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WELL TESTING IN THE BARENTS SEA

Risk Analysis; Methods and Procedures

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TEK-3901 Master Thesis in Technology and Safety in the high North

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Summary: The thesis is done in co-operation with DNV GL Harstad and Schlumberger. DNV GL has provided access to historical accidents data, by using technical documents. Schlumberger has provided technical information about well testing and hazards related to such an event, and an internal risk analysis document, which they use in their operations. This document is modified to suit, and account, for arctic hazards, and cold climate technologies. In addition, a probability calculation has been executed to show the methodology on how to use expert opinion in reliability challenges. The work on this analysis has been done in co-operation with Schlumberger, which resulted in a modified risk analysis where hazards, cold climate factors, influence on reliability & safety, mitigating and preventive measures is evaluated and included in the analysis for offshore operations. This was done to describe the event of implementing cold climate factors when calculating probability of an unwanted event to occur. This was done in dialog with experts, and a new predicted probability was calculated due to the influence done by the cold climate factors. The increase was suggested by experts, and the new generated probability for the component, in this case the transfer pump, was $1{,}762E^{-5}$ per 5 weeks in service. This means that the probability has increased by 31% after the influences by the arctic environment, according to the experts prediction.

Keywords: Hazard, Risk, Reliability, Surface Well Test, Risk Analysis, , Arctic, Darkness, Distance, Ice, Vulnerable Environment, Expert Opinion

Abstract

Surface Well Testing operation is a well-known operation, which has been executed in the oil&gas industry since the early 70's. Well Testing is an operation where a miniature process plant are installed and connected to a well. This miniature process plant takes samples of the oil and gas, so that specialist and well testing-engineers can examine the measurements and conclude which type of reservoir the well is connected to.

Since the start of the *oil era* in Norway oil&gas operations has been executed in the Norwegian Sea and in the North Sea. In the later years more discoveries are done in the region, and the number of wells is steadily increasing. ENI Norge is expecting to set up a *floating production, storage and offloading* vessel (FPSO) in the Barents Sea within the year, and is expecting to commence production from the reservoir *within the third quarter of 2014* (EniNorge, 2014). Statoil discovered Skrugard[1] and Havis in 2011 and 2012, respectively. The field is scheduled to commence production in 2018 (Statoil, 2014).

The Barents Sea is a sea located in the North of Norway, and is an area where commercial activity, in this form, never has been done before. As the industry is moving further north, more challenges arise, such as ice, weather, darkness, remoteness and vulnerable environment. The scope of this thesis is to present and explain how arctic factors can be implemented in a risk analysis, and make an example of this using historical data.

The thesis is done in co-operation with DNV GL Harstad and Schlumberger. DNV GL has provided access to statistical data, by using technical documents. Schlumberger has provided technical information about well testing and hazards related to such an event. In addition they have provided an internal risk analysis document, which they use in their operations.

The document (HARC) provided by Schlumberger has been used as basis for the risk analysis created in this report, and cold climate factors has been implemented as a part of the modification of the analysis. The work on this analysis has been done in co-operation with Schlumberger, which resulted in a modified risk analysis where hazards, cold climate factors, influence on reliability & safety, mitigating and preventive measures is evaluated and included in the analysis for offshore operations.

The next step in this thesis is to execute probability calculations. This was done to describe the event of implementing cold climate factors when calculating probability of an unwanted event to occur. The way this was executed was that in dialog with experts a new predicted probability was calculated due to the influence done by the cold climate factors. The increase was suggested by experts, and the new generated probability for the component, in this case the transfer pump, was $1{,}762E^{-5}$ per 5 weeks in service. Without the influence made by cold climate factors, the probability was $1{,}34E^{-5}$ leaks per 5 weeks. This means that the probability has increased by 31% after the influences by the arctic environment, according to the experts prediction.

[1] Now called Johan Castberg

Preface and Acknowledgement

This thesis is made as a completion of the master education in Technology and Safety in the high North. The thesis is a result from the master period, and is written I the spring of 2014 and is equivalent to 30 ECTS. The work started in the autumn of 2013, with a pre-report on the theoretical aspect of risk analysis for a surface well test. The author has a bachelor degree in Process and Gas Technology from the University of Tromsø. The report reflects some technical implementations from my process-technical background.

Several persons have contributed academically and practically to this master thesis. I would therefore firstly like to thank the two companies DNV GL and Schlumberger. They have given me guidance and support throughout the thesis, and contributed with information and knowledge. DNV GL contributed with meetings and feedback on the thesis, and especially Dag Julian Eilertsen and Øyvind Roland Persson, who personally supported me. Grateful for the help from Schlumberger's employee Olav Indrehus help me with information and literature about well testing. Friend and Schlumberger employee Cato Reiersen for his untiring effort in helping and supporting me within the subject of well testing. I will also like to thank Professor Javad Barabady for guidance and follow-up throughout the whole thesis period.

Acknowledgements are in order for Masoud Naseri and Abbas Barabadi for helping me scoping the work of my thesis. I've also like to thank all my student-colleagues throughout the years, and especially the people from the years at the university. Friendships and possible working colleagues which I look forward to meet in a future work-place. I'm grateful for the commitment and patience from my closest family, for encouraging me to continue with a university education.

Tromsø, Saturday, 31 May 2014

Espen Heiskel Mathisen
Student

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Terminology and Abbreviations

Terminology

Atomize	Convert a substance into very fine particles or droplets.
Explosive Substances	Explosive substances are in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings.
Flow Rate	The amount of fluid that flows in a given time.
Hydrocarbons	A compound of hydrogen and carbon.
Meter Factor	A factor used with a meter to correct for ambient conditions.
Permeability	The ability of a substance to allow another substance to pass through it, especially the ability of a porous rock, sediment, or soil to transmit fluid through pores and cracks.
Polar Lows	"A polar low is a small, but fairly intense atmospheric low pressure system found in maritime regions, well north of the polar front. Its typical diameter is 100-500km and average life span is 18 hours. The polar low gives strong and rapidly changing winds and dense showers of snow or hail, and is generally more unpredictable than the larger and more common synoptic lows." – DNV
Regulation	A rule, principle, or condition that governs procedure or behaviour
Reservoir Fluids	The fluids mixture contained within the petroleum reservoir which technically are placed in the reservoir rock.
Retention time	Time spent for effluent inside a separator.
Shrinkage Factor	The percentage of volume lost as a result of the process.
Vapor	A substance diffused or suspended in the air.
Viscosity	The internal resistance of a fluid to flow.
Volatile	Volatility is the tendency of a substance to vaporize.
Winterize	Adapt or prepare for use in cold weather.

Abbreviations

BOP	Blowout Preventer
CEN/CENELEC	The European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC).
CO_2	Carbon dioxide
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
EER	Evacuation, Escape and Rescue
ESD	Emergency Shutdown
ERC	Emergency Response Control
GOR	Gas and Oil Ratio
H_2S	Hydrogen sulfide
IEC	International Electrotechnical Commission
ISO	International Standard Organization

NCS	Norwegian Continental Shelf
NORSOK	Standards developed by the Norwegian petroleum industry.
PFEER	Prevention of fire and Explosion, and Emergency Response Regulations.
PSV	Pressure Safety Valve
WOAD	World Offshore Accident Databank

1. Introduction

In this chapter you will find a brief introduction in order to introduce the reader to the problem.

1.1 Background and Research problem

The Barents Sea, supports one of the world's major fisheries, and is already of economic importance. The region may also become a major oil and gas supplier in the future. The Sea is controlled by Norwegian and Russian authorities, and has for many years been a disputed zone between the countries. The 15 of September 2010, the foreign minister of Norway, Jonas Gahr Støre and Sergej Lavrov signed an agreement about the borderline in the Barents Sea. This agreement increased the area that can be of major interest for oil and gas activity in Norway.

New discoveries and high energy prices have provided opportunities for further development. A total of 14 discoveries have been made on the Norwegian Continental shelf (NCS) in 2013, including 10 which could potentially be developed. The good finding-rate the recent years is closely connected with the high level of exploration activity. 42 wells where drilled in 2012, of which 41 were completed and tested, and by the summer of 2013, 46 wells have been drilled (Norsk olje&gass, 2013).

Companies which operates on the NCS has the recent years focused more and more on the Barents Sea. This entails a need for identifying challenges related to exploration-activities in this region. This thesis will focus on the risk analysis connected to a well test operation. This is a small and fast operation which occurs after a well is drilled, and in solely for investigation purposes. Measurements, tests and research are executed to determine what type of reservoir the well is connected to.

The degree of risk associated with well testing will strongly depend on the location for the operation. The further north the operation is, thus more hazards will occur, and the severity connected to the operation will increase. This thesis will focus on general operational hazards related to a well test in the Barents Sea. Experts and experienced personnel will be involved to determined, evaluate and assess hazards related to the operation, so the result will reflect the reality as good as possible.

The thesis was done in co-operation with DNV GL, and technical documentation from them was used to calculate reliability and probability. The information they provided was used as basis for the probability calculations, and the suitability of the data which was used was evaluated and implemented with expert evaluations.

1.1 Purpose of this thesis

The purpose of this thesis is to describe the method of risk analysis for a surface well test operating in the arctic region. This thesis will also highlight deficiencies in emergency preparedness and information about hazards. The study will be performed by multidisciplinary persons, so hazards from known operations can be evaluated with regards to challenges and hazards in the arctic environment. The final report can serve as a support-document for companies, with regards to adapting risk policies to the arctic environment.

1.2 Research Questions

Safety and reliability are two important factors which will mitigate possible disasters. The question is to what level safety and reliability must be implemented to sustain a qualified level of safety, without ruining the project. The challenges for this type of operation is that the consequences are severe in the region, and the difficulty to sustain the necessary quality of the emergency system. Based on these challenges the questions which will need evaluation are:

- What type of environmental factors will influence the surface well test operation, and which factors will influence the function of the equipment used while operating?
- How todays available risk analysis, for a well test operation, can be modified and improved to implement cold climate factors?
- How can reliability data from an area (reference area) with a different environmental condition be evaluated and modified to suit the Barents Sea (target area)?
- How can statistical knowledge be used to estimate a probability for occurrence for an operation or equipment?

1.3 Objective of the research study

The objectives of this research study are:

- Identification of influencing factors under arctic conditions, with respect to safety and risk.
  - Evaluate the degree of influence
  - Evaluate the distribution of the influence degree (location vice)
- State of art/ current status for the arctic standards, with respect to safety and risk.
- Modify the risk analysis to incorporate cold climate factors:
  - Hazard identification for each activity step
  - Cause and Consequences
  - Barrier identification
  - Recommendation for improvement of safety, and reducing risk
  - Influence by cold climate factors
  - Preventive and mitigating cold climate measures
- Give an example on reliability calculations for an component
  - Use historical data to estimate probabilities
  - Evaluate probabilities
  - Evaluate reference data
    - Include expert opinion
    - Cold climate probability calculations

1.4 Limitations

The work on this thesis was limited by the amount of useful data from the arctic industry. The available data used in this report is from other industries in other areas, and is meant as an example on how to approach, and implement challenges related to the arctic industry. In addition the thesis was limited by the limited amount of technical information shared by companies.

1.5 Structure

The first chapter starts with a description of the background and research problem, and thereafter the purpose, objectives and limitations of the thesis is outlined. The second chapter starts with general knowledge about risk analysis, i.e. the identification of hazards and how hazards develop into consequences. Literature and theory about Hazard Analysis and Risk Control Record (HARC) is presented. In addition, some general theory on reliability data calculations and validation of data is included. General theory about surface well testing and the components used for such an operation. Literature on type of platforms used and associated standards for arctic operations. Lastly, the influencing factors for cold climate operations is presented and evaluated. The third chapter describes the purpose and strategy of the report. In addition, methods of data collection are discussed and presented. The fourth chapter is the risk analysis. This chapter presents the modification of the HARC and the implement ability for the risk analysis to be used in arctic environment. The chapter also includes the calculations of probability for the chosen component, the transfer pump, and evaluation of the reliability data used. Implementation of expert opinion is used to include for cold climate factors influence using methods described in the second chapter. The fifth chapter covers the discussion of the study from chapter 4. Pros and cons are evaluated and discussed, and a conclusion from this discussion is drawn. Future work within this topic is suggested.

2. Literature

General literature on methods, procedures and analysis of risk is presented in this chapter.

2.1 General literature on Risk Analysis

Resource companies utilize risk levels to group hazards so that adequate planning resources can be directed at areas that present the greatest risk. The process of managing hazards is a costly and time consuming process, which involves many disciplines, and may also involve high-level management approvals to ensure that all safeguards and mitigations are fully implemented. Risk assessment is the process of identifying hazards, deciding who and what can be harmed, evaluate the risk involved, record and implementation, and review (Modarres, Mohammad, 2006).

2.1.1 Identify the hazards

The first step when analysing risks, is to identify hazards[2]. All hazards must be thoroughly evaluated, and can with good documentation, be divided into critical and non-critical hazards. It is of great importance that the hazards considered as non-critical are clearly documented in order to demonstrate that the events in question could be safely disregarded (Nardone, Paul J, 2008)

The identification of hazards can be done using multiply methods and technics. Some of these can be:

- What if – method
- Checklists
- HAZOP

These three methods are considered as good methods for identifying hazards in a process-technical environment, therefor are all these methods good options to use for the purpose of this thesis.

2.1.1.1 What if – method

"What-if" hazard analysis is a structured brainstorming method of determining what things can go wrong and judging the likelihood and severity of these situations occurring. The answers to these questions form the basis for making judgements regarding the acceptability of those risks and determining a recommended course of action for those risks judged to be unacceptable. An experienced review team can effectively and productively discern major issues concerning a process or system. Lead by an energetic and focused facilitator, each member of the review team participate in assessing what can go wrong based on their past experiences and knowledge of similar situations (LabSafety, 2013).

2.1.1.2 Checklists

Checklist is a systematic evaluation against pre-established criteria in the form of one or more checklists. The way this analysis is executed is by defining the activity or system of interest. Problems related to those activities must be defined, to create a set of questions or checklists. These questions and checklists, can serve as a procedure for a specific operation or problem.

[2] A hazard is any source of potential damage, harm or adverse health effects on something or someone under certain conditions at work (Canadian Centre for Occupational Health and Safety, 2014)

Lastly, can the results from this analysis be used in decision making processes (Nardone, Paul J, 2008).

2.1.1.3 HAZOP

A hazard and operability study (HAZOP) is a systematic process where planned or existing process facilities undergo an examination to identify and evaluate problems that may represent risk to personnel, equipment or influence the efficiency of an operation. The HAZOP technique was initially developed to analyse chemical process systems, but has later been extended to other types of systems and also to complex operations. A HAZOP is a qualitative technique based on guide-words and is carried out by a multi-disciplinary team during a set of meetings. The main objective for HAZOP study is to detect any predictable deviation (unwanted event) in a process or a system (Berg H.P. 2010).

2.1.2 Hazard and Scenario Analysis

When all possible hazards for an operation is identified, the next step is to find out why hazards arise, and what the consequences can be if they occur. There are technics and methods for finding the causes of a hazard, and identifying the pathway that would lead to an unwanted event. This step is a time consuming step, and may also require high-level management approvals for initiating an operation which can involve possible fatalities or injuries.

There are many methods and analyses that can be used when calculating and identifying factors involved in an unwanted event and consequences. Some of the methods and analyses used in this step are:

- Fault Three Analysis (FTA)
- Event Three Analysis (ETA)
- Barrier Diagrams
- Reliability Data
- Human Reliability
- Consequence Models

Further in this chapter some of these methods and technics will be presented and explained.

2.1.2.1 Fault Three Analysis

FTA is a top down, deductive failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of Safety Engineering and Reliability Engineering to determine the probability of a safety accident or a functional failure, and to identify the pathway leading up to an unwanted event. An example of the structure of a FTA is showed Figure 1.

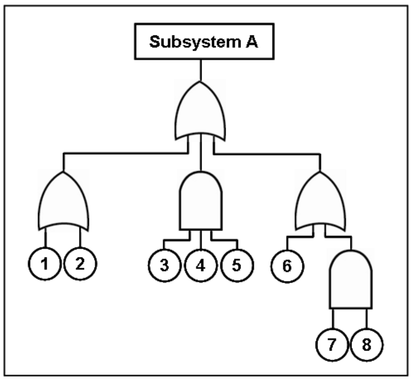

Figure 1; Example on a Fault Three Analysis (Bright Hub PM, 2014)

2.1.2.2 Event Three Analysis

A common and practical tool for identifying consequences is the ETA. The ETA uses the technique which involves statements or barriers to control the outcome of every unwanted event. An event tree is a visual model describing possible event chain, which may develop from hazardous situation. Figure 2, is an example of an ETA, and how it out folds. Beginning with an unwanted event, often called initiating event, and resulting in a variety of consequences. Deepening on which path the hazard will take through all barriers, will result in a specific consequence.

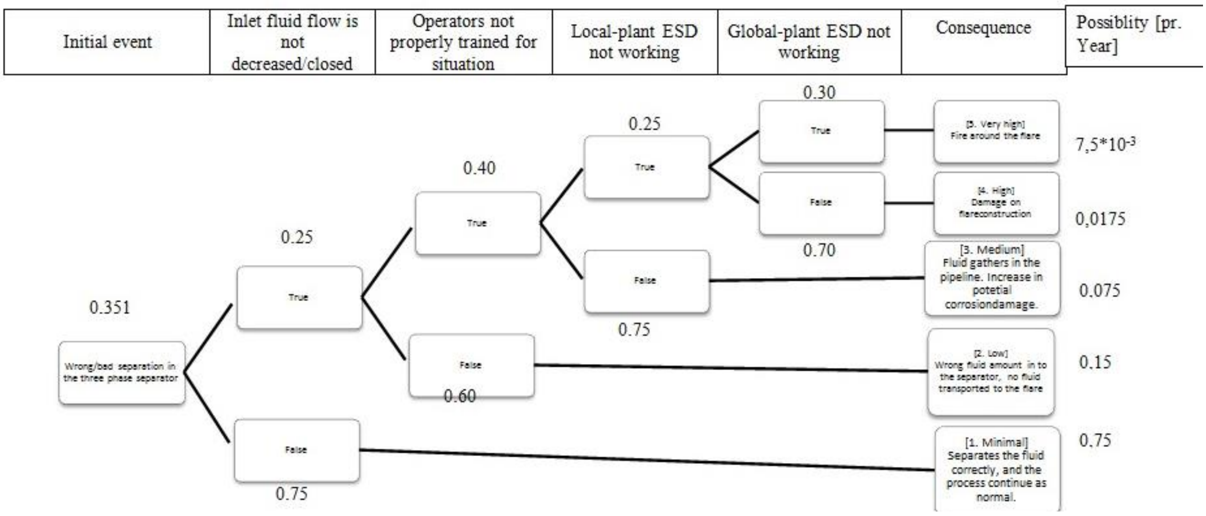

Figure 2; Example on an Event Three Analysis

2.1.2.3 Bowties

The bow-tie method provides a readily understood visualization of the relationships between the causes of the unwanted event, the escalation of such events, the controls preventing the event from occurring and the preparedness measures in place to limit the impact.

This a common visualization tool for showing causes and consequences for an unwanted event, in addition mitigating barriers before and after the occurrence of the events. An example is showed in Figure 3.

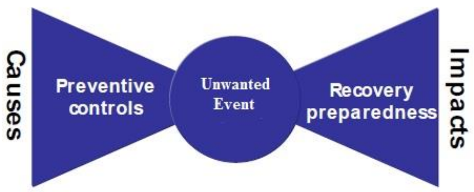

Figure 3; Example of a Bow tie (Book, Gareth, 2007)

2.1.2.4 Consequences

All consequences, which are identified, are structurally categorized after what branch they will influence. According to Mohammad Modarres (2006) a common way to categorize consequences is by:

- Human – from diseases, injuries and fatalities.
- Operational – to prevent downtime. Downtime can cause many critical factors; many of them are related to the economic specter.

- Reputational – to remain or build the company's reputation for potential and existing customers, and to prevent damage the market reputation.
- Political – from changes in tax, public opinion, government policy or foreign influence.
- Environment - Categories that relates to the preservation of specific components of the environment pertaining to air, water and soil ecosystems, including fauna and flora.

In addition safety can be included. Depending on the type of operation, the categories for consequences may vary.

2.1.3 Hazard Analysis and Risk Control Record

Hazard analysis and risk control record (HARC) is a risk analysis method which in many ways are similar to a preliminary risk analysis (PRA). The HARC analysis can be used on complex operations, and both preventive and mitigating measures are implemented in the analysis. Schlumberger is using this method in many of their operations, and has found it very good, practicable and user-friendly. The analysis entails that personnel can contribute when making the analysis and more people can be involved, which in terms increases the quality of the work.

In co-operation with Schlumberger this method was chosen for analyzing hazards for a surface well test. The foundations of the HARC analysis was solely done by experienced personnel at Schlumberger, and the objectives for this thesis is to suggest adaptive measures which will prepare the operation of a well test for the arctic climate.

2.2 Surface Well Test Facility

The main purpose for a surface well test facility is to operate and test the well (Nardone, Paul J, 2008). This is done to establish reservoir parameters, such as gas-oil ratio (GOR), pressure, temperature, flowrate and general reservoir parameters. The equipment on the surface must safely and reliably perform a wide range of functions. The bottomhole pressure in the well can be as high as 300 - 500 barg, this means that the equipment on the surface must be capable of handling a portion of that pressure, in a controlled and reliably way. The facility also needs to separate the effluent into three separate fluids, accurate meter the fluids, collect and separate solids as applicable, collect surface samples and dispose the resulting fluids in an environmentally safe manner. In appendix A, a descriptive process flow chart illustrates the design of the facility. The flow chart is a process technical document for process engineers to overview the design of the plant, and to monitor the construction process. In addition to this a lay-out of the process is illustrated in appendix B and appendix C. A schematic lay-out of the process is shown in appendix D. All these appendixes are support documentations to ensure a good overview of the process plant, and are normally used by process engineers and safety personnel.

When all measurements and parameters are established and evaluated, the organization can decide whether or not to begin a full-time production from the reservoir. This is a difficult task since some of the data from the test facility have uncertainties and are not finalised.

2.2.1 Data Measurements Points

Depending on the scale of the test, a variety of measurements may be obtained downhole, at the surface, and at different measurement points along the flow path. Besides establishing important flow-rate and pressure relationships, the information derived from these measurements helps project engineers track changes in clean-up fluids, understand heat flow and hydrate formation conditions in the system and evaluate performance of system components. Table 1, is a table explaining the type of measurements taken in the different areas around the process plant.

Table 1: Data Measurements Points

Surface Acquisition	
Flowhead	Pressure and temperature of tubing and casing.
Choke manifold	Pressure and temperature.
Heater	Pressure and temperature.
Separator	Pressure and temperature, differential pressure across the gas orifice; flow rates of oil, gas and water, oil shrinkage factor, basic sediment and water, oil and gas gravity, fluid samples.
Storage tanks	Temperature and shrinkage factor.
Subsea test tree	Annulus pressure, temperature.

