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BAT ASSESSMENTS

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TABLE OF CONTENTS

1 SUMMARY

Best Available Techniques (BAT) is the overriding principle for implementing environmental protection in design.

A BAT checklist was filled out in the environmental review performed 17th March 2022. The degree of compliance of what is considered as BAT to be documented. All items were identified to be compliant or partly compliant with BAT.

The following sections describe assessments performed and measures implemented contributing to either lower energy consumption or reduced emissions/discharges. Environmental requirements applicable for UPP system design are tabularized at the top of each section.

Table 1. BAT assessments for Krafla field

Topic	Environmental aspects	Measures in design
Energy	Reduce power demand	Bundle heating
Emissions to air	Diesel exhaust from drilling rig	
Discharges to sea	Discharge of hazardous chemicals	Environmentally friendly chemicals shall preferably be used Corrosion resistant alloys are used for piping and equipment
	Discharge of oil	Treatment and injection of produced water at PdQ

Table 2. BAT assessments for Krafla UPP

Topic	Environmental aspects	Measures in design
Energy efficiency	Minimize power demand	VSD on gas compressors and liquid export pumps Rebundling of gas compressors when well pressure drops
Emissions to air	Generally low CO_2 emissions	Power from shore Flaring only when emergency blowdown and PSV's blow off
	Minimize emissions of VOC	Hermetically sealed compressors
	Avoid emissions of SF_6	An environmentally friendly alternative will be used in GIS
Discharges to sea	No discharge of produced water	Water is routed to the PdQ for treatment and injection
	Treated drainage water	Oil/water separation due to gravity and residence time. Oil and oil-soluble chemicals to be skimmed off. Treated water (OIW <29 mg/l) is discharged to sea.
	Minimum discharge of hazardous chemicals	Low concentration of hypochlorite in returned seawater. Injected chemicals will be exported with liquid to the PdQ. Sea water lift pumps without any oil/seal imply no discharge.

The report does not cover emissions and discharges related to onshore power generation, drilling, subsea, SOV or marine operations.

Reference is made to the environmental budget for quantification of the environmental impacts [19].

2 HOLDS

Well clean-up study (Aibel/Equinor) [12]

Study for measuring Oil in Water concentration in open drain caisson (Aibel)

Driver selection study (Aibel) [8]

Update Functional and Design Requirements (FDR) (Equinor) [2]

3 ABOUT THE PROJECT

Krafla is mainly a gas/condensate field, with above 65% of total expected oil equivalents being gas. The Krafla reservoirs are complex, with large fluid variations. The field shall have power from shore.

Krafla field development consists of three drilling locations or Subsea Production Systems (SPS); Krafla, Sentral and Askja. The Krafla and Sentral areas are produced via one production pipeline to Krafla Unmanned Production Platform (UPP). The Askja area is produced via another production pipeline to the UPP. The UPP and the SPSs will be operated from Krafla Onshore Operation Centre (OOC).

Production from most oil reservoirs will be assisted with water injection for increased recovery. Oil producers will be assisted by gas lift. Gas reservoirs are produced with natural depletion. Fault blocks with minor oil reserves and gas reservoirs are produced by natural depletion.

NOA PdQ shall be host for the UPP and supply support systems and services needed to operate the Krafla field.

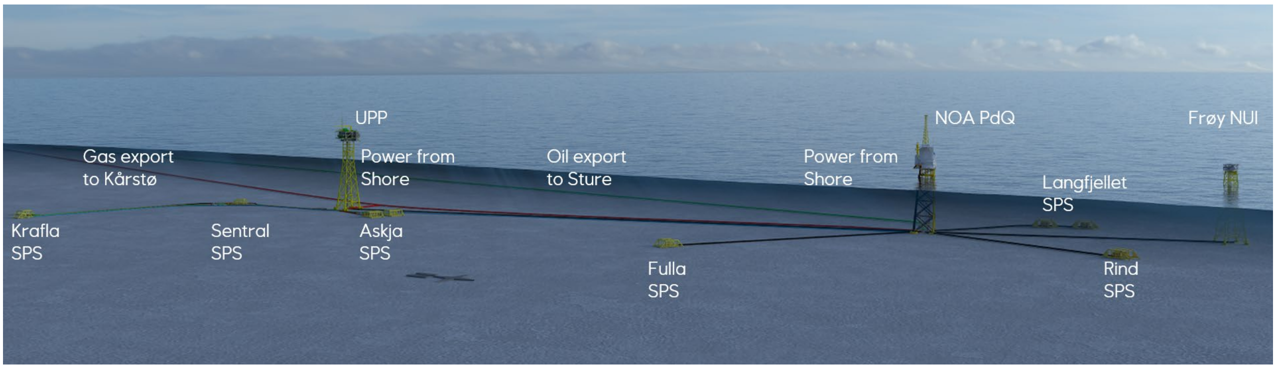


Figure 1. Krafla field development

The UPP will produce gas which is exported directly to Statpipe pipeline. Produced oil and water will be exported to the PdQ. Field lifetime is 25 years. Production efficiency target is 85% for the UPP and the SPS. Planned start-up is in 2027.

The field shall have power from shore.

During maintenance periods, where the SOV is connected, utilities like fresh water, compressed air and nitrogen are available from the SOV.

4

4 ABBREVIATIONS

BAT	Best Available Techniques
CH_4	Methane
CO_2	Carbon Dioxide
D2O	Design to operate
DEH	Direct Electrical Heating
DP	Dynamic Positioning
EIF	Environmental Impact Factor
FDR	Functional and Design Requirements for Krafla UPP Topside
GIS	Gas-Insulated Switchgears
GWP	Global Warming Potential
HC	Hydrocarbons
HEI	High Energy Ignition system for flaring
HOCNF	Harmonised Offshore Chemicals Notification Format
HP	High Pressure
HPU	Hydraulic Power Unit
HVA/C	Heating, Ventilation and Air Conditioning
JS P1	Johan Sverdrup processing platform 1
LED	Light-Emitting Diode
LP	Low Pressure
MEG	Mono Ethylene Glycol
MSL	Mean Sea Level
nmVOC	Non-methane VOC
NOA	North of Alvheim
NOROG	The Norwegian Oil and Gas Association
OOC	Onshore Operation Centre
OPEX	Operating Expenses
OSD	Oil Spill Detection
OSPAR	Oslo and Paris conventions for protecting the marine environment of the North-East Atlantic
PdQ	Production, (mobile) drilling, Quarter (Aker BP host platform)
PLONOR	Pose Little or No Risk to the Environment
PSV	Pressure Safety Valve
SBS	(Krafla) Safety Barrier Specification
SF6	Sulphur Hexafluoride
SOV	Service Operation Vessel
SPS	Subsea Production System
SURF	Subsea, Umbilicals, Risers and Flowlines
TEG	Tri Ethylene Glycol
UPP	Unmanned Production Platform
UPS	Uninterruptable Power Supply
VOC	Volatile Organic Compounds (including methane)
VSD	Variable Speed Drive
Y1	Chemicals that biodegrade completely
Y2	Chemicals that biodegrade to products not environmentally hazardous

5 REFERENCES

[1] PM786-PMS-050-001 Design Basis Krafla, Rev. 05, Draft, valid from 2021-10-01

[2] PM786-PMS-052-001_02 Krafla UPP Topside Functional and Design Requirements, Ver. 2, 2021-11-19

