures received by the PSA team, and parts of the system descriptions had not been updated.

The level of detail in the startup procedures for Tordis is limited, particularly for system 20 covering the inlet separators. On its own, the procedure fails to provide sufficient support in startup conditions. Important information is thereby largely based on experience and not written down. An example relevant to the incident is that corrosion inhibitor is continuously injected into the B flowline during a shutdown of the Tordis subsea facility to prevent hydrate forming in the injection line. The startup procedure does not describe what challenges this can create for separation in Tordis separator B when the inhibitor plug arrives, and what needs attention when starting up. A practice has been established of waiting to open the water outlets from the separators until water has been detected in measurements downstream of the oil outlet, but this is not described in the procedure.

Great variation exists in how updated the system descriptions are. These documents are important both for those operating the facility and for those following up its technical integrity.

An inadequate level of detail in descriptions and preconditions for safety functions may contribute to insufficient knowledge among the people responsible for following up the system, and to important safety functions thereby being followed up incorrectly.

The PSA team's understanding is that the SO documentation is not updated periodically. Such updating follows proposals made or modification projects. Ownership of operating documents is allocated to roles which can be shared by many people, such as the O&M leader, or by only a few, such as the asset integrity (AI) leader.

New AI personnel with system responsibility face an additional challenge because they must both familiarise themselves with the SO documentation and be responsible for getting it updated.

During the investigation, the PSA team was told that a common way of obtaining information about the structure and working of the system is to talk with somebody who knows a lot about the facilities. It was explained that Gullfaks C faces a change in generations, and that much knowledge will disappear with those retiring. Updated SO documents provide a means of preserving knowledge and experience, and are important for training and familiarisation.

8.2.4 Working conditions for CCR operators

When preparing to run up Tordis, it was agreed to reduce the number of activities in the process plant so that the CCR operators had the time to concentrate on the startup. The PSA team has been informed that the CCR was quiet until the incident occurred. As noted above, however, impairments exist in the process plant which the team believes can increase the load and negatively affect the way operators handle incidents and operate the facility.

- The PCS is configured in such a way that it is unable to regulate the liquid level in the Tordis separators within the permitted limits during startup.
- A large number of automatic shutdown functions were disconnected during the startup and required manual action. See also section 8.3.1.
- A screen envelope with inaccurate information on oil control valve leaks in Tordis separator A was on the display during startup.
- The startup procedure was insufficiently detailed to provide necessary support during the operation.
- Lengthy intervals can pass between each time the CCR operators start up Tordis, and simulator training is not available to them.
- Since the OiW meter for produced water was not working, the operators received no alert when oil flowed to the sea with the produced water.
- The PSD transmitter for low water level in Tordis separator A did not work during startup, and the corresponding transmitter in separator B was overridden.
- Repeated problems have been experienced with water-level transmitters in the Tordis separators.
- The CCR has a high level of standing alarms.

8.3 Other conditions significant for safe operation

The conditions described in the following sub-sections are not seen as underlying causes of the accidental spill, but have been identified by the PSA investigation as possibly significant for safe operation.

8.3.1 Overriding PSD functions

As described in section 6.3, a large number of PSD functions in the process safety system were overridden for the Tordis startup. That included virtually all such functions for liquid levels in the Tordis separators. Overriding PSD functions means that alarms only are received by the CCR, which must then shut down manually. Manual actions should be avoided as far as possible because they are less reliable than automatic responses. Alarms can be overlooked, and response times from alarm to action may be too long to prevent a leak. That applies particularly if several operating disruptions or incidents occur simultaneously.

As described in section 4.2, Equinor’s governing documentation permits non-critical PSD functions to be overridden in a startup. What counts as “non-critical” is unclear. During the startup, PSD functions were overridden because of the greater likelihood that the incident they protected against would occur. Shutdown in the event of low oil level was overridden, for example, and the CCR operators had to shut the oil outlet manually several times during the startup. PSD functions must not be disconnected because the circumstances they are protecting against are more likely to occur. On the contrary, it is then particularly important that the safety functions are connected and function as intended.

During the startup, one of the two PSD functions for high liquid level was overridden. The investigation has been unable to establish why one was overridden when the other remained active.

