Challenges and Solutions
in
Subsea Field Development
for the
High North and Arctic

University of
Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study Program / Specialization:

MSc. Subsea and Marine Technology

Spring Semester, 2012

Open

Writer:

Riad El-Wardani

…………………………………………

(Writer's signature)

Faculty supervisor: Ove Tobias Gudmestad

Title of thesis:

Challenges and Solutions in Subsea Field Development for the High North and Arctic

Credits (ECTS): 30

Key words:

Field development, subsea, high north, cold climate, sea ice, icing, winterization, polar lows, iceberg, HAZID, BAQT, subsea compression, subsea boosting

Pages: …………………

+ enclosure: …………

Acknowledgements

"It always seems impossible until it's done." – Nelson Mandela

…and so it did seem, *impossible*. However, if we consider it, the word itself spells I-M-Possible!

The journey of deciding to take on the challenge of writing a second master thesis was not an easy one and at times, did seem impossible. However, I believe that one of the greatest feelings is achieved by taking on challenges everyone else thinks are not possible, whether personal or professional, and proving to oneself firstly and the world secondly, that in fact it is possible. This journey would not have been possible without the great support provided by my professor and mentor Ove Tobias Gudmestad, who was one of the few who I felt truly believed in me and supported me through my entire master degrees, both in Asset Management and Subsea Technology. He reinforced in me the importance of being passionate about what one does while enjoying it at the same time. The late evenings and long sessions often closing in pleasant chats and light humor allowed me to understand his passion for education and for helping produce some of the best subsea engineers the industry will see.

Special thanks also to Tanja Bergby, who along with Professor Gudmestad fought for me to be allowed the opportunity to write my second thesis and by such complete the requirements of a MSc. in Subsea and Marine Technology. I wish you the best of luck in your future endeavors and hope you decide to come back to teach at the University of Stavanger one day. And how can I forget Sheryl Josdal, not sure if anyone else would take my never ending requests with a brighter smile, thanks.

Key people that helped me gain a better understanding and feeling for arctic engineering and subsea field development in the high north region are Professor Sveinung Løset and Erik Strand Tellefsen. Thanks to Professor Løset and his team, I now carry great memories of our field trip to Svalbard where we had the opportunity to conduct several tests on natural ice and see firsthand polar bears and arctic northern lights. It is a pleasure spending time with such knowledgeable and humble people.

I would like to thank my family, who has been a great support for me, encouraging me along the way and believing in me. My parents who raised me to believe in myself, challenge the norms and live life to the fullest; my brothers who are also my role models and best friends who have heavily supported in my character building and my baby sister who always reminds me what it means to love unconditionally, I am very proud of you. The past year has been eventful with deep lows and brilliant highs, and without my loving family, it would not have been possible to carry on with this journey. I pray for those who have left us and wish strength to those who are still with us.

A special thank you to a truly beautiful and loving person - Silje Paraply - who has survived all the ups and downs; the happy moments and the temperamental ones; the endless nights and the long days. I really appreciate having you by my side; you bring me joy and offer tremendous support.

Executive Summary

Masters Project Description

Name Riad El-Wardani
Project Title Challenges and Solutions in Subsea Field Development for the High North and Arctic

Problem / Challenge

Estimates indicate that approximately 25% of the world's unexplored hydrocarbon reserves lie beneath the depths of the Arctic regions, with around 1% (1.5 billion ton of oil equivalent) of that lying untapped under the depths of the Norwegian Barents Sea. Concurrently, the high north and Arctic are vaguely understood and lack of infrastructure in these areas makes it hard to gather sufficient data to be able to conduct detailed analysis. Furthermore, the distinct inhabitants and sensitive ecosystem make these regions extremely fragile and sensitive to change, which needs to be carefully considered by companies looking to explore for oil and gas in these areas.

This project reviews the currently identified challenges and by conducting hazard identification, failure mode and criticality analyses, different field development solutions are scrutinized. By ranking different best available and qualified technologies (BAQT), it enables engineers to narrow the analysis and go deeper into the details so that one day the untapped resources of the Arctic can be safely and sustainably harvested with the environment at the forefront of their considerations.

Project Scope

Project scope includes the review of currently identified and acknowledged challenges in the high north and Arctic regions specifically focusing on the Norwegian Barents Sea. This includes the characterisation of challenges and putting them into context as to why they pose threats on production systems. To complement the review of the latest field development concepts, a grid analysis helps highlight their strengths and weaknesses as well as their applicability to the high north and Arctic. Following, a hazard and failure mode identification analyses is carried out on the field development concept highlighted through the grid analysis before investigating best available and qualified technology (BAQT) related to the concept.

Project Tasks

1. Conduct review of currently identified and acknowledged challenges in the high north and Arctic regions with special focus on the Norwegian Barents Sea.
2. Conduct review of best available and qualified technologies (BAQT) to identify technical feasibility of developing high north and Arctic fields.
3. Conduct grid analysis comparing different BAQT for different concepts, highlighting the most favourable solution for high north and Arctic opportunities.
4. Propose field development concept for "Johan Castberg-type" field in the Norwegian Barents Sea based on analyses, review of BAQT and grid analysis mentioned above.
5. Conduct hazard and failure mode identification (HAZID) analyses on proposed field development concept in the high north and Arctic.

Deliverables (i.e. what are expected as outcomes/products from the project)

Deliverable 1: State of the art on field development technology
Deliverable 2: HAZID – Hazard Identification
Deliverable 4: Development concept for Johan Castberg-type field based on grid analysis
Deliverable 5: Master thesis
Deliverable 6: Paper summarizing the findings of the work

Table of Contents

List of Figures

List of Tables

1. Introduction

As the world’s global energy demand soars, engineers and innovators all around the world are pressed to come up with solutions to meet these needs. Even though large advances are made in fields such as solar and wind power generation, fossil fuels in the form of oil and gas are still proving to be the most popular and efficient sources of power. Therefore, within the oil and gas industry, exploring new territories coupled with enhancing hydrocarbons recovery technology is essential in continuing to supply this demand. Figure 1 shows the global demand for oil and gas in relation to the global populations from 1971 and ahead to 2030; the proportionality to the world’s population is notable but the question is, will it continue?

Having practically drained most of the reservoirs within the well-developed oil and gas regions, new territories are being uncovered to maintain production volumes. One of the areas gaining increasing attention is “*The Arctic*”. With around 58% of the world’s ocean resources lying beneath the dormant depths of the Arctic seas, making up over 25% of the world’s undiscovered resources, energy majors are eager to learn more about these areas (Ralph, King and Zakeri, 2011). An estimated 154 billion ton of oil equivalent, corresponding to 20x the world’s energy demand in 2003, is untapped and ready to be explored. The ultimate goal is profitable production of the area’s resources while safeguarding life, environment and assets.

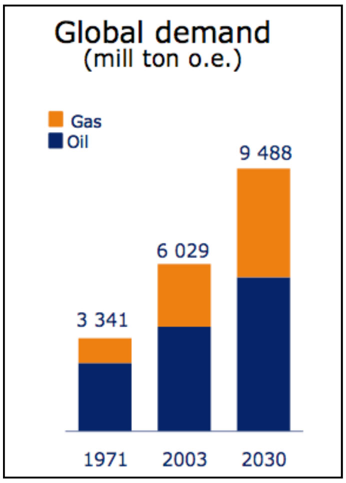


Figure 1. World's Energy Demand Relative to Population (data interpreted from International Energy Agency, 2005)

Furthermore, it is worth noting that a large fraction of these untapped resources are estimated, with high probability, to lie in Russian waters within close proximity to Norwegian territories (Figure 2 & Figure 3 in conjunction with Table 1). Therefore, combining Norwegian technology and experience from the Norwegian Continental Shelf (NCS), with Russian cold-climate expertise from areas such as Sakhalin and the Kara Seas, is essential in developing the entire region safely and effectively.

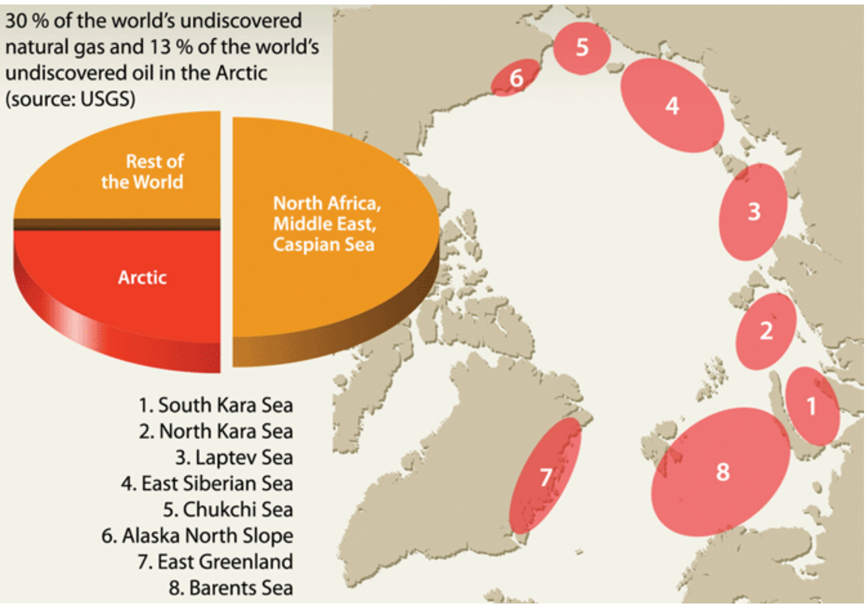


Figure 2. Energy Resources in the Arctic (Ministry of Foreign Affairs, 2012)

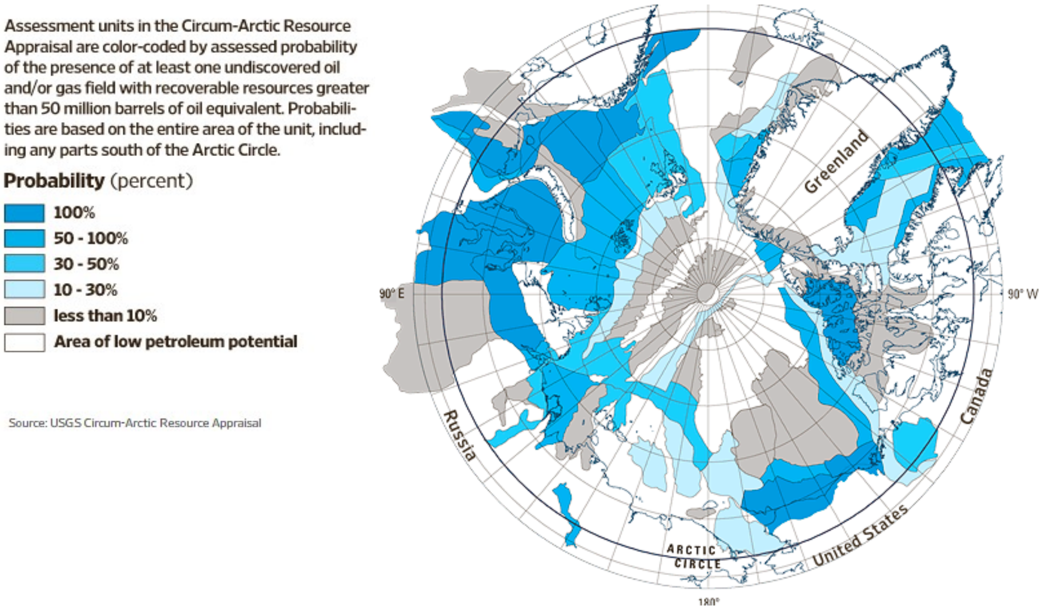


Figure 3. Probability of Oil and/or Gas Fields greater than 50 million barrels o.e. (Bird et al., 2008)

Table 1. Estimates of Undiscovered Reserves in Arctic in billion ton of oil equivalent, highlighting Norwegian High North Reserves (interpreted from "Summary of Assessment Results Offshore Allocations; U.S. Geological Survey, 2009)

	Estimated Resources (BTOE)	Jurisdiction
Kara Sea (1)	40.35	Russia
Barents West (8)	1.12	Norway
Grey Zone (8)	6.8	Norway / Russia
Barents Sea East (8)	27.63	Russia
Norwegian Sea	2.12	Norway
Norwegian North Sea	3.92	Norway

1.1 Problem Description

In contrast to the abundant opportunities described above, there exists a great deal of challenges. Challenges unique to the high north and Arctic, which, if not addressed, will lead to tremendous losses in terms of financial, environmental and social significance, need to be carefully addressed. With the increasing interest of the Norwegian government and oil and gas majors in moving into the high north territories for exploration and drilling, it is necessary to conduct a thorough review of the most crucial of these challenges, identified thus far.

1.2 Scope and Objectives

As described in the Problem Description, the oil and gas industry is facing several challenges that must be carefully understood and addressed prior to producing hydrocarbons from the high north and Arctic regions. Besides defining these challenges and their impact on production systems, the report presents some of the proposed technical solutions currently considered to be best available and qualified technology (BAQT). The field development solutions are considered with the results of several analyses in mind including a grid analysis to filter out the most promising concept then a hazard and failure mode identification study to identify the detailed hazards and threats as well as their respective mitigation strategies.

The objective is to gain a thorough understanding of the conditions encountered in the Arctic, assess the efficacy of several technical solutions in such environments and identify the most effective field development solution for the high north.

1.3 Limitations

Limitations of this project are somewhat difficult to identify since they appear both in the form of data scarcity, which is also one of the main challenges for Arctic exploration and production, as well as exclusions to the incorporated scope.

Firstly, in terms of scope, environmental implications of oil and gas exploration and drilling in the Arctic are intentionally not discussed in this report. It is understood that this will be one of the key issues in developing the northern territories due to the sensitive ecosystem of the area and the high risk of oil spills. Also, as the ice on the northern cap is melting at an alarming rate, there have been numerous reports expressing concern regarding ship fairing in the area, which breaks up ice sheets, melting them even faster. Due to the sensitivity of the topic, a purely technical engineering focus has been adopted, steering away from political and environmental concerns.

Furthermore, as will be discussed in later chapters, due to the lack of data from the Arctic and high north regions, not all challenges and restrictions are yet identified. In this report, the known and most notable challenges are presented and analysed, however there is a good chance that as more information and data is available from the region, more will emerge. With this in mind, only some field development concepts are discussed herein. Only the concepts most sensible and relevant to the conditions of the Norwegian Barents Sea are considered, disregarding technical solutions that would not be suitable or practicable.

1.4 Methodology

To fulfil the scope and objectives of this project, a detailed literature review covering more than one hundred – 100 - sources was conducted to get a clear understanding of the conditions encountered in the high north and Arctic. Making use of University of Stavanger library resources as well as the *High North Research Documents* database made publicly available by the University of Tromsø Library, an in-depth survey of Arctic challenges was carried out. Once the conditions were clearly identified, hazard and failure mode review was carried out to get a better understanding of the design basis and limitations that would need to be considered. The analysis was carried out based on knowledge gained during the master program as well as drawing from work experience and previous HAZID's conducted for oil and gas projects over the course of the author's career. Papers, publications, supplier webpages and marketing material were used to research available oil and gas production technology systems available, qualified and suitable for cold climate and Arctic conditions. Finally, building on the knowledge gained during the master program, a grid analysis was conducted to identify the most effective development solution. Throughout the project and documentation of the findings, close collaboration with university professors and industry experts was vital in achieving the results herein and ensuring an interesting and useful product results.

1.5 Structure of the Report

The report is split into four main sections. In the first section, a review of the various challenges associated with exploration and production in the high north and Arctic is carried out. Challenges are described and their impact on drilling, production systems and marine operations in the mentioned areas assessed. Secondly, development solutions for this challenging area of the world are explored, keeping in mind B.A.Q.T. (best available and qualified technology). The various concepts are scrutinized against the criteria of the northern regions as a backdrop and a grid analysis is carried out based on various utilities to highlight the most favourable development option. Finally, hazard and failure mode analysis (HAZID) is carried out for the solution identified in the grid analysis to get a better understanding and broader perspective of the threats and how they may be addressed. In the discussion and conclusion, the findings are summarized and suggestions for further work incepted through the various analyses are proposed.

In the first section, initially the scene is set. Different areas in the high north and their local communities are briefly described, in addition to a brief mention of the social and environmental impacts the oil and gas industry may have on the region. Following, the characteristics of the Norwegian high north are described such as sea states, water depth, soil conditions and other relevant factors for offshore exploration and production. This leads well into a presentation of the specific challenges encountered in the Norwegian high north and Arctic regions that are usually not encountered in such combinations elsewhere. Examples are polar lows, icing and iceberg encounters etc. An analysis of the effects of these challenges is considered as for exploration and production systems, illustrating the large extent of work that is required before commercial exploration and production of hydrocarbons in the high north and Arctic regions should be allowed and is viable.

Secondly, in light of the abovementioned challenges and their effect on different engineered solutions, development solutions are considered based on the premises of BAQT. Since the oil and gas industry is especially conservative and risk averse when it comes to testing out new technology or even existing technology in new areas, only those solutions which have been used in similar conditions are considered and the strengths and weaknesses of each are highlighted. Existing fields developed with similar technologies across the globe are presented and discussed, identifying the similarities and differences to field characteristics found in the southern Barents Sea – Johan Castberg-type field. Finally in this section, the development solutions are ranked using various utilities and grid analysis to identify the most favourable option. Results are presented in Appendix G.

Third, assuming that section two covers the "*Identify and Assess Opportunities*" phase, and the preferred option has been identified through the various analyses, the full field development of a Johan Castberg-type field, developed using the preferred option, is now considered and hazards are identified through a HAZID workshop. The HAZID will enable identification of the failure modes, threats, effects and most important barriers. Consideration of how to resolve some of these challenges using the latest technology are addressed in section 4.2 therefore an iterative process is used here where results from the HAZID in section 4.3 feed directly into the advantages of development through subsea system in section 4.2 and challenges from the selected concept in section 4.2 are fed back into the HAZID in section 4.3.

Discussion, main conclusions and references follow thereafter to reiterate the main findings and wrap up the report. Bulk data and tables are included in the Appendices.

2 Challenges in the High North and Arctic

2.1 Communities, Social and Environmental Impacts

As rugged and harsh as the northern environment seems to be, it is home to some of the most fragile and sensitive flora and fauna in the world. Not to mention, the small self-sustained communities having survived the climate and conditions in the area for several centuries. The ecosystem is so delicately intertwined and dependent on each element, that any disturbance or interference to it may cause it to collapse and vanish. Therefore it should be of utmost importance to developers and governments of these regions to protect and maintain this final pristine spot on earth.

One of the main public debates related to degrading this pristine environment is the extent of sea ice in the high north and whether this is a direct consequence of human consumption. Although the actuality and route cause of global warming will not be discussed, it is true that increased activity in the high north would reduce the amount of ice cover and the science behind it is simple. As water in ice form with a layer of snow on top reflects most of the sun's heat, the overall temperature of the ice does not raise significantly due to the good insulation properties of the snow, maintaining solid state. Once the ice is broken however whether by icebreakers or fixed structures, the water acts as a near black body, absorbing heat from the sun and accelerating the melting process. Seeing that the media advertise this as the most notable effect of the diminishing pristine Arctic environment, most people would associate environmental impact in the Arctic directly to sea ice extent. However, there are numerous other factors able to provide a more accurate indication of the ecosystem's well being. One such element is the quality rather than quantity of the actual ice in the region. As most of the ecosystem's life depend on this endangered resource, it is vital to maintain its purity. Pollution, such as a possible oil spills in the region, would cause a thin layer of hydrocarbons to get trapped between the water surface and ice sheet, which can then travel large distances and contaminate several acres. The cold temperature coupled with the emulsion of the hydrocarbons within the ice crystalline structure would make it almost impossible to evaporate or dissolve, meaning that it would last for centuries before it naturally decays. Furthermore, noise and vibration caused by vessel operations, drilling activities, pile driving and operation of equipment have a detrimental effect on sea life in the area. The mammals' sensitive receptors are able to pick up such signals that even humans are unable to detect. In Alaska's Cook Inlet, this has seemingly caused the beluga whale population significant distress, driving them away from the area and towards extinction (Kendall, 2010).

Looking further along the ecosystem chain and specifically at the top of it, are again humans. The local communities that have evolved around this serene and tranquil environment are now at risk since the environment they once knew so well is dramatically altered. Cultures and traditions are again forced to adapt in light of these changes, their limited source of nutrition will diminish and become more scattered and the ice they could once rely on will become their biggest hurdle to survival. Another common challenge that these communities will face is the complete restructuring of their social values and needs. Societies that once lived with and on their surrounding environment, will now be exposed to first world luxuries and incentives offered by the large multinationals and corporates that are looking to do business in these areas. Will they be able to resist and maintain their simple yet self-sufficient lifestyles or will they be inclined to give it up in chase of material gain? Stories such as those from the Canadian Arctic, where Inuit tribes have gone from eating caribou, polar bear, whale and seal to fried chicken and pizza are a bad example of how modern day society has affected the lives of such communities and destroyed cultures. To what extent should the governments protect these societies and to what extent must the corporate entities refrain from influencing these people? These are questions that have troubled the petroleum industry in several corners of the world and to date no silver bullet has been identified.

All these aspects must be considered and managed adequately to ensure minimal impact is passed onto the local ecosystem, communities and the social traditions and customs of the people in the area. Close consultation with locals and genuine dialogue should take place because even though they might not understand the intrinsic details of the design of the most sophisticated machinery, they understand their environment very well and have learned to sustain it, live with it and respect it for centuries and their knowledge is not only relevant but also first hand.

2.2 Setting the Scene in the Barents Sea

To get a broad understanding of the conditions at some of the fields located in cold climate or Arctic regions such as Johan Castberg (combination of previously Skrugard and Havis), Snøhvit and Goliat, it is useful to briefly discuss the environmental conditions at these sites and in the Norwegian high north in general. A breakdown based on area characteristics has been developed by DNV (Eide, 2008) as shown in Figure 1 of Appendix A. and the implications of these conditions will be further discussed in later sections of the report.

The main challenges encountered in this region, which will be discussed in more detail below, are the following:

- Icebergs
- Sea Ice Cover
- Polar Low Pressure Systems
- North Atlantic Hurricanes (June-November)
- Cold Climate (-45°C up to 5°C)
- Sea Spray and Atmospheric Icing
- Fog
- Polar Nights (November – February)
- Lack of Experience / Limited Data
- Distance to Market
- Limited to No Infrastructure / Oil and Gas Activity
- Evacuation

To provide a frame of reference, consider the characteristics of the Skrugard and Havis fields (combined as Johan Castberg field); the latest “elephants” (term used for large oil and gas fields) found 210 km NNW off the coast of Hammerfest (Statoil, 2011 and Statoil, 2012). The fields are located in close proximity of one another at approximately 72°31'00.78”N and 20°20'28.55”E) as shown in Figure 4 above, marked by a red dot and the title “Skrugard” (DNV, 2012a). Water depth at the location ranges from about 360m at Havis to a maximum depth of 403m at Skrugard with predominantly flat topography and mud/sand sediments (DNV, 2012b). This correlates well with data from around the Barents Sea where the average water depth is taken to be around 230 m and down to a maximum depth of about 500 m (depths for 70°-80° N) (Fugro, 2005). Following, some of the main characteristics of the Barents Sea will be presented and advantages and disadvantages highlighted.