[3] MM-4504051527-PM786-00006 Krafla UPP environmental review

[4] NOROG GL 044 Recommended guidelines for emission and discharge reporting (2015)

[5] NOROG Appendix B to GL 044 Handbook for quantifying direct methane and nmVOC emissions (2020)

[6] Environmental risk-based leak detection philosophy for the Krafla field development in the northern part of the North Sea, DNV report 2021-1128, Rev. 00

[7] C243-AI-E-LA-00001 Electrical load list Krafla field

[8] C232-AI-R-RA-00006 Driver selection study

[9] C232-AI-P-RA-00045 Technical note - Achievable gas dehydration temperature

[10] C232-AI-P-FD-00002 Flare philosophy

[11] C243-AI-P-LA-00002 Field utility load list

[12] C232-AI-P-RA-00034 Well clean-up study report

[13] C232-AI-T-RA-00002 Study report ISPAS Omnia radar

[14] C232-AI-P-RA-00007 Process and utility system report

[15] C243-AI-M-RA-00001 Materials selection report

[16] C243-AI-M-RA-00002 Corrosion protection and insulation report

[17] C232-AI-P-RA-00040 Technical note: Open drain

[18] C232-AI-S-RA-00014 Waste management plan

[19] C232-AI-S-RA-00013 Environmental budget

6 REQUIREMENTS AND GUIDELINES

Krafla design shall meet the requirement of zero harm to the environment by selecting BAT solutions - minimising energy demand, chemical consumption, discharges to sea, emissions to air, and waste production.

6.1 Acts and regulations

FOR-2020-01-10-39 The Activities Regulation

6.2 Company requirements and guidelines

TR1011 Environmental requirements to the design of offshore installations for drilling and production of petroleum, including pipelines, rev. 8 (draft)

TR1668 Prohibited and Restricted Chemicals, rev. 3.01 and 3.02 (2020)

TR3500 Process system design, rev. 1 (2021)

GL0300 Guideline for evaluation of Best Available Techniques (BAT), rev. 1.01 (2019)

GL0449 Identification and handling of environmental aspects, rev. 1.01 (2019)

GL0093 Guideline for quantification of CO_2 intensity, CO_2 emission reductions and abatement cost, rev. 03 (2021)

6.3 Other requirements and guidelines

NORSOK S-003 Environmental care (2017)

NORSOK Z-015 Temporary equipment (2012)

7 EXTERNAL ENVIRONMENT REVIEW

An external environment review was performed 17th March 2022 with participants from Equinor and Aibel. Scope was to evaluate environmental hazards and identify significant environmental aspects and ensure that design is according to BAT (= Best Available Techniques). Participant list, presentation with BAT check lists and actions are summarised in a Minutes of Meeting [3]. Actions are followed up by relevant disciplines in Aibel and Equinor and dealt with in this report.

The completed BAT checklists are attached in section 12.4.

8 KRAFLA FIELD

This chapter deals with BAT assessments performed for the Krafla field including Subsea, Umbilicals, Risers and Flowlines (SURF).

8.1 Drilling and well operations

Source	Section	Content
Activities reg.	68	Drill cuttings, sand and other solid particles shall not be discharged to sea if the attachment of base fluid in organic drilling fluid or formation oil is more than ten grams per kilo of dry mass. The operator shall have a permit under Chapter 3 of the Pollution Control Act (in Norwegian only) for the discharge of cuttings if the attachment of base fluid in organic drilling fluid is equal to or less than ten grams per kilo of dry mass. Drill cuttings with pendants of water-based drilling fluid, and sand and other solid particles may be discharged to sea if the content of formation oil is equal to or less than ten grams per kilo of dry mass, unless otherwise permitted by the Pollution Control Act Chapter 3. Chemicals that accompany cuttings, sand or other solid particles at sea shall be subject to a permit to discharge, cf. Section 66, first subsection
Activities reg	69	The operator shall plan and conduct the activity at the formation testing, clean-up and start-up of production wells to minimize emissions to air and sea
TR1011	6992	Mitigation measures for handling of drilling fluids that cannot be reused and cuttings shall be identified, assessed and implemented in accordance to the BAT principle.
TR1011	62903	The selection of drilling fluid shall minimise chemical consumption and environmental impact.
TR1011	62904	The design shall facilitate the reuse of drilling fluid
NORSOK S-003	6.7	Well clean-up operations shall be planned so that overall emissions to air are minimised.
NORSOK S-003	7.5	The drilling fluid shall be selected to minimize chemical consumption and environmental impact

Krafla field development has three drilling locations or Subsea Production Systems (SPS); Krafla, Askja and Sentral. Krafla and Askja will both have two subsea templates with slots for 6 wells while Sentral will have one subsea template with slots for 6 wells. Altogether, there will be 26 gas and/or oil producer wells and 4 wells for water injection (see section 12.1).

8.1.1 Emissions from drilling

An anchored semi-submersible drilling rig will be used [1]. According to GL0093, anchored and jack-up rigs have lower emissions than Dynamic Positioning (DP) rigs, however the latter will often use shorter time for the drilling operation. The emissions depend on the drilling operation time and the daily diesel consumption of the rig.

8.1.2 Drilling fluids

All wells are planned drilled with water-based system for the 42” and 26” top-hole sections. For some of the wells, water-based system is also planned in the 17 ½” sections. This is based on section lengths and inclination criteria.

8.1.3 Drill cuttings

When water-based system is used for drilling the wells, cuttings with drilling fluid adhered will be discharged to sea. Sections based on oil-based drilling fluids shall be transported to shore for further treatment [1].

8.1.4 Well clean-up

Production wells are planned to be cleaned up by backflow to host/NOA PdQ using the UPP production system, and further to shore. The water injectors will be cleaned up by backflow to the UPP separator and further to the PdQ. A well clean-up study is ongoing [12].

8.2 Chemicals

Source	Section	Content
Design Basis	3.9.1	Chemical selection shall be based on BAT principles. Black chemicals shall not be used. Red chemicals shall be avoided. The use of yellow chemicals impacting EIF shall be minimized. Harmful chemicals shall be replaced by green/yellow chemicals, if possible.
FDR	58536	All chemicals shall be imported from NOA PdQ through a common umbilical to Krafla UPP™ for further distribution.
FDR	53698	Environmentally friendly cleaning detergent shall be used
TR1011	7000	Facilities, equipment, systems and processes shall be designed and operated to avoid, minimise, and control adverse impacts to the environment from use of chemicals and additives. Mitigating measures to manage chemicals and additives shall be identified, assessed and implemented in accordance to the BAT principle
TR1011	7001	Chemicals shall be selected based on results of hazard and risk analyses, and availability of less hazardous substitutes. Chemicals containing substances of very high concern listed in Prohibited and Restricted Chemicals (TR1668) shall not be used.
NORSOK S-003	7.7	System design and operation shall minimize chemical consumption and allow for use of less hazardous chemicals.

The Krafla reservoirs are complex, with large fluid variations. Several chemicals are required for production [1]. NOA PdQ shall supply chemicals needed to operate the Krafla field. In the table below, the suggested chemical products are categorised according to the Harmonised Offshore Chemicals Notification Format (HOCNF). Some red chemicals may not be possible to substitute. Except from the antifoam and the asphaltene inhibitor, the chemicals are water soluble. For additional information about the tentative chemicals, see section 12.3.