2.2.2 Well Test Objectives

The objectives determines which type of test will be run, and frequently more than one objective must be achieved. Dynamic reservoir parameters are measured through well testing. Pressure and rate perturbations induced by the testing process provide important clues to the nature of a reservoir and its fluids. Wells are tested to determine reservoir parameters that cannot be adequately measured through other techniques, such as mud logging, coring, electrical logging and seismic surveys. In some cases the quality or scope may not be sufficient to meet the operator's objectives through these techniques. Pressure and temperature measurements, flow rates and fluid samples are keys to understanding and predicting reservoir behaviour and production capabilities. Well test data provide inputs for modelling reservoir, designing well completions, developing field production strategies and designing production facilities. Table 2 shows a list of productivity tests which are the objectives for a well test. Depending on the scale of the operations, set by the operator, the amount of testing executed will vary.

Table 2; Well Test Objectives

Productivity Tests
Obtain and analyse representative samples of produced fluids
Measure reservoir pressure and temperature
Determine inflow performance relationships and deliverability
Evaluate completion efficiency
Characterize well damage
Evaluate workover or stimulation treatments

2.2.3 Description of Surface Well Testing

Surface well test facility is a miniature construction of a process facility, meant for short operations and for data sampling purposes. Figure 4, is an overview showing the components involved in a surface well testing facility.

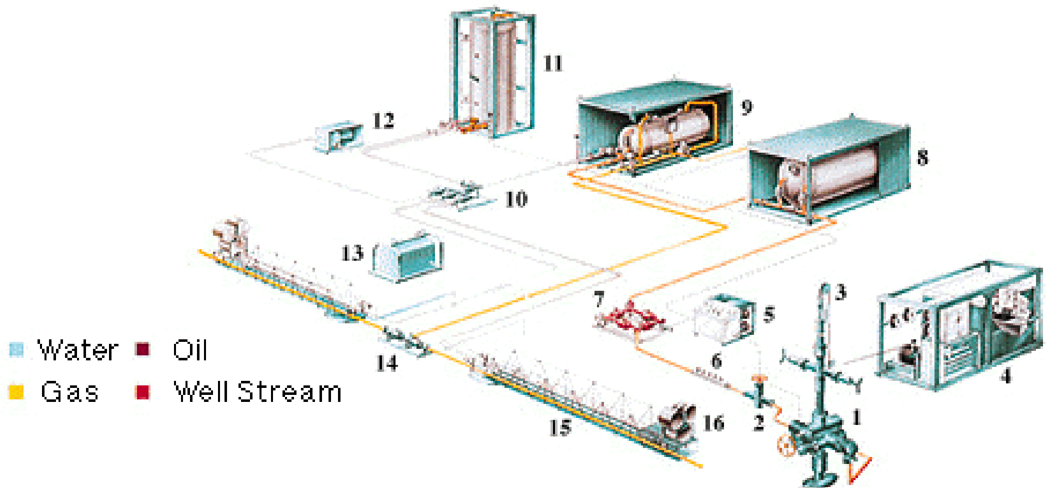

Figure 4; Overview of a Surface well testing facility (NIDC, 2014)

Component list for a Surface Well Testing Facility:

1. Flowhead
2. Flowhead safety valve
3. Wireline wellhead equipment
4. Offshore wireline unit with surface testing acquisition network
5. Emergency shutdown (ESD)
6. Data header
7. Choke manifold
8. Heater/steam exchanger
9. Three-phase separator
10. Oil manifold
11. Surge tank
12. Transfer pump
13. Air compressor
14. Gas manifold
15. Support boom
16. Burner

The most significant component for the process will be presented and explained further in this chapter.

2.2.4 Description of Components

An original process flow diagram from the surface well test on the Transocean Artic platform, which operates on the Tyrihans project is attached in appendix A. From that diagram all typical well test-components are listed up, and all process-technical safety barriers are also shown on that drawing. Further in this chapter will a detailed information about surface well test components be explained.

2.2.4.1 Flowhead

The main purpose for the flowhead is to essentially control the well (Schlumberger, 2013). The flowhead is a manifold installed at the top of the test string and performs several control functions. It directs produced fluid to the well test equipment through a production valve. It also provides a facility for introducing fluids into the test string through the kill valve, and it gives access to the test string for special tools. This component are the first surface equipment that the fluids from the reservoir meets, and provides a surface well control by the two off-wing valves connected to the kill- and the flow-line. The flowhead can also handle rotation from the string, preventing any rig movement from transferring torque into the riser. The swab valve, located near the top of the flowhead, Figure 5, is a feature developed for wireline wellhead equipment. With this feature personnel can hoist downhole equipment to measure pressure, temperature, permeability and so on.

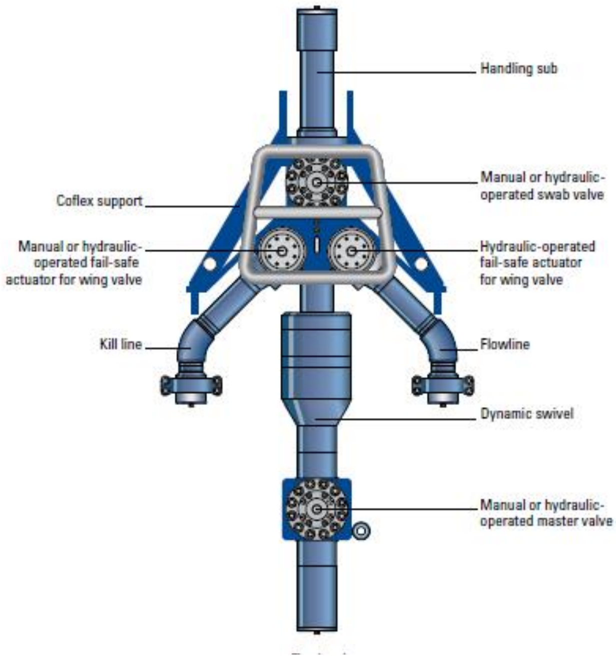

Figure 5; Flowhead (SLB, 2014)

2.2.4.2 Choke Manifold

The choke manifold consists of four different manual valves, which controls the flow rate and reduces the well pressure before the flow enters the surface processing equipment, as you can see on Figure 6. There are two flow paths through the choke manifold, one through an adjustable choke and one through a fixed choke (Schlumberger, 2013). The adjustable choke has a cone-shaped plug made of hardened material, that can be controlled by turning the threaded shaft, thereby adjust the size of the flow path. The fixed choke is useful in the way that it maintains a stable flow condition. It can also be replaced by other fixed chokes, so that it can cover a variety of flow conditions.

Figure 6; Floor Choke Manifold (SLB, 2014)

2.2.4.3 Heater/Steam Exchanger

The main purpose of the steam exchanger is to increase the temperature of the produced fluids in order to improve handling (Schlumberger, 2013). The fluids from the reservoir enters the jacket in the side (deepening on which type of heater), and are connected into many small diameters pipes, this is done to increase the area of heat-transferring, so that the jacket can operate as effective as possible. The steam enter the jacket through a control valve, making the jacket capable of handling varies flowrates. The steam fills the rest of the annulus area in the jacket, and warms the fluids inside the pipes. When the steam is cooled down and condensated into water, there is fitted a condensate trap in the bottom of the jacket, that will transfer the condensated water back to a reboiler, where new steam is generated. By installing a steam exchanger in a well test facility the safety is increased by eliminating the fire risk. A heater/steam exchanger is normally fitted in the beginning of a process facility. This is done to remove water from the fluid and to increase the temperature, so that the probability of hydrate formation is reduced. Figure 7 shows an example of a steam exchanger.

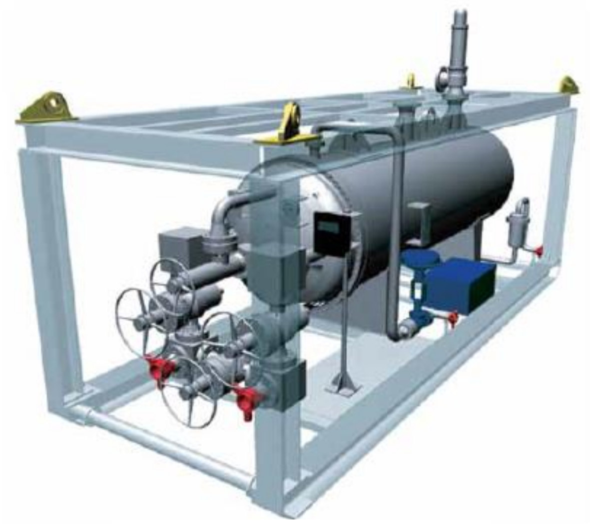

Figure 7; Heater/Steam Exchanger (SLB, 2014)

2.2.4.4 Separator

The purpose of a test separator is to separate fluids for metering and sampling. Specific for well test separators is that they operate manually in order to facilitate adjustment in response to a wide range of flowing conditions. This is in contrast to a production separator, which separates fluids for processing purposes and operates automatically to suit a particular set of production conditions. Common to most of the separators, well test- and production-separators, are that they utilize the difference in fluid density to achieve separation (Nardone, Paul J, 2008).

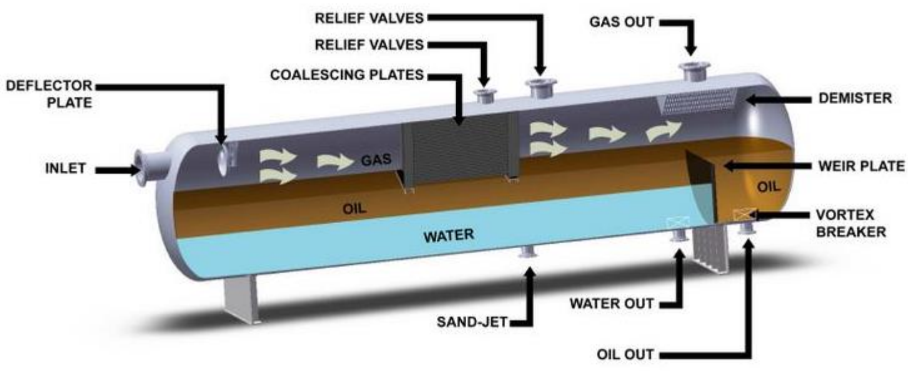

Figure 8; Three-phase Separator (SLB, 2014)

As the figure above shows, Figure 8, fluids enters the vessel in the inlet on the left, and the mixture of gas, oil and water separates, caused by the gravitational force acting differently on the substances. Since water have the highest density of the fluids, it lies on the bottom of tank, and are drained out in its own water-outlet. Because oil is lighter than water, the oil lies on top of the water, and a "weir plate" inside the separator is used to separate these substances. Oil is then drained out in its own oil-outlet. Gas is the lightest substance in the mixture, and takes the rest of the volume inside the vessel. The fluid enters the vessel with high velocity, and by colliding into the "deflector plate", some of the liquids trapped inside the gas will secede from the gas and fall like droplets into the liquids. There are in total three different "liquid-catchers" inside a separator, the deflector plate, coalescing plates and demister. The common feature for all these is to catch liquid-droplets from the gas. This makes the separation more efficient, and makes a cleaner gas. The efficiency of fluid separation relates directly to the time spent inside the vessel, the "retention time". The efficiency of the separation can also be maintained by installing a second-stage separator.

2.2.4.5 Oil Manifold

The purpose of an oil manifold is to divert oil, without flow interruptions, from the separator to the burners for disposal. It can also be used for diverting the oil to a tank for measurements and storage, or it can be used to divert oil to a production line. This equipment is used if a diversion-change is desirable.

Figure 9; Oil Manifold (SLB, 2014)

Two burners are normally available on offshore facilities, and with this component, the personnel are able to divert the oil to the safest burner, with respect to the wind direction. The oil manifold consists of five ball valves, and all valves are arranged as a manifold, as you can see on Figure 9. This gives stable conditions, with respect to flow rate (Schlumberger, 2013).

2.2.4.6 Gas Manifold

The purpose of a gas manifold is essentially the same as an oil manifold. It diverts the gas without interrupting the flow. The biggest difference is the design, while the oil manifold consists of five ball valves, the gas manifold only consists of two ball valves. Figure 10 shows an example of a gas manifold (Schlumberger, 2013).

Figure 10; Gas Manifold (SLB, 2014)

2.2.4.7 Surge Tank

The surge tank is a storage tank designed to store liquid hydrocarbons after separation. The surge tank is used to measure liquid flow rates and the combined shrinkage factor, and meter factor (Schlumberger, 2013). The vessel is also fitted with sampling connections, for pressure and temperature, as shown is Figure 11. Another advantage with this tank is that dead oil sampling is taken in large volumes; this will increase the accuracy of the sample. Since a surge tank can withstand a constant backpressure, it can also be used as a second-stage separator.

In normal process industry a surge tank is used as a buffer tank, with the option and features of providing good samplings. For a surface well test, this tank is used primarily for data sampling purposes.

Figure 11; Vertical Surge Tank (SLB, 2014)

2.2.4.8 Transfer pump

The transfer pump is primarily a pump that maintains, or increase, the flow. It is designed to pump oil from a tank to a burner, or to an existing flow line. Depending on the situation, the pump can be fitted with an electric motor that can withstand explosions. This feature is an important safety factor, for all offshore and onshore process facilities that handles hydrocarbons.

2.2.4.9 Disposal

For a surface well testing facility, the main purpose is to take samples and measurements of the reservoir fluids. When this is done it only remains to dispose the hydrocarbons, and other by-products. For a well test production there is neither practical of economical to handle and store hydrocarbons produced during an exploration well test. All the logistics involved would entail considerable double handling and cost. Therefore is the best, and most practical, alternative to dispose the hydrocarbons at site. This is done by burning the oil and gas (Nardone, Paul J, 2008).

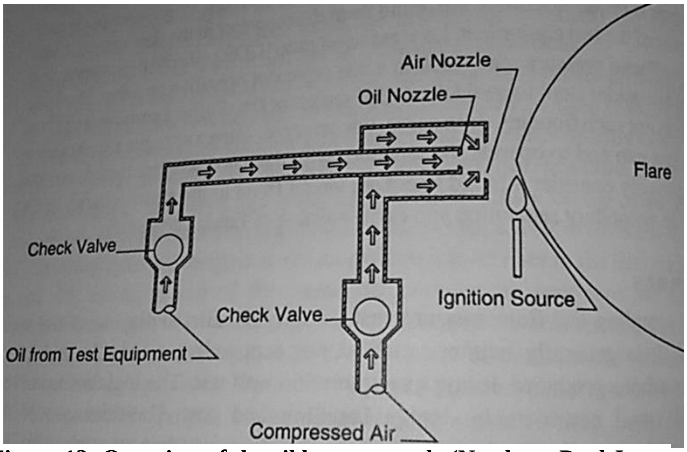

Figure 12; Overview of the oil burner nozzle (Nardone, Paul J, 2008).

Burners provide a safe and efficient way of deposing the reservoir fluids. In order to burn the oil efficiently, it is necessary to atomize the liquid into fine spray of droplets. The pressure of the liquid in the oil line, combined with compressed air at the nozzle outlet provides the energy necessary for atomization. Gas exits the separator and is immediately directed towards the gas flare, situated in close proximity below the oil burners. The flare from the oil burner ignites the gas flare, see Figure 12. The way it is done, is that the oil is ignited with its own ignition system, and the flare from the oil ignites the gas spray. By doing it this way, the facility does not need another set of ignition systems, to ignite the gas flare.

Figure 13; Evergreen burner (SLB, 2014)

Surface Well Test platforms burns hydrocarbons continuously while producing from the well, see Figure 13; this entails that air and structure nearby is heated (Schlumberger, 2013). This is a big safety concern, since the production facility operates with hydrocarbons under pressure. The method that is commonly used is a water shield, as shown Figure 14.

Figure 14; Water shield when burning hydrocarbons (SLB, 2014)

2.2.5 Designed Safety Systems

This section describes the engineered safety systems built into the design of the well test facility. There are, in general, three safety systems involved in a surface well test operation (Nardone, Paul J, 2008) .These are:

- Manual intervention
- Automatic shutdown
- Safe relief of pressure

2.2.5.1 Manual Intervention

Manual intervention is as the word describes; an intervention from the personnel crew on process equipment. This involved closing a production valve or opening a vent. Well test operations often have a changing production condition that involves frequently unpredictable changes in tank level, separators and other process equipment's. The crew on site must personally inspect and monitor these changes and do manual interventions. Manual observation of local gauges is supported by electronic sensing devices that trigger alarms of conditions exceeds pre-set values.

2.2.5.2 Automatic Shutdown

The second level of protection, with regards to safety systems, is automatic shutdown. Automatic shutdown of the system can be triggered two ways; by manual switches located at key points around the process facility, or by using sensors, which sense pressure locally and activate the emergency shutdown system (ESD). The emergency shutdown will be triggered if these electronic sensors sense that the real values exceed the pre-set values. For every process-facility the positioning and settings are indicated on the P&ID drawings. To decide where to locate these switches and sensors, a HAZOP analysis is often used.

2.2.5.3 Safe Relief of Pressure

The third level of protection is the pressure-relief devices. These devices are designed to vent off excess pressure to a safe area if values exceed pre-set limitations. The pre-set limits for automatic switches and pressure-relief devices are normally set under the safe working pressure for all segments of the process system. The location and settings of these pressure-relief devices is, in this case also, decided during a HAZOP analysis.

2.2.6 Emergency Response systems for process facility

The emergency response plan is a document that provides plans and procedures to mobilize resources in response to different emergencies (Nardone, Paul J, 2008). Some of these resources could be emergency response teams located at head offices or support facilities. This emergency response plan is a support-document, and is not the same as an EER plan (emergency, evacuation, and rescue). This plan lists up every reason for unwanted events, or conditions, and suggest by looking in this plan, some barriers to prevent and stop an emergency. The plan also identify that the emergency response team have to access further resource, for instance; transport, medical equipment and supplies to be mobilized in support of the well-site facility during the emergency. In addition, the plan details lines of communication and define roles and responsibilities in the event of an emergency. The emergency response plan is made as a product from the drilling and HSE departments. In the table below, Table 3, there is presented set of well test emergency response controls.

Table 3 Emergency Response Control

Condition	Emergency Controls	Well Test Specific Controls
Blowout	BOP Diverter Kill weight fluid	Test string design (valve barriers)
Fire and Explosion	Fire teams On board fire-fighting systems Blast walls	Well test specific fire and escape plans Well test emergency drills Fire-fighting equipment specific to well test needs
Weather Extremes	Emergency evacuation plan Operating parameters Emergency well suspension procedures	Well kill procedures Emergency disconnect
Oil Spill	Oil spill contingency plan	Spill containment and spill absorbent equipment

All possible conditions and hazards are listed up in the planning-phase of this document. This is done to identify and acknowledge these threats and to be able to control them. For instance, a condition as Blowout is a condition that is nearly impossible to out-design. Since a blowout can arise from many different sources, and some of them are difficult to detect or identify. For all conditions that can be a risk, there should be an emergency control plan. As the table above shows, Table 3 for a blowout condition, there are listed up three emergency controls examples; Blow out preventer, Diverter and Kill weight fluid. Emergency controls can be control measures involving a physical measure; it can also be a procedure, a plan, and humans and so on. Every aspect that can decrease the consequence of such an event can be an emergency control measure.

2.3 Platforms

The type of platform used for drilling and testing purposes are normally small drilling- rigs or ships. These platforms have a designated area for where the testing facility is meant to be built. Throughout the recent years more platforms are built and designed to withstand more severe conditions, and these are meant to operate in the arctic environment. Examples can be Statoil's Transocean Arctic, Shell's Kulluk, alongside many more. The Kulluk platform has a custom made hull, and is meant to withstand large ice loads. It was built and constructed in 1983, but has been upgraded and reviewed several times, and are in operability under the leadership of Shell. Statoil's Transocean Arctic is in full operability, and is drilling exploration wells in the Barents Sea, at this time. This platform has the design *Marotec AS Marosso 56*, and has the rig type *Harsh Environment Floater.* The classification of the rig is DnV + 1A1[3], which means it is designed to handle the arctic environment, both structure- and integrity vise.

2.3.1 Lifecycle of an Oil and Gas Project

The lifecycle of an oil and gas project can vary between projects, but most of them follow the same trend in development, from start to finish.

Figure 15, is a figure showing the lifecycle of an oil and gas project. From this figure we can see that the drilling phase is just before the completion and testing phase. Therefore, is it economical reasoning to construct this facility on deck of the drilling rig. Since the drilling and testing phase of the project can be executed on the same rig. This is also the most common way to execute the project in a reliable and safe manner.

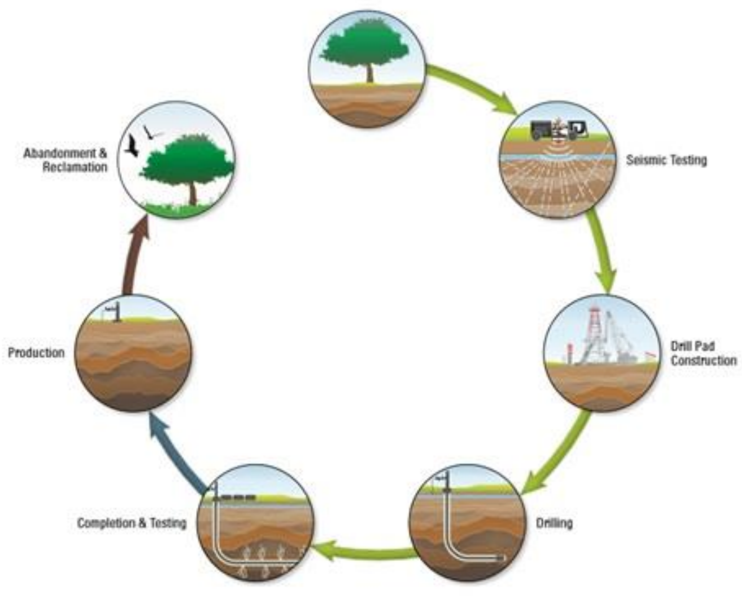

Figure 15; The lifecycle of an oil and gas project (PORI, 2013)

[3] The notation **1A1** will be given to mobile offshore units with hull, marine machinery and equipment found to be in compliance with the basic (common) requirements of the applicable DNV offshore Standards referred to in the rules (DnV energy, 2007).

On many drilling platforms the well test facility-area is clearly planned and sketched up. The reason why the test facility is reconstructed between every well test, is because the type of reservoir tested varies between operations, and process technical solutions must be specifically designed for each well. On some drilling rigs some parts of the well test facility is clearly sketched up, and some components, or type of components, have a designated area for where to be installed. This has to do with safety procedures and –plans.

2.3.2 Overview and description

The design of a test facility varies between every project, since the type of reservoir evaluated varies. A detailed overview over a drilling deck, which Schlumberger is operating, is shown in Figure 16. There is clearly instructed where components is meant to be placed, and what type of designed safety system the platform has on-board. As the figure shows, the designated area where the well test facility can be built, is in the top left corner. A better map is illustrated in appendix A, where component description also are included. The overview is also showing where support systems, like air compressor, steam generator, gun basket (for drilling) etc. is located on the platform deck. This is included in the planning phase, to maintain a high level of safety, and to make the execution and development of the project as effective as possible.