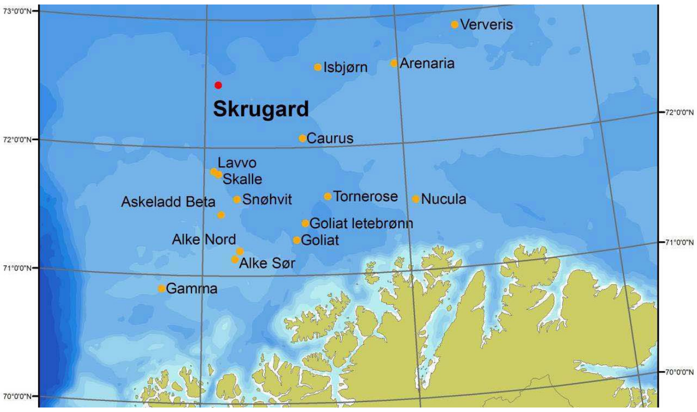
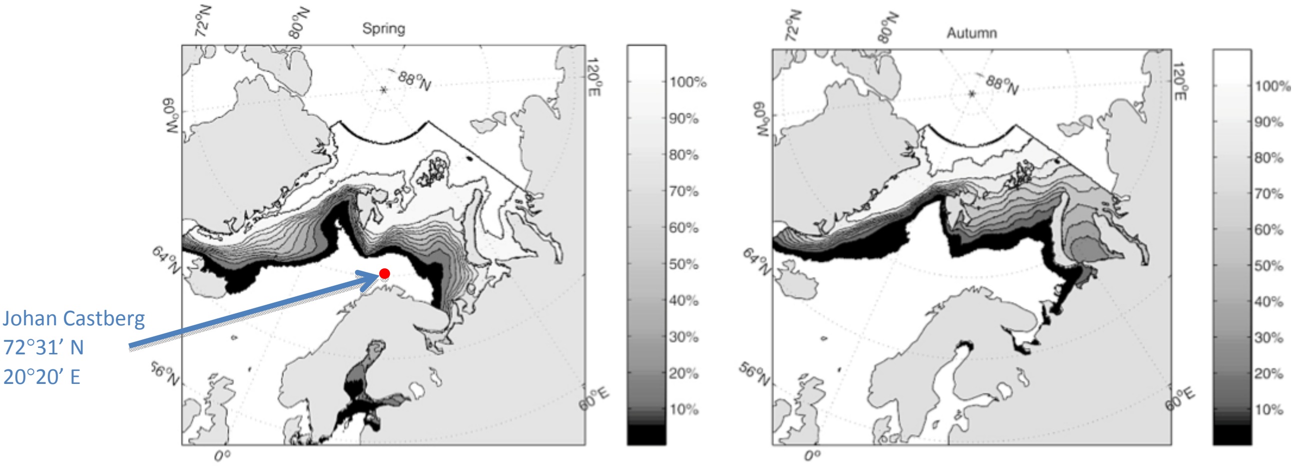


Figure 4. Map of the central Barents Sea (*DNV, 2012a*)

Primarily, the water depths and soil conditions indicate a fairly advantageous environment for subsea developments in the region. Consequently, installing subsea infrastructure at such a location provides the opportunity to avoid the effects of environmental phenomena witnessed at the sea surface such as icebergs and stamukas (pile up of large ice masses), sea ice, wave loads, cold temperature and icing to name a few. Considering the challenges in the order listed above, the risk of icebergs and stamuka interactions can be evaluated for this region. Icebergs pose significant risks in the form of global and local loads on impact with floating structures or by gouging the seabed and damaging subsea equipment. Different forms of icebergs are shown in Figure 5 below. For the case considered above, water depths are deep enough to avoid seabed gouging by natural features (trawling still poses a challenge, not considered here) and therefore iceberg risks need only be considered for floating structures and marine operations. In the southern Barents Sea, where Johan Castberg (previously Skrugard and Havis) are located, risk of exposure to icebergs is fairly low, below 10^{-4} per annum. However, several sightings have been made in 1881, 1929 and 1939. According to Vefsnmo et al.'s (1990b) model, two hotspots have been identified: the first being south of Bjørnøya (Bear Island), based on iceberg sightings in recent years and the second is East-Finnmark including the sea north of the coast, based on historical data. Sea surface currents largely influence iceberg drift and speed as shown in Appendix D. However, icebergs are not the only naturally occurring sea surface obstacles faced in the high north. Sea ice is another dangerous feature encountered that can cause large impact loads on and cause damage to seafaring structures.

Figure 5. Different forms of Icebergs (Eide, 2008)

Generally, it is accepted that the southern part of the Barents Sea is ice-free year round, i.e. no ice forming on the surface of the sea. However the northern most areas of the Barents Sea, around Svalbard and Franz Josef Land, are only ice-free from July to September as described by Det Norske Veritas' Barents 2020 report (Eide, 2008; see Appendix A). This causes great constraints for offshore operations since additional environmental loads must be taken into consideration, planned for and designed to withstand. A simple example is the construction of Hibernia, the world's first and only sea ice and iceberg resistant gravity based platform. It was designed for 1800 MN global load whereas operational data shows that 400 MN would have been sufficient (Jordaan and Pond, 2001). Consequently, due to the vast variations of ice features and limited knowledge about ice characteristics and properties, operations at present is recommended to be limited to summer months between roughly June and October. This is also due to environmental concerns where authorities are reluctant to allow companies to break ice sheets in fear that it will accelerate ice decay as discussed above. For the nominated field however, Johan Castberg, only first-year ice is a likely feature, more likely in the form of drift ice but also possible as pack ice. Mainly, the reason a Johan Castberg and especially Shtokman-type field developments are so challenging, is due to the vast variation throughout the year from pack ice to drift ice to open waters. The most extreme ice expansion of sea ice witnessed to date was in 1881 where pack ice, over a short period of time, reached down to 20 km off the coast of Finnmark and for a prolonged winter period was at 71°31'N to 72°N (this is further South of the location where Johan Castberg is located; Kvitrud, 1991). Figure 6 below shows this as an average for spring and autumn over a period from 1967-2002. Mean monthly ice concentration charts are presented in Appendix B. with ice statistics showing diminishing ice extent over time.



Johan Castberg
72°31' N
20°20' E

Figure 6. Seasonal means of Sea-Ice Extent from 1967-2002. Scales show probability (%) of encountering Ice (Kvingedal, 2005)

So now it has been established that icebergs are not a major concern however they need to be taken into consideration and mitigation plans put in place. Also, although sea ice is a rare feature that could occur in the southern Barents Sea from time to time, it is understood that it will not feature on a regular basis. Further to the described challenges faced in the high north of Norway, climate in the Barents Sea is fairly unpredictable due to several characteristic features such as polar lows, north Atlantic hurricanes, lack of data gathering stations, fog and icing among others. These features will now be discussed in further detail. What sets them apart from the first two mentioned above is that they are not immediately thought of, and do not receive the same amount of coverage, when considering the Arctic; even though they are consistently encountered on a yearly basis.

First off are polar lows. Many are not aware of this common phenomenon in the high north; even those who have heard of it, are not able to predict when or where they could occur. Polar lows are defined as low-pressure systems that normally generate when cold Arctic air breaks out over the warmer sea (Figure 7). Energy to drive the system is provided by heat and moisture transferred from the sea and by energy transforming within the atmosphere (Fugro, 2005). Wind speeds typically increase to storm force in a very short time ($^{1}/_{2}$ – 2 hours) reaching wind speeds of up to 35 m/s at a height of 10 m averaged over 10 minutes, with changing wind directions (Kvitrud, 1991 and Fugro, 2005). They are also associated with heavy snowfall and poor visibility. Often, high waves accompany the strong winds, creating a scenario almost impossible to manoeuvre in by vessels and putting a halt to all operations in the area. In the autumn of 1988 during the drilling of Norsk Hydro's block 7321/9, operations were halted for 22 hours during the passage of two polar storms. The dangers of getting caught in polar lows is high and can capsize vessels in the worst case but more often will hold up and push back operations; the question is: do the operators have the patience to wait out the storm or will they put safety on the line?

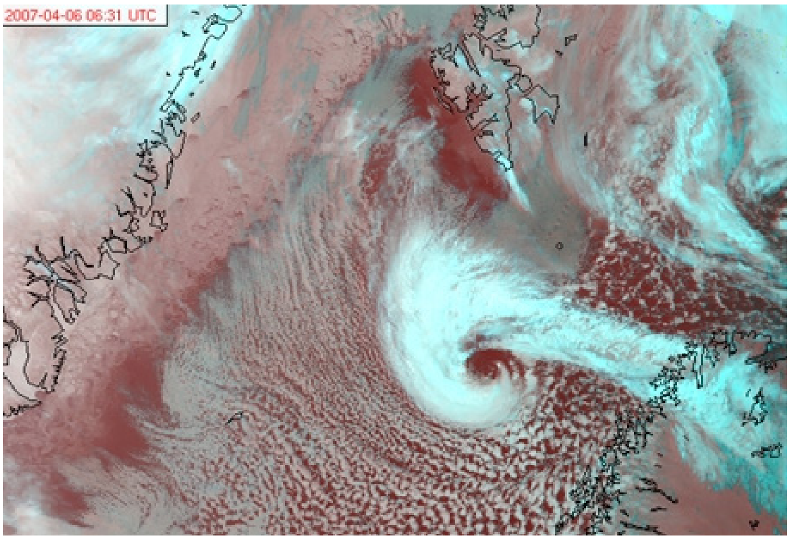


Figure 7. Cold air outbreak from ice edge off coast of Svalbard with polar low developing between ice edge and north coast of Norway (European Space Agency, 2011)

In addition to the polar lows, strong winds are dominated by the effects of the North Atlantic cyclones occurring further southwest (Fugro, 2005). Taking the measurements carried out by several offshore locations and extrapolating them to a probability of 10^{-2}, wind speeds of up to 30-36 m/s result at a height of 10 m averaged over 10 minutes. This is fairly significant and must be taken into account during planning of marine operations, construction activities and maintenance / intervention campaigns especially that such cyclones feature mostly from June to November, right in the midst of the operational summer season.

In addition to the harsh weather conditions, large waves, high wind speeds and extremely low temperatures are characteristic in the high north. In the Barents Sea, south of 74°N, absolute air temperatures as low as -20°C have been recorded over the ice-free area of the sea and -30°C in the north and south eastern part (Matishov, Golubeva, Titova, Sydnes and Voegele, 2004). On average, during the coldest month of the year, air temperature around the location of Johan Castberg is about -7°C (Løset, Shkhinek, Gudmestad, Strass, Michalenko, Frederkin and Kärnä, 1999) whereas the distribution is similar to that shown in Figure 8 for long-term average in January.

Temperatures close to or below 0°C pose several challenges and affect operations in numerous ways such as:

- Reduced mobility of personnel and increased risk of human error
- Need for winterization leading to increased need for ventilation and increased risk during gas leaks
- Malfunction of mechanical equipment
- Increased weight with high centre of gravity on vessel deck and superstructure (could lead to capsizing)
- Blockage of escape equipment, escape routes and process equipment
- Escape routes build up ice and become slippery
- Reduced effectiveness of satellite systems
- Atmospheric and sea spray icing (discussed further below)

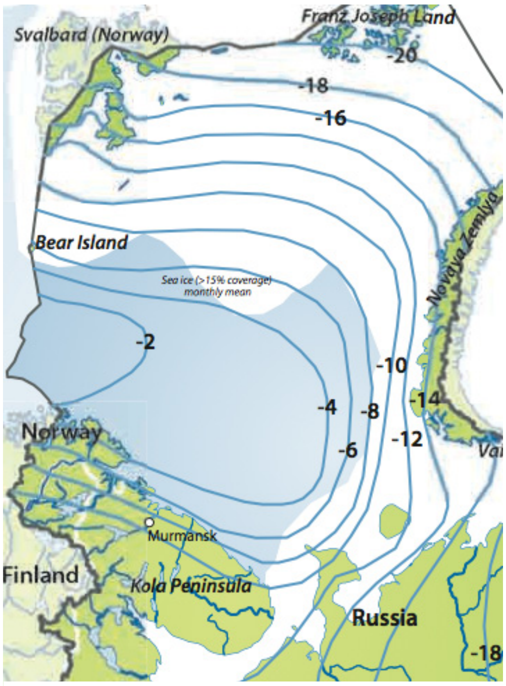


Figure 8. Average long-term air temperature, January (Matishov et al., 2004)

These challenges associated with particularly low temperatures must be taken into consideration both during design in the form of material selection, winterization, mitigation against freezing or blockages and in terms of ergonomics and human factors engineering.

Associated with low temperatures around and below 0°C is the freezing of water. Not only the fact that water expands by a factor of 10 when it freezes, which will damage valves and fittings, but simply the consequence of ice build up (sea spray and/or atmospheric icing). The two most common forms of ice accretion on vessels and structures located in the Barents Sea and high north are sea spray icing and atmospheric icing. Atmospheric icing is witnessed in mainly three forms: 1) under-cooled fog (in-cloud icing) at temperatures between 0°C and -15°C; 2) rain at temperatures between 0°C and -10°C; or 3) snow freeze at temperatures around 0°C to +3°C (Eide, 2008). This form of icing is limited and can be mitigated by heating or covering critical areas.

Sea spray icing on the other hand, is more of a concern since it can cause vessel instability and even capsize in some cases. It is mainly dependent on wave heights (driven by wind speed), air and sea temperature, vessel speed and shape. As the air temperature drops below -2° C (below seawater freezing temperature of -1.5 to -1.7°C) and seawater sprays onto the deck and superstructure of the vessel, it begins to build and can add up to thick layers weighing several tons (Eide, 2008). A layer of merely 30-50 cm can weigh up to 1,000 ton at a significantly high centre of gravity. Figure 9 shows different accretion zones on a vessel and the two pictures that follow show the possible extent of such icing. More pictures of ice accretion from Løset are shown in Appendix C.

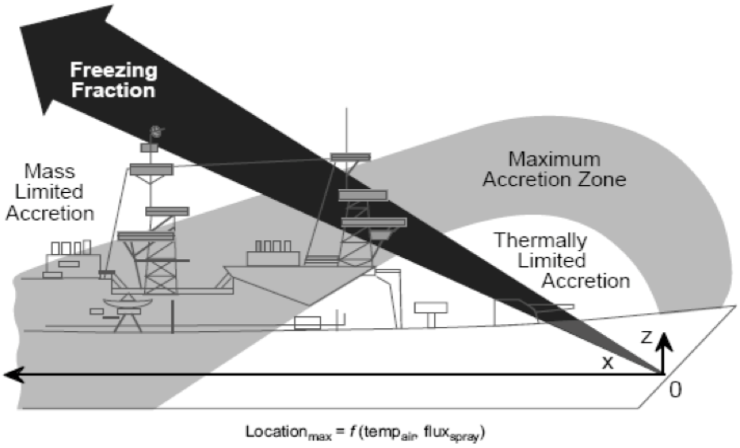


Figure 9. Sea Spray Ice Accretion Zones on a Vessel (Reyerson and Gow, 2000)

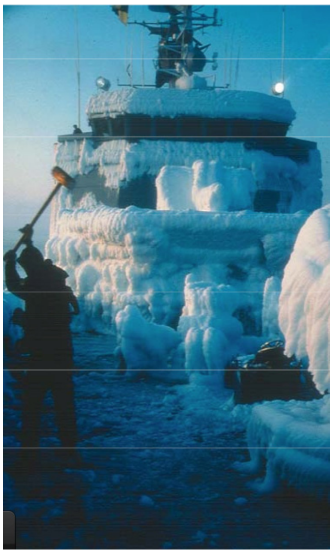


Figure 10. Ice Accretion Aboard K/V Nordkapp on Deck (Løset, 1987a)

Figure 11. Ice Accretion Aboard K/V Nordkapp around Lifeboat (Løset, 1987b)

Another of the major challenges in the high north and Arctic is the lack or limited amount of data to allow accurate forecasting of weather phenomena and changes (Allen, 2011). Due to the limited amount of weather stations, it is hard to predict when polar lows, fog build up or harsh weather is coming in and how it will travel along the sea. Bear Island (Bjørnøya), Hopen Island, Svalbard and Hammerfest house the nearest meteorological centres, which with some corrections are able to give an idea of the weather conditions in the area. It is very critical not to overlook this point since in fact one of the most challenging aspects of exploring the arctic and heading further and further north as the Arctic pack ice melts, is that the industry is going into unknown territory. Satellite effectiveness is significantly reduced since the horizontal component of the coordinate system is 25% of that in the tropics which significantly reduced the accuracy of coordinates and very small changes lead to large errors. Therefore navigation aids in the area are based on triangulated results of local signals received from weather stations, light houses and other vessels where possible. Again, since activity in the area is very little, such data is limited. Another dimension to this concern is that response times in case of personnel injury or oil spills is significantly increased since there is limited infrastructure or other facilities in the area that can support. Therefore it is understood that as the oil and gas industry moves further North, the general safety and preparedness level of the area will significantly increase therefore reducing the overall risk level currently witnessed by Northern shipping routes and other Arctic operations.

Development of thick fog is another one of the challenges to be added to the growing list of commonly overlooked or neglected natural challenges frequently encountered in the Arctic. This is quite significant however especially to crews that unfamiliar with the different phenomena that are unique to the arctic. Fog is a major issue in the Barents Sea especially around Bjørnøya, the island near which Johan Castberg is located. A National Geographic explorer, Magnus Forsberg, is quoted saying “fog made it almost impossible to see the island. Conditions for any zodiac operations were out of the question.” It builds in several forms: **1.** the first is simply called fog and is one of the main elements that hinder flying in the arctic. It is created when warmer, moist air from the sea streams over the cold land. Predominantly, it is encountered along and near the shore line. During the summer, the same effect occurs however the warmer air is advected over sea ice causing the same phenomenon (NAVEDTRA, 2001). **2.** Ice fog is when ice crystals form fog rather than the usual water droplets. It occurs generally around -45°C or colder but has also been encountered in temperature as high as -30°C (NAVEDTRA, 2001). **3.** Sea smoke is another unique feature encountered in the Arctic and it is when cold air hovers over warmer water and the air is no longer able to sustain the water content within. It can be compared to steam forming over boiling water however with “sea smoke”, both the sea, as well as the air temperature are relatively low with the air temperature being exceptionally low. This is one of the most dangerous types of fog since it forms in open waters and is often encountered in navigable channels and passages in the pack ice (NAVEDTRA, 2001). **5.** Arctic haze reduces horizontal visibility severely however vertical visibility is generally not affected since small ice particles form in the air and as the sun shines through the “diamond dust”, it refracts and hinders visibility (NAVEDTRA, 2001). Therefore any operations carried out will be hindered due to fog and could call for an additional “waiting on weather” delay.

Finally, one of the commonly overlooked characteristic features of the high north and Arctic regions is polar nights. Up to three months of the year, the sun does not rise above the horizon in Hammerfest, which is located at 71° N. This phenomenon manifests itself further as one travels further north and needs to be taken into consideration when planning operations, since visibility, human behaviour and productivity are significantly affected.

Although these hard-to-forecast features need to be carefully observed and planned for, some characteristics in the southern Barents and Pechora Seas are milder than those witnessed elsewhere. One example is wave loads. As presented by Hovland and Gudmestad (2006), the table below summarizes sea states for different areas including the Grand Banks, where two subsea developments, namely White Rose and Terra Nova, are currently in successful operation.

Table 2. One Year Return-Period Significant Wave Heights and Peak Periods for Different Regions (Hovland and Gudmestad, 2006)

	H_s (m)	T_p (s)
Southern North Sea	8.8	9.8
Northern North Sea	10.8	~14
Norwegian Sea	11.5	~15.5
Southern Barents Sea	10.0	14.7
Eastern Barents Sea	~9.4	14.1
Grand Banks	10.5	13.5

Apart from the above mentioned natural environment challenges that cannot be controlled and need to be taken into account when planning operations in the high north, there are other unnatural challenges. Distance to market is the first to be considered here and is fairly obvious. This links in quite closely to the lack of infrastructure in the northern area of the Barents Sea and Arctic. Currently, there are no fields operating in the Barents Sea with the Goliat oil field planning to start production in 2014. Snøhvit is the nearest gas development with a pipeline leading directly back to the onshore terminal in Melkøya, Hammerfest. The importance of the infrastructure comes in that most of the Norwegian oil and gas products are exported to Western Europe and with a lack of offshore infrastructure north of Norne (66°0′ N / 8°4′ E) leading south to the market, more innovative and expensive export solutions will be required. With the current technology in floating liquefied natural gas (FLNG), it is possible to utilize the volume compaction advantages for gas export however for oil fields such as Johan Castberg, this will be more complicated.

Finally, a very important factor that needs to be carefully assessed and researched is evacuation procedures both for personnel working on vessels in the high north as well as facilities as they come on in the near future. The further south the developments are, the less of a challenge it is due to the well established onshore infrastructure to support search and rescue. However, in the northern regions where pack ice is encountered the challenges increase exponentially. Firstly, there are currently no helicopters that are capable of carrying search and rescue missions for areas more than 250-300km offshore. The limit would be fairly close to this number since the reach of a Sikorsky S92 long-range helicopter is about 1000km, not considering hovering time. So including search and return consumption the reach would be insufficient even for fields found today such as Shtokman, which is 600km offshore. Another concern is the launching of evacuation rafts when the host facility or vessel is within pack ice or drift ice areas. This could be extremely dangerous and in some cases impossible especially that navigation tools in the high north are not as functional as they are elsewhere. Modern arctic amphibious escape vehicles are being purpose designed, built and tested for Arctic operations however no standards currently exist for these vehicles making it difficult to advance at the required pace. Conditions in the Barents Sea have not even been identified sufficiently to allow adequate scoping for such vehicles.

So as demonstrated, the main difference in challenges is environmentally as well as operational safety related. Through better understanding of such features, different solutions can be developed as suited to the individual region while being less conservative and offering more economically viable solutions. All this must be achieved in light of high HSE (Health, Safety and Environment) standards ensuring life, environment and assets are safeguarded.

3 State of the art – Technical Solutions

After screening through numerous sources, over 100, and dissecting all information to confirm the validity and accuracy, the physical environment in the Barents Sea has now been defined as per the above section. It demonstrates the harsh and ever changing conditions that engineers are faced with when developing fields in such remote, barely communicated and sensitive environments. The coming section of this report will not investigate some of the engineering feats undertaken over the years in similar high North and Arctic conditions to demonstrate that in fact such developments are possible if the risks are very carefully assessed, understood and taken into consideration during the concept select, detailed engineering, construction and operation phases. Local risks and mitigations will be discussed in light of field characteristics, which will assist in developing a robust and practical field development concept for the Barents Sea.

3.1 Platform Technology

The technologies focused on in this section will be mainly related to fixed structures, which have been used in Arctic and high north applications. Steel based structures (jackets), compliant towers and jack-up platforms will not be covered in this section. This is due to several reasons such as that they are not realistic from a design point of view to withstand the physical environment loadings nor are they suitable for water depths exceeding ~200 meters (exception compliant towers). Therefore, the technologies chosen below are both representative of the technologies used in such harsh conditions, and that may be an option for shallow water, Barents Sea applications.

Gravity Based Structures (GBS) – several GBS structures have been deployed in Arctic and sub-Arctic cold climate regions. One example is the world’s largest oil platform: Hibernia (Figure 12). Located 315 km east-southeast of St John’s, New Foundland in Canada (46° N and 48° W), it stands at a height of 224 m in only 80 m water depth. It witnesses some of the harshest conditions seeing on Earth, including extreme fog (~124 days/year), snow, rain and wind. Serrated edges allow the platform to withstand both sea ice and iceberg loads (up to 6 million ton) allowing year-round production.

Figure 12. Hibernia Platform off the Coast of St John's, New Foundland (Hibernia, 1997)

Not overlooking the 1.2 million ton dead weight of the structure and its 1.3 million barrels crude oil storage capacity (Hibernia, n.d. a), it is considered the largest of its kind in Arctic conditions. Although return period for such large icebergs reaching Hibernia is down to 10^{-4}, the structure has been designed to resist them sustaining only repairable damage. The number of icebergs within the Hibernia ice-monitoring zone has been 45 per year since the installation of the platform in 1997 (Jacques Whitford Ltd, 2009). Standby support vessels have to-date managed to tow away all icebergs encountered near the platform (Hibernia, n.d. b). Pack ice incursions are rare and have only been witnessed twice since installation (2003 and 2008).

A dedicated fleet of ice-strengthened shuttle tankers operates continuously between the platform and an onshore transhipment facility at Whiffen Head while the produced gas is re-injected. Again, similar conditions to the Barents Sea need to be accounted for such as fog, polar lows and icing.

Other examples of GBS structure Arctic developments are Piltun-Astokhskoye-B (PA-B) and Lunskoye-A (LUN-A) off the east coast of Sakhalin Island (Figure 14) in Russia (46° - 54° N). Although PA-B (Figure 13) is a production and export platform, LUN-A is mainly used for drilling with limited processing capacity. Climate conditions at Sakhalin are quite extreme and vary drastically over the 950 km length of the island. The northern end of Sakhalin is characterized by cold windy winters with minimum recorded temperatures of -48° C, although the average is around -22.8° C in January, and foggy summers with temperatures of up 14° C in August. Icing is extreme in the region where vessels and offshore facilities ice over between November and May and in some cases even during June, September and October. Combining these severe conditions with sea ice forming from November and developing migrating ridges along the coastline makes for a challenging design job for pipelines, shore approaches and platforms.