Table 3. Production chemicals [1]

Function	Typical product	HOCNF category	Comment
Hydrate inhibitor	MEG	G	PLONOR
Gas treatment	TEG	Y1	Biodegrade completely
Hydraulic fluid	Oceanic ECF	Y1	
H_2S scavenger (future)	HR2709	Y1	
Asphaltene inhibitor	Flotreat 3216	Y2	Biodegrade to products not environmentally hazardous
Scale inhibitor	SCAL12896A	Y2	
Antifoam	DF9020	R	Environmental hazardous chemicals/substances
Barrier fluid	Glythermin P44	R	
Antifouling	Hypochlorite	R	
Corrosion inhibitor	Unknown	Y / R (typically)	

The injected chemicals will after separation at the UPP follow the liquid (oil and water) to PdQ. The barrier fluid (red and costly) may be used as seal in the liquid export pumps. An alternative seal system using water, is considered. As far as possible all functions, safety, process and utility shall be covered by electrical actuators. It has been a challenge to find suitable electrical actuators for all use and applications (control valves, anti-surge valves). Alternatively, electro-hydraulic actuators would be required.

8.3 Pipeline heating

Heating is mainly required for the infield production flowlines to prevent formation of hydrate. The heating system will normally not be in operation, as it will only operate during shut down and possibly when the flow is low.

Base case is a hot water circulation system topside [1], with a 30 wt% MEG in water solution used as heating medium in the bundle. Total volume is approximately 250 m^3. Main equipment are one circulation pump (0,14 MW, fixed speed), one electric heater (1,65 MW) and one expansion tank. Batch dosing of a corrosion inhibitor may be required. The system will be in operation only during a platform trip or planned shutdown.

The hot water circulation system requires less energy than Direct Electrical Heating (DEH), which is an alternative solution with about 3MW duty.

8.4 Subsea leakage detection

Source	Section	Content
Activities reg.	52	The operator shall monitor the external environment. The monitoring shall be adapted to the existing pollution risk, be able to prove and map pollution of the external environment and indicate development trends in the environmental condition.
Activities reg.	57	The operator shall have a system for detecting acute pollution.
Design basis	3.9.2	Equipment for detection of oil spills from subsea and topside facilities shall be part of the design.
Krafla SBS	6.3.4	The subsea leak detection function shall cover the subsea production system from well to platform including intrafield systems. It shall also cover offloading pipelines and offshore export pipelines. It shall detect leaks that may represent risk of harm to people and/or the environment.

DNV has performed a subsea leak detection philosophy study for the Krafla field [6]. Functional requirements i.e. minimum time to detect leaks for the different locations and scenarios were proposed based on the environmental risks using the risk matrix and general Equinor tolerance criteria. BAT screening of leak detection techniques was executed as basis for proposing relevant techniques to comply with these functional requirements. In line with Equinor best practice functional requirement specifications for the different technologies are currently being prepared. For the infield flowlines (bundle), a more thorough assessment of detection technologies has been initiated.

For information regarding leakage detection on UPP, see section 9.7.

8.5 Material selection

Source	Section	Content
TR1011	68558	Materials for process equipment should be selected to avoid use of corrosion inhibitor
NORSOK S-003	7.11	Material for pipelines shall be selected to minimize impacts on the environment.

For the Krafla field, corrosion resistant alloys are used for piping and equipment [15]. This also includes pipelines and risers with corrosive fluids. To meet the required lifetime, coating shall be as described in the Corrosion protection and insulation report [16].

8.6 Produced water

Source	Section	Content
TR1011	6971	Concepts, facilities, equipment, systems and processes shall be developed, designed and operated to avoid, reduce or control discharge of produced water in order to minimise adverse environmental impacts. Mitigating measures shall be identified, assessed and implemented in accordance to the BAT principle and documented in the BAT assessment report

After separation at the UPP, the produced water will be exported to the PdQ for treatment and injection.

Barium content in produced water is high (ranging from 103 to 1533 mg/l) and shall be analysed and reported [4].

8.7 Produced sand

Source	Section	Content
TR1011	6997	Mitigating measures to manage produced sand shall be identified, assessed and implemented in accordance to the BAT principle.
TR1011	15933	Produced sand shall not be discharged to sea except when oil concentration is lower than 1% by weight on dry sand.
NORSOK S-003	7.6	Production process design shall include sand handling measures when sand production is foreseeable.

During well clean-up following shut-in periods some small level of extra sand production may be expected due to reorganization of partial sand pack around screen and reformation of particle bridges over screen opening [1].

The vertical inlet separator at UPP may be flushed to avoid sand collection. The sand will follow the liquid stream to PdQ. No sand will be discharged to sea.

Well completion shall keep sand production within the required limit of 10 ppm of fluid weight.

8.8 Exhaust from SOV

The UPP will be entered by Service Operation Vessel (SOV) during maintenance campaigns. The electrical load will be ≈0,7 MW. Exhaust from SOV/diesel engines, when located by UPP, to be included in the environmental budget.

9 KRAFLA UPP

This chapter deals with BAT assessments related to design of the UPP. The Krafla UPP process mainly consists of:

- one inlet separator
- two liquid export pumps pumping oil and water to NOA PdQ
- two stage gas compression and gas de-hydration
- an open relief and vent system, including a knockout/closed drain drum
- seawater system consisting of lift pumps, filter, and circulation pumps
- hypochlorite production on site
- chemical distribution to subsea consumers

9.1 Energy management

Source	Section	Content
Design basis	9.8	Krafla UPP will receive electrical power from Shore through NOA PdQ.
TR1011	6953	Facilities and systems shall be designed and operated to minimise energy demand and optimise energy efficiency. Mitigating measures shall be identified, assessed and implemented in accordance to the BAT principle and documented in the BAT assessment report.
NORSOK S-003	5.3	The field shall be designed to minimize the energy demand over the entire lifetime of the project.

Krafla will prepare a monitoring strategy with goal that all system/equipment shall be monitored. Production optimization and reduce energy consumption will be important parts of the strategy.

9.1.1 Power supply

The UPP shall receive power from shore; considered to be BAT. The power transmission system is designed for

- main power from shore via PdQ (35 MW)
- emergency power based on local batteries (UPS)
- essential power via PdQ generator (0.5MW)

9.1.2 Engine speed control

All rotating equipment will be electric motor driven, direct drive or Variable Speed Drive (VSD) as required by process conditions. The adjustment of the motor speed with variable speed/frequency drives can lead to significant energy savings. Use of VSD on larger equipment with variable loads is BAT, as for the compressors. Fixed speed has been selected where the benefits of VSD are limited. The main power consumers are shown in table below.

Table 4. Main power consumers. Configuration and driver selection

Equipment	Tag no.	Config.	Duty (MW)	Driver (HOLD)
Liquid export pumps	A-20PA001A/B	2 x 100%	2 x 1,0	VSD
1st stage compressor	A-27KA001	1 x 100%	12,0	VSD
2nd stage compressor	A-27KA002	1 x 100%	12,0	VSD
Seawater lift pumps	A-50PH001A/B	2 x 100%	2 x 0,95	Fixed speed

A driver selection study for major rotating equipment like compressors and pumps, is ongoing in Aibel [8].