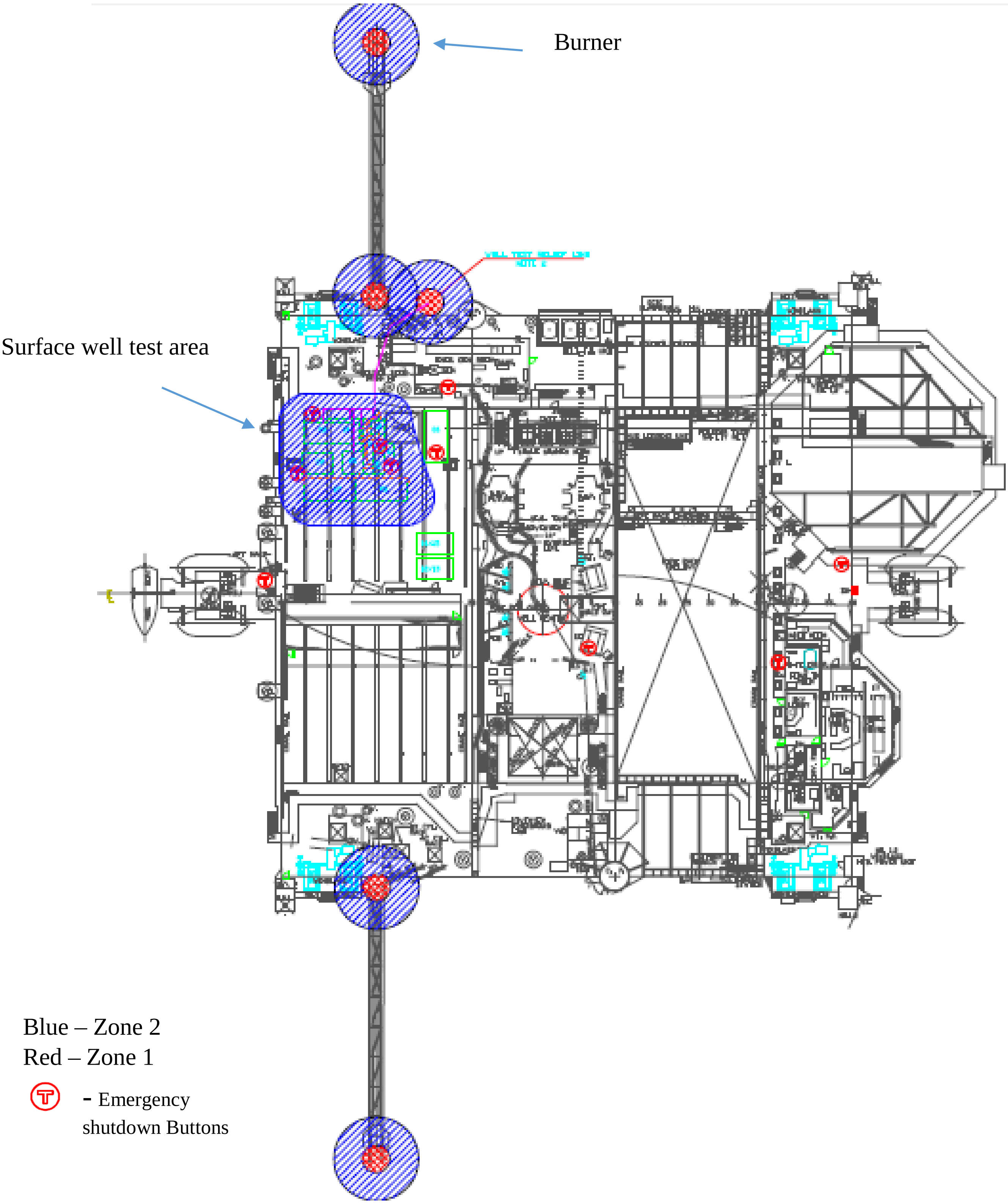

Figure 16: Lay-out of the deck of the drilling platform Transocean Arctic (SLB, 2014)

There are many factors which plays a significant role, when the lay-out of the rig deck is planned. Factors influencing the layout are:

- Rig space
- Safety
- Heat radiation
- Noise
- Electricity
- The working pressure and temperature
- Location
- Onshore or offshore
- Well conditions
- Flow rate and well head pressure expected
- Effluent properties (oil properties and hydrate formation conditions)
- Sand production
- Presence of corrosive fluids (H2S, CO2, acid)
- Exhaust from compressors

Because of the high number of influencing factors the deck of a drilling rig is divided into safety zones. These zones are categorized after risk level, and stretches from zone 0 to zone 2. The risk level are normally closely connected to the probability of a occurring disaster, and the degree of factors which will contribute in that regard. The definition of the different zones are: (Schlumberger, 2013).

- Zone 0; Area or enclosed space where any flammable or explosive substance (gas, vapor, or volatile liquid) is continuously present in a concentration that's within the flammable limits for the substance.
- Zone 1; Area where any flammable or explosive substance (gas, vapor, or volatile liquid) is processed, handled, or stored; and where, during normal operations, an explosive or ignitable concentration of the substance is likely to occur in sufficient quantity to produce a hazard.
- Zone 2; Area where any flammable or explosive substance (gas, vapor, or volatile liquid) is processed and stored under controlled conditions. The production of an explosive or ignitable concentration of such a substance in sufficient quantity to constitute a hazard is only likely to occur under abnormal conditions.

Table 4; Components divided into Safety Zones

Zone	Components	Comment
0	1. Wellhead 2. Well*	1 and 2: Since there is flammable or explosive substance (gas, vapor, or volatile liquid) continuously present in a concentration that's within the flammable limits for the substance.
1	1. Surge Tank 2. Gauge Tank 3. Electric-driven Transfer Pump 4. Choke Manifold 5. Flowhead	1 and 2: Because the presence of flammable gases in the immediate vicinity of the Gauge/Surge Tank vent. 3. Since the Electric-driven Transfer Pumps normally are placed in locations where flammable or explosion-gases are processed, handled, or stored. 4. The Choke Manifold is a common place to take samples from the effluent. When these samples are taken, some gas is released to the atmosphere. This means that some of the toxic gas is in the air around the manifold. 5. The Flowhead is used to introduce tools into the well during a well test, and thereby releasing possible toxic gases.
2	1. Three-phase separator 2. Steam Exchanger 3. Heater 4. Diesel Driven Transfer Pumps	1. The Separator is placed in this zone because the separator only releases flammable gases or vapors under abnormal conditions, such as leakage. 2. The Steam Exchanger can reach high temperatures, and thereby increasing the ignition probability. 3. The Heater uses a naked flame to increase the temperature of the effluent. This will increase the probability of ignition. 4. Diesel-driven transfer pumps can be located in this zone, if they are equipped with automatic shutdown devices, spark arrestors, inertia starters or special electrical starters.

* The well in general

This table, Table 4, shows a description of the categorization of components for a surface well test facility. There is listed up which components that are placed into the different zones, and the reason why they are placed in those specific zones. Appendix C shows a generic component-list over the significant components in the well test process. In addition, it also shows where its placed and in which zone its placed in. Figure 17 is the same figure as appendix C, the difference is that figure 17 is an excerpt from the entire original figure.

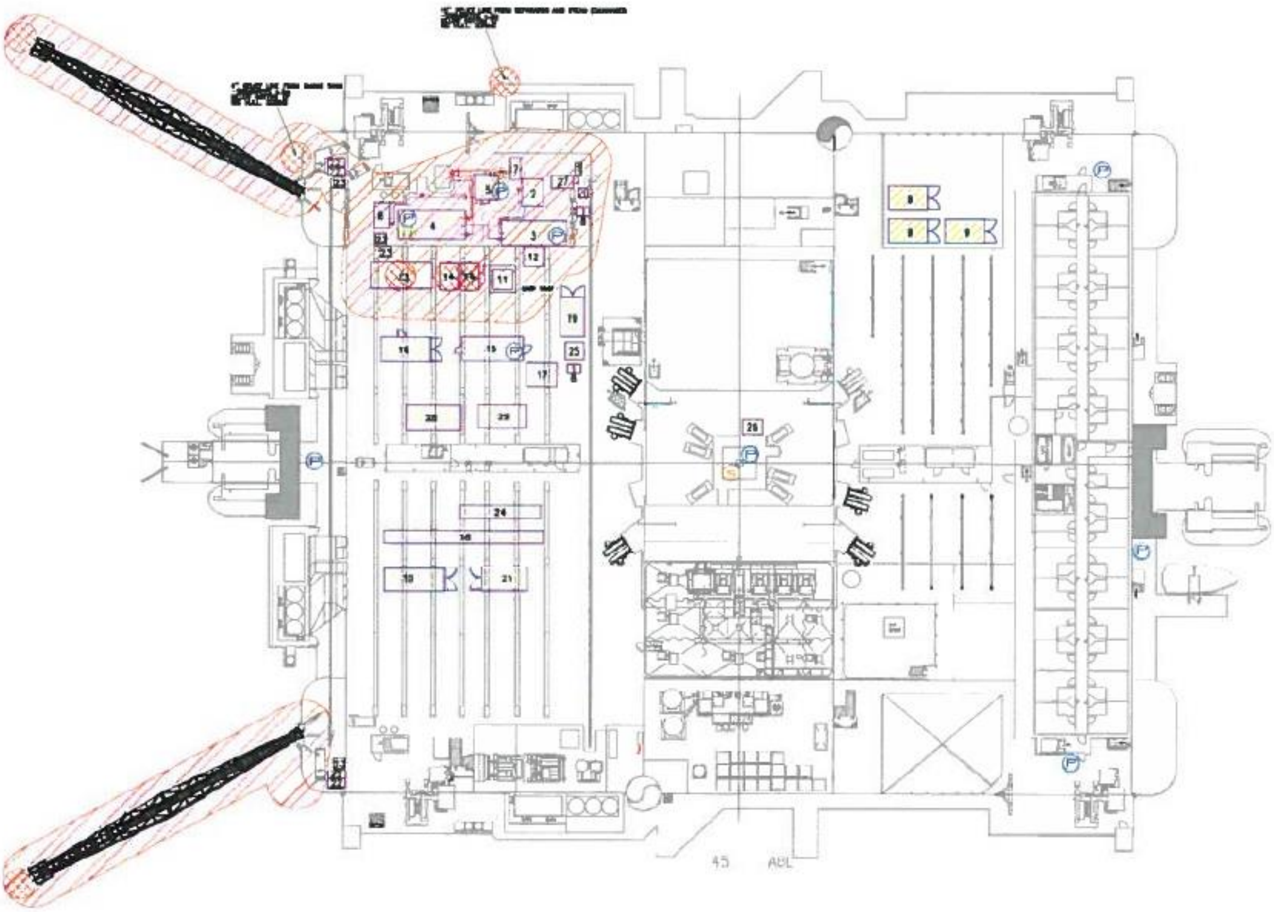

Figure 17; Drilling deck overview of a platform which operates in the Barents Sea (SLB, 2014)

2.3.3 General Hazards and Preventive Measures

Hazards are normally divided into different categories, such as; substance specific hazards, equipment specific hazards, operation specific hazards etc. Depending on the complexity of the production on the platform, the hazards related to the production will vary. General hazards for a production platform can be hazards related to each of the substances used in the production. It can also be hazards related to specified equipment, and hazards related to type of operation. Operational hazards are commonly dependent on location, environment, chosen set of standards etc. (PORI, 2013).

For an operator planning to develop oil and gas activity in the Barents Sea, on the Norwegian Continental Shelf, a lot of new hazards must be evaluated and mitigated. The critical part of this phase is to identify new hazards which will be encountered in the arctic region, especially outside the summer months. It will also be difficult to evaluate how hazards will vary with an increasing amount of new hazards, and to calculate how probabilities and severity will be influenced.

In this thesis general hazards is meant to describe hazards which will be encountered for all activities which plan to be developed in the arctic region. Factors which will impact the hazards can for instance be; bad weather-forecast, big temperature range, winds, storms, polar lows, rescue, evacuation, iceberg, ice, atmospheric icing and so on. Winterization of a platform means to make it capable of handling arctic environment. There are many ways to winterize a platform.

For instance cover a part of the deck to mitigate injuries on workers, to prevent icing and to increase the degree of monitoring. In addition, winterization can be modification on process-technical solutions. For instance, changing fluids and lubricants, which work better under this environment. It can also be to over-dimension the structures when constructing, so structures can withstand additional loads from ice.

2.4 Standards

Standards related to safety and reliability is widely used, and is design to safeguard that the operation is executed in a planned manner, with respect to safety. The list of applicable standards for oil and gas operations in areas where operations has been executed for decades is long, but for new areas, such as the Barents Sea, and especially north and south-east Barents Sea are almost absent. Therefore has companies in Russia and Norway executed a cooperation to investigate the implement-ability of standards used today. The report *Barents 2020,* is the end product from a shared expertise-workshop. In the report international-, national-, regional- and local standards was considered and evaluated, to see which can be applicable to use in the arctic areas. It also suggest which branches needed consideration and modification, before it can be applicable for arctic use.

In order to carry out a coarse screening of the standards, there was selected a set of conditions which could be applied for a uniform simplified check of the standards for suitability for Barents Sea application. The conditions are:

- Low temperatures
- Ice loading
- Darkness
- Remoteness
- Vulnerable environment

The conclusion from the report, is a list illustrating which standards can be suitable for use in the arctic, and which will need special consideration. The standards which needs a more thorough modification to suit the Barents Sea conditions was:

- Civil and Structural Engineering
- Evacuation and Rescue of people
- Lifting Appliances
- Mechanical (Mechanical static and rotating, HVAC, piping engineering, etc.)

In addition, some categories had severe lack of suitability of use in the Barents Sea. These categories was:

- Emission and Discharge to Air and Water
- Materials Technology
- Platform Technology
- Risk Management of Hazards (e.g. fires, explosion, blow-outs)

There are many concerns related to offshore operations in the Barents Sea, and many standards are not yet finalized for arctic use. This shows that there is more to be done before commencing commercial operations in this region.

The climate and environment is not uniform over the entire Barents Sea. Therefore has the industry began operation inside a safe area in the Barents Sea. This area is along the coast of Norway where factors and challenges are well documented, and mitigating actions are executed.

Barents 2020 "Final Report" has identified 130 relevant standards and gives an overview of which of these which can be used "as it is" (total 64) and which of these who needs modifications before it can be used in arctic areas (total of 66).

In the Barents 2020 "Final Report Phase 4" has been specified in more detail what should be done with these standards so that they could be used for projects in the Arctic. The complete list of standards which Barents 2020 has evaluated is listed up in appendix E. The list in the appendix is an excerpt from the original *Barents 2020* report.

2.5 Influencing factors

The Barents Sea is a subarctic shallow ocean of 1400000 km^2. The ocean adjacent to the Norwegian Sea in west, to Frans Josef Land and Novaja in East, to the polar ocean in north and the Russian and Norwegian coast in south. This ocean has many challenging obstacles, with regards to commercial oil and gas operations. Oil and gas companies uses a substantial amount of resources to explore and mitigate possible hazards before commencing operations in this subarctic environment.

By influencing factors, this report means, that this is factors which is new and special for this area. The influencing factors for the Barents Sea are:

- Cold
- Ice
- Darkness
- Distance (remoteness)
- Vulnerable environment

2.5.1 Cold

The degree of coldness is not uniform for the entire Barents Sea. The warm gulfstream warms up the south-west part of the Sea, and thereby will this part be much warmer than the north and east part of the ocean. The air temperature for the near area around the coast of Finnmark can be as cold as minus 20°C. The design temperature for Johan Castberg and Snøhvit area is minus 18°C and minus 17.5°C, respectively. From the coast of Finnmark and up to the coast of Svalbard the air temperature will develop itself with a constant incline, and at Svalbard can the temperature be as cold as minus 40°C. This steadily decrease, thus further northwards, will impact the working environment severely. Another, combining influencing factors can be wind. For this challenge the wind-chill factor can be a guidance for the effective temperature for workers onboard an offshore structure. In addition, this will heavily impact the ice-growth rate, and must be taken into account. This takes us to the next factor.

2.5.2 Ice

The ice prevalence in the north is not static, but varies with the season and can be very different from one year to another. Figure 18 illustrates the border between ice and open water from 2011 and 2012. In addition, there are many types of ice with specific features. Iceberg is large pieces of ice which has broken of a glacier, and thereby consist of pure water, and does not contain salt of any kind. This means that the ice is very hard and can impact structures and cause large damages. Sea ice is a different type of ice, and the occurrence of this type is much more common. This type consist of frozen sea water, and therefore will be softer than pure water ice, because of the large volume of salt trapped inside the ice. Another feature is atmospheric ice. This type of ice is cooled rain from the clouds, which can freeze when hitting an offshore structure. This generates an accumulation of ice, and can accumulate everywhere on the top-deck of a rig, or structure. This type of ice can also be created by waves hitting the structure, and thereby create a water spray which can when hitting the structure create an area where atmospheric ice is generated.

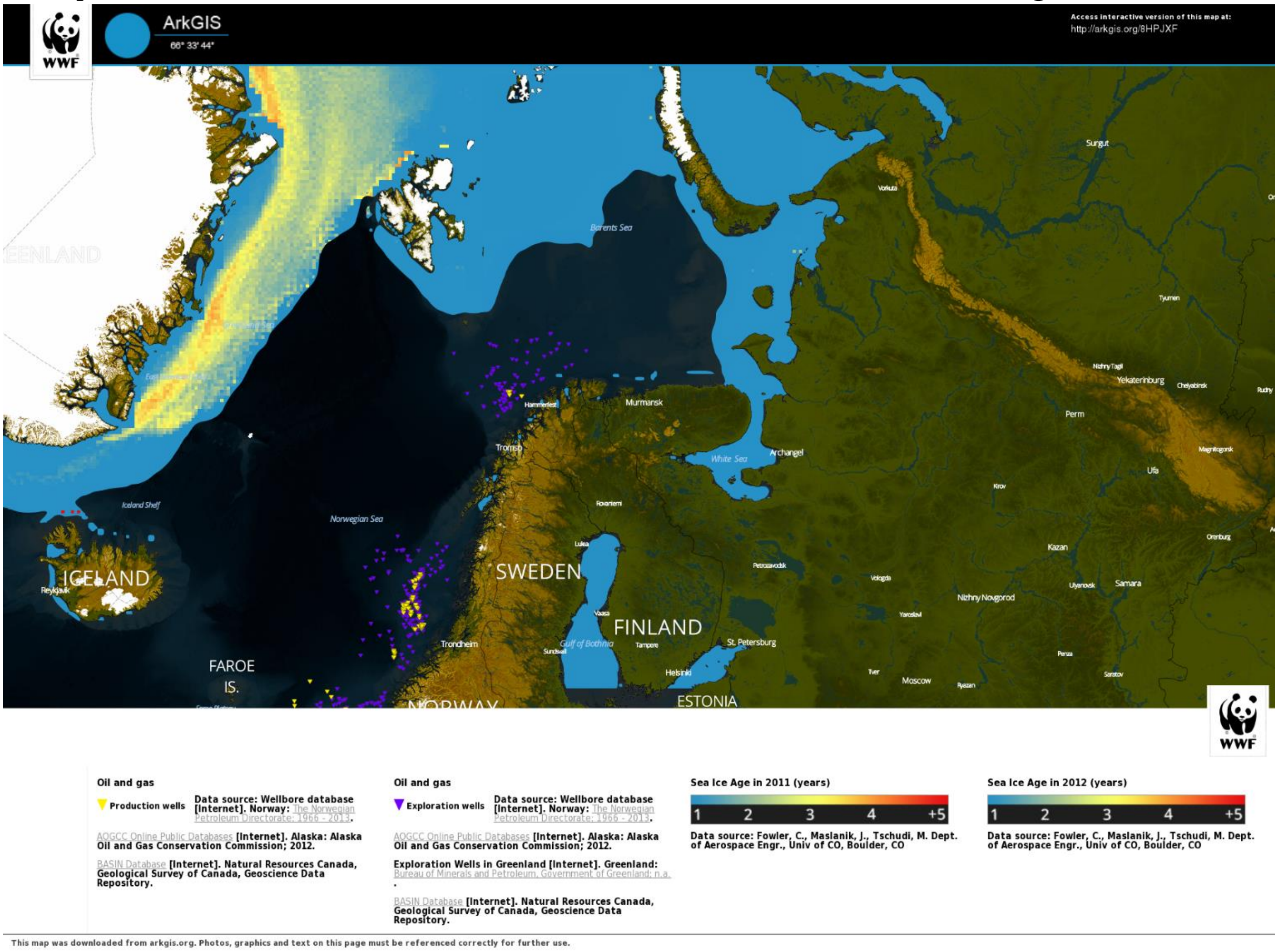

Figure 18; Picture showing the ice prevalence in 2011-2012 (WWF, 2014)

2.5.3 Darkness

The dark period lasts longer thus further northwards the industry is moving. On the North Pole the dark period lasts for six months, i.e. half the time it takes the earth to rotate one time around the sun. The areas which has darkness the whole winter has the midnight sun on night-time in the summer months. If the earth has been without an atmosphere would the border for the Arctic Circle goes be significantly marked. When the sun beams enter through the atmosphere will the beam break down and deflect, and we get what's called twilight on earth. Working in twilight can be difficult, and will vary in what form of twilight the operation is under. Twilight can be divided into three categories (*Sikkerhet Status og signaler*, 2014)

Ordinary Twilight
This event occurs when the center of the sun is below six degrees under the horizon at sunrise. The light under these conditions is sufficient, or at the border to sufficient, too see object on the ground. Outdoor activities can be executed without artificial light.

Nautical Twilight
This event occurs when the center of the sun is between six and twelve degrees under the horizon at sunrise. Under good atmospherically conditions can the human eye see the outline of objects. Normally would outdoor activities need artificial lighting under these conditions.

Astronomical Twilight
This event occurs when the center of the sun is between twelve and eighteen degrees under the horizon at sunrise. The sun do not contribute with any natural light, and normally would it be categorized as totally darkness. When the sun is lower than six degrees under the horizon at the highest peak, the location will have an event called polar night. Under these conditions the location will not have twilight, but total darkness under the whole day. In Longyearbyen on Spitsbergen they have polar nights from 11 November to 30 January. In this period the sun does not contribute with any light, and would be categorized as total darkness.

2.5.4 Distance

Exploration activities has been executed in the Barents Sea from the beginning of the 1980. But there is not any structures in the region, except from the Snøhvit project, which is a subsea structure connected to an onshore facility. The first structure, which will be on the sea-surface will be the Goliat project, where ENI is operator. A collaboration between Statoil and ENI has resulted in an "*All weather search and rescue"* (AWSAR) helicopter located in Hammerfest. This helicopter covers a specific area, as seen Figure 19. The pictures shows the distance and area covered with fuel stations on floating structures in the Barents Sea. The blue circle shows the area covered by the helicopter located in Hammerfest. The green circle shows the area covered by a helicopter, or fuel station, in the floating structure on Johan Castberg findings. The pointed black circle shows the area covered on a hypothetical facility in the eastern parts of the Barents Sea. The challenge companies' face is how to cover all areas within the commercial area of the Barents Sea (*Sikkerhet Status og signaler*, 2014).