Figure 13. Piltun-Astokhskoye-B Platform in Pack Ice Detail 1, Figure 14. (Dolby, 2007)

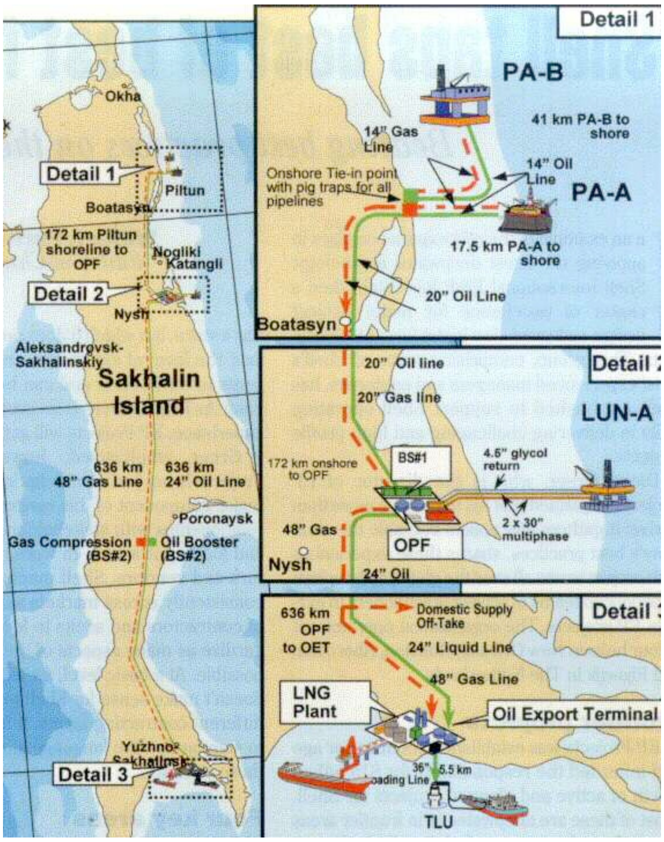


Figure 14. Sakhalin Island Developments (Gill, 2003)

Sea ice extends typically up to mid-May and during extreme years could last until end of June. Ice thickness is typically around 1.5 m while pack ice ranges from 3-4 m thick and ridges with keels in the range of 10-15 m (Reeves, R.R., Brownell, R.L., Burdin, A., Cooke, J.C., Darling, J.D., Donovan, G.P., Gulland, F.M.D., Moore, S.E., Nowacek, D.P., Ragen, T.J., Steiner, R.G., VanBlaricom, G.R., Vedenev, A., Yablakov, A.V., 2005.). There is no risk of icebergs in this region due to the protected location off the Sakhalin Island coast engulfed within Kamchatka Peninsula. One of the major concerns however, is the western grey whale population where strict conservation programs have been put in place.

3.2 Offshore Islands Technology

Steel-based ice-resistant Platform – an alternative development solution, that has been successfully installed in several locations. Such installations are characterized by shallow waters, such as the Caspian Sea, offshore Sakhalin island (Molikpaq platform, Figure 15), as well as the first Arctic-class ice-resistant platform in the world: Prirazlomnaya in the Pechora Sea. The basic idea of such installations is to take advantage of the shallow waters to create a sturdy and robust gravity based style structure. Sand, ballast, gravel or other materials are used to weigh down the structure. A typical example of such platforms is shown in Figure 13. Prirazlomnaya, as an example, has been stabilized making use of 100 thousand tons of rubble in addition to 122 thousand tons of ballast (ITAR-TASS, 2011). The 126 m square-shaped platform required an icebreaker and three tugboats to tow it to its final landing location, 55 km off the north coast of Russia just south of Novaya Zemlya (Figure 16).

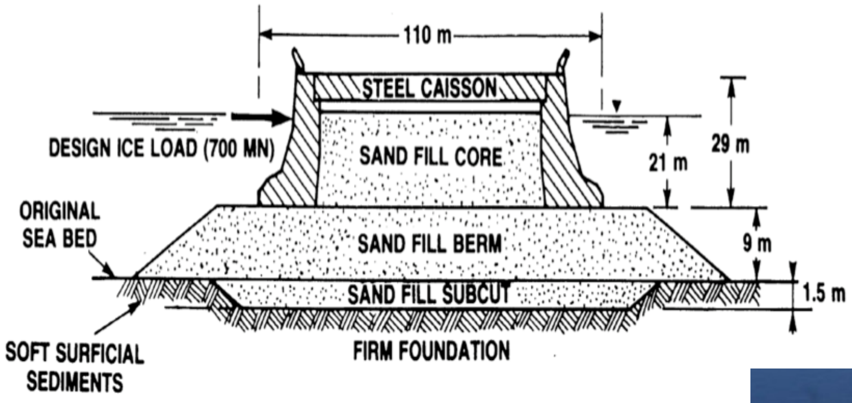


Figure 15. Schematic of Molikpaq (Løset, 2011a)

The area is characterized by heavy sea ice and extremely low temperatures, down to -50°C, in only 20 m of water. The combination makes design and operations of the platform very critical and complicated. Figure 13 below shows a typical example of how such developments can be designed for harsh conditions including waves, winds, ice loads and low temperatures (ITAR-TASS, 2011).

Figure 16. Prirazlomnaya during tow-out in Murmansk, August 18th, 2011 (GAZPROM, 2011)

Being located under cover 230 days per year, places large loads as well as constraints on the platform, increasing design consideration both for the platform itself as well as product export philosophy and emergency response (Offshore Technology, n.d.). Ice thickness can be up to 1.7 m requiring nuclear-powered icebreaker support on location at all times. Icebergs are not common for this location since it is out of the current drift (Appendix D). Wave loads are also lower than those witnessed on the Norwegian Continental Shelf (NCS) with a maximum wave height of 12 m (Offshore Technology, n.d.).

The platform has two shipping units located at opposite sides of the platform to allow loading from the opposite side to the direction of drift ice. Double-acting hulls are used for the shuttle tankers to allow them to maintain structural integrity even if the outer hull is damaged. Oil is transported from the field to a moored Floating Storage and Offloading (FSO) unit off the coast of Murmansk from which point it is exported to market (Niini, Kaganov and Tustin, 2007).

3.3 Subsea Technology

So what are some of the available solutions for Subsea Arctic Field Development that have been successfully deployed or are being recommended to date? There are several solutions already implemented, although only one of which is currently operational in the southern Barents Sea (Snøhvit). Others are predicted to come on-stream in the near future such as Goliat. Following, a brief description of the currently developed fields will be presented first, followed by some concepts that are yet to be implemented.

Note that although seabed and soil conditions are also important factors to consider when assessing subsea field development, there has been no direct focus on this area since it is forecast that no dredging will be required for the Barents region since the seabed conditions are fairly good.

Subsea Development with tieback to FPSO – on the Grand Banks, 350 km off the east-southeast coast of Newfoundland, Canada, two developments have taken place by making use of such technology. Terra Nova and White Rose (Figure 17, Figure 18) are both oil fields located in the *Jeanne d'Arc Basin* being produced through a combination of subsea completions, tied back to an FPSO.

Figure 17. Artist's Impression Terra Nova Field Development (Doyle and Leitch, 2000)

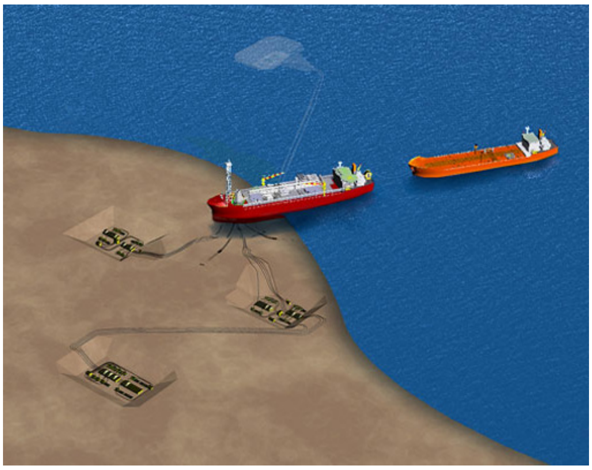


Figure 18. Artist's Impression White Rose Field Development (offshoretechnology.com, 2011)

Although the fields' latitude is much lower compared to the Barents and Pechora Seas (around 48° N compared to 72° N), they are susceptible to even harsher weather conditions. Icebergs are common and sea ice makes its way to the area once every three years (Doyle and Leitch, 2000). Sea ice reaches a maximum thickness of about 150 cm and a concentration of 2/10th up to 8/10th (Jacques Whitford Ltd., 2009). Therefore, risers on the fields are connected to the FPSO via "spider buoy" technology, which is also the vessels' mooring mechanism. It allows quick disconnection and reconnection in case of extreme weather conditions and environmental features. Since the fields are located in shallow waters (Terra Nova 94 m, White Rose 122m), gloryholes or excavated drill centres are required to contain subsea infrastructure. These are large excavated areas in the seabed, around 10m deep, within which the subsea equipment stands. Excavation techniques were trialled and many challenges resulted in extensive delays before trailer suction dredging was successfully applied at both sites. The idea is that icebergs scouring the seabed would dislodge and float through the gloryholes without coming in contact with the subsea infrastructure.

In addition, high-speed winds up to a maximum-recorded velocity of 145km/h result in steep waves in excess of 30m in the area. Although generally, wave conditions are comparable to other areas as demonstrated through Table 2. Storms, extreme low temperatures and icing are challenges similar to those encountered in the Barents and Pechora Seas, which also need to be taken into consideration. Another major concern for such developments is vessel stability; accounting for the effect of icing along with other environmental loads is necessary, especially during installation and intervention.

Subsea-to-Shore – one of the alternatives gaining a lot of attention in recent years and with increased efficiency and technological advances is becoming increasingly attractive, is subsea-to-shore or S2S. Snøhvit, a natural gas field located 143 km off the northwestern coast of Hammerfest, Norway, is the only such development in cold climate or Arctic waters (71.6° N, 21° E). The field is located in the southern Barents Sea in water depths of 310-340 m and includes six remotely operated subsea manifolds hosting 16 well slots each, control distribution template for power, controls and chemicals, as well as flowlines for connection of manifolds to the export pipeline (SUBSEAIQ, 2008). Remarkable features on the project include CO_2 capture at the onshore LNG facility after which it is re-injected into deeper formations as part of a carbon-capture initiative aside from the fact that this is the first subsea field to be remotely operated from an onshore facility. The site of the Snøhvit field (Figure 19) is ice-free year round but weather conditions in the area such as polar lows, high-speed winds and large waves make operations difficult at times. Temperature drops severely in winter and icing becomes more critical, taking some of the smaller vessels out of operation in the area due to instability risks.

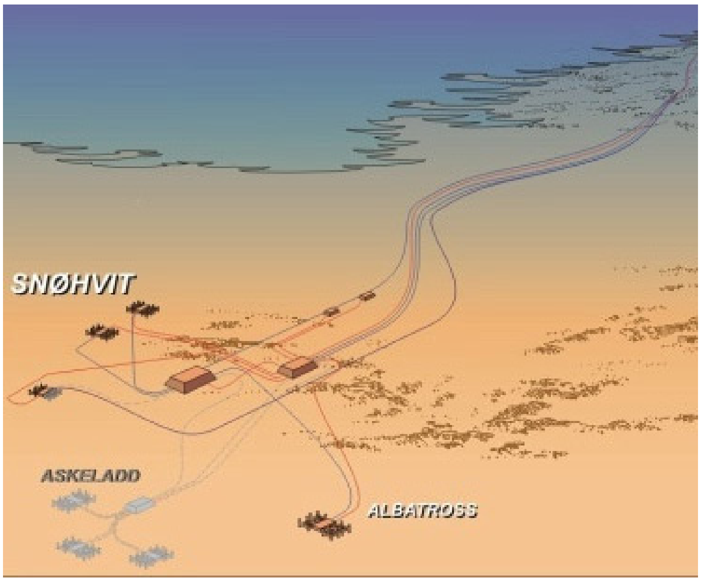


Figure 19. Snøhvit S2S Field Development (SUBSEAIQ, 2008)

Icebergs are also not a concern due to the drift currents (Appendix D.) and also since the field is sheltered by the mainland from iceberg generation areas such as Franz Josef Land and Svalbard. Wind and wave conditions are as presented in Table 2 for “Southern Barents Sea”, which are not much different from the conditions on the remainder of the continental shelf. Additional considerations on such developments will include reliability of subsea equipment, shore approach, maintenance and repair tasks carried out during winter or autumn months as well as well intervention for the same periods.

Futuristic Subsea Complex – although this might be a little too ambitious for the current technological advances and perhaps a little unrealistic at its scale, this development solution seems to hold great promise to one degree or another for the future of Arctic developments. The idea spawns from an article by Medved and Nedelin written in 1993, where the authors are well aware of the challenging environmental conditions in the region and suggest the following solution, Figure 20.

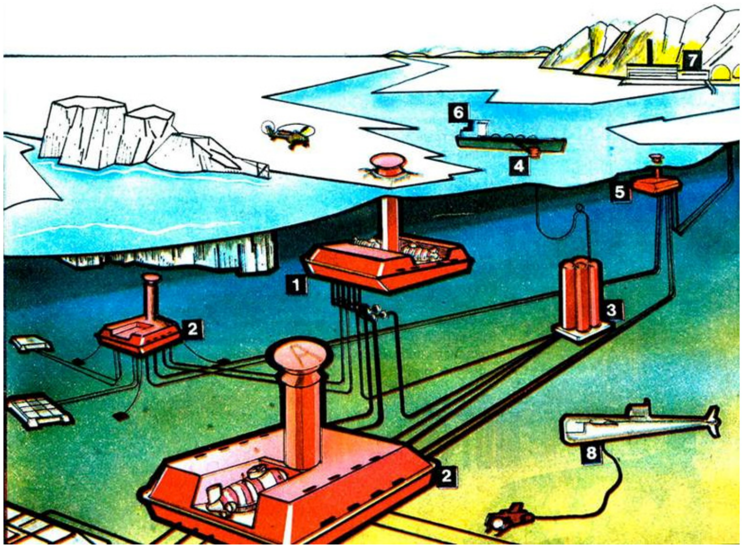


Figure 20. Designer's Impression of Subsea Processing Complex for Water Depths over 60 m.

1 - Control and Power Distribution Centre; 2 - Processing Units; 3 - Storage Tanks for Condensate; 4 – Pop-up Loading Terminals; 5 – Export Gas Compression Station; 6 – Export Shuttle Tanker; 7 – Onshore Facilities; 8 – Supply Vessel (Medved and Nedelin, 1993)

Accommodation on the subsea complex will be part of the control and power distribution centre (1). The plan seems simple enough and some aspects of this idea are actually being investigated today such as subsea gas compression and others already exist such as subsea separation and boosting on the Pazflor field in Angola. The designer also developed an IMR (inspection, maintenance and repair) vessel concept including ROV capabilities to service the installation (Figure 21). Similarly, a crude oil, submarine, transport system suitable for Arctic regions, was suggested by Jacobsen in 1971 (Jacobsen, 1971). Jacobsen claims “the design and construction [of the nuclear powered submarine] is within present state of the engineering art” however further engineering analysis is required to finalize design for the underwater terminal (Jacobsen, 1971). Divers, as depicted below, would most probably not feature in modern day developments due to the health and safety hazards associated.

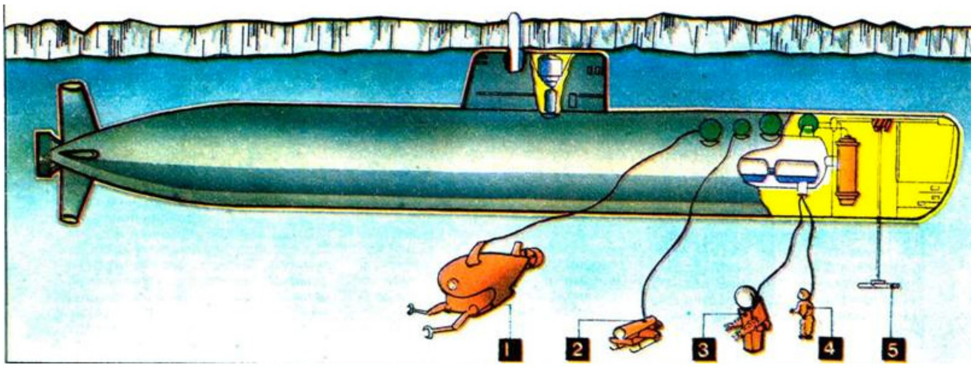


Figure 21. Subsea IMR Vessel Concept including ROV (Medved and Nedelin, 1993)

The pop-up loading terminal shown in Figure 22 is another ingenious concept not only since it is located in open waters out of the sea ice zone but also due to the fact that it can dodge icebergs by lowering itself to a depth lower than the draft of the berg.

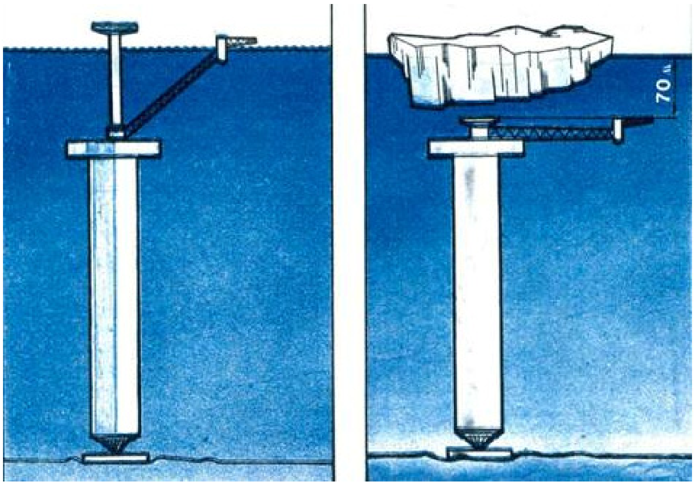


Figure 22. Pop-up Loading Tower Concept for Iceberg Evasion (Medved and Nedelin, 1993)

Further analysis of such concepts and their pragmatism should be analysed further to be able to qualify the technology and reject impractical solutions. Great benefit could be achieved by being able to implement some of these concepts especially for fields within 100 km of MIZ (marginal ice zone) and even further. Statoil however, have already adopted the idea of constructing an Arctic subsea factory under ice by 2030 (Øvrum, 2010).

4 Field Development Solutions for the Barents Sea

4.1 Results of Grid Analysis

Firstly, it has been demonstrated that the northern and Arctic regions hold great promise for meeting future energy demands. Now that an understanding is gained of the challenges and conditions being dealt with in the Barents Sea as well as the development options available in the "toolbox", it is time to develop a possible case for developing such a region.

In terms of defining the most favourable solution, a Grid Analysis (presented in Appendix G.) was carried out. The following section sheds light on the subjective conclusions drawn for each of the scores provided.

The grid analysis considered five different options based on the conditions available at the Johan Castberg field. These were: Floating Production Storage and Offloading facility (FPSO), buoy-shaped FPSO (e.g. Goliat field Sevan 1000 FPSO), Gravity Based Structure (GBS), Semi-submersible platform and Tension Leg Platform (TLP). In addition to the parameters presented below, automation of the topside facilities was considered as an important parameter however in the author's view, it was considered to be equally possible for all solutions therefore it was removed from the analysis. The parameters considered to be most important for the selection of the development concept are as follows:

Cost
Resistance to environmental loads
Ease of installation
Storage
Abandonment

Water Depth
Availability / uptime
Disconnection
Escape
Maintenance

Firstly, the top row in orange-labelled "Weight" defines the utility of each of the "Parameters" displayed as columns. "Resistance to Environmental Loads" and "Availability / Uptime" can be seen as having high utility values whereas "Abandonment" and "Water Depth" suitability have lower values since abandonment is technically feasible for all solutions and has been done whereas "Availability" directly affects production and hence revenue.

Secondly, the alternative development solutions considered for a Johan Castberg-type field are listed in the first column under "Weight" and they only include those technologies that can be and have been deployed in similar conditions. Parameters are scored from '0' to '5', where '5' is the best possible score.

The "Total Score" is calculated by taking the sum of the score of each parameter and multiplying it by the utility value (weight) then dividing the sum by the ideal score (200). This is demonstrated by the following equations:

$$Ideal\ Score = \sum_i^n Weight_i \times Max\ Score,$$

where i = parameter number, n = total number of parameters and Max Score is 5.

$$Total\ Score_{FPSO} = \frac{\sum_i^n Parameter\ Score_{i-FPSO} \times Weight_i}{Ideal\ Score},$$

Now taking each of the development alternatives considered and screening them against the various parameters:

FPSO or Buoy tie-back – this is a vessel type solution and would be a new build, specifically designed to cater for Arctic / harsh environments. This means that some form of winterization would be necessary as well as ice strengthening of the hull most likely in the form of a double acting hull to be able to take the potential loads in the area and maintain integrity in case the outer hull ruptures for some reason. The **cost** for such vessels has risen dramatically over the past years especially since they are in high demand (reference offshore West Africa, Asia and Australia – FLNG) and only few yards are able to produce such highly technological and large vessels. Buoys are considered slightly cheaper (new build considered), since they are smaller units and less complicated however the technology is not as widely available and to-date only Sevan Marine are producing such a unit. Although FPSOs have good weather vaning capabilities and when suitably designed are able to take large **loads**, they are still vulnerable to side loads especially when drift direction changes rapidly as demonstrated by Figure 24. Buoy shaped production units have much better resistance to ice and environmental loads since they are not sensitive to drift direction or “bad weather” direction due to their unique shape. Using sloping walls dramatically decreases ice loads on such structures since the ice sheet then breaks by bending rather than crushing. Typically flexural rigidity of ice is around 100x lower compared to its crushing strength. **Availability and uptime** are quite good on existing FPSOs although experience from Nova Scotia shows that some shutdowns or production minimisation are forced due to bad weather risks which can potentially be mirrored in the Barents Sea (i.e. Polar Lows, Iceberg sightings, storms, etc.). **Storage** on such vessels is generally good especially when designed as a double acting hull where the internal hull can be used to store large volumes of crude prior to offloading. Most existing facilities are able to store at least a week’s worth of production in case of bad weather and reduced tanker traffic. Large vessels reaching up to 400m in length are able to carry large amounts of crude compared to buoy shaped units where although storage is available, it is limited. Since the weather vanning on vessel shaped production facilities is so effective, **evacuation** then also becomes more reliable since there is always a side of the vessel that is protected from the elements. To be able to fully utilize this advantage, lifeboats and evacuation equipment needs to be accessible from opposite ends of the vessel. Flexibility of FPSOs in terms of **water depth** is quite an advantageous property where the technology can be deployed in anywhere between 20-30m water depth (Zeng, H.Y., Li, X.Z., Chen, J.C., Chen, M., Tan, J.X., Jing, Y., Shi, S., Li, Z.G. and Li, X., 2012) and several thousand meters of water (ref. Kikeh FPSO - 1320m, Iracema Norte Area Pre-Salt Field – 2000m). **Installation** of such vessels is fairly easy since most are self-propelled and can manoeuvre themselves into position. The same goes for disconnection however installing controlled sinking spider buoy systems where the buoy acts as both the riser tie-in system into the platform as well as the mooring point dramatically improves ability to disconnect. Since buoys do not have that natural vessel shape and in the case of the Goliat FPSO, lack self-propulsion, it is harder to install, disconnect and abandon such a facility especially in harsh climate since a complicated tug pulling exercise would be required. **Maintenance** is neither excellent nor is it cumbersome; some additional challenges are encountered due to the dynamic floating properties of the vessels however this is being carried out on several installations all over the world with no major impact. Finally abandonment, which can be compared to disconnection, is fairly straightforward and earns the FPSO solution the top score in this aspect.

Gravity Based Structures – assessing gravity based structures, one finds that such developments are capital expenditure intensive reaching billions of dollars in fabrication **costs** in addition to the high tow out and **installation** expenditure. This is why GBS solutions have been marked down on cost however in terms of **resistance to environmental loads**, it has been demonstrated by Hibernia that such facilities can be designed to withstand even the most extreme scenarios with only little damage. It is possibly the only development solution that will be able to handle iceberg impacts, for example, of up to 1 million ton without any damage and up to 6 million ton with only repairable damage. Its resilience also helps it in terms of **availability** score since there is no need to disconnect, continuously halt operations or move off location during harsh weather and in terms of **storage**, the concrete cells are an effective use of the space to store crude oil. Although this is good for the availability score, it affects disconnection and abandonment scores on the balanced view. **Escaping** such fixed facilities can be risky and dangerous especially during winter months where access to the location is difficult or ice is in the area. Due to the large air gap between the platform's cellar deck and the sea level, trying to jump onto vessels or into the sea can lead to fatalities or serious injuries. **Maintenance** on GBS facilities is generally viewed as good since the facility is fixed and rigid which simplifies topside operations, risers within the j-tubes are enclosed within the concrete structure, which protects them and there are generally large cranes on the installation for lifting of heavy equipment.