9.1.3 Energy efficiency

At the UPP, there is one separator followed by two stage gas compression. Generally, separate trains for LP and HP wells might save energy (considered as BAT) as the gas from HP wells will not have the same need for energy-intensive compression. For the Krafla field, the pressure in the HP wells is dropping continuously and separate trains are therefore not found cost- effective.

Surplus seawater will be used to cool the gas to the 2nd stage compressor to the lowest possible temperature [9].

Turbo-expanders (also called expansion turbines) for utilizing well pressure are not included in design. Turbo expanders are not qualified and applicable for unmanned concept.

The compressors will be re-bundled when the well pressure drops, probably twice during lifetime (considered as BAT).

Light Emitting Diodes (LED) is a highly energy efficient lighting technology which will be used for floodlights and lighting fixtures.

9.2 Flaring and venting

Source	Section	Content
Design basis	3.9.1	Flaring shall be minimized.
FDR	53586	The UPP™ shall have automatic ignition of the flare at emergency blowdown
FDR	53591	The flare system shall not have a closed flare gas recovery system.
TR1011	62868	Concepts, facilities, equipment, systems and processes shall be developed, designed and operated to avoid or minimise emissions to air of greenhouse gases.
TR1011	6960	Cold venting (emitting collected gaseous stream directly to the atmosphere without burning in flare) shall be avoided. Design shall facilitate routing gas to an efficient flare gas system for emergency events or equipment breakdown, or when facility upset conditions arise. Mitigating measures shall be identified, assessed and implemented in accordance to the BAT principle.
NORSOK S-003	6.3	Flare systems handling high pressure sources (HP) shall be designed to recover the gas during normal operation. Cold venting shall be minimised. The design and philosophy of the flare ignition system shall minimize overall emissions to air from the flare system.

Gas and liquid from the PSVs and blow down valves are routed to an open high-pressure flare system comprising vent piping and header, a knockout drum (A-43VD001) for liquid accumulation and a stack for gas discharge 100 m above the weather deck. The system has no continuous sources. Any leakages in the production system will be cold vented as the flare is normally not ignited. The leakage rate will be low and not measurable.

At emergency blowdown/depressurisations, the gas will automatically be ignited. For calculation of taxes, the gas rate is measured in the Relief Vent Metering Package (A-43JX001). Liquids from knockout drum are pumped back to inlet separator and recovered. To reduce flaring, start-up activities shall be part of operation procedures described in the flare philosophy [10].

The system shall ignite the gas on demand at larger flowrate. An electronic High Energy Ignition (HEI) system (A-43XX002) is planned for, using a capacitor to deliver a high-energy spark. The system requires pilot gas (propane). Fuel consumption associated with the pilot burner shall be minimized to the extent possible without reducing the ability to ignite the gas. The Aasta Hansteen platform have a HEI system working well. Aibel will receive information about their solution for implementation at Krafla. A ballistic ignition system is not compatible with unmanned operation.

Flare gas recovery is considered as BAT. Flare gas recovery requires a separate recompression system. For unmanned installations, a closed system is not feasible due to complexity and availability of technical solution. Besides, there is no low-pressure system to route the gas at the UPP as the process is high pressure. Flare gas recovery system is therefore not installed at the UPP. The UPP has no fuel gas system.

9.3 Fugitive emissions and gas leakages

The methane and nmVOC emissions from the UPP will be relatively low. The main sources will be unignited flare/cold venting, gas leaks in process (valves, flanges, couplings), slipstreams to analysers and gas freeing of process system. Produced water treatment and TEG regeneration, two normally large sources of diffuse emissions, will performed on the PdQ. Reference is made to handbook from The Norwegian Oil and Gas Association listing potentially VOC emission sources [5].

The UPP concept is based on two emission-free and environmentally friendly compressors: hermetically sealed without any seal gas and lube oil system (no gear box). The compressor package has magnetic bearings and high-speed variable frequency motor drives, considered as BAT.

An environmentally friendly alternative to sulphur hexafluoride (SF_6) will be used as insulating medium in Gas-Insulated Switchgears (GIS). SF_6 is an extremely potent and persistent greenhouse gas, with a Global Warming Potential (GWP) more than 20 000 higher than for CO_2.

9.4 Seawater

Source	Section	Content
TR1011	6979	Cooling water: The cooling water discharge depth should be selected to maximize mixing and cooling of the thermal plume to ensure that the temperature is within 3 degrees Celsius of ambient seawater temperature at the edge of the defined mixing zone, or if the mixing zone is not defined, within 100 meters of the discharge point.
TR1011	62154	The depth of the seawater intake shall be optimised with the purpose of minimising chemical antifouling treatment. Appropriate screens to the seawater intake, should be considered, if safe and practical, to avoid entrainment and impingement of marine flora and fauna.
TR3500	26	The hypochlorite concentrations specified below shall be used to prevent fouling of equipment and piping: Continuous design dosing concentration (equivalent free chlorine): 2.0 mg/l; Residual concentration (equivalent free chlorine): 0.3 to 0.7 mg/l. Residual concentration is measured near the seawater return outlet/dump line.
NORSOK S-003	7.9	The depth of the seawater intake shall be optimised with the purpose of minimising chemical antifouling treatment. The design shall minimize the potential for leakage of hazardous fluids from submerged seawater pumps.

Direct seawater cooling is selected for topside UPP. The two Seawater Lift Pumps (A-50PH001A/B) are submerged centrifugal type (line shaft) with motors located topside. The pumps are located 12m below MSL in a caisson going down to 72m below MSL, where the seawater intake is (considered BAT). The returned seawater is discharged to sea via seawater dump caisson, temperature will be 20-35 degrees. Temperature increases due to return of seawater is not considered to be a problem; design flowrate is 2 500 m^3/h.

The submerged line shaft seawater lift pumps (from Eureka) have no oil/seal circulation line that may go to sea.

9.4.1 Cooling demand

The main consumers are listed in the table below. The exchangers will be fitted with nozzles that may be used for biocide injection. The design capacity of seawater system is 2500 m^3/h.

Table 5. Heat exchangers. Main cooling demand

Hot side	Cold side	Equipment	Tag no.	Duty (MW)
Gas	Seawater	Gas Treatment Inlet Cooler	A-24HA001	15.6
Gas	Seawater	1st Stage Compressor Suction Cooler	A-27HA001	27.2
Gas	Seawater	Gas Export Cooler	A-27HA002	5.9
Gas	Seawater	2nd stage Compressor Cooling Gas Cooler	A-27HA003	1.2

In addition, seawater is used for cooling the compressors VSD (A-27HB001/002), the transformers (A-80ET001, A-27ET001/002) and the HVAC system (A-77GX001/002). To protect the riser and the initial length of pipeline from temperatures above design temperature, the Gas Export Cooler is required from year 2030 when the compression ratio increase.

9.4.2 Antifouling

Filtered seawater is routed to the Electro Chlorination Skid (A-47XX001) where hypochlorite is produced by electrolysis of seawater. The hypochlorite is injected to the suction side of the Seawater Lift Pumps (A-50PH001A/B) to ensure a concentration of 2 ppm at seawater injection point. The injected amount may be adjusted to achieve chorine residual concentration in discharge seawater between 0.3 and 0.7 mg/l (typically). Hypochlorite is a “red” chemical (see Table 3), and the residual concentration of hypochlorite at outlet shall therefore be minimized and controlled by measurements.