There are many possibilities with fuel refilling solutions, some of them are:

- Refueling on a production platform in the Barents Sea (Johan Castberg is located strategic for reaching large areas over the Barents Sea, except the southeastern parts)
- The helicopter can land on installations or vessels, which is placed between a safe area and an evacuations area, as a middle station for faster emergency evacuation.
- Refueling under flight. Refilling fuel from a ship in movement to a helicopter in air, is today performed in military operations, and could be implemented as a civil method.
- The rescue helicopters could use Bjørnøya as a fuel base, but this alternative has some challenges. The distance from the coast of Norway to Bjørnøya, is twice as long as to Johan Castberg, this entails a need for custom made fuel tanks, and/or helicopters with a longer distance capacity. In addition, Bjørnøya, has a challenge connected to the frequent fog in the summer, which will complicate landing actions on the island.

There are many challenges related to the distance between infrastructure and industry. Medical evacuation of personnel is one challenge which needs good preparedness and good planning before commercial activity can be executed. The demand in Norwegian law on the NCS is that one should get a patient to a hospital within three hours. One solutions which is proposed is increased medical preparedness on-board the structure, or the use of telemedicine[4]. This solutions could be used for activities in the Barents Sea, since the University hospital of North Norway (UNN) has created a center for telemedicine (*Sikkerhet Status og signaler,* 2014).

Another big challenge for activities in the Barents Sea is the satellite coverage in the area. North of the 74. Latitude the satellite coverage is absent because of the curvature of the earth. All communication in absent areas are executed using satellite coverage. For this area, north of 74. Latitude, this alternative is not valid no more. Thereby must another alternative for this type of communication be proposed. One alternative for fixed structures in the absent areas of the Barents Sea is to connect the structure by cable to land, and transfer the communication

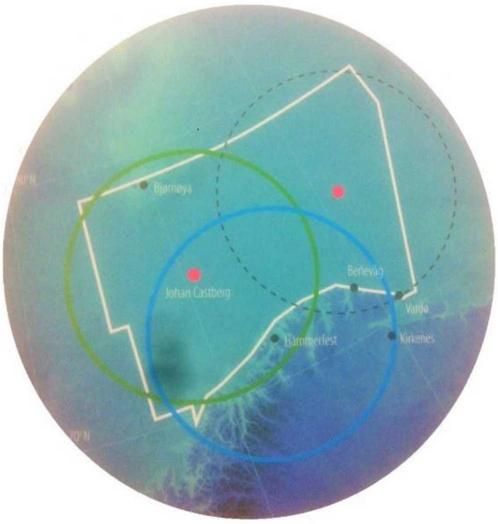

Figure 19; Area covered by helicopter (Sikkerhet: Status og signaler, 2014)

via a fiber optic cable. In addition, another big challenge for structures which plan to operate in the northest parts of the Barents Sea is a phenomena called electromagnetic storms. These storms influence the electric equipment on-board, and radars, GPS and other electrical equipment could be influenced by this, and thereby shows misleading result, and in worst case loss of signal.

[4] Telemedicine is the use of medical information exchanged from one site to another via electronic communications to improve a patient's clinical health status.

2.5.5 Vulnerable Environment

The environment of the Barents Sea is rich and varied. The warm Atlantic water ensures an ice free area all year round, and thereby creates a highly productive area for planktonic algae's. This is the foundation for other living creatures, such as fish, seabirds and marine mammals. The Barents Sea is relatively shallow, with a continental shelf area in the west bordering on the Norwegian Sea. At this continental edge, warm, nutrient-rich Atlantic water is forced up to the surface. Biological production is high in this area, and supports large fish stocks, that provides the basis for Norway's fishing industry. Therefore is it essential for other activities to ensure a productive future for this industry, and make barriers to prohibit any negative influence.

The most serious impacts on the Barents Sea area are being caused by fisheries, climate change and long-range transport of hazardous substances. The environment in the arctic is very fragile, and factors which can influence the stability of the environment, could result in terrible consequences. In 2006, the Ministry of the Environment presented an integrated management plan for the Barents Sea-Lofoten area. It was based on several years of work, including surveys of resources and studies to identify particularly vulnerable- areas and – species. The management plan provides a framework for commercial and other activities in the area and a basis for a management regime designed to prevent pressures on ecosystem from exceeding sustainable levels. For this to be successful, natural resources and the environment need to be closely monitored, (Norwegian Environment Agency, 2013).

According to *Norwegian Environment Agency* there are still substantial gaps in our knowledge of the area, which makes it difficult to assess the likely impacts of climate change and human activities in the future. A combination of surveys, monitoring program's and research, including impact studies, is needed to achieve a better understanding of the patterns we identify, and to evaluate the vulnerability of species and areas, and the stability of ecosystems.

3. Research Methodology

The purpose of this chapter is to provide a brief introduction to the research approach and methods. The chosen research approach and methods for achieving the research objectives are discussed.

3.1 Research Purpose

The ultimate goals of research are to formulate questions and to find answers to those questions. There are almost as many reasons to do research as there are researchers and the purpose of research may be organized into three groups based on what the researcher is trying to accomplish; explore a new topic "explanatory", describe a phenomenon "descriptive", or explain why something occurs "explanatory". Studies may have multiple purposes, but one purpose is usually dominant (Dane, 1990).

The research purpose of this thesis is to describe the methods of risk analysis. In addition, the purpose is to chart the design of a Surface Well Testing facility, and in a descriptive way show how a plant of this size operates, and why it operates the way it does. This is done to recognize where risks can be identified, and to show how reliability data can be used to calculate the probability for the system or component to fail while in service. This includes, the implementation of expert opinions.

3.2 Research Strategy

A research strategy may be thought of as providing the overall direction of the research including the process by which the research is conducted. When deciding on a research strategy the researcher must firstly decide how the research should be executed, theoretical or empirical (Remenyi, Williams, Money, 1998). In this case the study is done using evaluation-methods, and general risk analysis tools, in addition to well-known calculation formulas to execute the study, and to present the results.

In order to conduct effective research, we need to gather appropriate information for the topic. The type of research strategy depends on what kind of information the researcher is looking for due to the purpose of the study and the research questions. In this thesis the information gathered was a risk analysis used by Schlumberger in their operations. The objective for the thesis is too able the analysis to account for cold climate factors, in addition to comment on preventive and mitigating risk measures. In addition to using the method on a surface well testing operation. The other objective for the thesis is to calculate probability for a component used in the surface well testing facility. In this case the component chosen was the transfer pump. Reliability data was collected and expert review on the topic was executed to investigate the influence made by cold climate factors. The result from the analysis are presented in chapter 5.

3.3 Data Collection

Cooper & Schindler (2003) defines data as the facts presented to the researcher from the study's environment. There are different ways for data gathering and every researcher collects data using one or more techniques. According to Neuman (2003) the techniques may be grouped into two categories; quantitative, collecting data in form of numbers, and qualitative, collecting data in form of words and pictures.

For this thesis both methods was used. Qualitative, i.e. collecting data in form of words and pictures was done to present the way this type of operation is executed. In addition this methods was used to gather the risk analysis used by Schlumberger, and the modification applied into the analysis.

Quantitative, i.e. collecting data in form of numbers was executed when gathering reliability data for the component. In co-operation with DNV GL this method was used, and the data gathered was used to calculate the probability for a component to start leaking during the operations time. In addition, expert opinion on this matter was executed, and implemented in the result.

3.3.1 Reliability data and Expert Opinion

Reliability data can be historical information about a system, sub-system or component. Reliability data are an essential part of a probabilistic safety assessment. The quality of data can determine the quality of the study as a whole. The most appropriate data would be the component failure data which originated from the facility, or operation, being analyzed, but that data could not be found.

With many different sources providing different types of information, it is necessary to divide and evaluate the different sources and see if the reliability data from the reference area is transferable to the arctic environment. The reliability data which this report is based on is an internal report, made by DNV GL. They use this report as a support document for their projects, and because of confidential agreements their document cannot be rendered in this report. Only excerpts from that document is cited.

The probability density function expresses the function of the probability for an event to occur, as a function of time, for example the exponential distribution, probability density function (pdf) and reliability function, is given by:

$$f(t) = \lambda e^{-\lambda t}$$

From this distribution, we can derive the reliability function. The reliability for a component which has a constant failure rate, λ, can be explained by the exponential distribution, as shown in the formula:

$$R(t) = e^{-\lambda t}$$

When the reliability of the system, sub-system or component is calculated, the evaluation process starts. This is where the result from the reliability calculations is evaluated, with regards to validation of the reliability data used in the calculations. To evaluate these result experts are included in the evaluation.

Due to the lack of reliability data, i.e. mean time between failures, mean time to repair, etc., the best and most practical method to do this is by using expert opinions to modify reliability data from other areas to suit a preferred target area. Because of the complex, subjective nature of expert opinion, there has been no formally established methodology for treating expert judgment. In recent years, there has been an increasing effort in establishing a more systematic approach to eliciting expert opinion. According to Fumika Ouchi (*2004)* one of the most well-known behavior approaches is the Delphi technique, which was developed in the 1950's. In this method, experts are asked to anonymously judge the assessments made by other experts in a panel. Each of the experts is then given a chance to reassess his/her initial judgment based on the other's review. Typically, the process is repeated several rounds until a smaller spread of expert's opinions is achieved. The Delphi method later incorporated a self-rating mechanism, allowing experts to rate their own expertise. Theoretically, the Delphi process can be continuously iterated until consensus[5] is determined to have been achieved. However, according to Chia-Chien Hsu and Brian A. Sandford (2007) it was pointed out that three iterations are often sufficient to collect the needed information and to reach a consensus in most cases. In addition, it is also common to combined methods for a better custom made result. An example of a combination technique is using weights generated by the experts (presumably after some interaction) as input to a weighted opinion pool (Rama Gehris, 2008).

It is generally agreed that mathematical approaches yield more accurate results than behavioral approaches in aggregating expert opinions. To use any mathematical approaches reliability data, such as failure rate, time dependent failure, mean time between failures, mean time to repair etc. must be in place. This report will emphasize the behavior approach, and use the Delphi as foundation, when illustrating the method of using expert judgments when calculating probability for a component.

[5] An opinion or position reached by a group as a whole.

4. Case Study

This chapter provides the case study of the thesis, and the modified risk analysis (HARC) is presented and evaluated. The probability calculations is also presented to show the methodology of using expert opinion in reliability calculations.

4.1 Hazard Analysis and Risk Control Record

There are great challenges which must be encountered before commercial operations can start operating in the most challenging locations in the Barents Sea. The north and eastern parts are categorized as the most challenging area, due to the harsh environment. The reason for this is that factors like icebergs, seasonal ice, temperature, darkness and weather is contributing to making the area unfriendly for human operations. It is therefore important to make excellent plans and procedures before starting commercial operation. Documentations regarding associated risks and probabilities for events to occur is vitally important.

Schlumberger provided a useful risk analysis, HARC, which they use in their operations, as a procedure document. This is a document made from on-hand experienced personnel, and all hazards related to a well test operation is identified and listed. The document starts from the beginning of a project with client job request, and eventually ends with a job debrief. In this report the operational area of the risk analysis is enlighten and evaluated. The activity steps evaluated in this report are:

- Rig up surface lines
- Rig up boom
- Rig up burner
- Rig up/rig down wellhead equipment (WHE)
- Flush and pressure test
- Flow well
- Multiple flow periods
- Shut in well
- Flushing well test equipment
- Rig down
- Rig down boom

All steps mentioned above is included in the HARC in appendix G. The changes made from the original document are shown with three big arrows on the next page, table 5. The changes made in the document (HARC) is the implementation of influencing factors which is special for the arctic environment, *Cold Climate Technology*, *Reliability and Safety* and *Cold Climate Preventive and/or Mitigating Measures*, see Table 5. In addition, mitigating and preventive measures are listed up and evaluated. The analysis is also re-structured in the way that all hazards are numbered and specific preventive measures for that specific hazard can be proposed. All identified hazard are numbered and evaluated in the 11 activity steps in the appendix. The meaning of this document is that it can serve as a support document for personnel which operates under these conditions, and help in understanding the risks associated with the work they perform.

Table 5; Shows an excerpt from the modified Haz nalysis and Risk Con Record

Step	HAZ			Control Mesures		
	Hazard description and Worst Case consequences (w/no prevention/mitigation measures)	Cold Climate Technology (Darkness, weather-forecast, temperature-range, ice, remoteness, vulnerable environment) *Factors which will increase risk.*	Reliability and Safety	Current and planned prevention measures to reduce likelihood	Current and planned mitigation measures to reduce severity	Cold Climate preventive and/or mitigating measures, to reduce likelihood and severity *Measures and solutions which can decrease risk.*
Rig up surface lines	Gravitational Energy (Lifting, handling) 1. Multiple trip and handling hazards leading to SHL (stepping, handling and lifting) related injury.	1. Ice such as atmospheric ice will increase the difficulty when handling components. Darkness and coldness will complicate tasks, such as monitoring, lifting, handling modifications. Temperature (low and range) will complicate the work because of working-clothes workers and personnel need to wear. Weather-forecast can occur suddenly, and can have tremendous consequences, which will complicate the work severely.	1. Reliability and safety will be decreased severely, because of the increase in likelihood of occurrence.	Pre rig-up briefing with all personnel. All personnel SIPP trained and SIPP practices followed. Housekeeping managed throughout rig up. Footwear in good condition (especially soles) Employees trained in safe procedure for making up hammer unions. Wooden shafted brass headed hammers used to make up unions. Use crane to move pipe whenever possible. Pipe rests in use throughout. Effective supervision of line layout. Layout diagram available and followed. All equipment checked out prior to mobilization to well site to assure compatibility. All flow lines and connections secured; · Safety cable on all flow lines. · All flow lines secured to deck / ground. Flush all lines prior to connecting to burner. Ensure Adequate lighting is available. Condition of tools (Hammer, etc) checked. Sufficient room for swinging hammer. Pipe stands/supports used. Competent / Trained personnel. Consider positions of others in area while hammering. Minimise personnel in area while hammering. Consider impact on adjacent work areas.	PPE worn by all personnel as required by local standard. Emergency response plan to include: · Medevac plan · First aider · Communications protocol Contingency plan to include: · Alternate crane supplier defined. · Spare / replacement equipment identified. Communication protocol Use of back supports where available.	1. To completely, or partially cover the the rig-deck, will reduce the potential for ice to accumulate. A cover will also shelter the worker while operating on deck. Sufficient lighting will light up all the necessary parts on deck.
	2. Makeup Hammer union connections, risk of personnel injury.	2. Temperature can change the properties of rubber joints (o-rings). Ice can hide/cover joints, thereby complicate the modification.	2. Reliability will decrease if not accounted for.			2. Research and studies on this topic must be in place, so that the equipment can withstand the arctic environment. A complete cover will shelter the equipment.
	3. Incompatibility of connections or ratings of equipment, leading to failure to hold pressure.	3. Temperature range can cause change in properties to steel structures. Darkness, ice and coldness can complicate the task of monitoring, and thereby can personnel neglect to identify possible leakage.	3. Reliability will decrease if not accounted for.			3. Heated -floor and –cables could reduce ice accumulation on exposed areas. See nr. 2
	4. Handling of coflexip hose leading to personnel injury or damage to equipment.	4. Ice and coldness will increase the difficulty when handling coflex-hoses. Darkness will amplify the difficulty. Weather-forecast and weather can set the operations on hold.	4. Reliability and safety will decrease if not accounted for.			4. Heated floor, heated shelter, sufficient lightning will make it easier to handle coflex-hoses. To increase the quality of weather-foreast more weather stations must be installed on vessels and land, in and around the Barents Sea.
	5. Incorrect pipework layout applied, leading to lost time.	5. Remoteness will ensure for even longer downtime, due to the long distances and the lack of infrastructure in the Barents region.	5. Reliability will decrease, few/none mitigating actions before big upgrade in infrastructure.			5. This topic is difficult to handle, without large investments in the region. This investment would go to upgrade and update the infrastructure, especially in Troms and Finnmark.

4.2 Statistical data and Frequency Calculations

From the risk analysis in the previous chapter one component from the process facility is elected for further research review. This is done to calculate the components probabilistic, and to show the methodology on how to connect historical data to futuristic accidents, with special considerations on how to account for the uncertainties regarding arctic-influencing factors, see next chapter. A complete risk analysis must include all components installed on the plant to be sufficient as a risk mitigation-tool. This report will investigate and discuss one single component. This is to show the methodology on how to create a risk analysis with historical data, and how to calculate and account for influencing factors.

The transfer pump was selected for a thoroughly research, and type and condition of the pump will be evaluated and discussed. This transfer pump transports the oil from the surge tank to the burner. From the p&id, appendix F, the pump is pinpointed with a red square.

The type of transfer pump selected for a surface well testing operation varies from project to project. There are in general two types of pumps, centrifugal and reciprocating. To prevent overpressure conditions in the pipes, non-centrifugal transfer pumps are fitted with a pressure relief bypass valve. The centrifugal transfer pumps are self-protected against this problem, and therefore no measures are needed. The characteristic of the fluid being pumped and the specific application for the pump determine which pump technology is most suitable for the operation. A centrifugal pump have higher capacity than a reciprocating pump, but have a lower head[6]. In addition, a reciprocating pump can handle much more variations with regards to type of fluid being transported, e.g. oil, water, condensate etc. (viscosity, density etc.).

As mentioned, the pump being investigated is located after the surge tank and before the burner. This is to increase the pressure to a sufficient level, so the oil can be atomized and properly disposed in the burner. An important factor when disposing oil is to have a steady delivery from the pump. The centrifugal pump gives a nice steady flow and are therefore the preferred, and most common type of pump for process plants of this type.

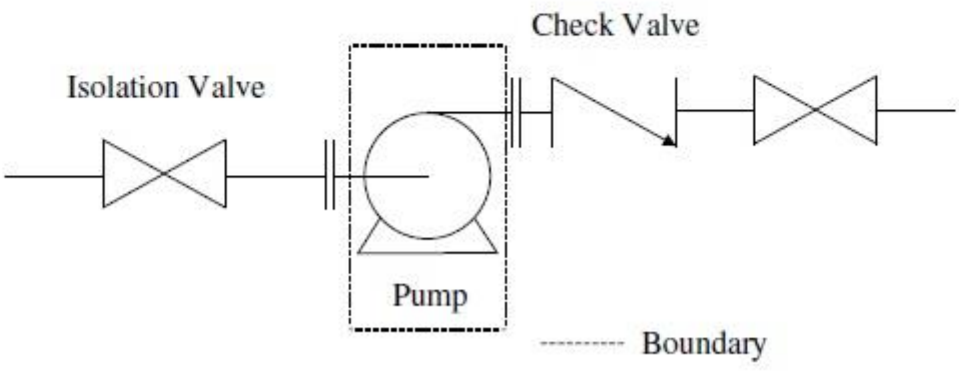

Figure 20; the boundary for this analyses regarding the transfer pump (DNV, 2014)

The boundary for this analysis is solely with regards to the pump itself. Figure 20 shows the technical boundary, and it is illustrated with a stippled square around the pump. Flenses and valves, and other equipment, in- and around is not included in this analysis. The pump

[6] Head is the term used to describe the maximum pressure a pump can generate. Head is defined as the height of the water column a pump can maintain.

investigated has a hole diameter of 4” (10,16cm = 101,6mm). The leak frequency for a given pump can be estimated from its service patterns as follows (DNV GL, 2014):

Equation 1; Leaks per year

$$Leaks\ per\ year\ in\ service = Leaks\ per\ operating\ hour\ \times hours\ in\ operation\ per\ year$$

Equation 1 shows that the end product is *leaks per year in service*, and this is the result from *leaks per operating hour*, multiplied with *hours in operation per year*. This equation is used when calculating frequencies, and can be modified to fit a more ideal event, like a surface well test facility.

A normal surface well test operation, from start to finish, can last for a one or two month’s deepening on the demands set by the operator. If we assume that an ideal arctic well test operation lasts for 5 weeks, with planned uptime of the well test facility for all 5 weeks. We can also assume that the pump is maintained and serviced between projects, and that the arctic factors does not play any significant role, with regards to reliability calculations. From this, we can calculate the probability of a leak during the operational time. In co-operations with DNV, it was decided that the leak frequency for a pump of this kind is 1,4E-04 per pump year in service. This is a result using historical data from data sources (OREDA, WOAD etc.). From this we can calculate the probability of leaks during X operational years (DNV GL, 2014):

Equation 2; Probability of leaks in x time.

$$The\ probability\ of\ leaks\ during\ X\ operational\ years \\ = The\ frequency\ of\ leaks\ per\ year\ in\ service\ \times Years\ X\ in\ service$$

By setting in the data we have identified already, we can use this formula to calculate the probability for this pump to start leaking during this project.

$$The\ probability\ of\ leaks\ during\ X\ operational\ years \\ = 1{,}4E^{-4}\ \times 0{,}09589\ years\ (5\ weeks) \\ = 1{,}34E^{-5}\ \text{leaks per 5 weeks}$$

As the calculations show the probability of a leak during this operation is very small, i.e. $1{,}34E^{-5}$ leaks per 5 weeks. This is the end result of the frequencies, assuming that the uptime of the project is for five weeks, that the pump has been maintained between every project, and that the arctic factors has no influence on the reliability of the pump.

4.2.1 Implementing reliability data from other areas into Arctic

From the previous chapter reliability data provided by DNV was used to calculate the probability of leakage during the operational time. This data is evaluated by the workgroup at DNV, and is collected from other statistical databases, such as OREDA-92, OREDA-97 WOAD, WASH-1400 etc. The WASH-1400 report is mainly based on US nuclear operation experience from 1972 and up to now. OREDA provides failure rate data for pumps in offshore services. It covers a wide range of failure modes, and classifies events by severity, i.e. critical, degraded, etc. There is comprehensive collection of exposure, i.e. time in service and time in operation, in addition to other technical information.

OREDA-92 covers 2.7 million operating hours of exposure. It subdivides the pumps according to drive type (electric, turbine, and diesel). OREDA-97 covers 1.4 million operating hours of exposure. It subdivides the pumps according to design, function and power. It also gives a breakdown of maintainable item for each failure mode. The OREDA database is statistical data from the offshore industry, and can be implemented as valid data in this risk analyses. The data used in this report originating from an intern report used by DNV GL.

The intern report is based on OREDA, WASH-1400, WOAD, experienced personnel and other minor reports. This means that much of the statistical data in this analysis is based on, are from a wide range of operations, from nuclear process plants to small offshore projects. Therefore is it safe to say that these leakage frequencies have not accounted for any arctic influence, and all data used is not directly valid for arctic use, but can give a statistical view of the reliability of the component. To suit historical data to fit the arctic environment in a best possible way, expert opinion can be included to get the most realistic view of the problem.