Semisubmersible and TLP – here, SPAR platforms are included within the TLP definition for simplicity. Although the two technologies are different, the general concept for the purpose of this exercise is similar. Semisubmersible and TLP solutions are somewhat similar to FPSO and buoy development solutions with some unique differences that will be explored herein. In terms of **cost**, semisubmersibles and TLP are slightly more cost effective compared to FPSOs due to the reduced complexity, lack of complicated vanning riser and mooring system (spider buoy turret system) and need for multiple offloading systems (one on each end of the FPSO). They are much more susceptible to **weather** and cannot operate in extreme sea states or in icy conditions. They rely heavily on the mooring system, which also means that they are fairly sensitive to installation accuracies. **Availability** and uptime is directly related and is seen to be lower than that of other development solutions. Semisubmersibles generally have no **storage** capacity whereas TLPs are in some instances able to store some volume within tanks installed in the submerged part of the installation. **Escape** from such facilities is comparable to that of the GBS structure with the added risk of relative motion with respect to other seafaring or airborne evacuation vehicles. Water depth for such installations is generally preferred to be around 500-2000 m, therefore they are considered more suitable for medium-deepwater installations. **Installation** as well as **disconnection** and **abandonment** are all complicated activities since mooring lines need to be carefully disconnected, the facility need to be towed using several tugs and support vessels and such facilities are not very stable during sea transport. Therefore these development solution categories score low on the all three areas. The only solution score that might be considered favourable is that of semisubmersibles with dynamic positioning capabilities and self-propulsion since they can make their way to location and maintain coordinates independently of other vessels however this type of facility is very expensive.

In summary, it is evident from the Grid Analysis that tieback of subsea fields to floating production, storage and offloading (FPSO) facilities are favoured especially those shaped like buoys with sloped sides. The following section will take this concept deeper in light of the overall field development concept, tying it back to other field development building blocks.

4.2 Advantages of Subsea Field Development in the Barents Sea

Furthermore, now that it has been demonstrated through the Grid Analysis presented in Appendix G and discussed in section 4.1 that subsea field development tied back to a buoy-shaped FPSO is the most favourable solution for such an environment, it is the author's intention to carry out a full analysis of the different phases of such a development in the Norwegian high north. A Johan Castberg-type field is considered, composed of a 33 m gas column blanketing a 90 m oil column and amounting to approximately 400-600 MMboe (Statoil, 2011). A full analysis of post DG4 (Decision Gate) will be made including construction, installation and operation. Abandonment phase is not discussed in much detail here since challenges will be similar to the installation and operation phases. Furthermore, most of the North and Norwegian Sea technologies will be adequately applied to the Barents and Pechora Seas by taking "Arctic factors" into account. The pre-DG4 phases are shown in Figure 23 and the assumption is made that at DG2, subsea field development tied back to a buoy-shaped FPSO is the chosen development concept.

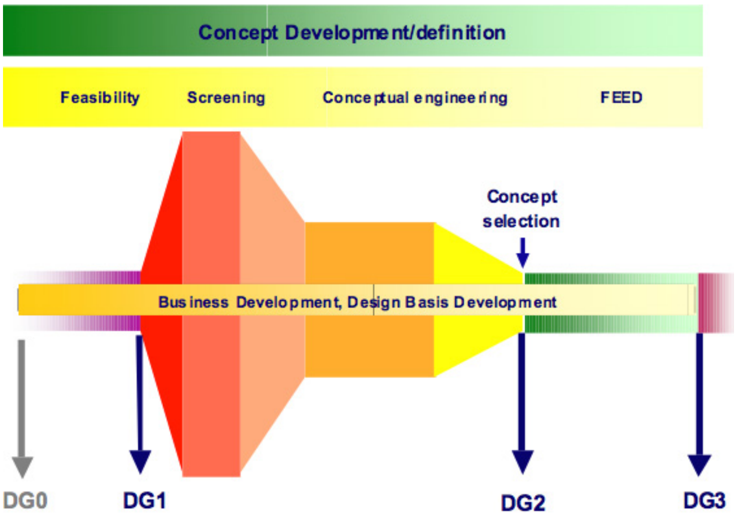


Figure 23. Concept Development / Definition Value Chain (Gudmestad and Løset, 2004)

The building blocks of a field development include the main components for commercially producing oil and gas. In this case, the chosen building blocks are as follows:

- Well and Xmas tree selection (completion concept)
- Host facility (if any)
- Export / transport system
- Receiving terminal
- Support and IMR strategy

Completion Concept (well-2-host) - the clear advantage of subsea field development in the Arctic is the fact that a great amount of permanent infrastructure is protected far beneath the waves, sheltering it from the harsh environment including waves, winds, cold climate, sea ice and icebergs. Only the host facility and vessels are required to resist these harsh elements of the Arctic. It is recommended to adhere to standard Norwegian practice and develop the field through over-trawlable templates, daisy-chained to one another leading back to the riser base. In doing this, horizontal drilling of multilateral/multizone wells is recommended such as those provided by

Weatherford, Schlumberger and others. A system such as the FlexRite® Multibranch Inflow Control (MIC) system developed by Halliburton may also add value in being able to control several branches separately although they all lead back to a single casing and X-mas tree. This would allow several wells to be drilled at each well slot and reduce the number of templates required. Flexible risers coming from the riser base are then connected to the disconnectable spider buoy turret system on the FPSO, similar to that of the Terra Nova FPSO. In terms of oil offloading, a remotely installed submerged turret and loading (STL) system will be used connected to subsea storage cells to offer flexibility, efficiency and safe offshore loading and storage (Smedal and Syvertsen, 1995). This is particularly interesting since it allows offloading even during the harshest weather conditions.

Host facility (FPSO) – the buoy-shaped FPSO is quite favourable in Arctic conditions due to several features:

- No need for weather vanning – i.e. rapid change in drift direction not a concern
- Ability to “lift” and “lower” itself in and out of the water depending on sea state: open water, FPSO “lifts” itself out of the water to reduce wave effects; sea ice, FPSO can “lower” itself into the water where sloped sides will change ice failure mode from crushing failure with high loads, to bending failure with much lower loads (up to 100x lower) (Løset, 2011a)
- Ability to go off-location during extreme weather conditions or for overhaul maintenance

In this case, the host facility must be winterized to allow year-round operations. Anti-icing philosophy needs to be implemented either through warm water circulation, electrical heating or use of antifreeze solutions such as glycol (Endrerud, 2011). Storage will also need to be incorporated into the vessel in case loading is not possible due to environmental conditions. This can be achieved through a combination or one of two methods, either storage within the hull (Sevan make FPSOs with up to 2 million bbl storage capacity) or subsea storage cells. As a minimum, the topside facilities must be able to handle 3-phase separation, oil stabilization and offloading, water treatment and injection and gas processing and compression for pipeline export. Necessity of water treatment and reinjection comes from the fact that no discharge to sea is allowed due to strict environmental regulatory requirements in the Arctic and high north of Norway. As an added benefit, reinjection of produced water aids in maintaining reservoir pressure. Export products will then be: stable oil and rich gas.

Additionally, the FPSO will need to be somewhat ice-strengthened to resist possible ice loads. Ice management strategy will define the ice class required for safe operations however as a minimum it is anticipated to design it with double bottom and sides. Inclusion of a disconnectable turret system will allow the FPSO to disconnect if conditions become too extreme and will reduce stresses on risers due to slight rotation due to waves, wind and surface currents. The FPSO is then able to leave its location safely without damaging risers and simplifies reconnection. Ideal turret location for the Terra Nova FPSO was found to be approximately 27% of the length of the vessel aft of the bow (Doyle and Leitch, 2000), for a buoy-shaped FPSO, it would be located in the centre under the moonpool.

The final point that is essential to consider during the design of the topside facilities, is the extent of automation. Reducing the manning in such remote and harsh conditions will significantly increase the risk picture by eliminating or reducing human presence. Automated, instrumented functions offer higher reliability, availability and reduce the need for safeguarding system however it introduces and extra element of maintenance that needs to be taken into account.

Transport and Loading – since stable oil and rich gas will be transported from the field, different strategies for the two need to be defined. For oil, a submerged turret and loading (STL) system located at a reasonable distance not less than 10 km south of the field is recommended to ensure a return period of less than 10^{-4} for sea ice and icebergs. STL systems have two main advantages; first of all during extreme seasons when the vessel is operating under ice cover (more common for fields further north), it would be able to quickly weathervane about the turret to "face the weather" and significantly reduce loads and pressure on the tankers. This is absolutely necessary since ice drift direction can change very quickly. Figure 24 below shows just how quickly this happens; it can be observed that the ice does not only change direction but also accelerates in the opposite direction within 30 minutes based on the three dots. The second benefit is that the tanker is able to disconnect rapidly in case weather conditions change quickly whether it is due to polar lows, cyclones or thick fog conditions making it unsafe to continue loading operations. Turret can then be submerged to a safe depth of 100-150 m (field located in 300-400 m water depth) and later recovered as the vessel returns to location.

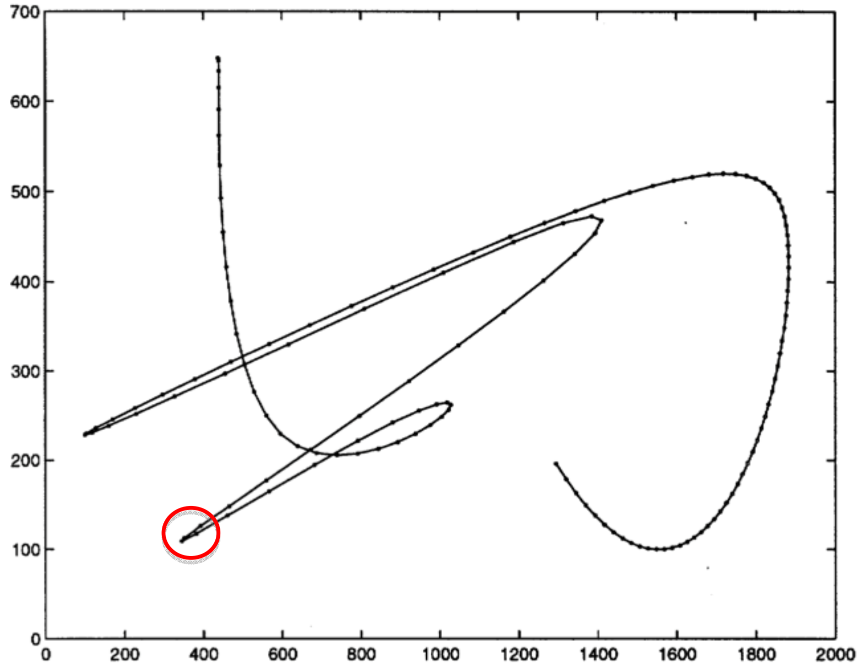


Figure 24. Plotted Iceberg Drift based on Recorded Data. Dots every 10 minutes (Løset, 2011c)

Since the loading terminal is now located away from the ice susceptible zone, winterized very- or ultra large crude carriers (V/ULCC's) can be used to transport oil straight from the field to the market. For fields further north, ice-strengthened shuttle tankers would be a more economical solution, transferring oil back to a transhipment terminal onshore, before the oil makes its way to the market. Ice-strengthening costs are high; amounting to almost the original cost of the vessel, therefore a detailed risk assessment should be carried out to establish whether it could be avoided.

Gas on the other hand will be dehydrated on-board the FPSO, compressed and exported through a 140 km, 26" pipeline connecting to the onshore terminal where it will be processed further. It might be necessary to install a subsea compression station similar to the one being implemented on the Ormen Lange field (dry gas) or the Åsgard field (wet gas) (Øvrum, 2010), to maintain production rates as the reservoir is depleted and pressure drops. In case the gas export solution from the Johan Sverdrup field is tied back to the Snøhvit field, it is wise to install such a station downstream of

Snøhvit to capitalize on the benefits. Flow assurance will be a major challenge here; pipe-in-pipe technology is recommended to maintain desired operating conditions and avoid risk of hydrate formation since alternative concepts such as Direct Online Heating (DOH) would be uneconomical as proven on some of the recent North Sea developments assessed in recent years (ref. Linnorm; Wilson, 2013). Optimal pipeline route needs to be defined and mitigation strategies such as MEG (Methyl Ethylene Glycol) injection can be utilized similar to how it is done on Snøhvit and Ormen Lange. It is worth noting that similar long-distance multiphase pipelines have been developed before for example the Huldra field where wells are tied back using a 22”, 140 km multiphase pipeline and at Kvitebjørn where a tie back distance of 147km has been achieved with a 30” export pipeline (Grini, 2009).

One of the main challenges associated with both the infield infrastructure and export facilities is pipeline installation. Considerations will be similar to Snøhvit and weather windows will need to be accurately estimated to limit “waiting on weather” downtime. This will be very challenging since limited data is available conditions are erratic. Nevertheless, making use of state-of-the-art submarine and sub-ice installation concepts, (Figure 25) such as the distance-deployed and remotely operated 400 mT lift/construction unit being developed by Hereema Marine Contractors (HMC), will make a large contribution to facilitating this challenge. Winter operations may well be possible in the near future (within 5 years), which might just become an enabler for developing Arctic fields (Lange, Zandwijk and Graaf, 2011).

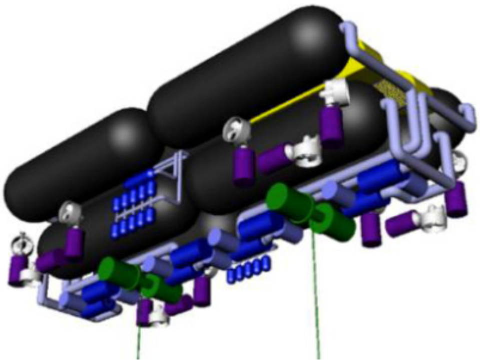


Figure 25. Sub-ice Construction Unit (Lange, Zandwijk and Graaf, 2011)

Support and IMR (inspection, maintenance and repair) strategy – the support strategy for the field must be carefully reviewed to decide whether a vessel will be constantly located at the field or whether it will be shared amongst neighbouring fields (possibly Johan Castberg, Snøhvit and Goliat). Currently, Goliat have elected to have several vessels on permanent station in the area, equipped with infrared cameras and oil detection radars (Eni Norge, 2013). The recommended solution is to have an ice-strengthened vessel capable of carrying out light intervention (Category A), maintenance and capable of launching AUV’s (automated underwater vehicle). However, there is no such vessel currently available on the market that can operate in temperatures below -20°C. This solution would ideally be combined with carrying out IMR and light interventions campaigns using an AUV such as SWIMMER (Tito and Rambaldi, 2009) during winter months. SWIMMER is able to operate continuously for up to 3 months, which seems to be a suitable solution for the current needs. Future developments further north in the Arctic will require a much longer operating period, more robust performance (currently a high number of failures is witnessed leading to many recovery missions) and a much longer range. During summer months, more extensive interventions by drill ships can be performed. Many AUV concepts are being developed and trialled, some more successful than others and according to Billingham (2006) from British Petroleum, this seems to be the answer to deep water and Arctic IMR and light intervention operating cost savings, the author agrees. Billingham estimates that savings can range from $1-4 million per annum, significant enough to justify the pre-investment. SWIMMER for example, is a concept that uses an AUV carrying a WROV (Work-over Remotely Operated Vehicle). Docking stations connect back to the host for power, controls and hydraulics and are necessary to launch the WROV for IMR and light intervention tasks. The AUV makes its way autonomously out to carry out certain tasks and returns to a docking station driven by a mission plan. Once it returns, it is able to feed data back to the host and is capable of launching the WROV from within the docking station with a tether range of 200 m.

The first application of SWIMMER is forecast to be on the Pazflor field off the West coast of Africa in 600-1200 m of water, which will adequately test the technology and offer validation and qualification for the rest of the industry (Figure 26).

Submarine intervention and IMR concepts can also be technically feasible, but in the near future do not offer an economically attractive alternative.

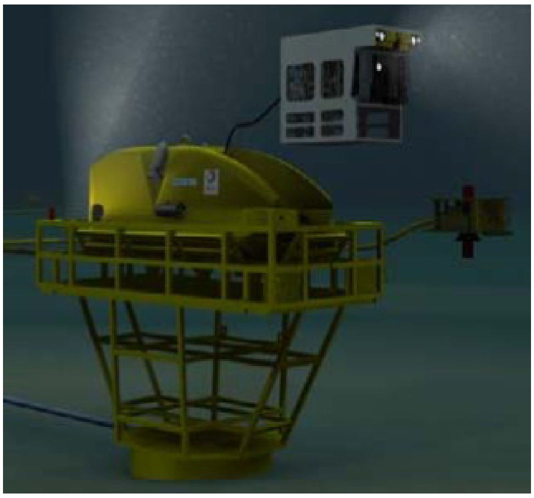


Figure 26. SWIMMER Docked into DS and Deploying the WROV (Tito and Rambaldi, 2009)

The most significant challenges with developing this field however, are not associated with extracting or transporting the products; on the contrary, they are associated with tasks that are quite dislocated from the seabed. The major challenges are associated with tasks that require marine operations such as installation of subsea equipment, intervention, inspection, maintenance and repair. The conditions in the Barents Sea are continuously changing and Table 3 summarizes conditions for the Barents Sea (Løset, Shkhinek, Gudmestad, Strass, Michalenko, Frederkin, and Kärnä, 1999). Appendix F gives a more detailed description of ice and meta-ocean conditions with respect to standards and data background from Barents 2020 report by DNV (Eide, 2008) where it can be seen that the challenges mentioned above are again highlighted by DNV.

Table 3. Summary of Conditions in Barents Sea

	Wind	Air Temperature	Current	Ice Conditions
Mean	8.5-9.0 m/s	-6° C	0.75-0.80 m/s	1.8 m
Maximum	36 m/s	-24° C	-	3-5 m

Table 4 (Hovland and Gudmestad, 2006) below however, shows the availability fraction for sea states with significant wave heights less than 3 m and 5 m respectively. It can be noted that availability on the Southern Barents is actually higher than that witnessed in the northern part of the North Sea and the Norwegian Sea. This means that similar considerations need to be taken into account and experience can be drawn upon, while using advice from local fisherman and seamen operating in and around the Hammerfest region.

Table 4. Fraction of Time Per Year where Sea State (H_S) is Less than 3 m and 5 m respectively (Hovland and Gudmestad, 2006)

	H_s = 3 m	H_s = 5 m
Southern North Sea	0.83	0.98
Northern North Sea	0.64	0.91
Norwegian Sea	0.67	0.91
Southern Barents Sea	0.75	0.95
Eastern Barents Sea	0.80	0.96

As can be seen from this section, subsea field development in the Arctic is very attractive and although there are many challenges that need to be addressed, there are also many opportunities that can be explored. The general conditions such as sea state are comparable to other developed regions on the Norwegian Continental Shelf however there are additional factors to consider and account for in the design.

For this reason, a simple hazard identification (HAZID) workshop has been carried out to fully scrutinize this concept and complete a thorough assessment of the hazards and threats in developing such a concept as presented above. The following section presents generally the process followed for the HAZID as well as summarizes the findings before discussing the results and concluding the report.

4.3 Subsea Field Development in the Barents Sea HAZID

One of the most effective ways to ensure all Health, Safety, Environment and Quality related risks and hazards are identified and mitigations considered, is by conducting a hazard identification (HAZID) workshop. This can and is usually done at several stages of a development, commonly at the outset of a new venture and then again at sensible intervals (commonly during Front End Engineering Design and Execution). It is a technique for early identification of potential hazards and threats. This is then fed into various development decisions to eliminate, isolate, minimize or contain the effect of the hazard or threat. At such sessions, a minimum variety of participants are usually required, representing a range of different expertise, disciplines and development phases such as design, installation, operations and maintenance. This adds to the quality of the hazard identification workshop since different perspectives on the same hazards and threats are reviewed and a more dynamic discussion results.

A chairman or coordinator always facilitates such HAZID workshops and is in turn assisted by a secretary (this could be one of the participants but generally not). A senior engineer with vast experience in the HAZID process is commonly selected as a HAZID chairman. As for the participants, different companies have different requirements however the minimum should include a delegate with knowledge of the local legal requirements and regulations and an experienced Operator in addition to the core development team. This could include representative from drilling, well services, subsea engineering, vendor representatives, fabrication and construction, offshore installation, logistics and subject matter experts in specialized areas such as flow assurance or process engineering.

Now that the team is assembled and the relevant expertise are gathered, it is essential to complement their skills with the relevant drawings, documentation and procedures to allow the most efficient and effective use of their time. At the initial HAZID carried out at an early stage of the development (as for the example later in this report), little concrete information is available. High level data including basic information on the proposed location, exploration and production facilities, quality and extent of infrastructure and data from the area and not least, information about the local population (both human, flora and fauna) and past use of the area. During an opportunity realization, some financial figures of different development options would have been considered already during the concept select phase, which can also be beneficial to the discussion. Due to the immaturity of the information and the high likelihood that information will change, it is essential to record all assumptions to allow future HAZID workshops to start off where the previous one left off.

Shortly before the HAZID is held, Terms of Reference (ToR) are sent out to all participants along with the details of where, when and how long the HAZID will be held for. ToR will contain the objectives, goals and reference documents relevant to the HAZID and will specify a list of minimum required attendees without whom the session could not be fulfilled.

During the HAZID, the process is fairly straightforward. Keywords are used to stimulate the discussion and allow participants to share their experience and knowledge in raising potential hazards and threats associated to those keywords. Different sub-categories are listed under each keyword to ensure a more concentrated, specific and detailed analysis is carried out while avoiding high-level generic risks. An example of the process and associated keywords is presented below. This was similar to the process followed by the participants of *Working Group 6* of DNV's *Barents 2020* report (Eide, 2008 and Russian-Norwegian Cooperation Project, 2012), during a meeting held on the 18th-19th of May 2011 in Oslo:

1. Identify generic HAZARDS through use of generic keyword; the hazards represent failures or deviations that can impair the ice management function (e.g. wrong data interpretation) OR which can represent a direct hazard to personnel/environment/assets (e.g. collision between ice breaker and offshore unit).
    a) Typical keywords are:
        i) Technology
            - Equipment failure
            - [Using] equipment [incorrectly]
            - Wrong equipment used
            - etc.
        ii) Man
            - Not complying to procedures
            - Not right competence
            - Communication failure
            - etc.
        iii) Organization
            - Unclear roles / responsibilities
            - Wrong decisions / interpretations
            - Resources not available
            - etc.
2. Identify the causes that can lead to each HAZARD
3. Identify the consequences to personnel/environment/assets from the HAZARD (Cause)
4. Rate Impact and Frequency for the identified HAZARD, according to qualitative scale shown below
5. Suggest recommendations (if relevant)
6. Iterate until no more HAZARDS / Causes can be found for given phase
7. Move to next phase

Using this technique of hazard and threat identification, the opportunity of field development in the Barents Sea was assessed, along with *Grid Analysis*, for the purpose of identifying the most suitable and robust development solution for the region. Considering technologies previously used in similar physical conditions, as presented in Chapter 3, combining that with specific local considerations demonstrated in Chapter 2, engineering judgment is applied to recommend possible development solutions and identify technology gaps.

The HAZID was conducted in two ways: one was through brainstorming sessions and the other through group discussions. Several hazards, causes and effects were identified and classified along with the identification of mitigating actions that could reduce the consequence or likelihood of such hazards. The results of these sessions are summarized below with the full worksheet and an example of a bow-tie diagram presented in APPENDIX H.