A slipstream of chlorinated seawater will continuously be routed to the open drain caisson to prevent biofouling. Glutaraldehyde (ex. Biotreat 7407, yellow) may be added batchwise as backup, also acting as H_2S scavenger.

9.5 Chemicals

Chemicals will be exported from the PdQ to the UPP. The UPP design includes:

- three chemical distribution cabinets (A-42XR001, A-42XR002 and A-42XR004)
- one hydraulic power unit (A-18CT001) incl. a two-compartment storage tank (≈9.5 m^3)

Hypochlorite for antifouling of seawater will be produced onsite in the Electro Chlorination Skid (A-47XX001) – see section 9.4.2. Hypochlorite is a substance in the red HOCNF category due to its high toxicity. The use and discharge of hypochlorite from the UPP shall be regulated in the field's permit in accordance with the Activity regulation.

The UPP has no firefighting system/foam.

9.6 Spill prevention and drainage

Source	Section	Content
Activities reg.	60a	Oily drainage water and other oily water may be discharged to sea subsequent to treatment. The oil content in water shall be as low as possible. In any event, the oil content shall not exceed 30 mg oil per litre of water as a weighted average for one calendar month. Treatment systems shall be operated such that the environmental strain from discharges to sea will be as low as possible.
Activities reg	70	The operator shall measure or calculate emissions and discharges to air and sea, consumption of chemicals and injected volume. The Norwegian Environment Agency can set more detailed requirements for measurements and calculations.
FDR	53691	An open drain water treatment system shall not be installed
FDR	53693	Water from the deck drains may be routed to the open drain tank during cleaning operations but shall normally be routed to sea.
FDR	53692	A drain tank shall be installed to collect drips for minimum 8 months of unmanned operation, and minimum one hour of cleaning operation.
FDR	53695	To prevent overfilling of drain tank, equipment drip trays connected directly to drain tank shall be protected from rainwater.
FDR	53696	Temporary or permanent drip trays shall be located where spills can be expected during maintenance work.
FDR	56463	Open drains going directly to sea shall be clearly marked with paint.
TR1011	6975	Mitigating measures to manage contaminated drainage water and other oily water shall be identified, assessed and implemented in accordance to the BAT principle.
NORSOK S-003	3.1.18	The open drain system shall handle rainwater, firewater, wash down water including spillage from equipment drip trays and bunded areas.
NORSOK S-003	7.3	The facility shall include sufficient drainage for containment of all liquids from decks according to NORSOK P-002.

Alternative design for handling drainage water have been assessed, mainly to ensure that government regulations regarding discharge of oil in drainage water are met. The alternatives were different tank design (located topside) and a caisson (consisting of a pipe submerged into the sea with an open bottom). Evaluations considering environmental, technical, economic and operation (D2O) concluded a caisson was the best solution both for the environment and operation. A caisson has been base case for further design development. Reference is made to a technical note for these evaluations [17].

Grane platform and Johan Sverdrup process platform 1 (P1) have similar drain caissons. The annually reported values of oil-in-water vary from 1 to 7 mg/l, well below the requirements. Measured concentrations for P1 from September 2019 to March 2022 are given in section 12.6. Only 6 out of 141 measurements are above the requirements of 29 mg/l. These exceedances are linked to two incidents; deluge testing and oily drilling fluids sent to open drain by accident Johan Sverdrup process platform 2 (P2) has the same caisson, but the platform is not yet in operation. The treatment system is compliant with BAT, see BAT checklist in section 12.4.

In the Open Drain Caisson (A-56CX001), drainage water will be handled via sloped gravity flow collection headers. The treatment is settling in the caisson where oil is separated from the water due to gravity and residence time. Oil and oil-soluble chemicals (see Table 3) are skimmed off during maintenance. Treated water (including any water-soluble chemicals) goes out at the bottom of the caisson, about 80 meters below the sea level. Rain, deck wash water, liquid spillage and fire water is collected in drain boxes and gullies and routed to the caisson. A guided wave radar will be used to measure the thickness (and volume) of oil layer in drain caisson. According to information received from Equinor, 13 cm is the smallest oil thickness that can be detected. The measurement uncertainty is assumed to be ±3 cm (representing 0,04 m^3). A study for measuring Oil in Water (OiW) content in the lower part of the caisson is ongoing.

Leakages from the HPU skid, the three chemical distribution cabinets and the liquid export pumps (equipment most likely to have spills) will be routed to a 5 m^3 chemical/oil spillage tank (A-56TB001). Reference is made to the Process and utility system report [14].

Any leakage from the oil filled transformers will be collected underneath the transformers. The liquid will be removed by a vacuum cleaner during maintenance.

9.7 Leakage detection

Source	Section	Content
TR1011	6962	Techniques for controlling and reducing leaks and fugitive emissions shall be studied and implemented in design, operations and maintenance. Detection, quantification and repair programs for leaks and fugitive emissions shall be implemented when in operation.
NORSOK S-003	6.5	The selection of valves, flanges, packings, seals and equivalent fugitive sources shall minimize leakage to the external environment

Current design for the UPP includes five 3D Oil Spill Detection (OSD) radar panels (A-86RR011/12/13/14/15) located in platform corners for 360 degrees coverage of oil spill on the sea surface. The system is optimized for oil spill detection from 150m to 3km (4km to be tested) [13].

Robots shall be used for leakage detection topside.

In connection with manual work, organizational barriers are required to prevent spillage and discharge to sea.

9.8 Waste

Source	Section	Content
Activities reg.	72	The operator shall, to the extent possible, avoid that waste is generated. The operator shall prepare a waste treatment plan.
Design Basis	3.9.3	Waste shall be minimized. The facility layout shall have space and logistics for waste management to ensure waste segregation. During maintenance campaigns offshore, all waste shall be segregated and transported to shore.
TR1011	7012	Waste generation shall be avoided. Where it has been deemed not practicable to avoid, waste generation shall be minimised through the design and the choice of materials and chemicals. Where waste generation cannot be avoided, technical and operational measures, including separation, collection and disposal solutions for different classes of waste, shall be implemented to optimise the reuse, material recycling or energy recovery of the waste.
TR1011	7014	Designated waste storage areas shall be provided. The layout shall include space for waste containers for the segregated collection of waste.
NORSOK S-003	9.2	Expected waste categories shall be identified and quantified during design. A waste management plan shall be established. Waste segregation shall be adapted to the receiving onshore treatment solution. The layout shall include space for waste containers for segregated collection of waste locally and centrally and facilitate transport of the containers.

Waste will only be generated during maintenance operations. Containers for segregated waste may be in storage area on weather deck before transport to shore. Generally, waste shall be minimized, for example by choice of materials. Waste minimized through the design and the choice of materials and chemicals is considered BAT.

To ensure long lifetime and reduce the amount of waste, material selection has been highly focussed. The material selection shall be robust, and an extended use of corrosion resistant materials are recommended [16]. Carbon steel will mainly be used for the structural steel. Corrosion resistant alloys shall be used for piping and equipment.

10 INSTALLATION PHASE

Exhaust from temporary diesel generators used for power production is expected.

10.1 NOx requirements

NORSOK Z-015 applies for the stand-alone phase. The standard has a separate section for diesel engines. However, there is no NOx requirement stated.