In this report, where only a transfer pump is investigated, we will use the Delphi method to investigate the degree of influence on the reliability. In this step experts will evaluate and discuss the factors which is influenced by the arctic environment, i.e. the failure modes, failure causes, failure mechanisms. For this report the Delphi method was modified to decrease the total work load, and to facilitate the work. To give the expert some insight in the operation and the process itself, the table, Table 6, was sent out to experts, and is meant as a basis for the discussion. Experts gave feedback on how the causes could be affected, and the reason for it, and from that they suggested a reasonable reliability-prediction.

Table 6; Expert Opinion data spreadsheet

Pump Type	**Centrifugal**
Distributor	Unknown
Hole size	4” (ca 100mm)
Reference area ***Historical reliability data collected from?***	US nuclear operation, Industries offshore database, World Offshore Accident Bank
Target area ***Reliability data to be used?***	The Barents Sea (southwest)
Failure Modes	- External leak through pump casing or seals - Failed to start - Failed while running - Fire
Failure Causes	- Bearing failure (typically due to misalignment, possibly resulting in seal failure) - Gland/seal failure (a common cause of minor leaks) - Maloperation damage, which may be due to; o Cavitation – vaporization of a liquid close to its boiling point within the pump, causing pitting and eventually serious damage to the impeller.

	○ Deadheading – pumping against a closed outlet, causing overpressure of the pump. ○ Dry running – loss of supply to the pump, causing internal damage.
Failure rate (Centrifugal, 4", double seal)	$1{,}34E^{-5}$ leaks per 5 weeks

The results and feedback from experts from this review is showed in Table 7.

Table 7: Table showing the feedback from experts

Failure Modes	Predicted increase in failure rate [range]	Predicted increase in failure rate [most likely value]
External leak through pump casing or seal	20-30%	30%
Failed to start	10-50%	20%
Failed while running	30-60%	45%
Fire	*20-40%	30%

*No change if the oil has no associated gas.

From the Table 7 the predicted result from the experts is shown. They have predicted an increase for all failure modes, which mean that the overall reliability for the component also is increased.

The leakage probability for the transfer pump is $1.4E^{-4}$ per year in service. If we calculate the new probability for the pump to leak, we must include the expert opinions on how the arctic environment will influence the probability. As the *expert opinion data spreadsheet* shows there are four different failure modes. For this report we assume that the causes of a leakage in the pump is uniformed distributed between the failure modes. This means that the probability of the top event Table 7, is divided on the four failures modes, i.e. ¼ of $1{,}4E^{-4}$ per year in service.

$$P(Cx) = 1{,}4E^{-4} \times \frac{1}{4}$$

$$P(Cx) = 3{,}5E^{-5}$$

As the calculations shows the probability of cause X (P(Cx)) to occur is $3{,}5E^{-5}$, since we have assumed an uniform distribution of the causes.

Now we will include the expert opinions, and include the increase in failure rate by multiplying it with the assumed failure rate:

$$P(Cx) = 3{,}5E^{-5} \times (X\%/100\%) + 1$$

Where X is the predicted increase in failure rate by the expert. For cause number one:

$$P(C1) = 3{,}5E^{-5} \times 1{,}3$$

$$P(C1) = 4{,}55E^{-5}$$

This is done for every step. As the table, Table 8, shows the results when implementing the expert opinions are:

Table 8; The results from the implementation of the expert opinion

P(C1)	4,55E^{-5}
P(C2)	4,2E^{-5}
P(C3)	5,075E^{-5}
P(C4)	4,55E^{-5}

The results reflect the probability for every cause to occur, when including the influences made by the arctic environment, which is predicted by the experts. From this we can calculate the total probability of the component. Figure 21; Excerpt of an event three for our example, shows a descriptive figure representing the structure of this failure. This is done my adding all these probabilities with each other:

$$P(pump, total) = P(C1) + P(C2) + P(C3) + P(C4)$$

$$P(pump, total) = 4{,}55E^{-5} + 4{,}2E^{-5} + 5{,}075E^{-5} + 4{,}55E^{-5}$$

$$P(pump, total) = 1{,}8375E^{-4} \text{ per year in service}$$

As you can see, the end probability, after including the expert opinion is $1{,}8375E^{-4}$ per year in service.

We can also show the probability for the pump to start leaking within the five weeks operation, when it operates under arctic conditions.

$$\begin{aligned} &The\ probability\ of\ leaks\ during\ X\ operational\ years \\ &\quad = 1{,}8375E^{-4} \times 0{,}09589\ years\ (5\ weeks) \\ &\quad = 1{,}762E^{-5} \text{ per 5 weeks in service} \end{aligned}$$

The results above show that the probability for a leakage during the well test operation of five weeks in the Barents Sea for the transfer pump is 1,762E^{-5} per five weeks in service. This is a frequency once per 5443 year, when the pump is in service the whole year.[7]

[7] If we disregard the R(t), i.e. reliability is a function of time. We assume constant failure rate, not influenced by time.

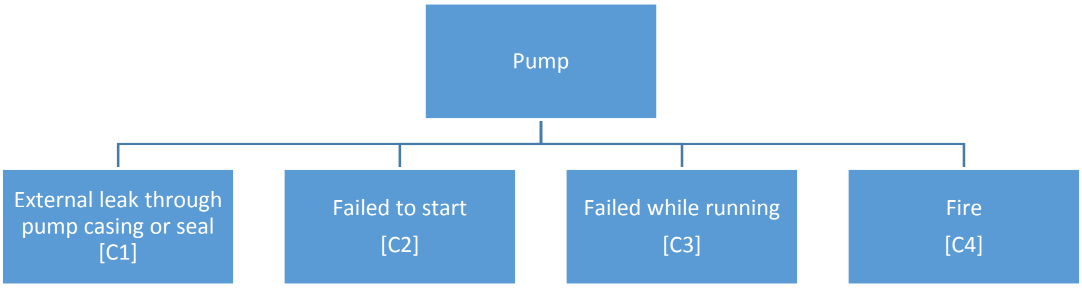

Figure 21; Excerpt of an event three for our example

5. Discussion, Conclusion and Suggested Future Improvements

In this chapter will the results from the risk analysis be evaluated and discussed. Key areas of the thesis will be evaluated and discussed. The conclusion for this thesis and suggestions to future improvements will be presented.

5.1 Discussion

5.1.1. Influencing Factors

The result from the case study is to show the methodology on how to perform and calculate the influence the arctic environment has on the reliability, i.e. the probability for an unwanted event to occur. The report show how data is gathered and how companies can account for other factors which plays a significant role with regard to reliability.

The influence by the environment is caused by a set of factors. These factors are cold, ice, darkness, distance and vulnerable environment. All these factors are not factors which will increase probability, but factors which will increase the overall risk picture. For instance, the vulnerable environment is not a factor which will increase the probability, but a factor which will increase the severity for the consequences, thereby increase the associated risk. A thoroughly explanation regarding cold climate factors is presented in chapter 2, section 5.

All influencing factors will influence the operation, and thereby in one way or another increase the associated risk. Either by increasing the probability for occurrence, or by increasing the severity of the consequences. Both events will increase the overall risk picture. The degree of influence by the cold climate factors will vary for each operation. For instance would the degree of influence by the cold climate factors be bigger in the north and/or the east of the Barents Sea, since some of the factors are more severe in those regions. Sea ice and atmospheric ice will occur more often, and wind and temperatures will be much more hostile, in addition to the absent of weather forecast and nearby infrastructure. All these additional factors will increase the degree of influence set by the cold climate factors, and thereby would the total risk picture be much higher than in other areas of the Barents Sea.

This means that the degree of influence by the cold climate factors is not uniformly distributed, but will vary, and individual evaluation for projects and operations which plan to operate in the region must be executed before commencing operations in the Barents Sea.

5.1.2 Hazard Analysis and Risk Control Record

The results from the case study is fully illustrated in appendix F. The appendix is showing the HARC analysis which is modified to suit, and accommodate, for other influencing factors. In this case the operations is due to operate in the Barents Sea. Therefore must the reliability and safety be modified to account for cold climate factors like coldness, weather, temperatures, darkness, remoteness, etc. The analysis in the appendix G is an excerpts from a fully developed risk analysis, provided by Schlumberger. In this modified analysis all the operational activity-steps have been evaluated. Every hazard in every activity-step has been identified and discussed. In addition, the hazard is evaluated with regards to how this could affect the reliability and safety of the operation. The analyse also includes mitigating and preventive measures on how to account for these additional hazards and additional risks.

Many of the hazards described in the analysis is a direct result of bad, or lack of, planning. It can also be because the industry sets to high requirements for the equipment, so the research and technology cannot fulfil the need. For instance, many hazards is a result of wrong usage of seals, casings, lubricants, rubber materials and so on. It can also be whole components, which is not designed to operate under these conditions, and where similar failure causes are common between components. The error can be seen as a result of bad planning, structuring and administrative errors, such as training, preparations and modifications. Every additional factor included in the project, when the operation gradually is moving northwards will decrease the total reliability and safety, se previous chapter, chapter 5, section 1. Therefore has this analysis commented how the reliability and safety is affected by the specific hazard or event. This is done to show how the cold climate factor influences on the specific hazard, and what type of preventive measure can be installed to mitigate the risk involved, see Figure 22. This is measures which is supposed to directly mitigate the additional risks set by the cold climate factors.

Step	HAZARD			Control Mesures		
	Hazard description and Worst Case consequences (w/no prevention/mitigation measures)	Cold Climate Technology (Darkness, weather-forecast, temperature-range, ice, remoteness, vulnerable environment) *Factors which will increase risk.*	Reliability and Safety	Current and planned prevention measures to reduce likelihood	Current and planned mitigation measures to reduce severity	Cold Climate preventive and/or mitigating measures, to reduce likelihood and severity *Measures and solutions which can decrease risk.*

Figure 22; Top row of the modified HARC table

The severity and the degree of influence, set by the cold climate factors, will increase exponential when the operation gradually is moving northwards. Additional factors also occur, such as seasonal ice, all year around ice, lower temperatures, longer darkness etc. This means that thus longer northwards the industry is moving, thus more research and preparations must be in place before we reach an acceptable level of safety and reliability. An extreme operation planned in the Barents Sea the coming year is the drilling operation in the Hoop area. As Figure 23 shows, *picture showing the ice prevalence in 2011-2012*, the seasonal ice accumulate almost as far south as Bjørnøya. The picture shows sea ice from 2011 and 2012. The area of industrial interest on the NCS is stretching all the way up to Bjørnøya. This means that the probability for ice occurrence is likely, and must be accounted *very probable*. Statoil plans to drill an explorations well in the Hoop area, which is the northernmost well ever drilled on the NCS. Statoil have defined the area to be an area where they have the necessary technology to commence drilling activities, but with a risk of ice occurrence. This is during the summer months and that would be the best option with regards to the lowest number of influencing factors, in addition to the lowest degree of influence done by the fators. The standards involved in such an operation dictates that reliability and safety must at all-time be highlighted, and that procedures and documents are up to date before the operations can begin. As mentioned in the literature chapter, the status for the standards related to arctic operation is “lacking” in some degree. In the degree that the industry is planning to operate in areas which is not sub-arctic, but full arctic. If that would be the case the technology and standards in place would lack a severe level of safety.

5.1.3 Expert Opinion

The results from the reliability data and probability calculations reflects the methodology on how to approach this challenge, i.e. descriptively show how historical data can be used to calculate the probability for an event, when including influencing factors. The results from the example, on the transfer pump, shows the probability for the pump to leak during time in service. The basis in this example is to show how factors which can influence the function of the component can be accounted for in the calculations. The example in this report uses the method *Delphi*, this is one out of many expert opinion methods. There are a lot of other methods which can suit an operation better, than this one, so an evaluation for which method would suit that specific operation, or that specific event best is necessary.

The expert opinion review resulted in a predicted increase in failure rate. This was done by sending an excerpt of technical information regarding the transfer pump to experts. The experts review and evaluate the challenges in accordance with their knowledge, and predict an outcome of the operation. This judgments is based on their experience and expertise, and there is not any right or wrong answer. The evaluation of these opinions, in this report, is based on two-three feedbacks from experts. As the results from the expert opinion shows, in the previous chapter, the four different failure modes has been predicted an arctic influence by these experts. The first failure mode, *external leak through pump casing or seal* was predicted to be increased by 30%. From DNV GL's technical reports there is highlighted that this failure mode is the most common one. And therefore would I think that this mode would increase most of all failure modes. The next failure mode is the *failed to start* mode. This mode would probably be influenced by the cold climate, and I can agree in the predicted increase in failure rate, from the experts, of 20%. The third failure mode is the *failed while running* mode. This is one of the common failure modes. The thing is that the mode does not entirely describe the error which is causing the failure, and therefore can the failure be a variety of modes, which all goes under the category *failure while running*. Therefore can this failure mode be caused by many different sources and a predicted increase of 45% would be a good approximation. As mentioned earlier, Schlumberger uses a pump type called gear pump for their arctic operations. This is a new and innovative pump for this type of operation, which means that this pump probably fit the conditions better, since reviews and research is done in relation with this concern. The last failure mode *fire* is a general failure concern and would always be a threat, especially when operating offshore. In relation with all other cold climate factors a predicted increase of 30% seems reasonable. All factors would influence the operation in one way or another, and all these influences will reduce the overall reliability. For instance, monitoring routines can be aborted or reduced, because of bad weather. It can also reduce the quality of the monitoring, and the overall reliability of other equipment will also be reduced, and thereby reduce the reliability on the specific component we are investigating.

The overall increase in probability in percentage is:

$$Percentage\ increase = \frac{New\ probability \div Old\ probability}{Old\ probability} \times 100\%$$

$$Percentage\ increase = \frac{1{,}8375E^{-4} \div 1{,}4E^{-4}}{1{,}4E^{-4}} \times 100\%$$

$$Percentage\ increase = 0{,}3125 \times 100\%$$

$$Percentage\ increase = 31{,}25\%$$

As shown in the calculations above, the overall probability for the transfer pump to leak during the operation has been increased by 31,25%, because of the expert opinion implementation. This is a severe increase with regards to safety, and planning and support documents must be reviewed before any activity can commence with this level of increase.

5.1.4 Probability Calculations

The results from the calculations in the previous chapter, chapter 4, section 2, show that the probability for the transfer pump to leak during a five week operation is 1,34E^{-5} . The data used to calculate this is provided by DNV GL. When gathering expert opinions, the experts is always looking at the testing conditions (conditions in the reference area), to see if some of the conditions can suit the target area. The reliability data provided by DNV GL was based on some requirements; these requirements was that the pump was of the type centrifugal pump, and the dimension of the hole diameter was about 4”. With these requirements, the data provided by DNV GL resulted in a leakage-probability of 1,4E^{-4} per year in service. In dialog with Schlumberger it was highlighted that their oil transfer pump, see appendix F, was neither of the type centrifugal or reciprocating. On that specific project they used a gear pump. The reason for this is that the centrifugal pump must have very high speed and several steps to achieve the same delivery pressure and volume. Reciprocating pumps cannot be used in this type of operation, pumping of crude oil, as it can cause self-ignition[8], although it’s only theoretically possible.

In this thesis we assumed that the pump used was of the type centrifugal. This type of pump is the most common pump to use in the process industry, because of the low maintenance need and low associated cost.

The calculations show that the probability for a leakage is 1,4E^{-4} per year in service for a centrifugal pump. Including the predicted increase set by the experts when implementing the pump for a different set of working conditions, this probability for leakage will increase to $1{,}8375E^{-4}$ per year in service. The overall leakage probability for a transfer pump during a fixed time period of five weeks would then be 1,762E^{-5}, see previous chapter. This number would be lower if we assume that the pump is maintained and inspected after every operation. This assumptions would be realistic on NCS, since every pump is maintained between operations. If time dependent reliability data was available a more realistic reliability development over time could have been provided.

The overall reliability is also dependent on other factors, such as cold climate factors. The distance, for instance, is an issue when unplanned maintenance must be executed. And especially maintenance of a component on an offshore platform. The distance from shore to the platform could be very long, and transporting spare parts could take days, possibly weeks. Therefor must the planning before operations begin, be up to date in all areas of the operation. All factors will in one way or another influence the reliability, directly or indirectly. Therefore is it important to implemented experts in the evaluation step of the reliability calculations. This will most likely give the best realistic picture of the operations.

[8] The same ignition-technique as in diesel engines.

5.2 Conclusion

From the results in the case study the risk analysis (HARC) was modified and upgraded. This analysis includes cold climate factors after being modified. There is also room to comment about how the reliability and safety would be interfered after operating under a different set of environmental conditions. In addition, the analysis also includes mitigating and preventive measures to inhibit these hazards developing. These preventive measures can be general winterization methods, such as shelter the deck, but also small event-specific measures, such as arctic lubricants. This enables the method to suit operations in the arctic environment, and can be extensively modified to include even more cold climate technology.

This procedure for identifying and evaluating hazards according to the analysis-setup is very good and practicable. This will allow the analyst to include cold climate factors, and comment and reflect on how these factors could influence the function of the operation. The analysis does not include any way to implement statistical information, such as probability. This means that the analysis is quantitative risk analysis. The original draft from, Schlumberger, was an edition where this, statistical information, was included, and therefore wouldn't it be any problem re-implement it to suit the analysis. This will increase the quality of the analysis, and be more user-friendly, and easier to adapt to a set of operations. This report only includes the quantitative risk analysis, and one example on how to estimate and predict the probability for an event. This example is meant as a methodology description.

The results from the probability calculations show that the probability for the transfer pump to leak is $1{,}762E^{-5}$ per 5 weeks in service. This results includes the influence caused by the cold climate factors, predicted by the experts. The frequency from this calculations indicates that once per 56754 surface well test operations will the transfer pump fail. Without the cold climate factors the frequency would be once per 74286 surface well test operations. These numbers are based on the fixed time period of five weeks for a surface well testing operation. The probability has increased by 31% after the influences by the arctic environment, according to the prediction of the experts.

5.3 Suggestion for Future Improvements

The purpose of this master thesis is to provide a descriptive methodology on how to include historical information about offshore operations outside the arctic and implement it into the risk analysis, which is set to operate in the arctic environment. Future work for this report would be to convert the risk analysis into quantitative risk assessment (QRA), for the entire plant. A QRA for a surface well testing facility is a really good tool for companies to utilize as a support document in future projects.

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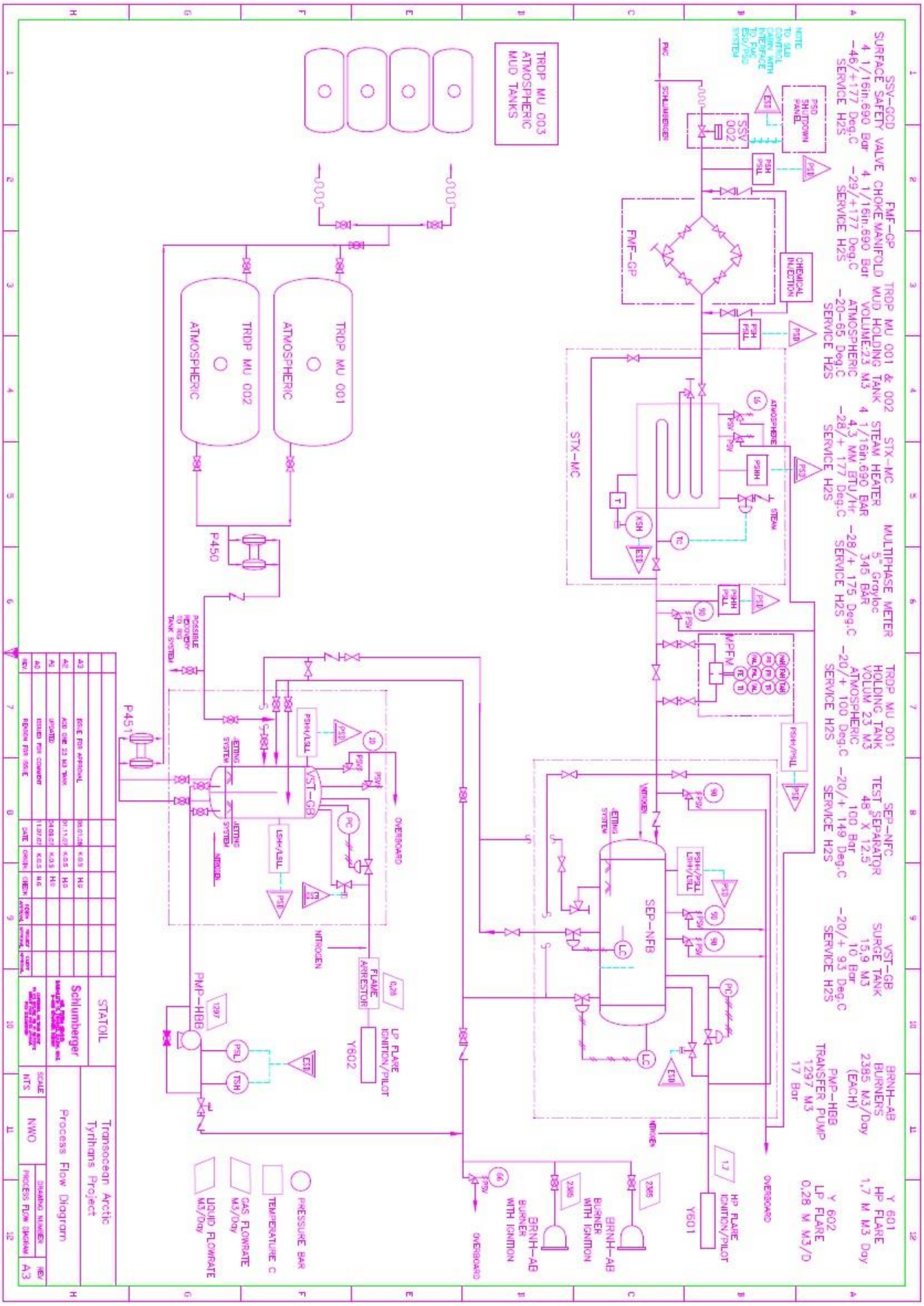
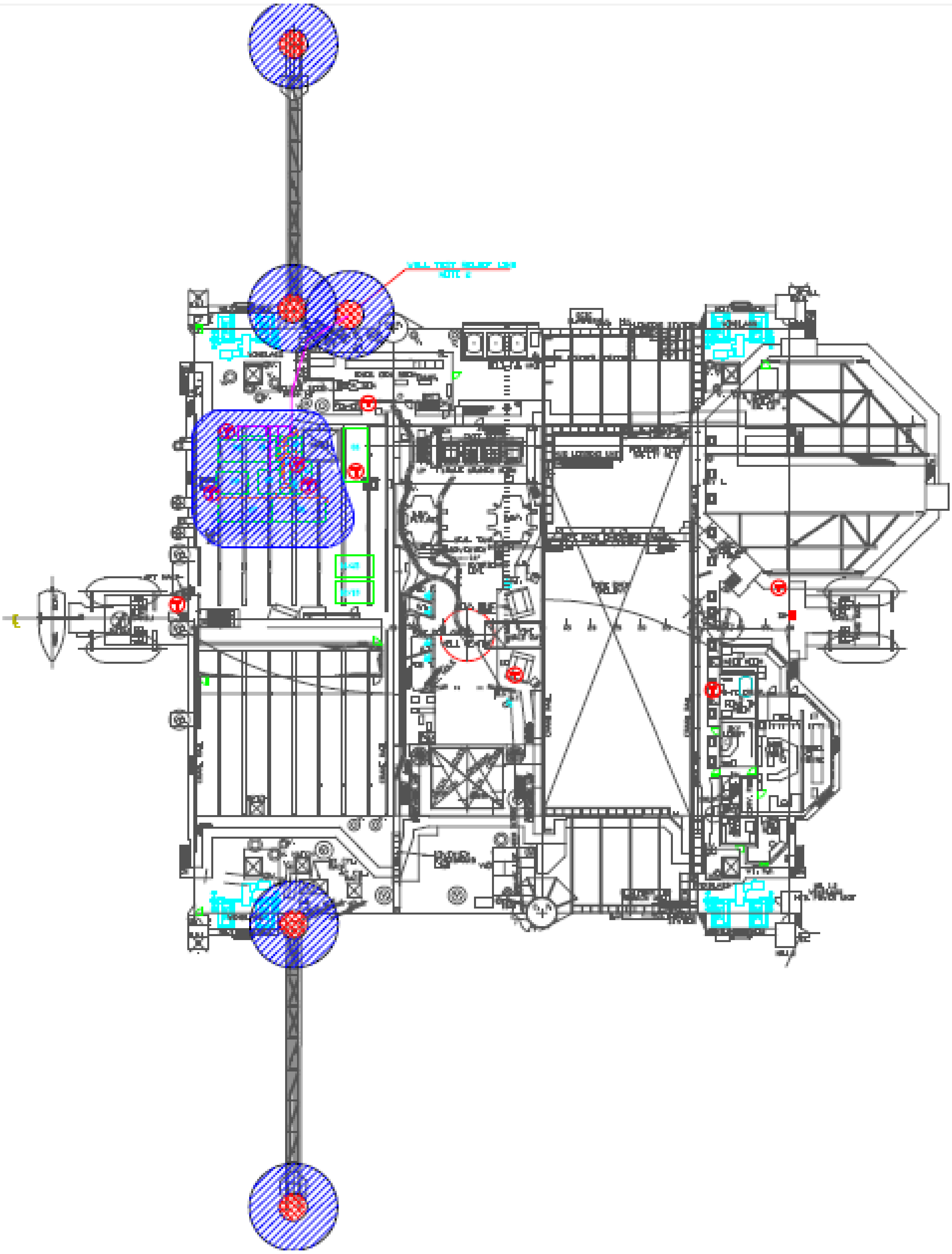
Appendix A