The results of the HAZID show that there is a heightened focus on the effects of the physical environment where novel challenges are introduced that have not been seen before on the Norwegian Continental Shelf. Incidents such as the grounding of Kulluk at the end of 2012 and others show just how crucial it is to have double and possibly triple barriers when working in such harsh and sensitive environments. The other main event that trends within the HAZID is loss of containment. Due to the remoteness of the Arctic region and the fragile ecosystem in the area, hydrocarbon leaks are detrimental to the environment. Added attention is required when working in the Arctic since vaporization of hydrocarbon on the sea surface is greatly reduced and containment is almost impossible especially in areas where sea ice is present. This is due to the physical properties of hydrocarbons where a thin layer builds on the surface of the water and yet is mobile enough to lodge between the ice sheet and water surface. Not only does this cause contamination to the ice that is irrecoverable, it also propagates much farther and quicker compared to the open seas. Below are two bow ties that summarize the two most critical main events summarized below and the full HAZID table including hazards and events, threats, controls and barriers as well recommended mitigation actions is presented in Appendix H.

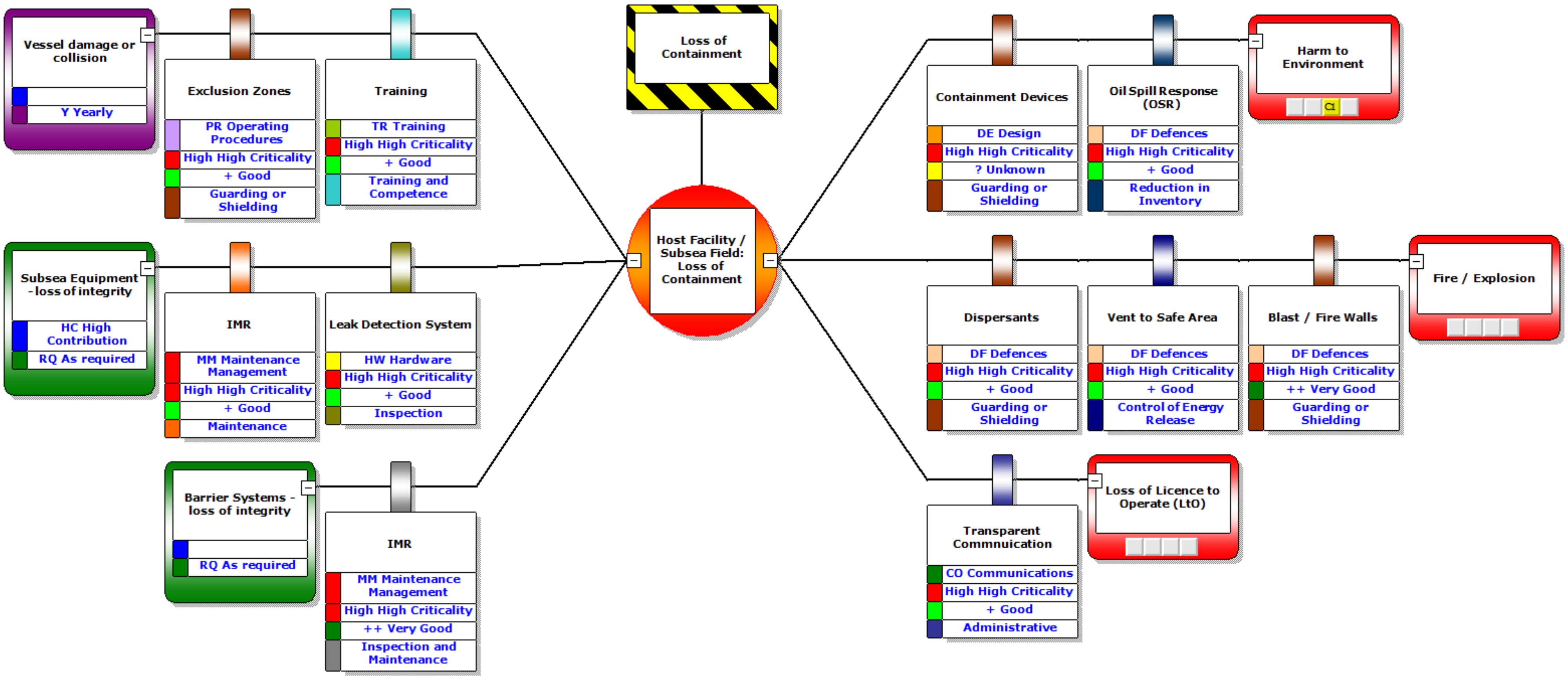


Figure 27. Bow Tie diagram for Main Event: "Loss of Containment" (developed using BowTieXP®)

5 Discussion

Going through the report, it is important to highlight limitations in some areas where the scope of the thesis has been limited. Initially, while setting the scene and presenting the local environment in the Barents Sea, the author has intended to keep the presentation brief due to several reasons. Primarily, this is a technical report that assesses the technical feasibility and associated risks of developing fields and prospects in the high north and Arctic regions of Norway. To ensure such a technical focus is maintained, the author has steered away from cluttering the reader's mind with information about local norms, environmental concerns and debates or socio-economical gains although this was to some degree part of the study. Future publications are planned that will address these topics in slightly more detail. Also, when setting the scene in section 2.2, the author focuses the attention of the reader on those challenges and threats that have received the least attention in the media and common sources of information even though most challenges are mentioned. This is to allow the reader to build a complete picture and develop their own "gut feeling", before starting to delve into development solutions and technology gaps. In the debates and discussions concerning Arctic challenges in the general media, cold climate, sea ice and iceberg concerns are most commonly mentioned since these instigate fear and enable writers to establish a nostalgic view of the Arctic. These in fact are not the only critical challenges as described by section 2.2, since some phenomena such as polar lows or the lack of data and navigation aids in the area, even though not as redolent, are considered to be even more challenging and foreign. However little effort has been made to address those and this is the main message the author attempts to communicate through the challenges section.

Secondly, when describing the development solutions, knowing the conservative nature of the oil and gas industry, the author has focused on presenting those technologies that have been tried and tested in harsh Arctic environments – back to the concept of best available and qualified technology. An additional touch of personal engineering judgment and critique was added to each of the solutions to highlight the limitations as well as the strengths of each of the solutions. As technology develops, this list of solutions will grow and more options will be available such as the semi-submersible solution Statoil are now proposing to use on the Johan Castberg development. The concept aims to tie back two subsea fields, one on each of Skrugard and Havis to a winterized semisubmersible host facility (. It is the author's view that this is a high-risk undertaking for several reasons including those mentioned in the results of the Grid Analysis and HAZID as well as that semi-submersible installation have had bad track record in harsh climates as in The Ocean Ranger, La Chispa and Thunder Horse amongst others.

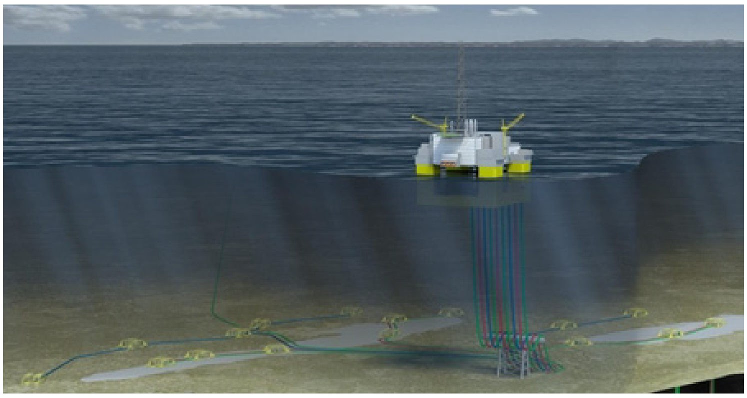


Figure 28. Johan Castberg Concept Selection (Marshall, 2013)

There is no better example to highlight the conservativeness and meticulous approach of the oil and gas industry as a whole as Klif's (Norway's Climate and Pollution Agency) reaction to Statoil's concept selection of the Johan Castberg field development solution. Klif has "urged" Statoil to go back to the drawing board and re-assess their concept in light of all the imminent challenges experienced in the Barents Sea and have highlighted that no contract shall be awarded prior to parliamentary approval (Marshall, 2013).

Finally, it is recommended that further work be carried out to further identify gaps between where the various subsea technologies have come to today and what is required to be able to safely deploy such kit in the high north and Arctic regions in more detail. This report presents both the current technology levels as well as possible development solutions in the future without dissecting technology gaps and attempting to develop solutions. Such areas of further work might include and are not limited to investigation of the following:

- **AUV technology** and how it may enable "subsea-to-near-shore" developments where the subsea field is located deep within the Arctic region beneath ice cover, icebergs, storms and sub-zero temperatures, the well stream is separated for the produced water to be reinjected and valuable liquids transported back via a pipeline to an accessible, safe zone free from ice, icebergs and other severe risks. There subsea-loading systems may be used to allow tankers to connect and export the oil. The has phase on the other hand would undergo subsea compression and transported back to shore with the possibility of a subsea recompression station for long distance tie backs such as Shtokman, the field located 600 km off the coast of Kola Peninsula in the Pechora Sea and holds an estimated 3.8 terra cubic meters (130 tcf) of gas (one of the world's largest gas fields) and 37 million tons of condensate. To develop such a field, one of the main challenges will be accessing it for well intervention / IMR (inspection maintenance and repair) during the spring, autumn and winter seasons. Here is where AUV technology will come in with longer range and more capability.
- **Long reach controls** will be another limitation where current technology is already being severely challenged with how much automation and control scope can be achieved over a 150km tie back distance. If the aim is to develop remote Arctic fields located some 500-600km offshore and controlling them remotely to avoid the high-risk environment the fields are located in, then more robust, flexible and efficient technologies will be necessary. Hydraulic control of valves and instruments subsea is a 1960s technology that has not developed much since then. Hydraulic fluids have become more environmentally friendly and are less elastic however the concept of using hydraulic fluids needs a step change in the right direction. Cameron Engineering have begun developing such concepts where they have produced the world's first all-electric X-mas tree and deployed in 2008 on Total's K5F gas field in the Dutch sector of the North Sea (Total website).

6 Conclusion

The debate surrounding Arctic exploration and development and the controversial question: “need or greed?” has been a hot topic now for several years and seems to continue. On one hand, the global demand for resources is increasing, people’s lifestyles are becoming more dependent on hydrocarbon-based products whether in the form of fuels, plastics or synthetic materials, and on the other hand supply is rapidly diminishing from currently developed fields; so what is the answer to this dilemma?

As this report has demonstrated through bringing together various sources of information and offering engineering judgement and risk analysis, it is evident that existing fields need to be further developed to maximize ultimate recovery as well as the dire need to find resources in unexplored parts of the world. One such area is the high north and Arctic regions of the world, where it is estimated that 30% of the world’s gas reserves and 13% of the world’s oil reserves still lie untouched.

The author’s contribution to the theme of field development in the Norwegian high north and Arctic is summarized in the following points:

1. Compilation of data about physical environment in the region and comparison with other regions where oil and gas fields have been developed to identify suitable development solutions that may be implemented to ensure safe and effective production
2. Compilation of a wide range of resources, never compiled in such a way previously, about what available and qualified technologies have been used in similar environments to the Norwegian high north as per point 1
3. Engineering judgment and critique of the solutions as per point 2 on their applicability, suitability and limitations taking the Norwegian high north scenario into perspective
4. Gap analysis of where the current technology is, and where it needs to develop to enable safe and effective production in the region
5. Grid Analysis to summarize the findings of points 2 and 4 and identify the most suitable, available and qualified technology to develop a Johan Castberg-type development
6. Conduct detailed HAZID to capture all the threats, hazards and mitigations associated with field development in the high north for the solution identified in point 5

So in conclusion, it can be seen that there have been in fact fields developed in regions where some parameters are harsher than the southern and central Barents Sea. For example, as per Table 2, it can be seen that sea states in the Norwegian Sea are generally higher with longer wave periods; sea ice extent and concentration is much higher off Sakhalin Island compared to the southern Barents Sea; iceberg risk is much higher and consequences much more extreme in the Grand Banks due to shallow waters and high frequency of iceberg sightings. However, the combination of high sea states, sea ice risk in open seas as well as in ice sheets, extreme cold temperatures, field remoteness, lack of infrastructure and data, limitation of navigational aids, polar low-pressure storms, fog and all other factors mentioned in section 2.2, make the development of fields such as Johan Castberg and Shtokman the most challenging the industry has seen to date. And even tough these fields are located in such challenging locations they hold great promise for large commercial production and an answer to the world’s growing energy demands. It is the author’s view however, that development in the Norwegian high north and Arctic should not commence until all risks are clearly understood and thorough mitigations are put in place. In the author’s view, one of the first steps towards better understanding this region is to install more data gathering stations, meteorological stations and satellites to obtain more accurate data. A suggestion made by Hovland and Gudmestad is to place radars aboard vessels and platforms (Hovland and Gudmestad, 2006), which would reduce uncertainty of forecasts and offer longer warning durations before "weather hits". It is also wise for international standardization organization such as ISO, API and DNV to commence on writing specific "Arctic" inclined guidelines, which can be developed during early design and qualification testing phases in conjunction with the oil and gas majors and service companies.

A more thorough understanding of the environmental impact is also necessary. Although the environmental impact was not discussed in much detail in this report, there are severe environmental impacts on fragile wildlife, marine life and possible effects towards global warming.

7 Bibliography

Abramov, V.A., 1992. Russian Iceberg Observations in the Barents Sea, 1933-1990. Norsk Polarinstitutt, Polar Research, vol. 11 (2), pp.93–97.

Aggarwal, R. and Souza, R.D., 2011. Deepwater Arctic - Technical Challenges and Solutions. In: Arctic Technology Conference, paper no. OTC22155. Houston, USA. February 7-9th, 2011.

Allen, S., 2011. 10 Years of Sub Arctic Subsea Projects – Stepping Stones for Arctic Development. In: Arctic Technology Conference, paper no. OTC22115. Houston, USA. February 7-9th, 2011.

American Petroleum Institute, 2009. Recommended Practice for Coiled Tubing Well Control Equipment Systems, (API RP 16ST).

American Petroleum Institute, 2006. Recommended Practice for Completion / Workover Risers, (ANSI/API RP 17G, ISO 13628-7:2005).

American Petroleum Institute, 2012. Recommended Practice for Flexible Pipe, (ANSI/API RP 17B, ISO13628-11:2007).

American Petroleum Institute, 2010. Recommended Practice for Marine Operations, (ANSI/API RP 2MOP, ISO19901-6:2009).

American Petroleum Institute, 2005. Recommended Practice for Measurement of Multiphase Flow, (API RP 86).

American Petroleum Institute, 2012. Recommended Practice for Subsea High Integrity Pressure Protection Systems (HIPPS), (API RP 17O).

American Petroleum Institute, 2002. Recommended Practice on TFL (Through Flowline) Systems, (ANSI/API RP 17C).

American Petroleum Institute, 2004. Remotely Operated Vehicle (ROV) Interfaces on Subsea Production Systems, (ANSI/API Recommended Practice 17H, ISO 13628-8:2002).

American Petroleum Institute, 2008. Risk-Based Inspection Technology, (API RP 581).

Anda, I., 2004. Light Well Intervention provides the potential for increased safety and recovery. [online] Available at: http://www.ptil.no/news/ligh-well-intervention-provides-the-potential-for-increased-safety-and-recovery-article1275-79.html [Accessed March 11, 2012].

Apeland, S., Aarhus, B. and Rossebø, Ø.H., 2012. Gassco (Norwegian Contintential Shelf) NCS2020: En studie av fremtidens gassinfrastruktur. DMS Document No. 065136 (Norwegian)

Berg, T.E., Berge, B.O., Hänninen, S., Suojanen, R. and Borgen, H., 2011. Design Considerations for an Arctic Intervention Vessel. In: Arctic Technology Conference, paper no. OTC22078. Houston, USA. February 7-9th, 2011.

Bergen Tanker Brokers, n.d. MT Xanthia. [image online] Available at: http://www.btb.no/index.php?n=20 [Accessed November 8, 2012]

Billingham, L., 2006. Autonomous Underwater Vehicles: The commercial application of the technology to future subsea fields. In: Advances in Technology for Underwater Vehicles (ATUV) at the World Maritime Technology Conference (WMTC). London, UK. March 6-10th, 2006.

Bird, K.J., Charpentier, Ronald R., Gautier, D.L., Houseknecht, D.W., Klett, T.R., Pitman, J.K., Moore, T.E., Schenk, C.J., Tennyson, M.E. and Wandrey, C.J., 2008. USGS Arctic Oil and Gas Report, US Geological Survey. Available at: http://pubs.usgs.gov/fs/2008/3049/fs2008-3049.pdf [Accessed May 14, 2012].

Bjørn Rasen, 2009. Facing up to a subsea future. [online] Available at: http://www.npd.no/en/Publications/Norwegian-Continental-Shelf/No3-20091/Facing-up-to-a-subsea-future [Accessed March 11, 2012].

Blanchet, D., O'Connor, P., Kovalsky, K., Nyborg, A. and Munkeby, J., 1999. Comparison Between Hibernia and the West Bonne Bay Concrete Gravity-Based Structure Concept. In: Offshore Technology Conference, paper no. OTC11022. Houston, USA. May 3-6th, 1999.

Botros, F., Noel, C., Brookes, D. and Perry, R., 2008. BP's Subsea Developments: Past Successes and Future Challenges. In: Indian Oil and Gas Technical Conference and Exhibition, paper no. SPE113652. Mumbai, India. March 4-6th, 2008.

Braden, A., Manikian, V., Rice, D., Swank, G., Hinnah, D., Monkelien, K. and Walker, J., 1998. First Arctic Subsea Pipelines Moving to Reality. In: Offshore Technology Conference, paper no. OTC8717. Houston, USA. May 4-7th, 1998.

Brekne, T.M., Holmemo, S. & Skeie, G.M., 2004. Preparing for Improved Near Shore and Arctic Oil Spill Response. Full Scale Testing of Equipment Developed in the NOFO R&D Programme. In: Society of Petroleum Engineers International Conference on Health, Safety and the Environment in Oil and Gas Exploration and Production, paper no. SPE86765. Alberta, Canada. March 29-31st, 2004.

Bulakh, M., Zolotukhin, A.B. and Gudmestad, O.T., 2011. Potential For Oil And Gas Projects In The New Oil And Gas Province Shared Between Russia And Norway. In: SPE Arctic and Extreme Environments Conference & Exhibition, paper no. SPE149654. Moscow, Russia. October 18-20th, 2011.

Canatec Associates International Ltd, 2004. SALM Offshore Sakhalin Island, December 16 2004. [image online] Available at: http://www.canatec.ca/wp-content/uploads/2011/06/Sakhalin-offshore_SALM_Fall-2004_2004-12-16.jpg [Accessed March, 2012]

Canatec Associates International Ltd, 2013. Past Projects – where we work. [online] Available at: http://www.canatec.ca/index.php/the-company/past-ice-projects/ [Accessed March, 2012]

Crocker, G., Wright, B., Thistle, S., and Bruneau, S. 1998. An Assessment of Current Iceberg Management Capabilities. Contract Report for: National Research Council Canada, Prepared by C-CORE and B. Wright and Associates Ltd., C-CORE Publication 98-C26.

Curtino, J., Ouaguennouni, M., Judd, T. and Al Habsi, A., 2012. Design, Application, and Implementation of Well Intervention Services within a Deep HP/HT Tight Gas Exploration and Appraisal Project. In: SPE Middle East Unconventional Gas Conference and Exhibition, paper no. SPE152458. Abu Dhabi, UAE. 23-25th of January, 2012.

Curtis, M.I. and Huxley, D.B., 1987. Endicott Development - Making the Arctic Offshore Economical. In: 12th World Petroleum Congress, paper no. 22208. Houston, USA. April 26-May 1st, 1987.

Det Norske Veritas, 2010. Environmental Conditions and Environmental Loads, (DNV-RP-C205).

DNV, 2012a. Baseline Surveys at Havis, Skrugard appraisal and Ensis 2011. [online] Available at: http://www.klif.no/publikasjoner/offshore/grunnlag/IX_X_havis_skrugard_ensis_2011.pdf [Accessed November, 2012]

DNV, 2012b. Visual Baseline Surveys in the Barents Sea, 2011. [online] Available at: http://www.klif.no/publikasjoner/offshore/grunnlag/ix-x-barentshavet_2011.pdf [Accessed November, 2012]

Dolby, I., 2007.The Lunskoya A – The newish Production Platform of the Sakhalin II project, Offshore Russia! taken in December as the ice starts to seriously build up all around. [image online] Available at: http://www.oilrig-photos.com/picture/number260.asp [Accessed March 11, 2012].

Doyle, T. and Leitch, J., 2000. Terra Nova Vessel Design and Construction. In: Offshore Technology Conference, paper no. OTC11920. Houston, USA. May 1-4th, 2000.

Duguid, A. and McBeth, R., 2000. Drake F-76, In Situ Abandonment of a High Arctic Offshore Completion and Facilities. Journal of Canadian Petroleum Technology, vol. 39 (5), pp. 33–40.

Edmond, C., Liferov, P. and Metge, M., 2011. Ice and Iceberg Management Plans for Shtokman Field. In: Arctic Technology Conference, paper no. OTC22103. Houston, USA. February 7-9th, 2011.

Eide, L.I., 2008. Barents 2020: Phase 1 – Establish Norwegian Baseline on HSE Standards, Ice and Metaocean (Maritime & Offshore). For the Norwegian Ministry of Foreign Affairs by DNV (Report No. 2008-0664)

Endrerud, O.E., 2011. Winterization of production platforms for arctic conditions operations. In: Arctic Frontiers - "Lomonosov, Nansen, and beyond" Seminar and Workshop. Arkhangelsk, Russia. November 15th, 2011.

Eni Norge, 2013. The Development Concept. [online] Available at: http://www.eninorge.com/en/Field-development/Goliat/Development-solution/ [Accessed March, 2013]

Erlandsen, J., 2010. Vega Subsea Development: a high pressure & high temperature challenge. Presented In: 16th Underwater Technology Conference. Bergen, Norway. September 22-23rd, 2010.

European Committee for Standardization, 2005. Petroleum and natural gas industries — Design and operation of subsea production systems, (BS EN ISO 13628-1:2005+A1:2010).

European Space Agency, 2011. 2012 International Workshop on Polar Lows. [image online] 14th of July, 2011. Available at: http://due.esrin.esa.int/stse/news/stse_inews.php?id=192&idf [Accessed March, 2012]

Fardy, K.J. and Singeetham, S.P., 1988. Application of a Modified Subsea Wellhead System on Molikpaq, a Mobil Arctic Caisson Rig in the Canadian Beaufort Sea. In Offshore Technology Conference, paper no. OTC5790. Houston, USA. May 2-5th, 1988.

Fiddler, C.D., Hancock, J.A. and Hudson, T.A., 1978. Offshore Arctic Technology Research and Development Projects. In: American Petroleum Institute Annual Meeting Papers, Division of Production, paper no. 78-A001. Denver, Colorado. April 2-5th, 1978.

Fugro, 2005. Regional Reference: Barents Sea. http:\\www.oceanor.com

GAZPROM, 2011. Prirazlomnaya platform is towed out to sea from Murmansk on Aug.18, 2011. [image online] Available at: http://www.thestar.com/news/world/2011/12/17/russia_blasting_into_fragile_arctic_in_search_of_oil.html [Accessed March, 2012]

Gill, P. 2003. Sakhalin Oil and Gas Projects: Sakhalin island looks to boost its feasibility. The Russian Journal. Available at: http://www.users.uswest.net/~kryopak/RussianSakhalin.htm [Accessed March, 2012]

Grini, P.G., 2009. Subsea to beach solutions; StatoilHydro technology advances. In: INTSOK Conference 19-20th of March, 2009. Veracruz, Mexico, unpublished. Available at: http://www.intsok.com/style/downloads/Statoi-PDF-2--StatoilHydro-tech.pdf [Accessed March, 2012]

Google Earth Oljedirektoratet Application, 2011. Available at: http://www.npd.no/no/Kart/Fakta-i-Google-Earth/ [Accessed March, 2012]

Gu, M. and Gudmestad, O.T., 2011. Uncertainties, risks, and opportunities in development of hydrocarbon fields. In: 30th International Conference on Ocean, Offshore and Arctic Engineering OMAE, paper no. OMAE2011-49183. Rotterdam, The Netherlands. June 19-24th, 2011.

Gudmestad, O.T. and Løset, S., 2004. Key Considerations in the Design of Offshore Production Facilities for Arctic Offshore Conditions. In: 17th International Symposium on Ice, International Association of Hydraulic Engineering and Research. Saint Petersburg, Russia. June 21-25th, 2004.