TR1011 provide minimum performance requirements for emissions from small combustion facilities and thermal power plants. Attached to the TR, there are World Bank General EHS guideline limits applying to facilities operating more than 500 hours per year that may be relevant here.

11 DECOMMISSIONING AND REMOVAL

Source	Section	Content
Design Basis	3.8	Decommissioning and removal are based on authority requirements and available technical solutions. ---- The topside and jacket can then be transported from offshore location and brought to shore for safe disposal.
TR1011	7022	Assessment of alternative disposal options should consider cost, disposal methods and disposal sites. Environmental and social impact, including interference with other sea users, impact on safety, energy consumption and emissions should also be assessed. [Remaining text of requirement.
NORSOK S-003	11.2	During design and modification, design choices shall take into account the decommissioning of the asset. Material and equipment shall be selected and designed with the objective of avoiding the use of hazardous material and facilitating the future reuse or recycling.

To be followed up in the next phase.

12 ATTACHMENT

12.1 Number and types of wells

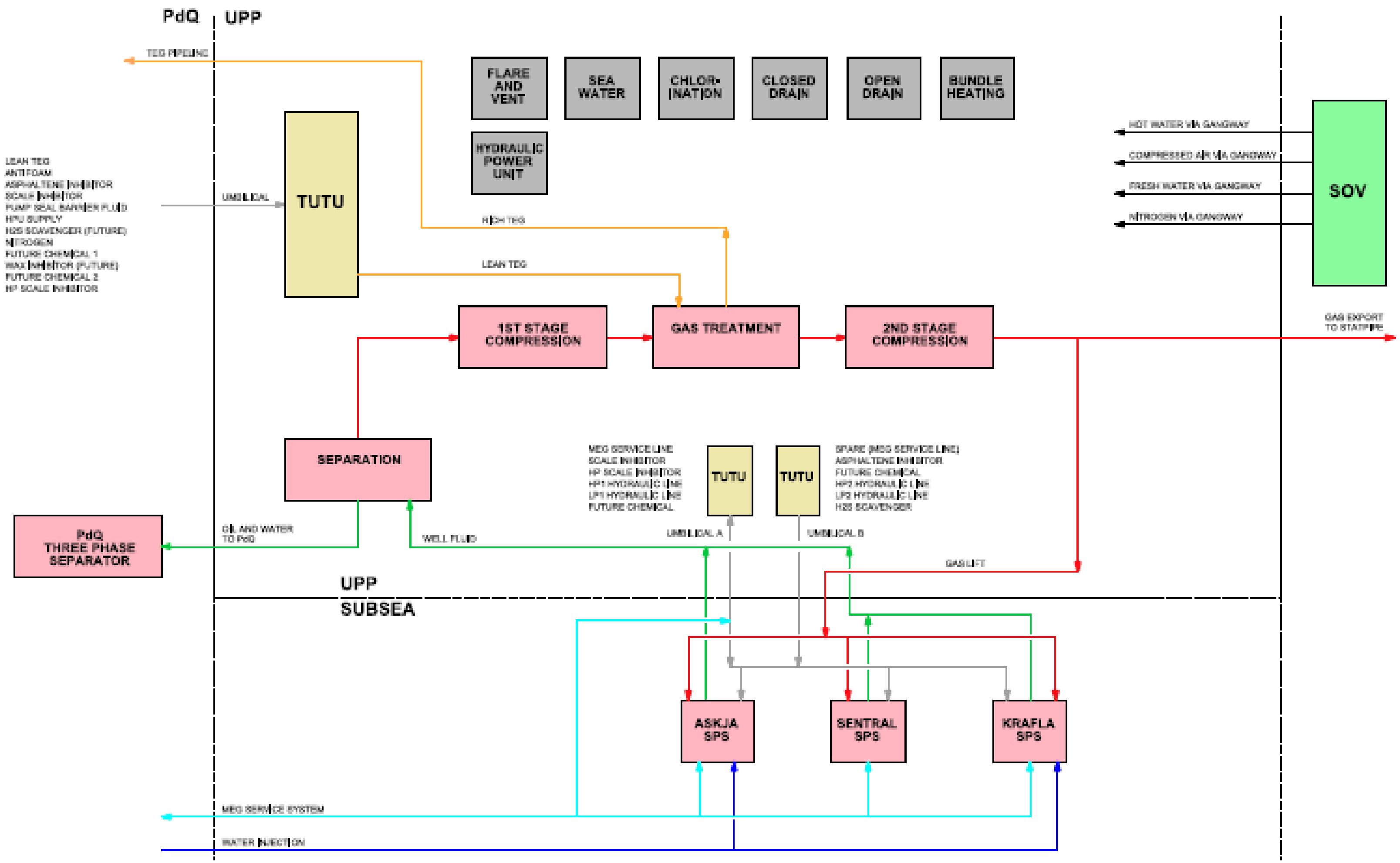
Krafla field development consists of three drilling locations, Krafla, Sentral and Askja. Both on Krafla and Askja, there will be two 6 slot subsea templates (A/B). On Sentral there will be one 6 slot subsea template. Drilling will be started in 2025. Production from most oil reservoirs is assisted with water injection for increased recovery. Oil producers will be assisted by gas lift. Gas reservoirs are produced with natural depletion.

Table 6. Overview wells and type of wells [1]

Location	Well name	Segment	Well type
Krafla SPS A	A5_O1	Krafla Nord	Oil Producer
	A5_W1	Krafla Nord	Water Injector
	A4_O1	Krafla Midt	Oil Producer
	Spare	Prospect future	Water Injector
	A4_W1	Krafla Midt	Water Injector
	A4_O2	Krafla Midt	Oil Producer
Krafla SPS B	A5_G1	Krafla Nord	Gas and Oil producer
	Spare	Prospect future	Gas and/or Oil Producer
	Spare	Prospect future	Gas and/or Oil producer
	A3_G1	Krafla Vest	Gas producer
	A3_O1	Krafla Vest	Oil Producer
	Spare	Prospect future	Gas and/or Oil Producer
Sentral SPS	E4_G1	Beerenberg	Gas producer
	E5_GO1	Haraldsplass	Gas and Oil producer
	D5_G1	Slemmestad	Gas producer
	D4_X1	Haukeland	Gas producer
	H6_X1	Samantha	Gas and/or Oil Producer
	Spare	Prospect future	Gas and/or Oil Producer
Askja SPS A	F2_G1	Askja Vest	Gas producer
	F2_G2	Askja Vest	Gas producer
	D1_X1	Katarina	Gas producer
	G2_W1	Askja Øst	Water Injector
	Spare	Prospect future	Gas producer
	Spare	Prospect future	Gas producer
Askja SPS B	G2_O1	Askja Øst	Oil Producer
	G1_O1	Askja Sørøst	Oil Producer
	H1_O1	Madam Felle	Oil Producer
	E3_X1	Steinbit	Gas and/or Oil Producer
	G3_X1	Askja Nord	Gas and/or Oil Producer
	D0_X1	Magdalena	Gas and/or Oil Producer

12.2 Main process

Block diagram (C232-AI-P-XA-00035-01)