SSV-CCD
SURFACE SAFETY VALVE
4 1/16in.690 Bar
-46/+177 Deg.C
SERVICE H2S
FMF-CP
CHOKE MANIFOLD
4 1/16in.690 Bar
-29/+177 Deg.C
SERVICE H2S
TRDP MU 001 & 002
MUD HOLDING TANK
VOLUME:23 M3
ATMOSPHERIC
-20-65 Deg.C
SERVICE H2S
STX-MC
STEAM HEATER
4 1/16in.690 BAR
4,3 MM BTU/Hr
-28/+ 177 Deg.C
SERVICE H2S
MULTIPHASE METER
5" Grayloc
345 BAR
-28/+ 175 Deg.C
SERVICE H2S
TRDP MU 001
HOLDING TANK
VOLUM 23 M3
ATMOSPHERIC
-20/+ 100 Deg.C
SERVICE H2S
SEP-NFC
TEST SEPARATOR
48" X 12.5'
100 Bar
-20/+ 149 Deg.C
SERVICE H2S
VST-GB
SURGE TANK
15,9 M3
10 Bar
-20/+ 93 Deg.C
SERVICE H2S
BRNH-AB
BURNERS
2385 M3/Day
(EACH)
PMP-HBB
TRANSFER PUMP
1297 M3
17 Bar
Y 601
HP FLARE
1,7 M M3 Day
Y 602
LP FLARE
0,28 M M3/D
TRDP MU 003
ATMOSPHERIC
MUD TANKS
TRDP MU 001
ATMOSPHERIC
TRDP MU 002
ATMOSPHERIC
STX-MC
FMF-CP
SEP-NFB
VST-GB
PMP-HBB
P450
P451
Y601
Y602
HP FLARE
IGNITION/PILOT
LP FLARE
IGNITION/PILOT
FLAME
ARRESTOR
BRNH-AB
BURNER
WITH IGNITION
OVERBOARD
NITROGEN
PRESSURE BAR
TEMPERATURE C
GAS FLOWRATE
M3/Day
LIQUID FLOWRATE
M3/Day
STATOIL
Schlumberger
Transocean Arctic
Tyrihans Project
Process Flow Diagram
NWO
PROCESS FLOW DIAGRAM
A3

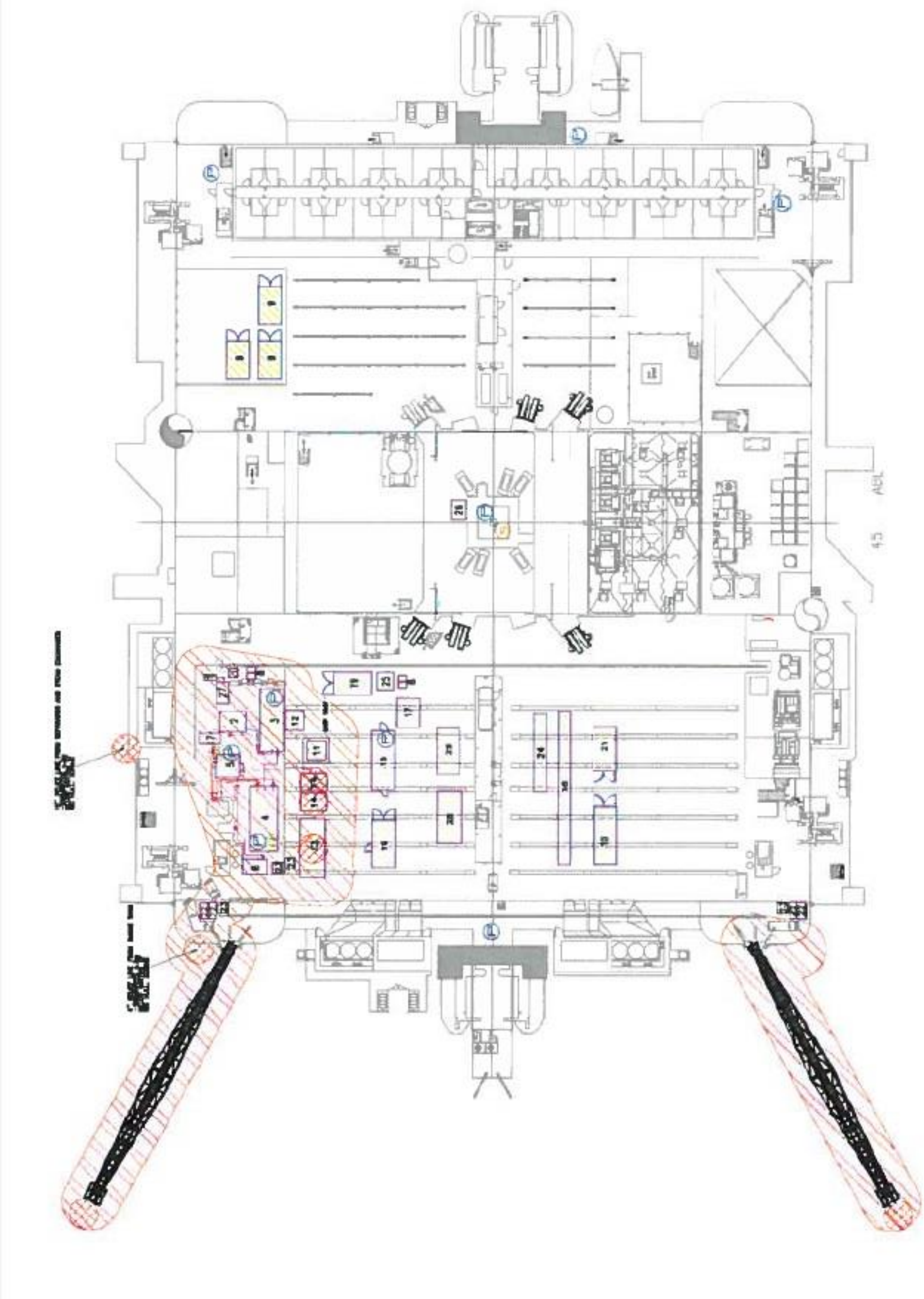
Appendix B



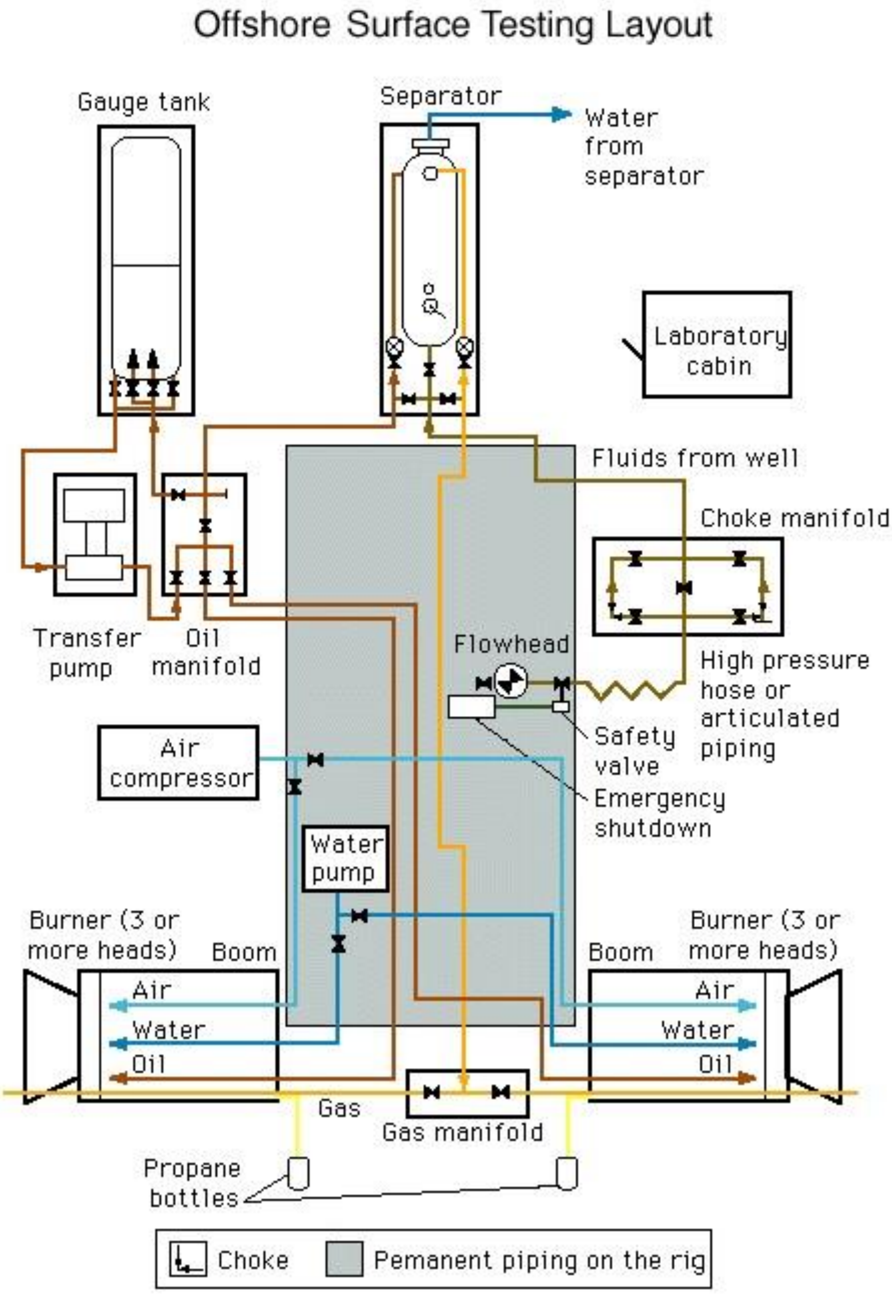
Appendix C

1	SURFACE SAFETY VALVE	350	10k
2	CHOKE MANIFOLD*	350	10K
3	STEAM EXCHANGER*	350	10K
4	SEPARATOR*	350	1440
5	VERTICAL SURGE TANK*	212	150
6	TRANSFER PUMP (ELECTRIC)	-	-
7	AIR DRIVEN TRANSFER PUMP*	212	150
8	CHEMICAL INJECTION UNITS	212	10K
9	AIR COMPRESSORS**, 50Nm3/min	-	145
10	DST WORKSHOP	-	-
11	METHANOL TANKS***(WET+DRIP TRAY WEIGHT)	-	-
12	MEG TANKS***	-	-
13	20m3 TOTE TANK***	-	-
14	4.5m4 TOTE TANK***	-	-
15	DATA ACQUISITION CABIN	-	-
16	SWT WORKSHOP	-	-
17	EQUIPMENT CONTAINER	-	-
18	SUBSEA BASKET	-	-
19	STEAM GENERATOR****	-	-
20	ESD PANEL	-	-
21	SUBSEA WORKSHOP	-	-
22	PROPANE RACK	-	-
23	NITROGEN RACK	-	-
24	TCP GUN BASKET	-	-
25	CHEMICAL INJECTION REELER (DOWNHOLE)	-	-
26	HYDRAULIC UMBILICAL	-	-
27	EXPRO MIXING MANIFOLD	350	15K
28	BAKER HUGHES N2 PUMP	-	-
29	BAKER HUGHES N2 TANK ***	-	-

NOTE: * WET WEIGHT QUOTED (VESSEL 80% FULL H2O)
NOTE: ** WET WEIGHT QUOTED (WITH 100% FUEL LOAD)
NOTE: *** WET WEIGHT QUOTED (FULL RESPECTIVE FLUID)
NOTE: *** WET WEIGHT QUOTED (100% FUEL LOAD, FULL



Appendix D


Offshore Surface Testing Layout
Gauge tank
Separator
Water from separator
Laboratory cabin
Fluids from well
Choke manifold
Transfer pump
Oil manifold
Flowhead
High pressure hose or articulated piping
Safety valve
Emergency shutdown
Air compressor
Water pump
Burner (3 or more heads)
Boom
Air
Water
Oil
Boom
Burner (3 or more heads)
Air
Water
Oil
Gas
Gas manifold
Propane bottles
Choke
Pemanent piping on the rig

Appendix E

Excerpts from the *Barents 2020* report:

4.7.8 Standards selected and suitability considerations

1. Arctic Technology (incl. ice management, ice loading) - (Scope of Group RN02)

Standard	Title	Barents Sea Suitability	Comments
ISO 19906	Petroleum and Natural Gas Industries – Arctic Offshore Structures	A	- Further amendments proposed by RN02

2. Civil and Structural Engineering

Standard	Title	Barents Sea Suitability	Comments
NORSOK C-001	Living quarters area	B	Air condition, ventilation, heating needs additional low temp. consideration. Dimensions due to special arctic clothing and tools
NORSOK C-002	Architectural components and equipment	B	Dimensions need special consideration due to special arctic clothing and tools

4. Drilling and Well

Standard	Title	Barents Sea Suitability	Comments
ISO 10423	Drilling and production equipment — Wellhead and christmas tree equipment	A	
ISO 10432	Downhole equipment — Subsurface safety valve equipment	A	
ISO 11960	Steel pipes for use as casing or tubing for wells	A	
ISO 13535	Drilling and Production Equipment - Hoisting Equipment	B	Needs additional low temp. consideration
ISO 14693	Drilling and well servicing equipment	B	Needs additional low temp. consideration

5. Electrical

Standard	Title	Barents Sea Suitability	Comments
IEC 60085	Electrical insulation - Thermal evaluation and designation	A	
IEC 60034	Rotating electrical Machines	A	Needs additional low temp. consideration Russian version = ГОСТ РМЭК 60092
IEC 60364	Low-voltage electrical installations (relevant parts)	B	Needs additional low temp. consideration
IEC 60529	Degrees of protection provided by enclosures (IP Code)	A	
IEC 61000	Electromagnetic compatibility (EMC)	A	
IEC 61892	Fixed and mobile offshore units – Electrical installations	B	Needs additional low temp. consideration
IEC 61936	Power installations exceeding 1 kV a.c.	B	Needs additional low temp. consideration

6. Emissions and Discharges to Air and Water (RN07)

Standard	Title	Barents Sea Suitability	Comments
ISO 14001	Environmental Management Systems	A	Ref.RN07
International Finance Corporation / World bank Group	Environmental, Health, and Safety Guidelines: Offshore Oil and Gas Development	B	Ref.RN07
International Finance Corporation / World bank Group	Environmental, Health, and Safety Guidelines: Ambient Air Quality (2007)	B	Ref.RN07
IMO	MARPOL 73/78 Annexes with amendments	B	Ref.RN07
IMO	Ballast Water Convention	B	Ref.RN07
IMO	Antifouling Convention	B	Ref.RN07
NORSOK S-003	Environmental Care	B	Ref.RN07

7. Environmental Conditions, Loads and Load Effects

Standard	Title	Barents Sea Suitability	Comments
ISO 19900	Petroleum and natural gas industries – General requirements for offshore structures	B	- To be used together with ISO 19906 for arctic application
ISO 19901-1	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating considerations	B	- To be used together with ISO 19906 for arctic application
ISO 19901-2	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 2: Seismic design procedures and criteria	A	
NORSOK N-002	"Collection of metocean data"	A	
CLASS RULES	Relevant Classification rules for floating offshore units	A	Cat. A, provided including Polar Class notations

8. Evacuation and rescue of people (RN04)

Standard	Title	Barents Sea Suitability	Comments
ISO 15544	Offshore production installations – Requirements and guidelines for emergency response	B	Ref. RN04 report

9. Geotechnology & Foundations

Standard	Title	Barents Sea Suitability	Comments
ISO 19901-4	Petroleum and Natural Gas Industries – Specific Requirements for Offshore Structures – Part 4: Geotechnical and Foundation Design Considerations.	B	Ice needs additional consideration
ISO 19901-8	Marine soil investigations	A	

10. Instrumentation and automation

Standard	Title	Barents Sea Suitability	Comments
IEC 61508	Functional safety of electrical/electronic/ programmable electronic safety-related systems	A	
IEC 61511	Functional safety – Safety instrumented systems for the process industry sector	A	
ISO 11064	Ergonomic design of control centres	A	
EEMUA 191	Alarm Systems – A Guide to Design, Management and Procurement	A	
PSA YA-711	Principles for alarm system design	A	
NORSOK I-002	Safety and automation systems (SAS)	A	
NORSOK I-005	Systems Control Diagrams	A	
CLASS RULES	Relevant Classification rules for floating offshore units	A	Cat. A, provided including Polar Class notations

11. Life Cycle Information (LCI)

Standard	Title	Barents Sea Suitability	Comments
ISO/TR 13881	Classification and conformity assessment of products, processes and services	A	
ISO/TS 29001	Sector-specific quality management systems – Requirements for product and service supply organizations	A	
ISO 14040	Environmental management -- Life cycle assessment -- Principles and framework	A	
NORSOK Z-001	Documentation for Operation	A	

12. Lifting Appliances

Standard	Title	Barents Sea Suitability	Comments
EN 13852-1	General-purpose offshore cranes	B	Needs additional low temperature considerations
ILO 152	Cargo Gear Safety and Health in Dock Work	B	Needs additional low temperature considerations

13. Materials technology

Standard	Title	Barents Sea Suitability	Comments
ISO DIS 21457	Materials selection and corrosion control for oil and gas production systems	B	Needs additional low temperature considerations
ISO 15156:	Materials for use in H2S-containing environments in oil and gas production	A	
ISO 23936-1	Non-metallic materials in contact with media related to oil and gas production - Thermoplastics	A	
EN 1090-3	Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures	B	Needs additional low temperature considerations
NORSOK M-101	Structural steel fabrication (referred to from ISO 19902)	B	Needs additional low temperature considerations
CLASS RULES	Relevant Classification rules for floating offshore units	A	Cat. A, provided including Polar Class notations

14. Mechanical (Mechanical static and rotating, HVAC, piping engineering, etc.)

Standard	Title	Barents Sea Suitability	Comments
ISO 3977	Gas Turbines – procurement	B	Needs additional low temperature considerations
ISO 10437	Petroleum, petrochemical and natural gas industries – Steam turbines – Special-purpose applications	B	Needs additional low temperature considerations
ISO 10439	Petroleum, chemical and gas service industries – Centrifugal compressors	B	Needs additional low temperature considerations
ISO 10440	Petroleum, petrochemical and natural gas industries – Rotary-type positive-displacement compressors	B	Needs additional low temperature considerations
ISO 10442	Petroleum, chemical and gas service industries – Packaged, integrally geared centrifugal air compressors	B	Needs additional low temperature considerations
ISO 13631	Petroleum and natural gas industries – Packaged reciprocating gas compressors	B	Needs additional low temperature considerations
ISO 13703	Design and installation of piping systems on offshore production platforms	B	Needs additional low temperature considerations
ISO 13707	Petroleum and natural gas industries – Reciprocating compressors	B	Needs additional low temperature considerations
ISO 13709	Centrifugal Pumps	B	Needs additional low temperature considerations
ISO 13710	Reciprocating positive displacement pumps	B	Needs additional low temperature considerations
ISO 14692	Petroleum and natural gas industries -- Glass-reinforced plastics (GRP) piping	B	Needs additional low temperature considerations
ISO 15138	Petroleum and natural gas industries – Offshore production installations – Heating, ventilation and air-conditioning	B	Needs additional low temperature considerations
ISO 15547	Petroleum, petrochemical and natural gas industries -- Plate-type heat exchangers	B	Needs additional low temperature considerations
ISO 15649	Piping	B	Needs additional low temperature considerations
ISO 16812	Petroleum, petrochemical and natural gas industries -- Shell-and-tube heat exchangers	B	Needs additional low temperature considerations
API 616	Gas turbines for refinery services	B	Needs additional low temperature considerations

Standard	Title	Barents Sea Suitability	Comments
EN 13445	Unfired pressure vessels	B	Needs additional low temperature considerations
NFPA 20	Standard for the installation of stationary pumps for fire protection	B	Needs additional low temperature considerations
CLASS RULES	Relevant Classification rules/standards for floating offshore units	A	Cat. A, provided including Polar Class notations

15. Operation and maintenance (incl Regularity & Criticality)

Standard	Title	Barents Sea Suitability	Comments
ISO 14224	Collection and exchange of reliability and maintenance data	A	
ISO 19901-6 (FDIS)	Specific requirements for offshore structures – Part 6: Marine operations	A	
ISO 20815	Petroleum, petrochemical and natural gas industries – Production assurance and reliability management	A	

16. Pipeline Technology

Standard	Title	Barents Sea Suitability	Comments
ISO 13623	Petroleum and natural gas industries – Pipeline transportation systems	A	
ISO 21809	External coatings for buried or submerged pipelines used in pipeline transportation systems	A	
DNV OS-F101	Submarine Pipeline System	A	
Russian Maritime Register of Shipping (RS)	Rules for the Classification and Construction of Subsea Pipelines	A	
Russian Maritime Register of Shipping (RS)	Guidelines on Technical Supervision during Construction and Operation of Subsea Pipelines	A	