Gudmestad, O.T., 2012a. A Risk Analytical Approach to Key Technology Challenges in Arctic Field Developments. Presentation to Norwegian Oil and Gas Operators. University of Stavanger, unpublished

Gudmestad, O.T., 2012b. Construction and Installation Challenges. Presented In: The 8th Annual Arctic Oil and Gas Conference. Oslo, Norway. October 4-5th, 2012

Gudmestad, O.T., 2012c. How to Reduce the Probability of Oil Spills in Arctic Operations and Mitigating Measures to Reduce Consequences of Potential Spills. Presented In: Oil Spill and Ice Management in Arctic Operations. Amsterdam, Netherlands. September 12-14th, 2012.

Gudmestad, O.T., 2012d. New trends in Subsea Developments. Presented In: PETRAD Conference. Baku, Azerbaijan. October 17th, 2012.

Gudmestad, O.T., 2012e. Understanding the key Technological Challenges and how Technology may help in Unlocking Arctic Resources. Presented In: Arctic Oil and Gas Conference. St John’s, Canada. May 23-24th, 2012.

Gudmestad, O.T. and Karunakaran, D., 2012a. Challenges Faced by the Marine Contractors Working in Western and Southern Barents Sea. In Arctic Technology Conference, paper no. OTC23842. Houston, USA. December 3-5th, 2012.

Gudmestad, O.T. and Karunakaran, D., 2012b. Planning for construction work in cold climate regions. In 31st International Conference on Ocean, Offshore and Arctic Engineering (OMAE), paper no. OMAE2012-83301. Rio de Janeiro, Brazil. July 1-5th, 2012.

Gudmestad, O.T. and Quale, C., 2011. Technology and Operational Challenges for the High North. Report for Petroleum Safety Authority, Norway. ISBN 978-82-490-0730-1. Stavanger, Norway.

Gudmestad, O.T. and Strass, P., 1994. Technological Challenges for Hydrocarbons Production in the Barents Sea. Journal of Hydrotechnical Construction, vol. 28 (8), pp.29–34.

Haugen, E., Costello, J., Wilcox, L., Albrechtsons, E. and Kelly, I., 2007. Reservoir Management Challenges of the Terra Nova Offshore Field: Lessons Learned After Five Years of Production. In: Society of Petroleum Engineers Annual Technical Conference and Exhibition, paper no. SPE109587. Anaheim, California. November 11-14th, 2007.

Headworth, C. and Cowan, P., 1989. Advances in Riserless Intervention for Subsea Well Servicing. Advances in Underwater Technology and Offshore Engineering. Second Generation Subsea Production Systems, vol. 20 (11), pp.11–19.

Henery, D. and Inglis, R.B., 1995. Prospects and Challenges for the FPSO. In: Offshore Technology Conference, paper no. OTC7695. Houston, USA. May 1-4th, 1995.

Hibernia, n.d.a. About Hibernia. [online] Available at: http://www.hibernia.ca/about.html [Accessed May, 2012]

Hibernia, n.d.b. Ice Management. [online] Available at: http://www.hibernia.ca/ice.html [Accessed March, 2012]

Hibernia, 1997. The absence of the flare indicates that this photo of the Hibernia platform was taken before First Oil in Novemeber 1997. [image online] Available at: http://www.hibernia.ca/gallery/thumbs/p13_platform.jpg [Accessed March, 2012]

Hibernia Management and Development Company Limited, 2008. Hibernia Drill Centres Construction and Operations Program – Project Description. St John's, Canada. Available at: http://www.cnlopb.nl.ca/pdfs/hibdrill/hibprojectdesc.pdf [Accessed March 14, 2012]

Hjermann, B.K., 2004. Fram Vest project - Subsea tie-back to a floating production unit. In: Offshore Technology Conference, paper no. OTC16532. Houston, USA. May 3-6th, 2004.

Holgate, M.J.M., Davies, G.J. and Meyer, T. De, 2000. Assessing Risk in the Selection of Drilling and Production Concepts in the Caspian. In: Society of Petroleum Engineers International Conference on Health, Safety and the Environment in Oil and Gas Exploration and Production, paper no. SPE61226. Stavanger, Norway. June 26-28th, 2000.

Hovland, E. and Gudmestad, O.T., 2006. Vessels for Subsea Intervention in the Arctic - from Field Development to Inspection, Maintenance and Repair. In: International Conference and Exhibition on Performance of Ships and Structures in Ice, paper no. ICETECH06-101-R0. Banf, Canada. July 16-19th, 2006.

International Energy Agency, 2005. World Energy Outlook – Middle East and North Africa Insights. France: International Energy Agency. ISBN 92-64-1094-98-2005

International Organization for Standardization, 1999. Design and Operation of Subsea Production Systems - Part 1: General Requirements and Recommendation, (ISO 13628-1).

International Organization for Standardization, 2010. Petroleum and natural gas industries -- Arctic offshore structures, (ISO 19906:2010).

ITAR-TASS, 2011. Prirazlomnaya sea platform to be delivered to offshore oil field. ITAR-TASS News Agency, [online] 26th of August, 2011. Available at: http://www.itar-tass.com/en/c154/212479.html [Accessed March, 2012]

Jacobsen, L.R., 1971. Submarine Transport of Arctic Oil. In: Society of Petroleum Engineers Annual Technical Meeting, paper no. 7620. Banff, Canada. June 2-5th, 1971.

Jacobsen, S.R. and Gudmestad, O.T., 2012. Evacuation from Petroleum Facilities Operating in the Barents Sea. In: Offshore and Arctic Engineering (OMAE), paper no. OMAE2012-83329. Rio de Janeiro, Brazil. July 1-5th, 2012.

Jacques Whitford Ltd., 2009. Screening Report - Hibernia Drill Centres Construction and Operations Program. Report to Hibernia Management and Development Company, report no. 1042664.01. St John's, Canada. Available at: http://www.cnlopb.nl.ca/pdfs/hibdrill/hibeareportfinal.pdf [Accessed August, 2012]

Jenkins, C.D. and Boyer, C.M. 2008. Coalbed- and Shale-Gas Reservoirs. Journal of Petroleum Technology, Distinguished Authors Series, SPE103514.

Jordaan, I. and Pond, J., 2001. Scale Effects and Randomness in the estimation of compressive ice loads. Published in IUTAM Symposium on Scaling Laws in Ice Mechanics and Ice Dynamics, vol. 94. Netherlands: Springer.

Jøssang, S.N., Friedberg, R., Buset, P. and Gramstad, B., 2008. Present and Future Well Intervention on Subsea Wells. In: International Association of Drilling Contractors/SPE Drilling Conference, paper no. IADC/SPE 112661. Florida, USA. March 4-6th, 2008.

Kendall, L.S., 2010. Construction Impacts on the Cook Inlet Beluga Whale (Delphinapterus leucas) at the Port of Anchorage Marine Terminal Redevelopment Project. Master of Science in Environmental Science at

Alaska Pacific University. Available at: http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/theses/kendall_cibeluga.pdf

Klo, A., 2006. "Narve" i Finnmark. Finnmark Dagblad, [image online] 24.01.2006. Available at: http://www.finnmarkdagblad.no/bildeserier_fd/article1920428.ece?start=39 [Accessed November, 2012]

Kvingedal, B., 2005. Sea-Ice Extent and Variability in the Nordic Seas, 1967—2002; The Nordic Seas: An Integrated Perspective (editors Drange, H., Dokken, T., Furevik, T., Gerdes, R. and Berger, W.), American Geophysical Union. Washington, D. C., USA. DOI:10.1029/158GM04

Kvitrud, A., 1991. Environmental Conditions in the Southern Barents Sea. Available at: http://home.online.no/~akvitrud/Environmental-condtions-Barents-Sea.htm [Accessed March, 2012]

Lanan, G.A., Cowin, T.G., Hazen, B., Maguire, D.H., Hall, J.D. and Perry, C., 2008. Oooguruk Offshore Arctic Flowline Design and Construction. In: Offshore Technology Conference, paper no. OTC19353. Houston, USA. May 5-8th, 2008.

Lange, F., Zandwijk, K.V. and Graaf, J.V.D., 2011. Offshore Pipeline Installation in Arctic Environment. In: Society of Petroleum Engineers Arctic and Extreme Environments Conference & Exhibition, paper no. SPE149581. Moscow, Russia. October 18-20th, 2011.

Le Marechal, G., Anslot, P., Mravak, Z., Liferov, P. and Le Guennec, S., 2011. Design of a Floating Platform Hull for Arctic Conditions in the Barents Sea. In: Arctic Technology Conference, paper no. OTC22161. Houston, USA. February 7-9th, 2011.

Long, P.E., Wurstner, S.K., Sullivan, E.C., Schaef, H.T. and Bradley, D.J., 2008. Preliminary Geospatial Analysis of Arctic Ocean Hydrocarbon Resources. Report for the U.S. Department of Energy, report no. PNNL-17922. Oak Ridge, Tennese.

Løset, S., Shkhinek, K., Gudmestad, O.T., Strass, P., Michalenko, E., Frederkin, R. and Kärnä, T., 1999. Comparison of the Physical Environment of some Arctic Seas. Cold Regions Science and Technology, vol. 29 (3), pp. 201–214.

Løset, S., 1987a. Ice Accreted on K/V Nordkapp, 26-27 February, 1987. [photograph] Retrieved through lecture notes 'Operations in Cold Climate' by Gudmestad, O.T. for University of Stavanger and Norwegian University of Science and Technology (NTNU)

Løset, S., 1987b. Starboard side and railing of K/V Nordkapp, 26-27 February, 1987. [photograph] Retrieved through lecture notes 'Operations in Cold Climate' by Gudmestad, O.T. for University of Stavanger and Norwegian University of Science and Technology (NTNU)

Løset, S., 1987c. Iced up lifeboat K/V Nordkapp, 26-27 February, 1987. [photograph] Retrieved through lecture notes 'Operations in Cold Climate' by Gudmestad, O.T. for University of Stavanger and Norwegian University of Science and Technology (NTNU)

Løset, S., 1995. Science and Technology for Exploitation of Oil and Gas - an Environmental Challenge. In: European Networking Conference on Research in the North. Svalbard, Norway. September 12-16th, 1995.

Løset, S., 2011a. Schematic Cross Section – Beaudrill Molikpaq from Global and Local Ice Loads lecture, AT-327 Arctic Offshore Engineering. University Centre in Svalbard, unpublished.

Løset, S., 2011b. Sea surface currents – BS [Barents Sea]. [image] Retrieved through lecture notes 'Icebergs in the Barents Sea' by Løset, S. for Norwegian University of Science and Technology (NTNU)

Løset, S., 2011c. Analysis of Buoy Drift Data. [image] Retrieved through lecture notes 'Arctic Offshore Challenges' for Arctic Technology AT-327 by Løset, S. for University Centre of Svalbard (UNIS)

Løset, S. and Carstens, T., 1996. Sea Ice and Iceberg Observations in the Western Barents Sea in 1987. Cold Regions Science and Technology, vol. 24 (4), pp. 323–340.

Løset, S., Jensen, A. and Ravndal, O., 2000. Submerged Turret Loading of Oil in Ice. In: APL Technology Conference. Arendal, Norway. July 25-27th, 2000.

Marr, J.G., Elverhøi, A., Harbitz, C., Imran, J. and Harff, P., 2002. Numerical simulation of mud-rich subaqueous debris flows on the glacially active margins of the Svalbard-Barents Sea. International Journal of Marine Geology, Geochemistry and Geophysics, vol. 188 (3-4), pp. 351–364.

Marshall, S., 2013. Statoil 'jumping gun' on Johan Castberg, [online] Available at: http://www.upstreamonline.com/epaper/article1327186.ece [Accessed June, 2013]

Matishov, G., Golubeva, N., Titova, G., Sydnes, A. and Voegele, B., 2004. Global International Water Assessment - Barents Sea, GIWA Regional Assessment 11. Kalmar: University of Kalmar on behalf of United Nations Environment Programme

Matskevitch, D.G., 2007. Technologies for Arctic Offshore Exploration and Development. In: SPE Russian Oil and Gas Technical Conference and Exhibition, paper no.SPE102441. Moscow, Russia. October 3-6th, 2007

McGennis, E., 2001. Subsea Tree Changeout with a Light Subsea-Well-Intervention Vessel. In: Offshore Technology Conference, paper no. OTC12945. Houston, USA. April 30-May 3, 2001.

Medved, S. and Nedelin, A., 1993. Underwater Equipment for Developing of Deepwater Gas Deposits. Armament and Equipment (Tekhnika i Vooruzhenie), [online] Available at: http://lib.rus.ec/b/328566/read [Accessed March, 2012] (Translated)

Meteorological Service of Canada, 2002. Vessel Icing. [image online] Available at: http://www.qc.ec.gc.ca/meteo/secrets_stlaurent/vessel_icing_e.htm [Accessed March, 2012]

Ministry of Foreign Affairs, 2012. The High North. [image online] Available at: http://www.regjeringen.no/en/dep/ud/documents/propositions-and-reports/reports-to-the-storting/2011-2012/meld-st-7-20112012-2/12.html?id=697783 [Accessed May 18th, 2013]

Moreira, O.M., 2004. Installation of the World's First All-Electric Intelligent Completion System in a Deepwater Well. In: SPE Annual Technical Conference and Exhibition, paper no. SPE90472. Houston, USA. September 26-29, 2004.

Randell, C., Morgan, V. and Ralph, F., 2008. Protection and Risk Mitigation Strategies for Subsea Infrastructure in Ice Environments. In: Offshore Technology Conference, paper no. OTC19272. Houston, USA. May 5-8th, 2008.

Smedal, A., and Syvertsen, K., 1995. STL, A New Approach to Field Development. In: Offshore Technology Conference, paper no. 7912. Houston, USA. May 1-4th, 1995

Munkerud, P.K. and Inderberg, O., 2007. Riserless Light Well Intervention (RLWI). In: Offshore Technology Conference, paper no. OTC18746. Houston, USA. April 30th-May 3rd, 2007.

National Petroleum Directorate (NPD), 2009. Why do we not recover 100 per cent of the oil? [online] Available at: http://www.npd.no/en/Topics/Improved-Recovery/Temaartikler/Why-do-we-not-recover-100-per-cent-of-the-oil/ [Accessed May, 2012]

NAVEDTRA, 2001. Aerographer's Mate – Module 5: Basic Meteorology. [online] Naval Education and Training Professional Development and Technology Center, report no. NAVEDTRA 14132. Available at: http://www.hnsa.org/doc/pdf/aerographer5.pdf [Accessed March, 2012]

Niini, M., Kaganov, S. and Tustin, R.D., 2007. Development of Arctic double acting shuttle tankers for the Prirazlomnoye project. In: TSFC 2007 Shipbuilders Meeting. Available at: http://www.krs.co.kr/kor/file/ppt/12Shuttle%20Tankers.PDF [Accessed May, 2012]

Njå, O. and Gudmestad, O.T., 2012. Disasters in Arctic Areas. In: 4th International Disaster and Risk Conference IDRC. Davos, Switzerland. August 26-30th, 2012. Available at: http://idrc.info/userfiles/file/IDRC%20Davos%202012/IDRCDavos2012-ExtendedAbstracts_v100.pdf, pp. 523-526.

Norwegian Petroleum Directorate (NPD), 2011. Subsea wells produce most. [online] Available at: http://www.npd.no/en/news/News/2011/Subsea-wells-produce-most [Accessed March 11, 2012].

Offshore Technology, n.d.. Prirazlomnoye Oilfield -, Russian Federation. [online] Available at: http://www.offshore-technology.com/projects/prirazlomnoye [Accessed February, 2012]

OG21, 2006. Technology Strategy for Subsea Processing and Transport. Report by Technology Target Areas (TTA6) Lead by Statoil. [online] Available at: http://www.forskningsradet.no/servlet/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobheadername1=Content-Disposition%3A&blobheadervalue1=+attachment%3B+filename%3DTTA6.pdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1274460323241&ssbinary=true [Accessed May, 2012]

Okstad, K.A., 2012. EkstremArbeid. Magasin fra Universitetet i Stavanger, nr. 3, 2012 [online] Available at: http://issuu.com/univers/docs/univers_nr._3_-_2012, pp. 4-6. [Accessed November, 2012]

Paulsen, J.E., Hoset, H., Rørhuus, T., Larsen, V., Alm, D., Birkeland, Ø. and Marker, R., 2005. Exploration Drilling in the Barents Sea; Prevailing Zero Discharge Regime, Challenges and Learning From Recent Exploration Drilling. In: Society of Petroleum Engineers Asia Pacific Health, Safety and Environment Conference and Exhibition, paper no. SPE96507. Kuala Lumpur, Malaysia. September 19-20th, 2005.

Petroleum Safety Authority, 2006. Well Integrity Challenges on the NCS. [online] Available at: http://www.ptil.no/well-integrity/well-integrity-challenges-on-the-ncs-article4155-145.html [Accessed March 11, 2012].

Pilisi, N., Maes, M. and Lewis, D.B., 2011. Deepwater Drilling for Arctic Oil and Gas Resources Development: A Conceptual Study in the Beaufort Sea. In: Offshore Technology Conference, paper no. OTC22092. Houston, USA. February 7-9th, 2011.

Pipelines International, 2010. Constructing Sakhalin Island's pipeline network. [image online] Available at: http://pipelinesinternational.com/news/constructing_sakhalin_islands_pipeline_network/040185/# [Accessed March, 2012]

Polar View, 2011. Sea Ice Monitoring. [image online] Available at: http://www.polarview.org/services/simf.htm [Accessed March, 2012]

Ralph, F., King, T. and Zakeri, A., 2011. Alternative Concepts to Gloryholes for Protection of Subsea Infrastructure in Ice Prone Regions. In: Offshore Technology Conference, paper no. OTC22137. Houston, USA. February 7-9th, 2011.

Reeves, R.R., Brownell, R.L., Burdin, A., Cooke, J.C., Darling, J.D., Donovan, G.P., Gulland, F.M.D., Moore, S.E., Nowacek, D.P., Ragen, T.J., Steiner, R.G., VanBlaricom, G.R., Vedenev, A., Yablakov, A.V., 2005. Report of the Independent Scientific Review Panel on the Impacts of Sakhalin II Phase 2 on Western North Pacific Gray Whales and Related Biodiversity – Chapter 3: Western Gray Whale Environmental Impact Assessment. IUCN, Gland, Switzerland and Cambridge, UK.

Reyerson, C.C. and Gow, A.J., 2000. Ship Superstructure Icing: Crystalline and Physical Properties. Cold Regions Research and Engineering Laboratory Technical Report no. ERDC/CRREL TR-00-01. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA381910 [Accessed March, 2012]

Reyes, A.R. and Arias, J.L., 2004. Challenges and Solutions for Installing an Intelligent Completion in Offshore Deepwater Brazil. In: Rio Oil and Gas Expo and Conference, paper no. IBP213-04. Rio de Janeiro, Brazil. October 4-7th, 2004.

Russian-Norwegian Cooperation Project, 2012. Assessment of International Standards for Safe Exploration, Production and Transportation of Oil and Gas in the Barents Sea. DNV Report No. 2012-0690. Available at: http://www.dnv.com/binaries/barents_2020_report_phase_4_tcm4-519595.pdf [Accessed Dec, 2012]

Sandven, S., Pettersson, L.H. and Volkov, V., 2006. Observation and Modelling of the Arctic Marine Environment. In: Second Norway-Russia Arctic Offshore Workshop. University of Stavanger, Stavanger, Norway. August 19th, 2006. Available at: http://sbbu.no/Internet/akva.nsf/wvDocId/C03F1C4DD79D7A84C12571EE004B5E34/$file/NERSC-pres.pdf [Accessed March, 2012]

Scott, S.L., Devegowda, D. and Martin, A.M., 2004. Assessment of Subsea Production & Well Systems. Final Report submitted to the U.S. Department of Interior – Minerals Management Service (MMS), Technology Assessment and Research (TA&R) Program, project no. 424. College Station, Texas, USA. Available at: http://wenku.baidu.com/view/68c3f1c1bb4cf7ec4afed0f3 [Accessed March, 2012]

SINTEF, 2011. A new vessel for the Arctic. [image online] Available at: http://www.under-water.co.uk/articles/2011/0311sintef.htm

Sivertsen, A., 2011. Stacking up seabed benefits 04.05.2011. [image online] Available at: http://www.npd.no/en/Publications/Norwegian-Continental-Shelf/No1-2011/Stacking-up-seabed-benefits [Accessed March 11, 2012].

Snel, J., 2008. Mooring Systems in Arctic Environments. Delft University of Technology. Available at: http://www.citg.tudelft.nl/fileadmin/Faculteit/CiTG/Over_de_faculteit/Afdelingen/Afdeling_Waterbouwkunde/Offshore_Engineering_CITG/Recent_Thesis/doc/2008-04-08_Jannes_Snel.pdf [Accessed March, 2012]

Sœttem, J., Rise, L., Rokoengen, K. and By, T., 1996. Soil investigations, offshore mid Norway: A case study of glacial influence on geotechnical properties. Global and Planetary Change, vol 12 (1), pp.271–285.

Soelvik, N.A. and Sollie, L.P., 2004. Deepwater NuDeep™ Technology for Subsea Development. ABB Review Report 2/2003, pp. 30-35 [online]. Available at: http://library.abb.com/global/scot/scot271.nsf/veritydisplay/ac00a0ce2358a8ecc1256ddd003470fc/$File/30-35%20M818.pdf [Accessed March, 2012]

Statoil, 2011. Major oil discovery in the Barents Sea. Statoil News and Media, [online] 1st April, 2011. Available: http://www.statoil.com/en/NewsAndMedia/News/2011/Pages/01AprSkrugard.aspx [Accessed February, 2012]

Statoil, 2012. Major new oil discovery in the Barents Sea. Statoil News and Media, [online] 9th January, 2012. Available: http://www.statoil.com/en/NewsAndMedia/News/2012/Pages/08Jan_Havis.aspx [Accessed February, 2012]

Stenger, B., Van Maren, P., Otabor, M., Meyenburg, R., Okoro, M., Ezeukwu, T. and Blommerde, J., 1998. Meeting the challenge of subsea field development offshore Nigeria, the Okwori oil field case. Poster In: 18th World Petroleum Congress, Block 1, Forum 1 poster. Johannesburg, South Africa. September 25-29th, 1998.

thenauticalsite.com, n.d.. Cargo Work. [online] Available at: http://thenauticalsite.com/NauticalNotes/CargoWork/MyCargoWk-Lesson03-DkCargo.htm [Accessed March, 2012]

SUBSEAIQ, 2008. Offshore Field Development Projects - Snohvit. [online] 12th June, 2008. Available: http://subseaiq.com/data/Project.aspx?project_id=223#history [Accessed February, 2012]

Tito, N. and Rambaldi, E., 2009. SWIMMER: Innovative IMR AUV. In: Offshore Technology Conference, paper no. OTC19930. Houston, USA. May 4-7th, 2009.

Torgersen, R.C. and McGregor, I.D., 1989. A remote system for subsea well maintenance. In: Society of Petroleum Engineers Offshore Europe 89, SPE19225. Aberdeen, United Kingdom. September 5-8th, 1989.

Utseth, R.H. and Strøm, S., 2007. Subsea IOR: Keynote Introduction. In: Offshore Technology Conference, paper no. OTC18743. Houston, USA. April 30th-May 3rd, 2007.

Vefsnmo, S., Johansen, Ø. and Løvås, S.M., 1990a. Platform and foundation behaviour during combined hydrodynamic and ice loading - location A and B. ESARC report no 21, Sintef report STF71F90015, Trondheim.

Vefsnmo, S., Mathiesen, M. and Løvås, S.M., 1990b. IDAP 90 - Statistical analysis of the sea ice data. Volume 1: Extreme Southern Limit analysis. Sintef report STF60 F90079, Trondheim

Wiencke, M., 2007. The Partnership Between Solution Providers and Oil Companies. In: Offshore Technology Conference, paper no. OTC18576. Houston, USA. April 30th-May 3rd, 2007.

Wilcken, S., 2012. Alpha Factor for the Calculation of Forecasted Operational Limits for Marine Operations in the Barents Sea. Master of Science. University of Stavanger.