12.3 Chemical properties

Table 7. Chemical properties

Function	Typical product	Water solubility	HOCNF category	G	Y1	Y2	R
Hydrate inhibitor	MEG	100%	G	100%	-	-	-
Gas treatment	TEG	100%	Y1	-	100%	-	-
Hydraulic fluid	Oceanic ECF	100%	Y1	94%	6%	-	-
H_2S scavenger (future)	HR2709	100%	Y1			-	-
Asphaltene inhibitor	Flotreat 3216	≈ 0%	Y2	93%		7%	-
Scale inhibitor	SCAL12896A	100%	Y2	76.5%	-	23.5%	-
Antifoam	DF9020	≈ 0%	R				<1%
Barrier fluid	Glythermin P44	100%	R	10.8%	88.5%		0,7%
Antifouling	Hypochlorite	100%	R				

Green category (G) - Pose Little or No Risk to the Environment (PLONOR)

Yellow subcategory 1 (Y1) - Biodegrade completely

Yellow subcategory 2 (Y2)- Biodegrade to products not environmentally hazardous

Red category (R) - Environmental hazardous chemicals/substances

Reference is made to the Activities regulation, § 63 Categorisation of substances and chemicals

12.4 BAT checklist

A checklist from GL 0300 was filled out in the environmental review performed 17th March 2022 [3]. The degree of compliance of what is considered as BAT to be documented (green = compliant/yellow = partly compliant/red = not compliant). No items were identified to be not compliant with BAT (red). Some items were found not applicable (NA) for Krafla UPP.

Table 8. BAT checklist for Krafla UPP

Topic	Techniques, system design	Comments and References	BAT	Actions/Comment
Energy management	BAT: Optimum number, size and design of turbines		NA	
Energy management	BAT: Well design to minimize water cut and minimize pressure loss	Minimised pressure loss has been considered, standard well size. Multiphase flow meter installed per well; no water cut measurements. Petek are looking into different lower completion solutions like ICD in oil wells, placing swell packers in shale zones and the cased hole functionality, with oriented perforation to delay water breakthrough or/and reduce formation water production. Cased hole-oriented perforation will also have a good effect on minimizing pressure loss. Concept: Two UWPs included in design, which were removed in FEED	NA	To be followed up and evaluated by PETEK
Energy management	BAT: Maximized operating pressure in first stage separator	The separator is adapted to the production in the wells/ wellhead pressure. Based on production profiles, optimised based on technical, environmental and cost considerations. The inlet pressure starts at ≈50 bar and drops ends up at ≈20 bar after 8-10 years of production.	G/Y	
Energy management	BAT: Partly separate process trains for high- and low-pressure wells	Separate trains for LP and HP wells might save energy. At the UPP, there is one separator followed by two stage gas compression. The pressure in the HP wells is expected to drop rapidly, separate trains are therefore not considered cost-effective - related to topic above	G/Y	
Energy management	BAT: Use of turbo-expanders to utilize well pressure	Turbo expanders (also called expansion turbines) are not used in design. Turbo expanders are not qualified and applicable for an unmanned concept at this maturity level.	NA	
Energy management	BAT: Correct sizing of power demanding equipment to achieve maximum efficiency	Re-bundling of compressor as the pressure drops. Replacement of impellers on the liquid export pumps	G	
Energy management	BAT: Use of variable speed drives on larger equipment with variable loads	VSD on main power consumers; gas compressors and liquid export pumps. SW lift pumps will have nearly constant flowrate during lifetime.	G	
Energy management	BAT: Waste heat recovery/process integration to minimize the need for fired heaters or electrical heaters	No surplus heat. Low heat demand, few electric heaters	NA	

Topic	Techniques, system design	Comments and References	BAT	Actions/Comment
Energy management	BAT: Energy use monitoring and control systems to allow optimum operation and tuning.	Krafla/EQN will prepare a monitoring strategy with goal that all system/equipment shall be monitored. Production optimization and reduce energy consumption will be important parts of the strategy. The energy consumption will be measured continuously.	G	
Flaring and venting	BAT: Flare gas recovery systems (recycling of gas from high /low pressure relief systems during normal operation)	No continuous sources to flare. Flare gas recovery requires a separate recompression system.	G	
Flaring and venting	BAT: Planning of start-up activities to reduce flaring;	Start-up activities will be a part of operational procedures/flaring strategy, ref. C232-AI-P-FD-00002 Flare philosophy and C232-AI-P-FD-00003 Process operational philosophy. Must be seen in the context with the field and PdQ	G	
Flaring and venting	BAT: Recovery of hydrocarbon gas used as blanket gas	Hydrocarbon gas will not be used for tank blanketing.	NA	
Flaring and venting	BAT: Avoid use of cold vent (venting of unburned gas)	No continuous sources. High Energy Ignition system used for gas ignition. Ballistic ignition system (back up) removed during Concept phase	Y	Check regularity for HEI system
Fugitive emissions and cold vents	The process system should be designed to minimize emissions to air of hydrocarbon gas from different sections of the system. The gas should be either contained or routed back to the process system, if the pressure level and safety considerations allow this. This is considered BAT. This applies, but is not limited to: ~~• gas from seal oil traps~~ • gas from sampling points • purge gas and leak gas ~~• gas from start-up of the fuel gas system~~ ~~• gas from compressor seals~~ ~~• gas from produced water~~	Some sampling will be required. Sampling shall be performed without use of manually operations where feasible (KRAF-58546). Nitrogen will be used for purging of flare, ref. C232-AI-P-XA-43001-01	Y	

Topic	Techniques, system design	Comments and References	BAT	Actions/Comment
Fugitive emissions and cold vents	Emissions of hydrocarbon gas to the air, including glycol and BTEX, from stripping processes should be minimized. This is considered BAT. This can be done e.g. by use of: ~~• systems that do not require stripping gas (e.g. trace water extraction process)~~ • systems using low glycol concentrations ~~• glycol recycle systems~~ • systems that recover hydrocarbon stripping gas • systems based on vacuum deaeration systems using inert gas	Glycol (MEG) will be used as antifreeze	Y	
Drain system	BAT: Have the number of stages for water from the open drain system been evaluated?	Concept phase: Design included no water treatment system, only an open drain tank with an overflow line to sea. Drain caisson for oil water separation included in FEED. Vendor guarantee the effluent quality will be ≤ 29 mg/l (TR1011). Grane and Johan Sverdrup P1 with similar caissons have reported annual OIW content to be <10 mg/l.	G	To be handled in meeting with the Norwegian Environment Agency (MD) in April 2022
Drain system	BAT: Have injection of contaminated drainage been considered, especially drainage from the drilling area, which may be injected together with contaminated cuttings.		NA	
Chemicals and materials	BAT: Choice of materials not requiring corrosion inhibitor	Corrosion resistant alloys are used for piping and equipment, ref. C243-AI-M-RA-00001 Materials selection report	Y	
Chemicals and materials	BAT: Material selection to limit the use of chemicals.	Corrosion inhibitor may be used in the heating bundle system (closed system, made in carbon steel). must be clarified with SURF. Potential leakages to be followed up	Y	
Chemicals and materials	BAT: System designed with heat tracing to limit use of chemicals.	See point below	Y	
Chemicals and materials	BAT: Direct Electrical Heating (DEH)	To be used for the LP pipeline	G	
Chemicals and materials	BAT: Use of environmental friendly chemicals	Design basis: Chemical selection shall be based on BAT principles. Black chemicals shall not be used. Red chemicals shall be avoided. The use of yellow chemicals impacting EIF shall be minimized. Harmful chemicals shall be replaced by green/yellow chemicals, if possible.	Y	
Cooling water	BAT: Has the intake of cooling water (depth) been optimized with respect to minimize the need for use of chemicals to prevent marine fouling, i.e. growth of algae, mussels, etc.?	Seawater intake is 72 m below MSL. Outlet temperature from coolers is 35-40°C	G	