17. Platform Technology

Standard	Title	Barents Sea Suitability	Comments
ISO 19901-3 (DIS)	Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 3: Topsides structure	B	- To be used together with ISO 19906 for arctic application
ISO 19902	Petroleum and natural gas industries — Fixed steel offshore structures	B	- To be used together with ISO 19906 for arctic application
ISO 19903,	Petroleum and natural gas industries — Fixed concrete offshore structures	B	- To be used together with ISO 19906 for arctic application
ISO 19904-1,	Petroleum and natural gas industries — Floating offshore structures – Part 1: Monohulls, semi-submersibles and spars	B	- To be used together with ISO 19906 for arctic application
ISO 19905-1 (DIS)	Petroleum and natural gas industries -- Site-specific assessment of mobile offshore units -- Part 1: Jack-ups	B	- To be used together with ISO 19906 for arctic application
CAA CAP 437	Offshore Helicopter Landing Areas - Guidance on Standards	A	
Russian Maritime Register of Shipping (RS)	Rules for the Classification, Construction and Equipment of Floating Offshore Oil-and-Gas Production Units	A	Cat. A, provided including Polar Class notations
Russian Maritime Register of Shipping (RS)	Rules for The Classification, Construction and Equipment of Mobile Offshore Drilling Units and Fixed Offshore Platforms, 2008	A	Cat. A, provided including Polar Class notations
Russian Maritime Register of Shipping (RS)	Guidelines on Technical Supervision of Mobile Offshore Drilling Units and Fixed Offshore Platforms in Service, 2004	A	
DNV	Rules for Classification of Offshore Drilling and Support Units	A	Cat. A, provided including Polar Class notations
DNV	Rules for Classification of Floating Production, Storage and Loading Units	A	Cat. A, provided including Polar Class notations

18. Process Technology, incl. cold climate protection of process plants and flow assurance / fiscal measurement

Standard	Title	Barents Sea Suitability	Comments
ISO 4126	Safety devices for protection against excessive pressure	B	Needs additional low temperature and icing considerations
ISO 10418	Basic surface process safety systems	A	
ISO 23251	Pressure relieving and depressurizing systems	B	Needs additional low temperature and icing considerations
ISO 25457	Petroleum, petrochemical and natural gas industries -- Flare details for general refinery and petrochemical service	B	Needs additional low temperature and icing considerations

19. Riser technology

Standard	Title	Barents Sea Suitability	Comments
ISO 13628-2 (API 17J),	Design and operation of subsea production systems -- Part 2: Unbonded flexible pipe systems for subsea and marine applications	A	
ISO/NP13628-12 (DNV OS-F201)	Design and operation of subsea production systems -- Part 12: Dynamic production risers	B	Needs additional low temperature and ice load considerations

20. Risk Management of major Hazards (e.g. fires, explosions, blow-outs) – RN03

Standard	Title	Barents Sea Suitability	Comments
ISO 13702:	Control and mitigation of fires and explosions on offshore production installations – Requirements and guidelines	B	Ref. RN03 report
ISO 17776	Offshore production installations – Guidelines on tools and techniques for identification and assessment of hazards.	B	Ref. RN03 report
ISO 31000	Risk management – Principles and guidelines	A	Ref. RN03 report
IEC 60079	Explosive atmospheres	B	Ref. RN03 report
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems	A	Ref. RN03 report
IEC 61892-7	Mobile and fixed offshore units - Electrical installations - Part 7: Hazardous areas	B	Ref. RN03 report
ISO/IEC 80079 (CD)	Explosive atmospheres – Part 34: Application of quality systems for electrical and non-electrical equipment	B	Ref. RN03 report
NORSOK D010	Well integrity in drilling and well operations	B	Ref. RN03 report
NORSOK S-001	Technical Safety (for review by Russian delegates)	B	Ref. RN03 report
NORSOK Z-013	Risk and emergency preparedness analysis	B	Ref. RN03 report

21. Safety, Health and Environment (SHE)

Standard	Title	Barents Sea Suitability	Comments
IMO MODU CODE	Code for the construction and equipment of mobile offshore drilling units	B	Needs additional consideration on life saving appliances
DNV-OS-A101	Safety Principles and Arrangement	A	
CLASS RULES	Relevant Classification rules/standards for floating offshore units	A	Cat. A, provided including Polar Class notations

22. Ship Transportation – (RN06)

Standard	Title	Barents Sea Suitability	Comments
IMO	International Code of Safety for Ships in Polar Waters (Polar Code) (IMO doc. DE41/10)	B	Ref. RN06 report
IMO	IMO guidelines for ships operating in Arctic Ice Covered waters (MEPC/Circ.1056)	B	Ref. RN06 report
IACS	International Association of Classification Societies (IACS): Requirements concerning Polar Class	A	Ref. RN06 report
DNV	DNV: Rules for classification of ships, Part 5, Chapter 1: Ships for navigation in ice	A	Ref. RN06 report
DNV	DNV Seaskill no.3.312: Competence of Officers for Navigation in ice	B	Ref. RN06 report
ISGOTT	International Oil Tanker and Terminal Safety Guide	A	Ref. RN06 report
OCIMF	Oil Companies International Maritime Forum Publications	B	Ref. RN06 report

23. Station keeping (mooring)

Standard	Title	Barents Sea Suitability	Comments
ISO 19901-7	Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units	B	- To be used together with ISO 19906 for arctic application
CLASS RULES	Relevant Classification rules/standards for floating offshore units	A	Cat. A, provided including Polar Class notations

24. Subsea Technology

Standard	Title	Barents Sea Suitability	Comments
ISO 13628 -1	Design and operation of subsea production systems -- Part 1: General requirements and recommendations	A	
ISO 13628 -4	Design and operation of subsea production systems -- Part 4: Subsea wellhead and tree equipment	A	
ISO 13628 -5	Design and operation of subsea production systems -- Part 5: Subsea umbilicals	A	
ISO 13628 -6	Design and operation of subsea production systems -- Part 6: Subsea production control systems	A	
ISO 13628 -7	Design and operation of subsea production systems -- Part 7: Completion/workover riser systems	A	
ISO 13628 -8	Design and operation of subsea production systems -- Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems	A	
ISO 13628 -9	Design and operation of subsea production systems -- Part 9: Remotely Operated Tool (ROT) intervention system	A	
ISO 13628 -10	Design and operation of subsea production systems -- Part 10: Specification for bonded flexible pipe	A	
ISO 13628 -11	Design and operation of subsea production systems -- Part 11: Flexible pipe systems for subsea and marine applications	A	
ISO (DIS) 13628-15	Petroleum, petrochemical and natural gas industries — Design and operation of subsea production systems — Part 15: Subsea structures and manifolds	B	Iceberg considerations

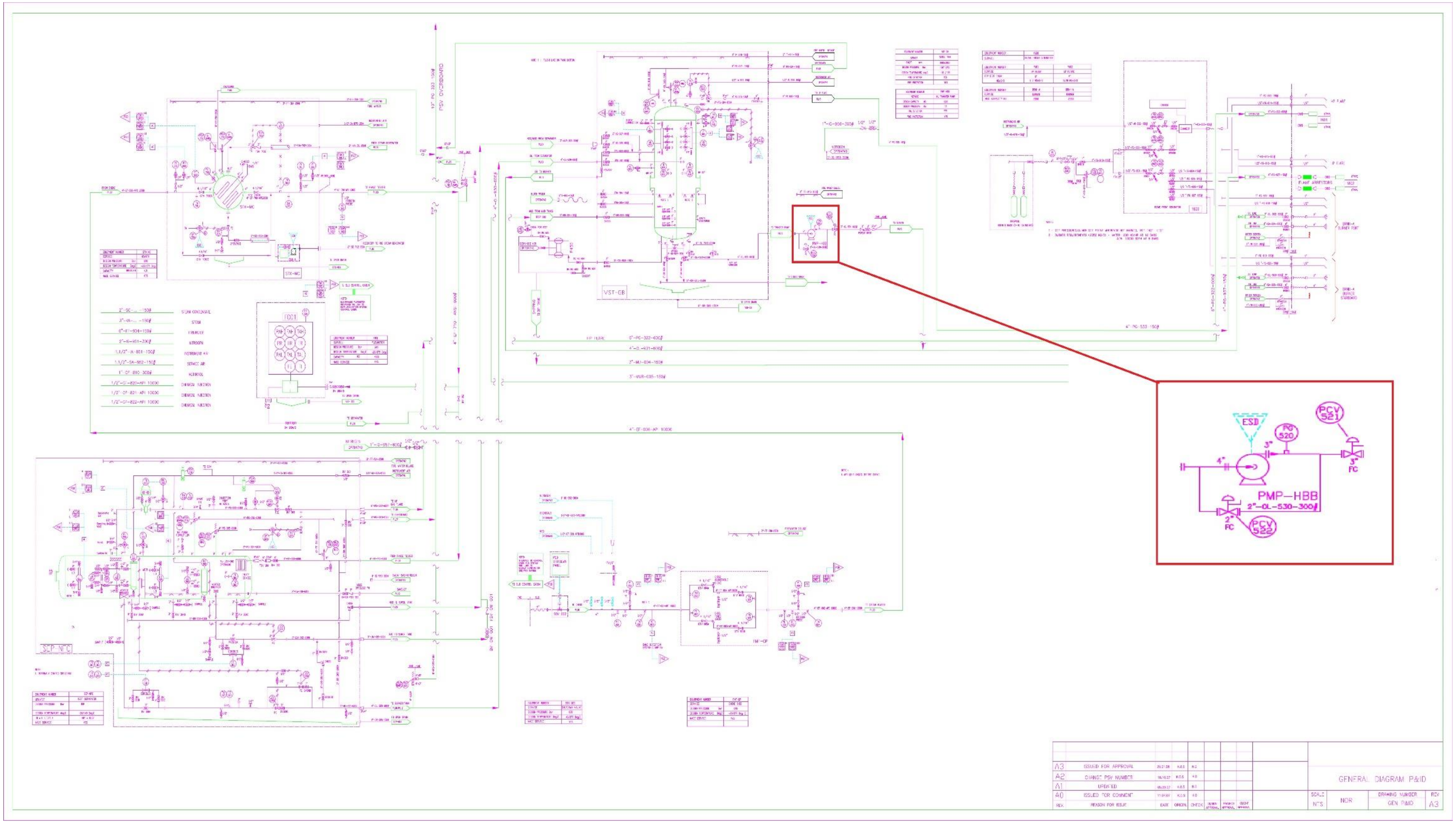
25. Telecommunication

Standard	Title	Barents Sea Suitability	Comments
NORSOK T-001	Telecom systems (for further study)	A	
GOST P 50829-95	GOST P50829-95 Safety of radio stations, the radio-electronic equipment with transmit/receive equipment and its constituent parts. General requirements and test methods	A	
GOST P52454-2005	GOST P52454-2005 Global navigating satellite system and global system of positioning. Personal receiver. Technical requirements	A	
GOST P 52455-2005	GOST P52455-2005 Global navigating satellite system and global system of positioning. Marine receiver for common use. Technical requirements	A	
GOST P52866-2007	GOST P52866-2007 Global navigating satellite system - Station control-adjusting local civil purpose. Technical requirements	A	
ISO/IEC 18044	Information technology. Methods and supporting means of a safety. Management of incidents of information safety.	A	

26. Working Environment and safety related to Human factors (input from RN05)

Standard	Title	Barents Sea Suitability	Comments
NORSOK S-002	Working Environment	B	Ref. RN05 report
OGP	Health Aspects of Work in Extreme Climates (Report 398, Dec 2008)	A	Ref. RN05 report

Appendix F


ESD
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GENERAL DIAGRAM P&ID

Appendix G

The following pages (1-13) in this appendix G is the result from the work with the Hazard Analysis and Risk Control Record, HARC.

Step	HAZARD			Control Mesures		
	Hazard description and Worst Case consequences (w/no prevention/mitigation measures)	Cold Climate Technology (Darkness, weather-forecast, temperature-range, ice, remoteness, vulnerable environment) *Factors which will increase risk.*	Reliability and Safety	Current and planned prevention measures to reduce likelihood	Current and planned mitigation measures to reduce severity	Cold Climate preventive and/or mitigating measures, to reduce likelihood and severity *Measures and solutions which can decrease risk.*
Rig up surface lines	Gravitational Energy (Lifting, handling) 1. Multiple trip and handling hazards leading to SHL (stepping, handling and lifting) related injury. 2. Makeup Hammer union connections, risk of personnel injury. 3. Incompatibility of connections or ratings of equipment, leading to failure to hold pressure. 4. Handling of coflexip hose leading to personnel injury or damage to equipment. 5. Incorrect pipework layout applied, leading to lost time.	1. Ice such as atmospheric ice will increase the difficulty when handling components. Darkness and coldness will complicate tasks, such as monitoring, lifting, handling modifications. Temperature (low and range) will complicate the work because of working-clothes workers and personnel need to wear. Weather-forecast can occur suddenly, and can have tremendous consequences, which will complicate the work severely. 2. Temperature can change the properties of rubber joints (o-rings). Ice can hide/cover joints, thereby complicate the modification. 3. Temperature range can cause change in properties to steel structures. Darkness, ice and coldness can complicate the task of monitoring, and thereby can personnel neglect to identify possible leakage. 4. Ice and coldness will increase the difficulty when handling coflex-hoses. Darkness will amplify the difficulty. Weather-forecast and weather can set the operations on hold. 5. Remoteness will ensure for even longer downtime, due to the long distances and the lack of infrastructure in the Barents region.	1. Reliability and safety will be decreased severely, because of the increase in likelihood of occurrence. 2. Reliability will decrease if not accounted for. 3. Reliability will decrease if not accounted for. 4. Reliability and safety will decrease if not accounted for. 5. Reliability will decrease, few/none mitigating actions before big upgrade in infrastructure.	Pre rig-up briefing with all personnel. All personnel SIPP trained and SIPP practices followed. Housekeeping managed throughout rig up. Footwear in good condition (especially soles) Employees trained in safe procedure for making up hammer unions. Wooden shafted brass headed hammers used to make up unions. Use crane to move pipe whenever possible. Pipe rests in use throughout. Effective supervision of line layout. Layout diagram available and followed. All equipment checked out prior to mobilization to well site to assure compatibility. All flow lines and connections secured; · Safety cable on all flow lines. · All flow lines secured to deck / ground. Flush all lines prior to connecting to burner. Ensure Adequate lighting is available. Condition of tools (Hammer, etc) checked. Sufficient room for swinging hammer. Pipe stands/supports used. Competent / Trained personnel. Consider positions of others in area while hammering. Minimise personnel in area while hammering. Consider impact on adjacent work areas.	PPE worn by all personnel as required by local standard. Emergency response plan to include: · Medevac plan · First aider · Communications protocol Contingency plan to include: · Alternate crane supplier defined. · Spare / replacement equipment identified. Communication protocol Use of back supports where available.	1. To completely, or partially cover the the rig-deck, will reduce the potential for ice to accumulate. A cover will also shelter the worker while operating on deck. Sufficient lighting will light up all the necessary parts on deck. 2. Research and studies on this topic must be in place, so that the equipment can withstand the arctic environment. A complete cover will shelter the equipment. 3. Heated -floor and –cables could reduce ice accumulation on exposed areas. See nr. 2 4. Heated floor, heated shelter, sufficient lightning will make it easier to handle coflex-hoses. To increase the quality of weather-foreast more weather stations must be installed on vessels and land, in and around the Barents Sea. 5. This topic is difficult to handle, without large investments in the region. This investment would go to upgrade and update the infrastructure, especially in Troms and Finnmark.

	6. Pipework sagging leading to equipment damage and / or inability to make connections. 7. Scale / debris in rig permanent lines, leading to plugging and / or damage to equipment and burner.	6. Coldness can change properties in rubber and steel, which can cause brittle sections in the pipework. Ice can provide ice-loads, and thereby burst or crack the material, due to the severe loads applied by the ice. 7. Coldness can change lubrication properties, this can be one type of debris. Other factors which can follow the same trend can be rubber joints, hydrates formation, pre-pollution in pipework etc. .	6. Reliability and safety will decrease if not accounted for. 7. Reliability will decrease if not accounted for.			One solutions for this problem can be collaboration between companies which operates in the region. If companies collaborate on a shared storage to supply the ongoing industry in the Barents Sea, much capital and investment can be reduced. 6. See nr.2 and nr. 1. In addition, must equipment and installations meant to operate in the arctic be built after arctic standards, with regards to structure integrity and structure strength. 7. Research and studies on this topic must be in place, so that the process-technical solutions can withstand, and operate normally in the arctic environment. A complete cover will shelter the equipment, and in relation with heated equipment and heated areas on deck, could this problem be accounted for.

Rig Up Boom	**Machinery/ Equipment/ Hand Tools Gravitational Potential Energy (Stepping, Handling, Lifting)** 1. Incorrect dimension of king post, leading to incorrect length of hanging wires and incorrect boom placement. 2. Failure of mechanical lifting equipment, leading to dropped boom, personnel injury and / or damage to or loss of equipment. 3. Placement of side wire eyes in rig not optimal for boom. 4. Side wires incorrect tension, leading to boom swinging, potential personnel injury and or equipment damage. 5. Safety pin incorrectly installed, leading to boom falling off / detaching at rig end. 6. Safety pin dropped overboard. 7. Man overboard. 8. Pinch points leading to personnel injury. 9. Boom shifts when disconnecting from crane.	1. Ice, applied load from ice can complicate the calculations of dimensions. Severe weather, such as winds can cause difficulties. 2. Darkness will make the task more difficult. In addition will ice and cold increase the likelihood of hazardous situation occurrence. 3. Darkness, ice and cold can influence this hazard. 4. Increasingly effect on hazardous situation, with respect to severe weather conditions, in addition to absent, inaccurate, weather-forecast. Additional applied stress from ice loads. 5. and 6. Ice can do the installation of the safety pin difficult. Large and thick working clothes can make the installation difficult and the pin can be dropped overboard. 7. Atmospheric icing can make slippery surfaces. Insufficient lighting can cause personnel to stumble on equipment, pipes etc. on the surface, and thereby cause man overboard situation. 8. Darkness can increase likelihood. 9. Coldness can influence on the properties of the steel-structure, and	1. Reliability and safety will decrease if not accounted for. 2. Reliability and safety will decrease if not accounted for. 3. Reliability and safety will decrease if not accounted for. 4. Reliability and safety will decrease if not accounted for. 5. and 6. Reliability and safety will decrease if not accounted for. 7. Reliability and safety will decrease if not accounted for. 8. Reliability and safety will decrease if not accounted for. 9. Reliability and safety will	Pre rig-up briefing with all personnel. Boom rigup dimensions and calculations confirmed from rig visit. Rig visit form completed to capture critical information. Follow FOH rig up procedures: • Sling selection and certification • King post height • Pad eye and base plate relative position verified and included in calculations • Crane reach verified • Angle from side wire eyes to boom calculated to determine correct length of side arm required. • Minimum height of king post – 7.5m All mechanical lifting components certified, and inspected, including; pad eyes, shackles, slings, fishplates and turn buckles. Tag lines in use at all times. Lock pins inserted in boom safety pin. Safety pins chained to base plate to prevent accidental loss overboard. No personnel allowed on boom while rigging up, before safety pins are inserted. Clear communication protocol defined between crane operator and banks man. Crane not released till side and main slings at correct tension and load test complete. Certified personnel basket used. Communication protocol between basket riding and crane agreed in advance.	PPE worn by all personnel as required by local standard, including flotation aid per local regulations when working near side of rig. Emergency response plan to include: • Medevac plan • First aider • Communications protocol Contingency plan to include: • Alternate crane supplier defined. • Spare / replacement equipment identified. • Communication protocol Fall arrestor worn and secured to crane block, not basket.	1. Arctic standards include this problem. A cover over deck will mitigate and/or prevent winds from causing problems. 2. To completely, or partially cover the the rig-deck, will reduce the potential for ice to accumulate. A cover will also shelter the worker while operating on deck. Sufficient lighting will light up al the necessary parts on deck. 3. See nr. 2. 4. Training on procedures, and properly monitoring program, to identify as early as possible. 5. and 6. Training and procedures for personnel. 7. Emergency rescue vessels onboard, medevac plan for arctic evacuation. 8. Sufficient lightening, and training og workers will reduce risk. 9. Training

	10. Riding basket to connect main sling to king post, risk of falling.	thereby can increase likelihood of brittle damage. 10. Atmospheric icing can influence the likelihood of falling, due to slippery surfaces. .	decrease if not accounted for. 10. Reliability and safety will decrease if not accounted for.			10. Heated surfaces could reduce risk.
Rig Up Burner	**Machinery/ Equipment/ Hand Tools** **Gravitational Potential Energy (Stepping, Handling, Lifting)** **Fire/Flammable** 1. Risk of person falling overboard from boom. 2. Dropped object when lifting burner head to end of boom, leading to personnel injuries or equipment damage. 3. Incorrect connections made to burner, failure to burn correctly; environmental spills. 4. Incompatibility of connections between SLB and 3rd party equipment. 5. Unintentional discharge of propane, leading to fire, explosion hazard, personnel injury and / or equipment damage. 6. Insufficient capacity in water delivery system for deluge / cooling systems.	1. Likelihood of accidents related to climbing on boom will severely increase due to atmospheric icing on the structure. Darkness, in association with large and thick working clothes will also increase the possibility of accidents related to this type of modification. 2. Darkness (insufficient lighting) can lower the visibility when executing a crane-lifting operations, and thereby increase the likelihood of objects being dropped. 3. Coldness can affect properties in steel- and/or rubber-connections, which can cause incorrect or inaccurate connections, and thereby influence the burners. 4. Icing could increase associated risk. 5. Monitoring routines can decline during bad weather, coldness, ice, winds, polarlows etc. which will increase the likelihood of undetected leakage. 6. Ice can accumulate in inlet and outlet in the water delivery-system, which can potentially cause lack of water. Darkness, cold, weather can also degrade the monitoring routines, and thereby can the likelihood of such an event increase.	1. Safety severely decreased. 2. Safety and reliability decreased. 3. Safety and reliability decreased. 4. Safety and reliability decreased. 5. Safety and reliability decreased. 6. Reliability decreased. Safety could be affected.	Trained, competent and certified personnel to carry out installation work. Assure that oil, gas and water connections and pipe routings per design. Verify with drawings. Verify compatibility of all connections to be made during pre-mobilization rig visit and at rigup. Ensure propane line is of correct material. Ensure connections to propane bottle are effective. Waterproof cable used for ignition system. Cables checked for damage. Intrinsically safe electrical connections to be used. Rig visit required information: • Compatibility of rig power to ignition system – install transformer if required. • Water delivery capacity of rig systems (rate and pressure • Compressor capacity of third party compressor, (do not use rig compressor)	Work vest worn. Standby vessel in close attendance. Watch stander in place monitoring all activities and in radio contact with radio room. Safety line, if worn, be secured to rig, not booms.	1. Heated surfaces and light will reduce the associated risk. 2. Light will increase the visual aspect of the operations, and thereby reduce the risk. Training of personnel, with regards to crane lifting operations. 3. Procedures- and planning will help workers in using the right equipment, when connecting burner. Using arctic standards with regards to equipment, and/or monitoring routines. 4. Arctic standards (e.l. ISO 19906:2010) mandates which type to use, and close co-operations to ensure right type. 5. Shelter of the rig deck will help keeping monitoring routines, and other routines, when operating under severe conditions. 6. Shelter and heated surfaces, in relation with monitoring routines will prevent/reduce risk associated with this event.