Wilson, A., 2013. World's Longest Electrically Heated Flowline Allows HP/HT Field Tieback to Existing Host. In: 2012 Abu Dhabi International Petroleum Exhibition and Conference. Abu Dhabi, UAE. November 11–14th, 2012. Contains highlights of SPE paper no. 161572, "HP/HT Field Development Tied Back to an Existing Host," by Trevor Crowe of Shell and Jean-Paul Koninx of SPE and Crispin Slater of A/S Norske Shell. Available at: http://www.mydigitalpublication.com/display_article.php?id=1293389 [Accessed May, 2013]

Zakarian, E., Holm, H., Saha, P., Lisitskaya, V. and Suleymanov, V, 2009. Shtokman: The Management of Flow Assurance Constraints in Remote Arctic Environment. In: 24th World Gas Conference. Buenos Aires, Argentina. October 5-9th, 2009.

Zeng, H.Y., Li, X.Z., Chen, J.C., Chen, M., Tan, J.X., Jing, Y., Shi, S., Li, Z.G. and Li, X., 2012. TUMSAS: A New Solution for Shallow Water FPSO Mooring. In: Offshore Technology Conference, paper no. OTC23266. Houston, USA. April 30th-May 3rd, 2012.

Zhang, J., Rothrock, D. and Steele, M., 2000. Recent Changes in Arctic Sea Ice: The Interplay between Ice Dynamics and Thermodynamics. Journal of Climate, vol 13 (17), pp. 3099-3114

Zolotukhin, A. and Gavrilov, V., 2011. Russian Arctic Petroleum Resources: Challenges and Future Opportunities. In: Arctic Technology Conference, paper no. OTC22062. Houston, USA. February 7-9th, 2011.

Øvrum, M., Statoil, 2010. Longer, Deeper, Colder – Technology to cross energy frontiers. In: 16th Underwater Technology Conference. Bergen, Norway. 22-23 September 2010. Available at: https://www.etde.org/etdeweb/servlets/purl/993270-s4AwEm/993270.pdf [Accessed May, 2012]

Appendix A

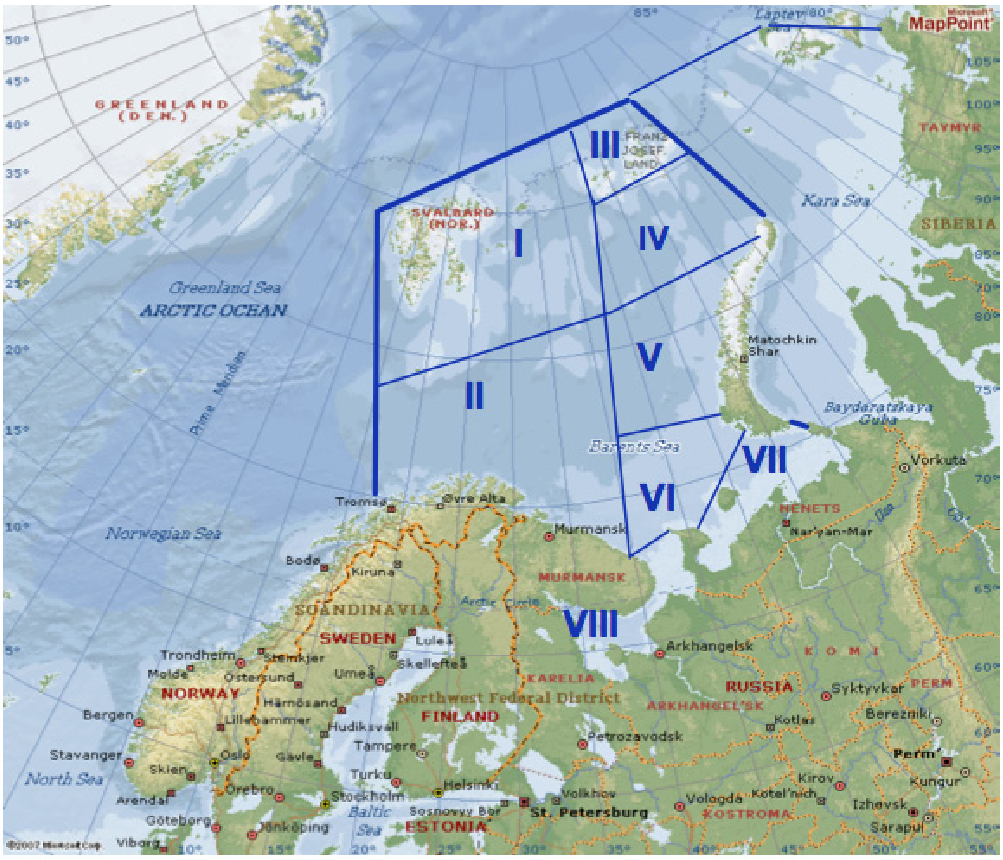


Figure A-1. Borders and sub-areas of the Barents Sea. The bold lines show the borders. The sub-areas are (modified from AARI): I) Spitsbergen; II) Norwegian; III) Franz Josef Land; IV) Northeast Barents Sea; V) Novozemelsky; VI) Kola; VII) Pechora; VIII) White Sea. Sub-area II is generally ice-free. Sub-areas I, III, IV, VII and VIII usually have ice every winter. Sub-areas V and VI are in-between. (Eide, 2008)

Appendix B

Figure B-1. Icing on Melkøya, January 2006.
(Klo, A., 2006)

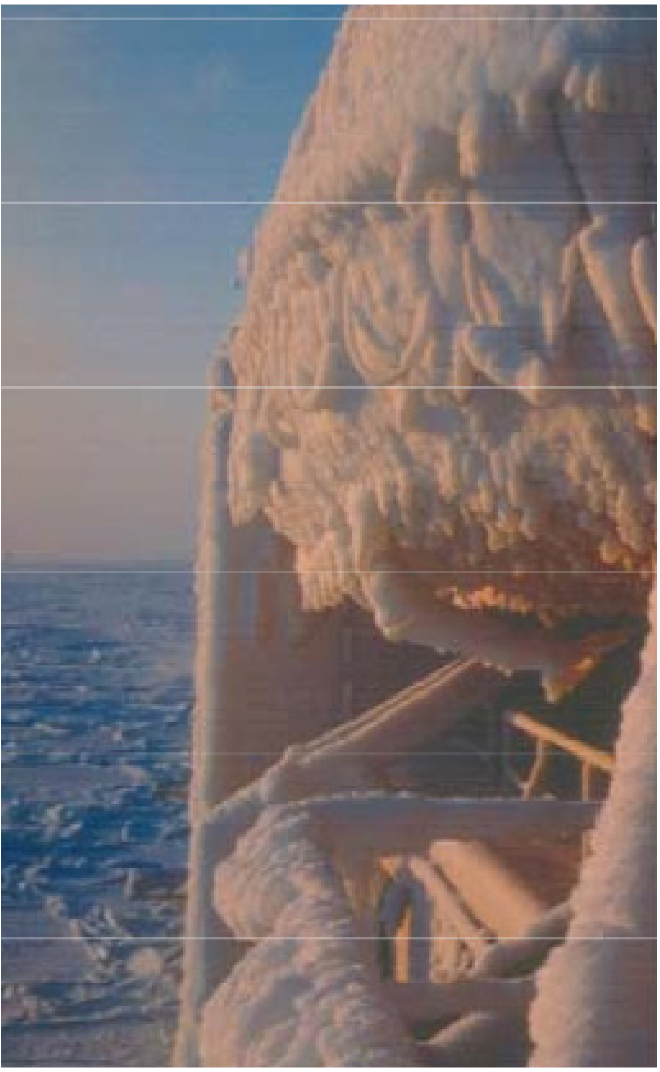


Figure B-2. Iced-up Lifeboat on K/V Nordkapp, February 1987.
(Løset, 1987c)

Figure B-3. Icing on deck, reels and equipment.
(thenauticalsite.com, n.d.)

Figure B-4. Icing on SALM (Single Anchor Leg Mooring) on Sakhalin II.
(Canatec Associates International Ltd, 2004)

Figure B-5. Icing of winterized Arctic vessel. (Meteorological Service of Canada, 2002)

Figure B-6. Removing icing on-board deck vessel (Bergen Tanker Brokers, n.d.)

Appendix C

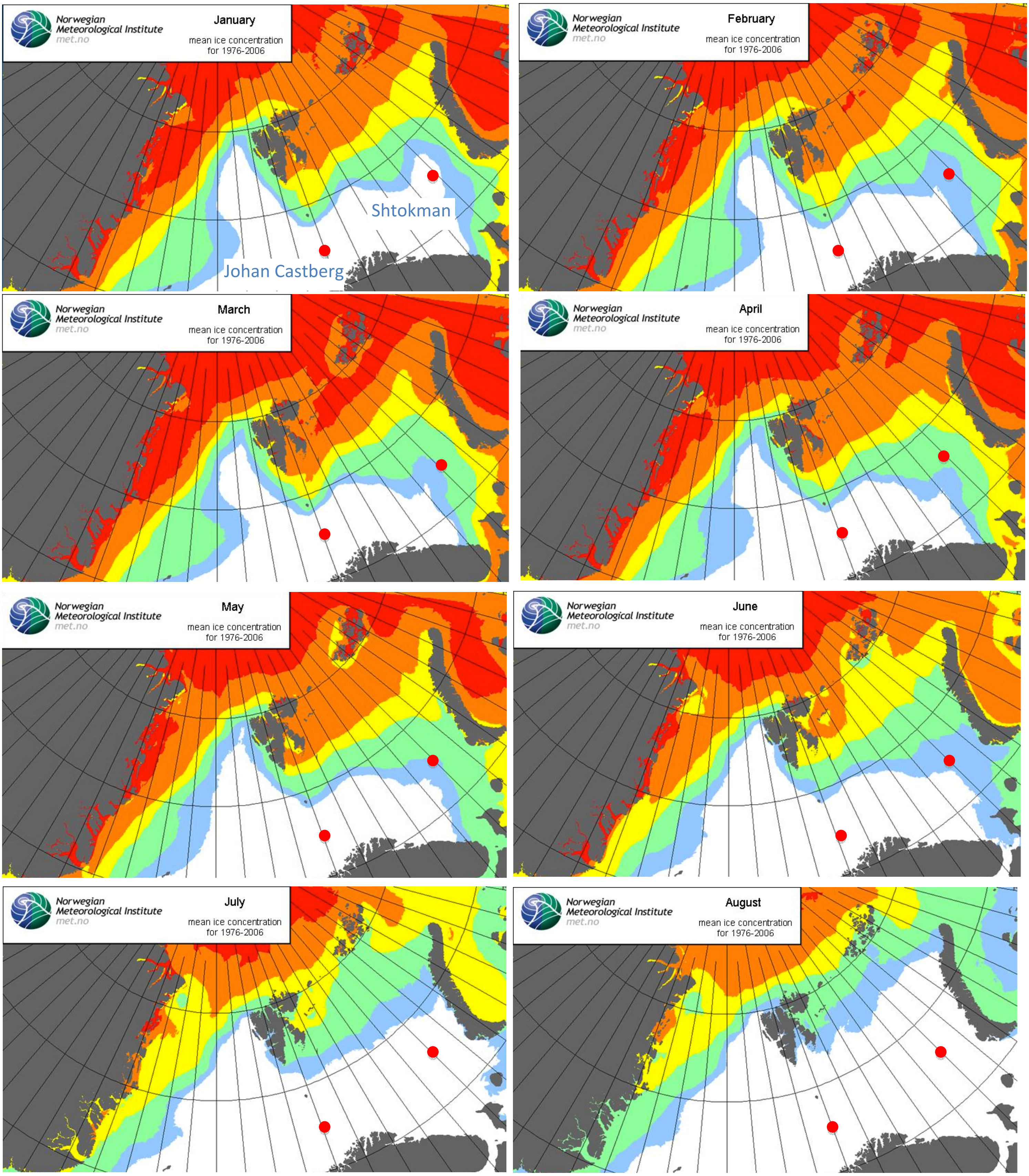


Figure C-1. Mean monthly ice concentration charts 1976-2006. (PolarView, 2011)

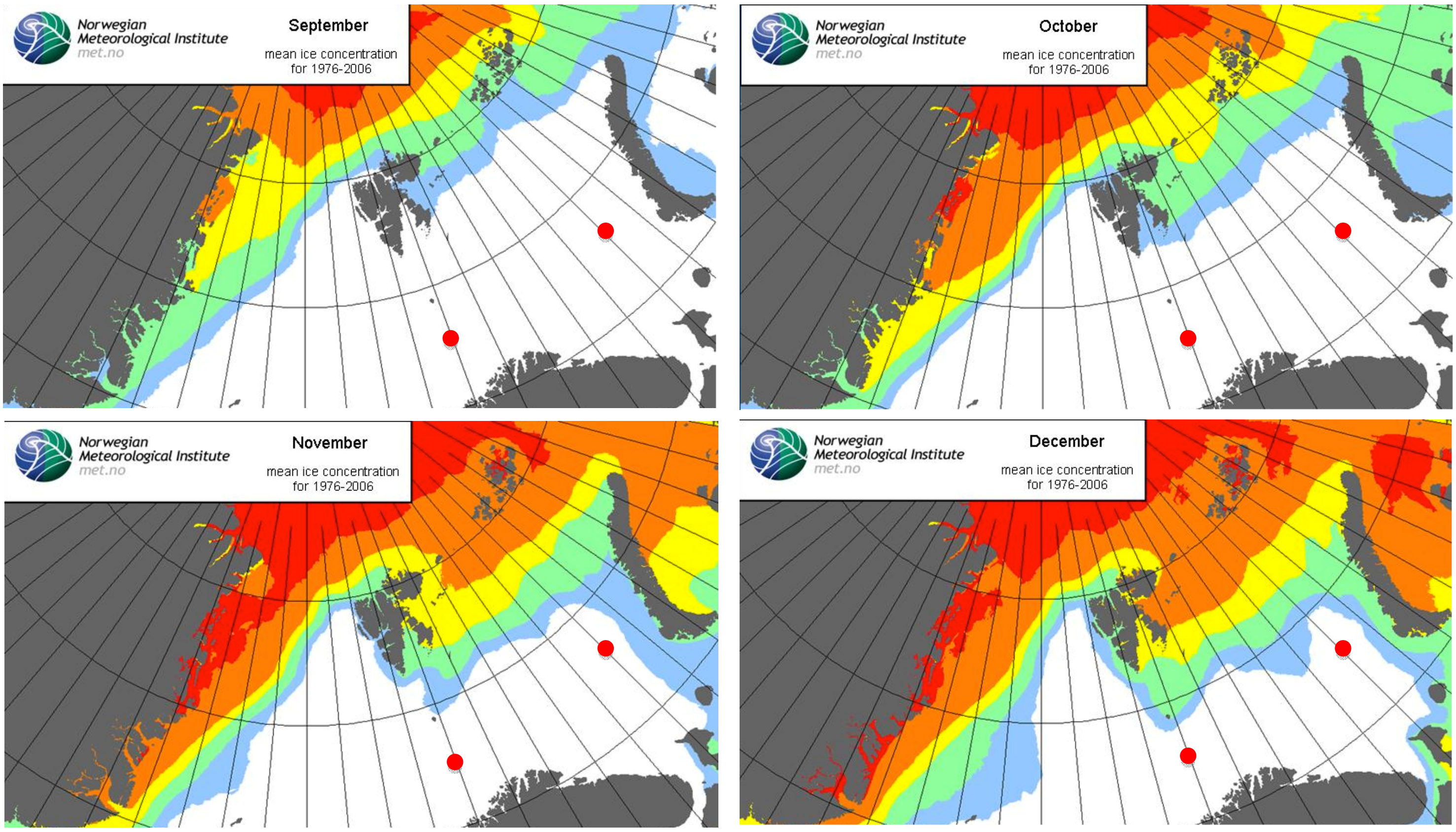


Figure C-1 (continued). Mean monthly ice concentration charts 1976-2006. (PolarView, 2011)

Ice extent development over time and average ice covered area for April and September over time. A declining trend can be seen in both charts, especially over the past two decades (PolarView, 2011).

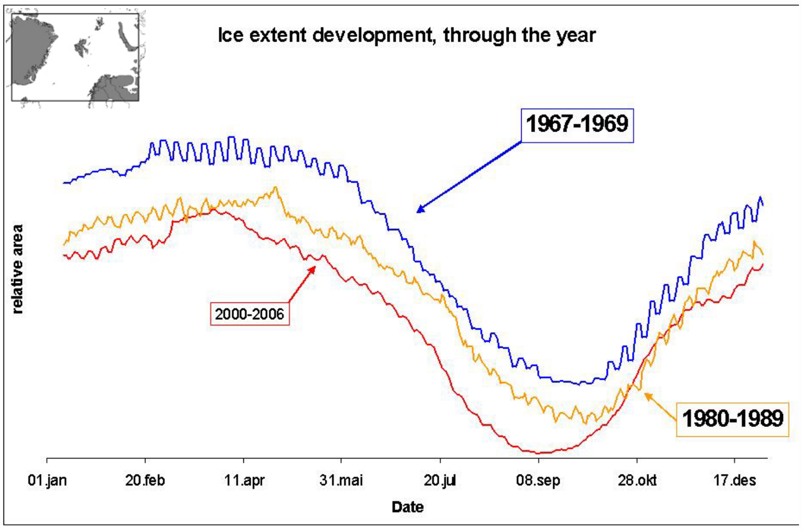


Figure C-2. Ice extent development over time. (PolarView, 2011)

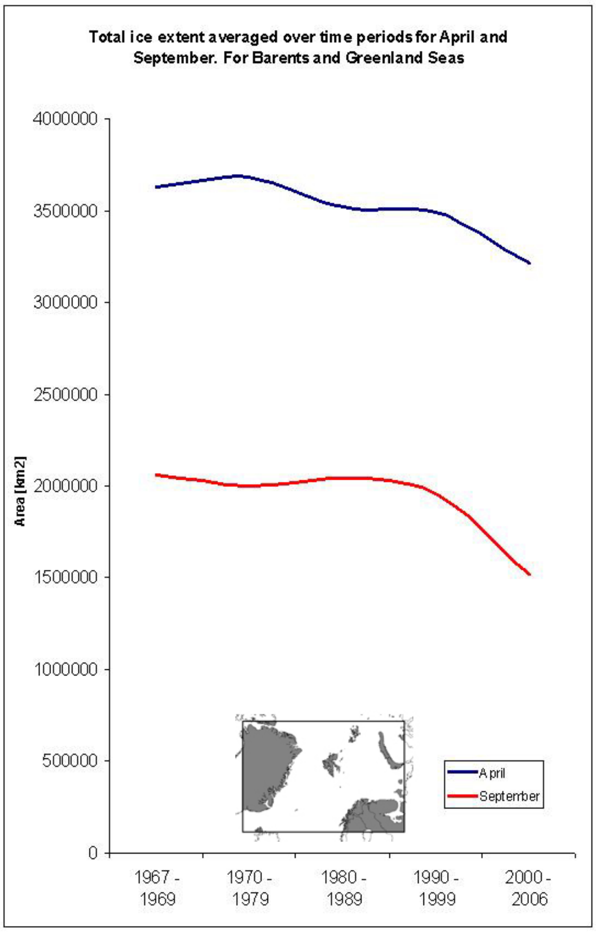


Figure C-3. Ice extent average for April (max) and September (min). (PolarView, 2011)

Appendix D

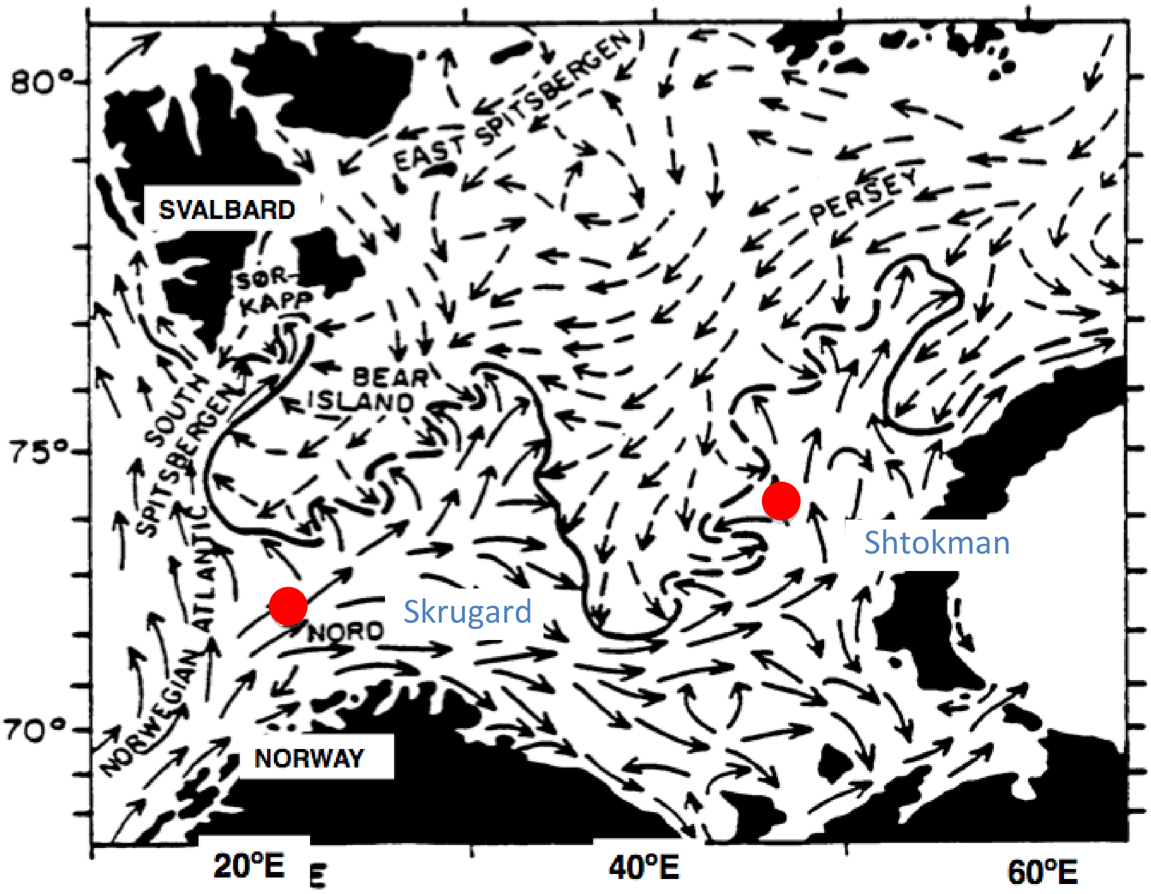


Figure D-1. Sea surface currents for Barents and Pechora Seas. (Løset, 2011b)

Appendix E

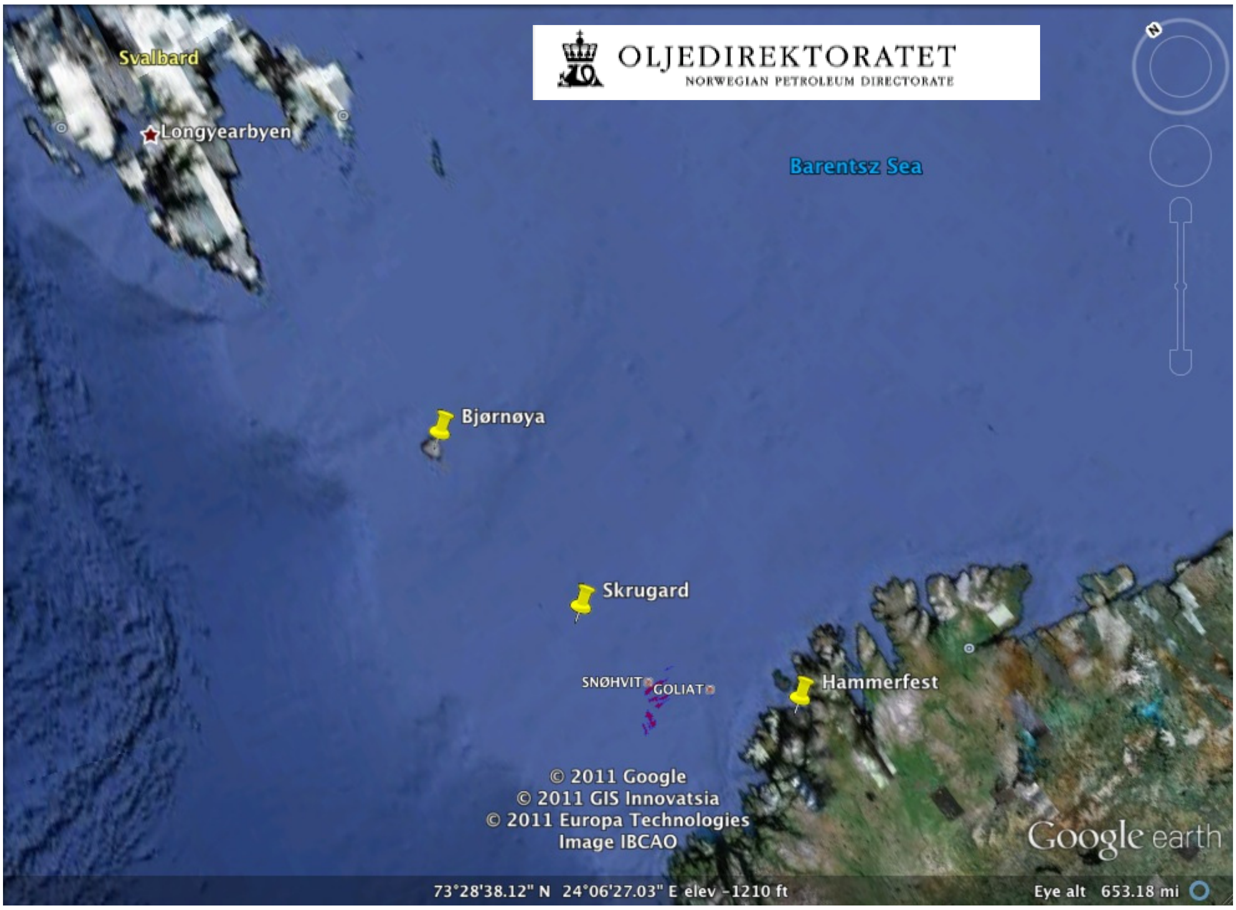


Figure E-1. Barents Sea field location illustration with respect to Hammerfest, Bjørnøya and Svalbard. (generated using Google Earth Oljedirektoratet Application, 2011)