Topic	Techniques, system design	Comments and References	BAT	Actions/Comment
Waste	BAT: Has waste been minimized through the design and the choice of materials and chemicals?	During maintenance campaigns, waste handling units to be located on Weather Deck as needed. No permanent waste containers on the UPP. Waste shall be transported to shore by SOV and handled according to Norwegian regulations. Ref. C232-AI-S-RA-00014 Waste management plan. Preferably use tote tanks for handling/transport of chemical spill/waste	G	
Waste	BAT: Discharge of slop water to sea.		NA	
Decommissioning	BAT: Design for easy decommissioning.	Decommissioning shall be performed according to procedures described in Design basis. The topside and jacket shall thereafter be transported from offshore location to shore for safe disposal.	G	

12.5 Sources to VOC emissions

Reference is made to *Handbook for quantifying direct methane and nmVOC emissions* [5]

Source ID	Main Source	Sub source	Applicable
1.1	Measured emissions	Atmospheric common vent	No
10.1	TEG regeneration	TEG degassing tank	No (on PdQ)
10.2		TEG regenerator	
10.3		Stripping gas	
20.1	MEG regeneration	MEG degassing tank	No
20.2		MEG regenerator	
20.3		Stripping gas	
30.1	Amine regeneration	Amine degassing tank	No
30.2		Amine regenerator	
40.1	Produced water handling	Produced water degassing tank	No (on PdQ)
40.2		Flotation tank / CFU	
40.3		Flotation gas	
40.4		Discharge caisson	
50.1	Centrifugal compressor sealant oil	Degassing pots	No (no seal oil system)
50.2		Sealing oil retention tank	
50.3		Sealing oil storage tank	
60.1	Piston compressor	Separator chamber	No
60.2		Crank shaft housing	
70.1	Dry compressor seals	Primary seal gas	No (hermitically sealed compressors)
70.2		Secondary seal gas	
70.3		Leakage of primary seal gas to secondary vent	
80.1	Flare gas that does not burn	Extinguished flare and ignition of flare	Yes
80.2		Non-flammable flare gas	Yes
80.3		Inert gas flushed open flare	Yes
90.1	Leaks in the process	Larger gas leaks	Yes
90.2		Small gas leaks	Yes
100.1	Purge and blanket gas	Purge and blanket gas	No
110.1	Gas analysers and test stations	Gas analysers and test stations	Yes
120.1	Drilling	Drilling	No
130.1	Storage tanks for crude oil at FPSO/FSOs	Gas freeing in connection with tank inspection	No
130.2		Abnormal operating situation	No
140.1	Gas freeing of process systems	Gas freeing of process systems	Yes
900.1	General addition	FPSO/FSO	No
910.1		Fixed facilities	Yes

12.6 Oil in water measurements Open drain Johan Sverdrup

Johan Sverdrup processing platform 1 (JS P1) has a similar open drain caisson solution as planned for Krafla UPP. The figures below summarise the measured oil in water concentrations (OIW) from September 2019 to March 2022.

Only 6 out of 141 measurements are above the requirements of 29 mg/l. These exceedances are linked to two incidents; deluge testing (August 2020) and oily drilling fluids sent to open drain by accident (November 2021).

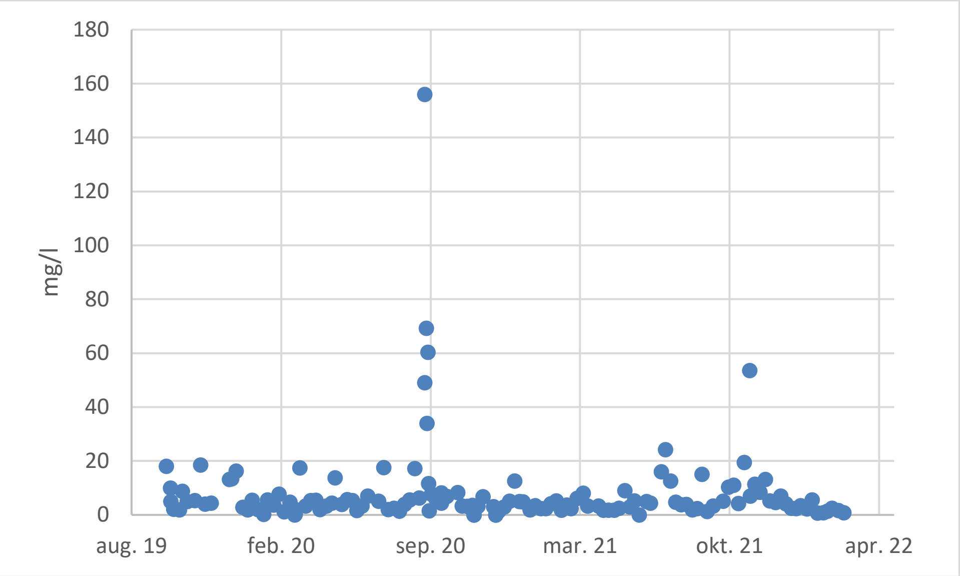


Figure 2. JS P1. OIW concentrations (mg/l). Sept 2019 to March 2022

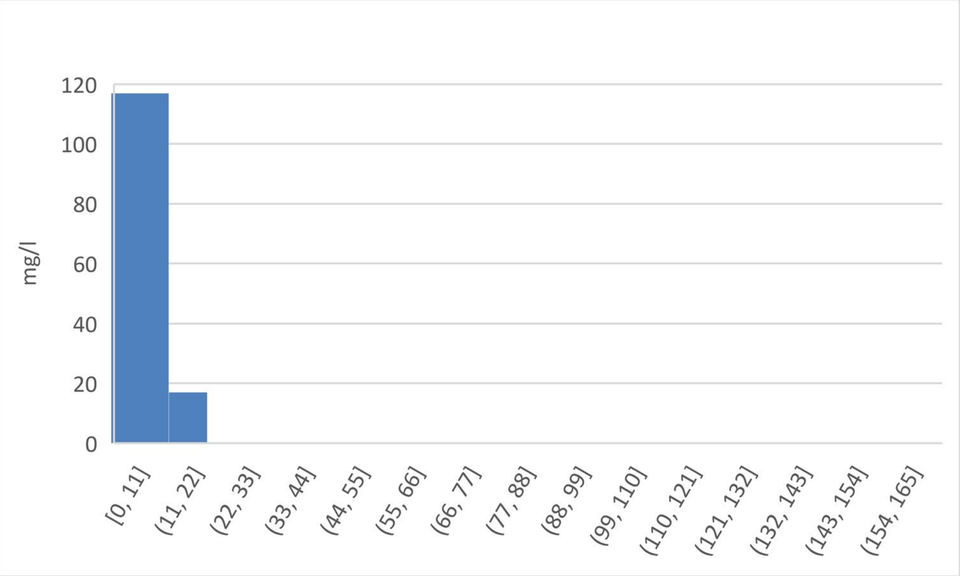


Figure 3. JS P1. OIW concentrations (mg/l). Sept 2019 to March 2022. Histogram