	7. Insufficient capacity of compressed air for burner leading to incomplete burn of hydrocarbons and environmental spill.	7. No/little influence by cold climate factors.	7. Reliability decreased. Safety could be affected.			7. Lightning of area will help detect these types of failures.
Rig Up / Rig Down Well Head Equipm ent (WHE)	**Falling objects** **Trapped fingers** **Tripping** **Struck by skid** **Damaged equipment** **Flow tubes and lubricator tip over.** Release of grease / hydraulic oil	Generally will cold climate factors influence the daily operations, and an increasing occurrence of accidents can be expected, if no mitigating or considerations are done with respect to cold climate factors. All factors which can influence are: - Darkness - Weather-forecast - Harsh weather - Temperature-range - Temperature - Cold - Ice - Remoteness - Vulnerable environment All these will in one way interfere, or influence, the daily operations.	Safety and reliability is decreased.	Only deck crew to position skid. SLB personnel to stand back and give direction Attach tag line to equipment to position. Use certified lifting equipment including slings and pad-eyes. If using Light weight lubricators make sure 2 section of 10ft lubricators connected horizontally to grease tube section prior to pickup assembly. Good housekeeping around work area. Use crane for heavy lifts Apply SIPP techniques for lifting/moving equipment Hold toolbox talks to identify hazards in work site Use of rig-up shackle or locally made spreader bar around slings to prevent flow tubes from tipping over Certified and pressure tested hoses. Fixture design making it impossible to swap hose connections.	Personnel trained on workshop safe practices and crane operations Use correct PPE Minimize amount of personnel on the rig floor. Training on ELMAR skid operation.	A set of general arctic preventive and mitigating actions can be; - Shelter - Heated surfaces - Heated areas - Lightning - Arctic standards - Protection of personnel (and equipment) against wind, low temperatures, rain sleet, hail, snow and icing.

Flush and Pressure Test	**Pressure** 1. Closed valve causing overpressure, leading to equipment failure and personnel injury. 2. Equipment failure (union or plug failure, line burst) leading to personnel injury. 3. Incorrect flow line rigup for burner boom, leading to environmental spill. 4. Scale / debris in flow lines and cooling lines clogs burner head / water spray system, leading to non-pressurized test (NPT). 5. Over-pressuring of low pressure valve, leading to equipment failure and personnel injury. 6. Leaking connections, leading to equipment failure and / or personnel injury. 7. Trapped pressure in flow lines, leading to personnel injury. 8. Incorrect identification of location of leak during pressure test, leading to NPT. 9. Hydrate formed on valve opening, leading to well plugging and NPT.	1. Darkness, cold and ice can influence the likelihood of occurrence. 2. Likelihood for equipment failure can increase due to all cold climate factors. 3. Coldness can influence properties of effluent. No/little influence from cold climate factors. 4. Cold can amplify the likelihood for hydrate formation, or other clogging situations. Ice can accumulate on pipelines and equipment, which can help in cooling down/freeze effluent, or other clogging materials. 5. Harsh weather can influence monitoring routines, which can enhance possibility of occurrence. 6. Coldness can change properties in steel- and/or rubber-joints, and thereby enhance the possibility of leakage. 7. Cold can amplify the likelihood for hydrate formation, or other clogging situations. Ice can accumulate on pipelines and equipment, which can help in cooling down/freeze effluent, or other clogging materials. 8. Ice can cover equipment and make monitoring difficult and inaccurate, thereby increase the likelihood of occurrence. 9. Cold can enhance the possibility of hydrate formation.	1. Safety and reliability decreased. 2. Safety and reliability decreased. 3. Reliability decreased. 4. Reliability decreased. 5. Safety and reliability decreased. 6. Safety and reliability decreased. 7. Safety and reliability decreased. 8. Safety and reliability decreased. 9. Safety and reliability decreased.	Pre-job safety briefing. PTW prepared prior to pressure operations. • Non required personnel removed from area. • Area of test cordoned off. • PA announcement Supervisor or competent delegate at pump unit in communication with testing crew. Identify lines of fire and safe areas. • Clear flow path established behind valves / equipment being pressure test. Employees certified in pressure operations in compliance with POM. Equipment certified and tagged in compliance with POM. Lines secured in compliance with POM. Verify flow during flushing. All lines flushed prior to connecting to boom. Verify all connections prior to testing. Bleed down pressure to zero and verify prior to backing off or making up connections. Pressure test components of surface equipment in defined order. Permit to work to be raised. If pressure testing flow head above live well, ensure test fluid is hydrate inhibited. Increase pressure gradually (500psi intervals) Pressure test equipment according to maintenance manual pressure test procedure	Work vest worn. Standby vessel in close attendance. Watch stander in place monitoring all activities and in radio contact with radio room. Safety line, if worn to be secured to rig, not boom. PPE worn by all personnel as required by local standard, including flotation aid per local regulations when working near side of rig. Emergency response plan to include: • Medevac plan • First aider • Communications protocol Data recorder in place for pressure test verification. Area of test cordoned off. Contingency plan to include: • Spare parts / components • Communication protocol No entry in to area unless absolutely necessary (for leak detection only).	1. Shelter and heated areas will help in maintaining monitoring routines, and thereby increase the probability of identifying such a local overpressure. 2. See nr. 1. 3. See nr. 1. In addition, including arctic standards in the planning stage will help in reducing associated risk. 4. Proper and sufficient training of personnel to maintain a high level of safety. Monitoring routines kept high. 5. See nr. 1. 6. Research and studies to develop new and innovative ways of encountering such problems. Use arctic standards. 7. Heater surfaces and areas will mitigate some of the associated risk. See also nr. 1. 8. See nr. 1. 9. See nr. 1.

Flow Well	**Electrical** 1. Static electricity leading to fire. 2. Lost of power leading to lost of data / process **Pressure** 1. Hydrate formed on valve opening, leading to well plugging and NPT. 2. Hydrates formed due to temperature drop. 3. Equipment failure / Unexpected pressure release, overpressure. 4. Pipe break / burst, leading to personnel injury, environmental spill, fire, NPT, equipment damage. 5. Flare extinguished, leading to environmental spill. 6. Unintentional closure of valve or choke washout, leading to overpressure of equipment, equipment damage and personnel injury.	**Electrical** 1. Ice can cover the platform-surface, and thereby cause residual current, which can cause static electricity. 2. Weather phenomena can cause strong winds, which can cause loss of power, and thereby a power shut-down. **Pressure** 1. Coldness can help to facilitate ideal conditions for hydrate formation, and thereby increase the likelihood for such an event. This can eventually lead to sections which is NPT. 2. Coldness can help to facilitate ideal conditions for hydrate formation, and thereby increase the likelihood for such an event. This can eventually lead to sections which is NPT. 3. Darkness and coldness can inhibit sufficient monitoring of equipment, and thereby could failures be more rapid. 4. Ice accumulation on equipment and pipes can lead to large additional ice loads, which can amplify in relation with cold, where steel can become brittle. This can increase the likelihood of pipes bursting, and thereby cause potential personnel injuries. 5. Harsh weather could eventually lead to flare extinguished, and this will lead to an environmental spill. 6. Darkness and cold can lead to opaque conditions and failures will occur more rapidly.	1. Safety and reliability decreased. 2. Reliability decreased. 1. Safety and reliability decreased. 2. Safety and reliability decreased. 3. Safety and reliability decreased. 4. Safety and reliability decreased. 5. Reliability decreased. 6. Safety and reliability decreased.	All equipment grounded. Identify an alternative power supply source. If pressure testing flow head above live well, ensure test fluid is hydrate inhibited. Chemical injection as required and on well opening. Pipe sized and selected to ensure WP and fluid velocity not exceeded. No crane operations over equipment. Ensure compressors working properly. Ensure continuous supply of propane to pilot. Ensure proper fluid separation prior to flare. Fixed choke to be used when required (high solids production). Confirm flow lineup before opening well. Continuously monitor WHP and cycle adjustable choke when necessary. Choke size to be verified by company man prior to insertion. Wind direction indicator in place and clearly visible from sampling area. Blower fans to be available. Sample liners to be correctly sized. Personnel trained in proper use of Daniels Orifice Meter, ensure pressure bled off before opening. Maintenance procedures followed for all equipment. Select correct orifice size, start with oversize. Ensure orifice plate inserted right way round. Verify orifice plate with company man prior to insertion. Bypass Barton DP cell before changing or inserting orifice. Correct use of sight glass check valve. Frequent monitoring / flushing of sight glass check valve. Correct use of separator; monitor levels, monitor Daniels drain, separator pressure.. Alternate boom available and in place. Change booms following defined procedure, including: • Pilot lit on alternate boom • Water and air supply present and on. • Valve lineup correct to alternate boom • Radio room and standby boat alerted • Simultaneous operations managed (personnel and activity clear of alternate boom) Personnel trained and competent. Clear communication process agreed with stimulation crew.	All lines with whip check and anchors in place. Work area cordoned off. All non-essential personnel removed from work area. Watch in place for flare. Hi-lo pilot and ESD systems in place and tested. Continuous checks of adjustable chokes. Double valve sample / drain points with outer valve used for sampling / draining. ERP in place, including • Medevac • Communication protocols • Spill, spill kits in place. BA to be used in presence of H2S concentration. Buddy system when sampling.	1. Heated areas or surfaces will mitigate and/or prevent this hazard from occurring. 2. Shelter of the rig floor will shelter the personnel and the equipment. 1. Heated areas or surfaces will mitigate and/or prevent this hazard from occurring. 2. See nr. 1. 3. See nr. 1 and Shelter of the rig floor will shelter the personnel and the equipment. 4. See nr. 1 and nr. 3. In addition, following arctic standards under construction and planning will prevent and/or mitigate associated hazards. 5. Difficult to completely out-design. 6. Winterization measures, in general, must be in place to mitigate general hazards. Type of winterization measures can be : - Shelter - Heated areas - Lighting - Training - Over-design - Design with respect to arctic standards

	7. Choke plugging by debris. 8. Incorrect choke setting, leading to incorrect data. 9. Sample / drain points plugged. 10. Spill during sampling. 11. Incorrect sampling liner, leading to personnel injury, fire and environmental spill. **Toxic/ Corrosive/ Hazardous Chemicals** 1. H2S present in effluent, leading to personnel injury. 2. Incorrect use of Daniels orifice meter, leading to personnel injury and equipment damage. 3. Incorrect selection of orifice size, leading to erroneous data or damage to equipment. 4. Separator sight glass plugged, leading separator flooding, gas flow to tank, water to oil line.	7. Debris can form from many sources, and some of them can be trigged to formation by cold climate conditions. Coldness can influence the formation of hydrates, it can also disengage contamination from lubrication fluid etc. 8. No/little influence by cold climate factors. 9. Can be influenced by cold climate factors, which will increase the likelihood of plugged sections in equipment and pipes. 10. The likelihood of human errors during sampling, can be increased due to thick and large (uncomfortable) working clothes. 11. No/little influence by cold climate factors. **Toxic/ Corrosive/ Hazardous Chemicals** 1. No/little influence by cold climate factors. 2. No/little influence by cold climate factors. 3. No/little influence by cold climate factors. 4. Coldness can increase likelihood of plugging. In addition can accumulated ice cover equipment, and thereby block visibility of separator sight glass.	7. Reliability decreased. 8. Reliability decreased. 9. Reliability decreased. 10. Reliability decreased. 11. Safety and reliability decreased. 1. Safety decreased, and possible decrease in reliability. 2. Safety and reliability decreased. 3. Reliability decreased. 4. Reliability decreased.	Separator bypassed during cleanup / live acid flow. Install in-line choke on oil line from separator to surge tank. Correct selection of chemical injection pump. All lines to be regularly checked.		7. Fitting more filters to clean and filtrate the effluent. 8. Planning and training will reduce risk. 9. Heated surfaces. 10. Enclosed shelter will increase the quality of the work being executed. Personnel does not always need large, uncomfortable clothes, and thereby could this risk be reduced. 11. Cold climate factors could reduce the barriers in place to prohibit development of an emergency event, i.e. fire, evacuation etc. 1. Note: Enclosed area will hold much longer on the toxic gas, and wind and other natural dissolve events will be lost. Important to prevent this hazard from developing, for instance could gas sensors, leak sensors, and other measures be the solutions, if measurements must be done inside the enclosed area on the rig deck. 4. Heated areas will prohibit accumulation of ice and/or snow.

	5. Fluid carryover into gas line, leading to incorrect data and environmental spill.	5. This event can happen if barriers in place refuse to work properly, and monitoring and sight glass is covered by ice and/or snow.	5. Reliability decreased.			5. See nr. 4
	6. Change in wind direction, leading to environmental spill and excessive heat radiation or gas on rig.	6. Weather-phenomena like polarlows entails strong winds which can rapidly change direction. Thereby can changing wind direction be a direct threat to the safety of the burners.	6. Safety and reliability decreased.			6. Winterization measures, in general, must be in place to mitigate general hazards. Type of winterization measures can be : - Shelter - Heated areas - Lighting - Training - Over-design - Design with respect to arctic standards
	Pressure 1. Sudden increase in pressure due to gas at surface, leading to line rupture, equipment damage, personnel injury and environmental spill.	**Pressure** 1. No/little influence by cold climate factors.	1. Safety and reliability decreased.			
	2. Overpressure of surge tank due to gas blow by from separator and leading to equipment damage and personnel injury.	2. No/little influence by cold climate factors.	2. Safety and reliability decreased.			
	3. Air supply failure, leading to environmental spill.	3. No/little influence by cold climate factors.	3. Reliability decreased, and possible safety concerns.			
	4. Failure of chemical injection pump, leading to foaming and carry through or hydrate formation.	4. Cold could amplify the likelihood of occurrence.	4. Reliability decreased.			
	Toxic/ Corrosive/ Hazardous Chemicals 1. Live acid at surface, leading to personnel injury and equipment damage.	**Toxic/ Corrosive/ Hazardous Chemicals** 1. No/little influence by cold climate factors.	1. Safety and reliability decreased.			

Multiple Flow Periods	**Pressure** **Toxic/ Corrosive/ Hazardous Chemicals** 1. Changing choke size; failure to bypass separator, leading to environmental spill, fire, personnel injury, equipment damage or incorrect data to customer.	**Pressure** **Toxic/ Corrosive/ Hazardous Chemicals** 1. Darkness, cold, ice and other cold climate factors can influence the operation, and could to a given degree participate in the occurrence of such an event.	1. Safety and reliability decreased	Bypass flow meters and separator prior to changing choke. Oil or gas line to be selected depending on flow rates.		1. Winterization measures, in general, must be in place to mitigate general hazards. Type of winterization measures can be : - Shelter - Heated areas - Lighting - Training - Over-design - Design with respect to arctic standards
Shut in Well	**Pressure** 1. Meters not bypassed prior to shut in, leading to equipment damage. 2. Separator bypassed prior to shut in, leading to incorrect data to customer. 3. Leaking flow head or choke valves, leading to incorrect data to client. 4. Pressure gauges overpressured from increase in pressure, leading to damage, and personnel injury.	**Pressure** 1. No/little influence by cold climate factors. 2. No/little influence by cold climate factors. 3. Seal not designed for cold climate could entail leakages, and cold can be an amplifying factor in that event. 4. No/little influence by cold climate factors.	1. Reliability decreased. 2. Reliability decreased. 3. Reliability decreased. 4. Safety and reliability decreased.	Shut in procedure to be followed, including: • Bypass Barton meter and DP cell • Bypass oil meter • Downhole valve closed prior to choke manifold. • Shut in prior to bypass separator. Select the correct gauge range for maximum expected shut in pressure.	Contingency plan to include shut in procedure in event of leaking choke. Correct PPE Barriers erected to minimize access	1. and 2. Human errors. 3. Research and studies on new solutions which can withstand the arctic environment.
Flushing well test equipment	**Fire/Flammable**, **Pressure** 1. Personnel Injury/Death Equipment Damage / Loss Line Rupture - Spill	**Fire/Flammable**, **Pressure** 1. Many of the cold climate factors can influence and amplify the severity and likelihood for accidents to occur. This can lead to hazardous situations like injuries, damages (both on equipment and personnel), environmental spills etc.	1. Safety and reliability decreased.	Programme detailing method, flowrates etc. Safety systems fully tested and on line. Relief valves fitted to pumping unit. Relief valves fitted to equipment. Line of communication set up. Ensure pumping is stopped before changing status of any valve. Check line up prior to commencing operation. Flare / Spill watch personnel in place. Competent personnel operating equipment.	Reduced inventory of hydrocarbons during shut in procedure. Correct PPE	1. Winterization measures, in general, must be in place to mitigate general hazards. Type of winterization measures can be : - Shelter - Heated areas - Lighting - Training - Over-design - Design with respect to arctic standards

Rig Down	**Gravitational Potential Energy (Stepping, Handling, Lifting)** 1. Multiple trip and handling hazards leading to SHL related injury.	**Gravitational Potential Energy (Stepping, Handling, Lifting)** 1. Ice such as atmospheric ice will increase the difficulty when handling components. Darkness and coldness will complicate tasks, such as monitoring, lifting, handling modifications. Temperature (low and range) will complicate the work because of working-clothes workers and personnel need to wear. Weather-forecast can occur suddenly, and can have tremendous consequences, which will complicate the work severely.	1. Safety and reliability decreased.	Pre rig-down briefing with all personnel. All personnel SIPP trained and SIPP practices followed. Housekeeping managed throughout rig down. Footwear in good condition (especially soles) Employees trained in safe procedure for breaking out hammer unions. Wooden shafted brass headed hammers used to break out unions. Use crane to move pipe whenever possible. Flush all lines prior to disconnecting. Rig down procedure to be followed, including: • Bleed off all lines All tanks and waste solids tested for Ra contamination before leaving well site on previous job and on reception to base. Contaminated waste to be characterized and disposed of by customer. Spill kits available.	PPE worn by all personnel as required by local standard. Emergency response plan to include: • Medevac plan • First aider • Communications protocol	1. To completely, or partially cover the the rig-deck, will reduce the potential for ice to accumulate. A cover will also shelter the worker while operating on deck. Sufficient lighting will light up all the necessary parts on deck.
	2. Hammer union connections, risk of personnel injury.	2. Temperature can change the properties of rubber joints (o-rings). Ice can hide/cover joints, thereby complicate the modification, and thereby increase the risk associated with the operation.	2. Safety and reliability decreased.			2. Research and studies on this topic must be in place, so that the equipment can withstand the arctic environment. A complete cover will shelter the equipment.
	3. Handling of coflexip hose leading to personnel injury or damage to equipment.	3. Ice and coldness will increase the difficulty when handling coflex-hoses. Darkness will amplify the difficulty. Weather-forecast and weather can set the operations on hold, and in worst case occur during operations, and thereby amplify the risk severely.	3. Safety and reliability decreased.			3. Heated floor, heated shelter, sufficient lightning will make it easier to handle coflex-hoses. To increase the quality of weather-foreast more weather stations must be installed on vessels and land, in and around the Barents Sea.
	Pressure 1. Well not shut in prior to rig down procedure, leading to equipment damage and or personnel injury.	**Pressure** 1. No/little influence by cold climate factors.	1. Safety and reliability decreased.			
	2. Trapped pressure upstream of choke manifold, leading to personnel injury.	2. Snow and ice can cover sight of local gauges, and thereby could the sufficient monitoring be absent. This can result in possible hazardous events.	2. Safety and reliability decreased.			2. Heated areas will prohibit ice and snow to accumulate in unwanted areas.
	Radiation 1. Sand / scale residue in separator is TENORM contaminated, leading to Ra environmental contamination / liability.	**Radiation** 1. No/little influence by cold climate factors.	1. Reliability decreased.			

	2. Hydrocarbon Spill 3. Environmental Pollution	2. and 3. The severity associated with environmental contamination in the arctic region is much higher than in other oil&gas locations. This has to do with the sensible environment, and the preventive oil spill measures available.	2. and 3. Reliability decreased.			2. and 3. Arctic standards dictates the level of oil spill preparedness which is necessary to be prepared on challenges in the north.
Rig down Boom	**Machinery/ Equipment/ Hand Tools Gravitational Potential Energy (Stepping, Handling, Lifting)** 1. Failure of mechanical lifting equipment, leading to dropped boom, personnel injury and / or damage to or loss of equipment. 2. Safety pin incorrectly removed, leading to boom falling off / detaching at rig end. 3. Safety pin dropped overboard. 4. Man overboard.	**Machinery/ Equipment/ Hand Tools Gravitational Potential Energy (Stepping, Handling, Lifting)** 1. Darkness will make the task more difficult. In addition will ice and cold increase the likelihood of hazardous situation occurrence. 2. and 3. Ice can do the installation of the safety pin difficult. Large and thick working clothes can make the installation difficult and the pin can be dropped overboard. 4. Atmospheric icing can make slippery surfaces. Insufficient lighting can cause personnel to stumble on equipment, pipes etc. on the surface, and thereby cause man overboard situation.	1. Safety and reliability decreased. 2. and 3. Safety and reliability decreased. 4. Safety decreased severely.	Pre rig-down briefing with all personnel. Follow FOH rig down procedures: All mechanical lifting components certified, and inspected, including; pad eyes, shackles, slings, fishplates and turn buckles. Tag lines in use at all times. Safety pins chained to base plate to prevent accidental loss overboard. No personnel allowed on boom while rigging down, after safety pins are removed. Clear communication protocol defined between crane operator and banks man. Certified personnel basket used. Communication protocol between basket riding and crane agreed in advance.	PPE worn by all personnel as required by local standard, including flotation aid per local regulations when working near side of rig. Emergency response plan to include: • Medevac plan • First aider • Communications protocol Contingency plan to include: • Alternate crane supplier defined. • Spare / replacement equipment identified. • Communication protocol Fall arrestor worn and secured to crane	1. Shelter the rig floor to reduce the level of ice accumulated on exposed areas. 2. and 3. Training will increase the quality of the work executed. 4. See nr. 1.

	5. Pinch points leading to personnel injury. 6. Boom shifts when disconnecting from rig. 7. Riding basket to disconnect main sling from king post, risk of falling.	5. Darkness can increase likelihood. 6. Coldness can influence on the properties of the steel-structure, and thereby can increase likelihood of brittle damage. 7. Atmospheric icing can influence the likelihood of falling, due to slippery surfaces.	5. Safety decreased. 6. Safety and reliability decreased. 7. Safety and reliability decreased.		block, not basket.	5. Light and training. 6. See nr. 1 7. See nr. 1.