The PSD function for low water level (intended to prevent oil in the water outlet) in Tordis separator B was overridden without it being clear why this was done. However, the overriding was not significant for the incident, because no level low enough to trigger a shutdown signal was measured. The knowledge that the return of both corrosion inhibitor and MEG from the subsea plant could cause oil-water separation problems after a shutdown made it particularly important that this function was not overridden during startup. After the incident, Equinor concluded that the water outlet from Tordis separator B had to be closed because this PSD function did not work as intended.

Overriding PSD functions was not a direct reason for the oil spill to the sea. The CCR operators took manual action in those cases were they received PSD alarms, but overriding affects safe operation of the plant.

8.3.2 Process control system

The PCS functions as an “autopilot” which ensures that the process plant is operated within specified limits of pressure, liquid level and temperature. A well-functioning PCS is important for maintaining good process safety. Stable operation helps to reduce the number of process incidents, and thereby the need for PSD functions to shut down the plant. As described in chapter 6, the Tordis separation system in combination with process control caused the oil level in the Tordis separators to be run down below the permitted level during the startup. In this case, automatic shutdown at low oil level had been overridden, and the CCR operators shut down manually. If system control]had been adjusted to suit the startup, the latter could have been implemented with liquid levels within the permitted limits.

8.3.3 Faults in non-safety-critical equipment

Both Tordis separators A and B had experienced large internal leaks in their control valves for both water and oil level. The control valves for separator A had been repaired, but those for separator B were behind schedule for repair. Although the valves are not defined as safety-critical, substantial leaks in these – estimated at up to 45 m^3/h – create operational challenges.

Where the Tordis separators are concerned, valve leaks will increase the probability that the liquid level falls so that oil can escape to the water outlet and gas to the oil outlet. The workload for the operators increases, and more things must be taken into account in operating the plant. In this case, the internal leaks in the control valves were the reason why the PSD functions for low liquid level were overridden. It is therefore important that such considerations are taken into account when setting repair deadlines and when defining what can be considered acceptable leak rates – even if the valves themselves are not defined as safety-critical equipment. As mentioned above, Equinor had assessed the leaks as so large in this case that the valves had to be repaired.

9 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.

9.1 Nonconformities

9.1.1 Overriding the process safety system

Nonconformity
PSD functions which should have been active in the process safety system were overridden.

Grounds
When starting up process equipment, it can be necessary in certain cases to override automatic PSD functions until normal process conditions obtain. With the Tordis

startup, this was done with PSD functions which should not normally be overridden, such as:

- low oil level in the Tordis separators
- low water level in Tordis separator B
- low oil level in the oil collector in the degassing tank for produced water.

Equinor's governing document states that input signals in the PSD system can be blocked when running the process up or down, for example, if these are non-critical and last such a short time that they can be activated and reinstated by the same person without leaving the CCR. In this case, critical PSD functions have also been overridden for long periods.

The Equinor guidelines do not make it clear what is meant by non-critical PSD functions.

A WP is required if critical PSD functions are to be overridden, which includes an assessment of compensatory measures. That was not done for overrides in this startup.

Requirement
Section 26 of the activities regulations on safety functions

9.1.2 Deficiencies in safety and operating documentation

Nonconformity
Inadequate updating of technical operating documents and level of detail in procedures.

Grounds
Startup procedures for Tordis have a limited level of detail related to equipment on the platform. By themselves, they do not provide the necessary startup support, and important information which calls for action during a startup is not described. That applies, for example, to handling challenges with oil/water separation during startup, and a description of necessary overrides of PSD functions.

Operating documents received which describe system 44 reveal that they have not been updated and contain inaccurate information. Changes to operating preconditions and requirements are not reflected, and inconsistencies exist between the various documents. Examples include:.

- the description of the produced-water separators differs between the documents – one describes them as identical, while the other gives them different functionalities and capacities
- requirements for water purity do not accord with current discharge requirements

- the method for skimming the produced-water separators does not accord with today's practice
- the description specifies that two 100 per cent level control valves are installed on the water outlet from the Tordis separators, but both are now in use.

Inadequate updating of technical operating documents was also noted by the PSA following an audit of barrier management on Gullfaks C in 2014.

Requirement
Sections 20, litera b and 24 of the activities regulations on startup and operation of facilities and on procedures respectively

9.1.3 Lack of risk assessment when starting up Tordis production

Nonconformity
No systematic assessment was made of risk associated with starting up Tordis production.

Grounds
Known conditions existed which could cause challenges with emulsion, level control and identifying high OiW values. These were not covered in the start-up procedures nor systematically assessed or compensated for.

- MEG and corrosion inhibitor injected in the B flowline can create oil/water emulsion problems. Since this may mean that oil and water are not adequately separated in the separator, it is important that the water outlet on Tordis separator B is not opened too early.
- The online OiW meter did not work. A notification of this had been written four days before the startup.
- Level measurement/control for the oil/water interface in the Tordis separator was unstable, and several notifications had been written on this.
- The control valves had high leak rates, which affected level control in Tordis separator B.

Requirements
Section 29 of the activities regulations on planning and section 5 of the management regulations on barriers

9.2 Improvement points

9.2.1 Regulation of the process plant

Improvement point
Process control for liquid levels in the Tordis separators is not tailored for startup, thereby increasing the probability of process incidents.

Grounds
When starting up the Tordis separators, the PCS cannot manage to control the oil level in the separators within the permitted limits in the startup phase. The oil level falls so low that the PCS will initiate shutdown.

The regulations require the responsible party to select technical, operational and organisational solutions which reduce the likelihood that harm, errors and hazard and accident situations occur.

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

9.2.2 Use of information envelopes on displays in the CCR

Improvement point
It is unclear whether the use of information envelopes on operator stations in the CCR provide sufficient support for the CCR operators.

Grounds
Information envelopes posted on the displays provide good support for the operators in keeping track of impairments in the process plant and informing them of actions required to deal with these. However, the displays contain a large number of envelopes, and the one reporting a leak in the oil-level control valve in Tordis separator A had not been updated on the display. No description has been established concerning which information is to be posted as an envelope on displays.

Requirement
Section 15 of the management regulations on information.

10 Barriers which have functioned

When the incident occurred and the pressure in the produced-water separators rose, the CCR operators detected this. They took action and sent the plant operators to check the produced-water system. The oil spill was discovered and halted.

11 Discussion of uncertainties

11.1 Size of the spill

The quantity of oil discharged to the sea in produced water was not measured during the incident. This volume has been estimated on the basis of how much produced water was discharged during the discharge period, and the quantity of oil found in the water samples taken when the spill was discovered. The PSA team does not know how much oil was in the produced water before the samples were taken but, based on the quantity of oil produced from Tordis separator B when the discharge occurred, it takes the view that the amount discharged presented by Equinor seems reasonable even though the spill could have been both larger and smaller than the estimate.

11.2 Cause of the spill

It seems probable that the spill was caused by oil/water emulsions which formed because of the large quantity of corrosion inhibitor which most probably entered separator B during the same period that the water outlet was opened. The pressure buildup in the produced water separators indicates that oil from the wells had begun to flow into the separator, and that the stabilised oil had been produced out. The inhibitor was then produced into Tordis separator B. However, it cannot be excluded that faults in the water-level transmitters also contributed to the incident. Problems have occurred with these transmitters before and, after the incident, the water outlet was closed because confidence no longer prevailed that the PSD transmitter for low water level functioned as it should.

12 Assessment of the player's own follow-up

The PSA team has been given a presentation of how the actual incident was handled, and how Equinor has followed up in Synergi so far. It has registered the following actions:

- seek to achieve faster delivery of new water measurement, using a new measurement principle, for 20-LT853
- communicate lessons learnt from the incident to all shifts, and discuss updating operating procedure SO 05520 (system 20)
- update operating procedure SO 05520 based on input
- install OiW meters on both flotation cells
- develop a written A standard to be placed in the production portal before the next time Tordis is run up
- establish a plan for simulator training on startup scenarios.

Equinor is conducting a level-3 investigation of the incident. The PSA report will be published before this is completed, and the team will review Equinor's report when it becomes available.

13 Other comments

13.1 Simulator training

The PSA team has been informed that a joint project is under way on Gullfaks to establish a process simulator, to be completed in the summer of 2021, and that efforts are being made to obtain a dedicated simulator station on Gullfaks C. This report has noted that weaknesses exist with SO documentation. See section 8.2.3. Startup procedures with the right level of detail combined with simulator training for

CCR operators will make a useful contribution to safe startup. That applies particularly to activities which seldom occur, such as starting up Tordis after a lengthy shutdown.

14 Appendices

Appendix A – list of documents
Appendix B – overview of personnel interviewed