Appendix F

Table F-1. Summary of present state of ice and metaocean conditions w.r.t. standards and data background. Yellow: standards OK but more data needed to reduce uncertainties; Red: needs updating in standards as well as more knowledge. (Eide, 2008)

Hazard	Add. Challenge in Barents Sea	Implication	Mitigation	Addressed in code	Needed for change
Metaocean					
- Wind	No	None, unless combined with low temps	None but better spatial data coverage needed	NORSOK N-002 and N-003, ISO19901-1, DNV-RP-C205	No, but more data needed
- Waves	No	None, unless combined with ice and glacial features			
- Current	No	None			
- Weather forecast	Yes, more demanding – less data and smaller scale	Few observations from open water gives less reliable forecasts. Particularly for Polar Lows	Increased observation network, automated stations at sea, higher resolution models	Mentioned in NORSOK N-003	Yes, see mitigation
- Visibility (not incl. darkness)	No, somewhat worse conditions	Hamper operations incl. ice management	Procedures, more data		Probably not
- Temperature	Yes	Wind chill, tougher working conditions, icing	Limit exposure, enclosures, procedures, ventilation, choice of materials	NORSOK S-002 and N-003	Yes, see mitigation
- Icing	Yes	Change dimensions, freezing valves and other process equipment, block escape routes, slippery gangways, falling loads, reduced gas detection, reduced effectiveness of radars and communications	Ice removal manually by chemical de-icing, choice of coatings and materials, heat tracing (elect. heating calculations), steam and salt	NORSOK N-003, old and uncertain table	Yes, more knowledge, data and improved prediction models. Should be included in standard
Sea Ice					
- Level Ice	Yes	Extra loads, hampering operations, complicates rescue and spill response, complicates maintenance and inspection	Design, ice management	In ISO19906-1 (Draft), API, CSA,DNV	Yes, more data and less spread in load predictions in standards
- Ice Ridges	Yes				
- Icebergs	Yes				
Combined Loads Ice and Metaocean	Yes	Extra loads, hampering operations, complicates rescue and spill response, complicates maintenance and inspection	NORSOK N-002 and N-003, ISO19901-1	Not properly in any	Yes, should be included in any standard for the Arctic, incl. Barents Sea

Appendix G

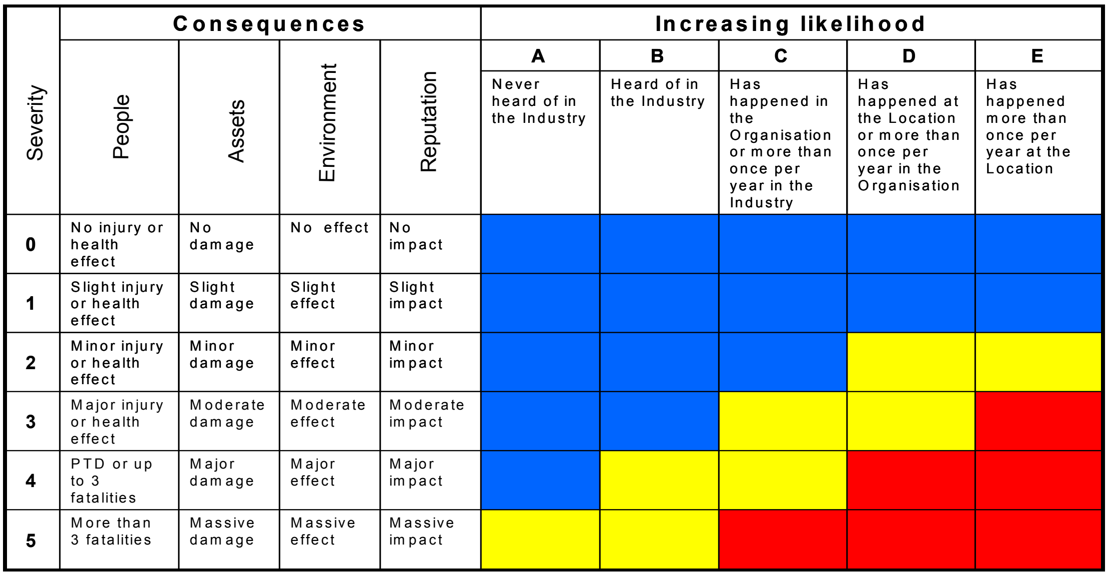
Table G-1. Grid Analysis of various technical solutions for Field Development in the Arctic

Parameters	Cost	Resistance to environmental loads	Availability / uptime	Storage	Escape	Water depth	Ease of installation	Disconnection	Maintenance	Abandonment	Total Score
Weight	4	5	5	4	5	3	4	4	3	3	200
FPSO	3	3	4	5	4	5	5	5	3	5	0.83
GBS	2	5	5	5	3	2	2	0	4	0	0.60
Semi	4	2	3	0	2	3	5	2	2	3	0.52
TLP	4	3	3	2	2	2	3	1	2	2	0.49
Buoy	4	5	4	4	4	5	5	5	3	3	0.85

Appendix H

The HAZID sheet used is moulded from several examples of HAZID sheets to serve the purpose of this specific exercise. Power phrases, buzzwords and keywords were adapted from several HAZIDs conducted previously both for Arctic and high north projects as well as non-Arctic projects. The bow-tie diagrams were produced by the use of a trial version of BowTieXP® courteously provided by CGE Risk Management Solutions, a company specializing in the distribution of risk management and incident analysis software solutions and services. They offer their services through a global network of experienced consultancy partners and their contribution with the trial version of the software has been key to effectively presenting the results of this analysis.

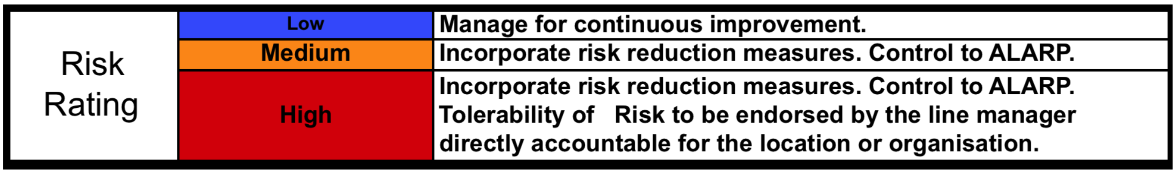
In terms of the risk assessment matrix used, the following figure depicts the different severity and consequences adapted as well as the likelihood classification.



Severity	Consequences				Increasing likelihood				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in the Industry	Heard of in the Industry	Has happened in the Organisation or more than once per year in the Industry	Has happened at the Location or more than once per year in the Organisation	Has happened more than once per year at the Location
0	No injury or health effect	No damage	No effect	No impact	🟦	🟦	🟦	🟦	🟦
1	Slight injury or health effect	Slight damage	Slight effect	Slight impact	🟦	🟦	🟦	🟦	🟦
2	Minor injury or health effect	Minor damage	Minor effect	Minor impact	🟦	🟦	🟦	🟨	🟨
3	Major injury or health effect	Moderate damage	Moderate effect	Moderate impact	🟦	🟦	🟨	🟨	🟥
4	PTD or up to 3 fatalities	Major damage	Major effect	Major impact	🟦	🟨	🟨	🟥	🟥
5	More than 3 fatalities	Massive damage	Massive effect	Massive impact	🟨	🟨	🟥	🟥	🟥

Figure H1. Risk Assessment Matrix

Based on the risks applied to each of the consequence categories, the combination is summarized as a "*Risk Rating*". This is shown in Figure H2 below.



Risk Rating	Low	**Manage for continuous improvement.**
	Medium	**Incorporate risk reduction measures. Control to ALARP.**
	High	**Incorporate risk reduction measures. Control to ALARP. Tolerability of Risk to be endorsed by the line manager directly accountable for the location or organisation.**

Figure H2. Risk Rating

Hazard Number	Hazard Description	Safety	Health	Env	Sources
H-01	**Hydrocarbons**				
H-01.01	Crude oil under pressure	MH	C	D	Flowlines, pipelines, pressure vessels and piping
H-01.02	Hydrocarbons in formation	MH		D	Oil wells especially during well drilling and entry/workover operations
H-01.03	LPGs (eg Propane)	MH	C	D	Process fractionating equipment, storage tanks, transport trucks and rail cars
H-01.04	LNGs	MH	C	D	Cryogenic plants, tankers
H-01.05	Condensate, NGL	MH	C	D	Gas wells, gas pipelines, gas separation vessels
H-01.06	Hydrocarbon gas	MH	C	D	Oil/gas separators, gas processing plants, compressors, gas pipelines
H-01.07	Crude oil at low pressures	MH	C	D	Oil storage tanks
H-01.08	Wax	F	C	D	Filter separators, well tubulars, pipelines
H-01.09	Coal	F	P	R	Fuel source, mining activities
H-02	**Refined Hydrocarbons**				
H-02.01	Lube and seal oil		C	D	Engines and rotating equipment
H-02.02	Hydraulic oil		C	D	Hydraulic pistons, hydraulic reservoirs and pumps
H-02.03	Diesel fuel		C	D	Vehicle fuelling stations, vehicle maintenance
H-02.04	Petroleum spirit/gasoline	F	C	D	Vehicle fuelling stations, vehicle maintenance
H-03	**Other flammable materials**				
H-03.01	Cellulosic materials	F			Packing materials, wood planks, paper rubbish
H-03.02	Pyrophoric materials	F	C	D	Metal scale from vessels in sour service, scale on filters in sour service, iron sponge sweetening units
H-04	**Explosives**				
H-04.01	Detonators	WP	C		Seismic Operations, pipeline construction
H-04.02	Conventional explosive material	MH	C	Pr	Seismic Operations,pipeline construction
H-04.03	Perforating gun charges	MH			Well completion activities associated with drilling rigs and workover operations
H-05	**Pressure Hazards**				
H-05.01	Bottled gases under pressure	WP			Welding and metal cutting operations, laboratory gas sources
H-05.02	Water under pressure in pipeworks	WP			Water disposal, water floods and injection operations, strength testing of pipeworks, well fracturing and treatments
H-05.03	Non-hydrocarbon gas under pressure in pipeworks	MH			Purging and leak testing of facilities
H-05.04	Air under high pressure	WP			Seismic air guns and related piping,
H-05.05	Hyperbaric Operations (diving)	WP	P		Undersea operations
H-05.06	Decompression (diving)	WP	P		Undersea operations
H-06	**Hazards associated with differences in height**				
H-06.01	Personnel at height >2m	MH			Work involving scaffolding, suspended access, ladders, platforms, excavations, towers, stacks, roofing, working overboard, working on monkey board
H-06.02	Personnel at height <2m	WP			Slippery/uneven surfaces, climbing/descending stairs, obstructions, loose grating
H-06.03	Overhead equipment	MH			Objects falling while being lifted/handled or working at a height over people, equipment or process systems, elevated work platforms, slung loads
H-06.04	Personnel under water	MH			Objects falling on to divers from operations overhead
H-06.05	Personnel below grade	WP			Pipeline trenches, excavations, repairing buried facilities
H-07	**Objects under induced stress**				
H-07.01	Objects under tension	WP			Guy & support cables, anchor chains, tow & barge tie-off ropes, slings
H-07.02	Objects under compression	WP			Spring-loaded devices such as relief valves and actuators and hydraulically operated devices
H-08	**Dynamic situation hazards**				
H-08.01	On land transport (driving)	WP			Driving to and from locations and camps, transporting materials, supplies and products, seismic operations, moving drilling rigs and workover rigs
H-08.02	On water transport (boating)	WP			Boat transport to and from locations and camps, transporting materials, supplies and products, marine seismic operations, barges moving drilling rigs and workover rigs
H-08.03	In air transport (flying)	MH			Helicopter and fixed wing travel to and from locations and camps, transporting materials, supplies and products
H-08.04	Boat collision hazard to other vessels and offshore structures	MH			Shipping lane traffic, product transport vessels, supply and maintenance barges and boats, drifting boats
H-08.05	Equipment with moving or rotating parts	WP			Engines, motors, compressors, drill stems, thrusters on DP Ships
H-08.06	Use of hazardous hand tools (grinding, sawing)	WP			Workshop, construction sites, maintenance sites, rotating equipment
H-08.07	Use of knives, machetes and other sharp objects	WP			Galley, seismic line clearing, grubbing operations
H-08.08	Transfer from boat to offshore platform	WP			Basket transfer, rope transfer

Hazard Number	Hazard Description	Safety	Health	Env	Sources
H-09	**Environmental Hazards**				
H-09.01	Weather	WP			Winds, temperature extremes, rain, etc
H-09.02	Sea state/river currents	MH			Waves, tides or other sea states, river currents
H-09.03	Tectonic	MH			Earthquakes or other earth movement activity
H-10	**Hot surfaces**				
H-10.01	Process piping and equipment between 60 and 150 deg. C	WP	P		Oilwell piping, piping in fractionation systems, glycol regeneration
H-10.02	Process piping and equipment over 150 deg. C	MH	P		Hot oil piping, piping associated with stills and reboilers
H-10.03	Engine and turbine exhaust systems	WP	P		Power generation, gas compression, refrigeration compression, engine driven equipment such as forklifts
H-10.04	Steam piping	WP	P		Sulphur plants, power boilers, waste heat recovery systems, heat tracing and jackets
H-11	**Hot fluids**				
H-11.01	Temperatures between 100 and 150 deg. C	WP	P		Glycol regeneration, low quality steam systems, cooling oils, galley
H-11.02	Temperatures greater than 150 deg. C	MH	P		Power boilers, steam generators, sulphur plants, waste heat recovery units, hot oil heating systems, regeneration gases used with catalysts and desiccants
H-12	**Cold surfaces**				
H-12.01	Process piping between -25 deg. C and -80 deg. C	MH	P		Cold ambient climate, Joule-Thomson expansions (process and leaks), propane refrigeration systems, LPG gas plants
H-12.02	Process piping less than - -80 deg. C	MH	P		Cryogenic plants, LNG plants, LNG storage vessels including tankers, vapour lines off liquid nitrogen storage
H-13	**Cold fluids**				
H-13.01	Oceans, seas and lakes less than 10 deg. C		P		North Sea, Arctic Ocean
H-14	**Open flame**				
H-14.01	Heaters with fire tube	F	P	D	Glycol reboilers, amine reboilers, salt bath heaters, water bath heaters (line heaters)
H-14.02	Direct fired furnaces	F	P	D	Hot oil furnace, Claus plant reaction furnace, catalyst and desiccant regeneration gas heaters, incinerators, power boilers
H-14.03	Flares		P	D	Pressure relief and blowdown systems
H-15	**Electricity**				
H-15.01	Voltage > 50 to 440 V in cables	MH			Power cables, temporary electrical lines on construction sites
H-15.02	Voltage > 50 to 440 V in equipment	WP			Electric motors, electric switchgear, power generation, welding machines, transformer secondary
H-15.03	Voltage >440 V	MH			Overhead power lines, power generation, transformer primary, large electrical motors
H-15.04	Lightning discharge	WP			Major lightning-prone areas
H-15.05	Electrostatic energy	WP			Nonmetallic storage vessels and piping, product transfer hoses, wiping rags, unearthed equipment, aluminium/steel, high velocity gas discharges
H-16	**Electromagnetic radiation**				
H-16.01	Ultraviolet radiation		P		Arc welding, sunshine
H-16.02	Infra-red radiation		P		Flares
H-16.03	Microwaves		P		Galley
H-16.04	Lasers		P		Instrumentation, surveying
H-16.05	E/M radiation : high voltage ac cables		P		Transformers, power cables
H-17	**Ionising radiation - open source**				
H-17.01	Alpha, beta - open source		P	D	Well logging, radiography, densitometers, interface instruments
H-17.02	Gamma rays - open source		P	D	Well logging, radiography
H-17.03	Neutron - open source		P	D	Well logging
H-17.04	Naturally occurring ionising radiation		P	D	Scales in tubulars, vessels and process plant fluids (especially in C3 reflux streams)
H-18	**Ionising radiation - closed source**				
H-18.01	Alpha, beta - closed source		P		Well logging, radiography, densitometers, interface instruments
H-18.02	Gamma rays - closed source		P		Well logging, radiography
H-18.03	Neutron - closed source		P		Well logging
H-19	**Asphyxiates**				
H-19.01	Insufficient oxygen atmospheres		C		Confined spaces, tanks
H-19.02	Excessive CO2		C	D	Areas with CO2 firefighting systems such as turbine enclosures
H-19.03	Drowning		C		Working overboard, marine seismic operations, water transport
H-19.04	Excessive N2		C		N2 purged vessels
H-19.05	Halon		C	D	Areas with halon firefighting systems such as turbine enclosures and electrical switchgear and battery rooms
H-19.06	Smoke		C	D	Welding/burning operations, fires

Hazard Number	Hazard Description	Safety	Health	Env	Sources
H-20	**Toxic gas**				
H-20.01	H2S (hydrogen sulphide, sour gas)	MH	C	D	Sour gas production, bacterial activity in stagnant water, confined spaces in sour operations
H-20.02	Exhaust fumes		C	D	Sleeping in cars with running engines, heating devices, car garage
H-20.03	SO2		C	D	Component of H2S flare and incinerator flue gas
H-20.04	Benzene		C	D	Component of crude oil, concentrated in glycol vent emissions and Wemco units
H-20.05	Chlorine	MH	C	D	Water treatment facilities
H-20.06	Welding fumes		C		Construction and metal fabrication/repair, welding toxic metals (galvanised steel, cadmium-coated steel), metal cutting, grinding
H-20.07	Tobacco smoke		LS		Accommodation, office buildings, inside cars, boats, helicopters, aeroplanes
H-20.08	CFCs			D	Air conditioning, refrigeration, aerosol sprays
H-21	**Toxic liquid**				
H-21.01	Mercury		C	D	Electrical switches, gas filters
H-21.02	PCBs		C	D	Transformer cooling oils
H-21.03	Biocide (gluteraldehyde)		C	D	Water treatment systems
H-21.04	Methanol		C	D	Gas drying and hydrate control
H-21.05	Brines		C	D	Hydrocarbon production, well kill fluid, packer fluids
H-21.06	Glycols		C	D	Gas drying and hydrate control
H-21.07	Degreasers (terpenes)		C	D	Maintenance shops
H-21.08	Isocyanates		C	D	Two-pack paint systems
H-21.09	Sulphanol		C	D	Gas sweetening
H-21.10	Amines		C	D	Gas sweetening
H-21.11	Corrosion inhibitors		C	D	Additive to pipelines and oil/gas wells, chromates, phosphates
H-21.12	Scale inhibitors		C	D	Cooling and injection water additive
H-21.13	Liquid mud additives		C	D	Drilling fluid additive
H-21.14	Odorant additives (mercaptans)		C	D	Custody transfer facilities for gas, LPG and LNG
H-21.15	Alcohol-containing beverages	WP	LS		
H-21.16	Recreational drugs	WP	LS		
H-21.17	Used engine oils (polycyclicaromatic hydrocarbons)		C	D	Used engine oils
H-21.18	Carbon tetrachloride		C		Plant laboratory
H-21.19	Grey and/or Black Water				Septic systems, camps, detergents
H-22	**Toxic solid**				
H-22.01	Asbestos		C	D	Thermal insulation and construction materials, old roofing (encountered during removal)
H-22.02	Man-made mineral fibre		C	D	Thermal insulation and construction material
H-22.03	Cement dust		C	D	Oil well and gas well cementing, civil construction
H-22.04	Sodium hypochlorite		C	D	Drilling fluid additive
H-22.05	Powdered mud additives		C	D	Drilling fluid additive
H-22.06	Sulphur dust		C	D	Sulphur recovery plants
H-22.07	Pig trash		C	D	Pipeline cleaning operations
H-22.08	Oil-based muds		C	D	Oil and gas well drilling
H-22.09	Pseudo-oil-based muds		C	D	Oil and gas well drilling
H-22.10	Water-based muds		C	D	Oil and gas well drilling
H-22.11	Cement slurries		C	D	Oil and gas well drilling, plant construction
H-22.12	Dusts		C		Cutting brickwork and concrete, driving on unpaved roads, carpenter shops, grit blasting, sand blasting, catalyst (dumping, screening, removal, drumming)
H-22.13	Cadmium compounds and other heavy metals		C	D	Welding fumes, handling coated bolts
H-22.14	Oil based sludges		C	D	Oil storage tank cleaning
H-23	**Corrosive substances**				
H-23.01	Hydrofluoric acid	WP	C	D	Well stimulation
H-23.02	Hydrochloric acid	WP	C	D	Well stimulation
H-23.03	Sulphuric acid	WP	C	D	Wet batteries, regenerant for reverse osmosis water makers
H-23.04	Caustic soda (sodium hydroxide)		C	D	Drilling fluid additive

Hazard Number	Hazard Description	Safety	Health	Env	Sources
H-24	**Biological hazards**				
H-24.01	Poisonous plants (poison ivy and oak, stinging nettles, nightshade)		B		Natural environment
H-24.02	Large animals (dogs, cats, rats, African wild animals)		B		Natural environment
H-24.03	Small animals (snakes, scorpions, lizards)		B		Natural environment
H-24.04	Food-borne bacteria (eg E. Coli)		B		Contaminated food
H-24.05	Water-borne bacteria (eg legionella)		B		Cooling systems, domestic water systems
H-24.06	Parasitic insects (pin worms, bed bugs, lice, fleas)		B		Improperly cleaned food, hands, clothing, living sites (pin worms, bed bugs, lice, fleas)
H-24.07	Disease transmitting insects (mosquitoes-malaria and yellow fever, ticks-lime dis		B		Natural environment
H-24.08	Cold and Flu Virus		B		Other people
H-24.09	Human Immune deficiency Virus (HIV)		B		Contaminated blood, blood products and other body fluids
H-24.10	Other Communicable Diseases		B		Other people
H-25	**Ergonomic hazards**				
H-25.01	Manual materials handling		E		Pipe handling on drill floor, sack handling in sack store, manoeuvring equipment in awkward locations
H-25.02	Damaging noise	WP	P	Pr	Releases from relief valves, pressure control valves
H-25.03	Loud steady noise > 85 dBA		P	Pr	Engine rooms, compressor rooms, drilling brake, air tools
H-25.04	Heat stress (high ambient temperatures)		P		Near flare, on the monkey board under certain conditions, in open exposed areas in certain regions of the world during summer
H-25.05	Cold stress (low ambient temperatures)		P		Open areas in winter in cold climates, refrigerated storage areas
H-25.06	High humidity		P		Climates where sweat evaporation rates are too low to cool the human body, personal protective clothing
H-25.07	Vibration		P	Pr	Hand-tool vibration, maintenance and construction worker, boating
H-25.08	Workstations		E		Poorly designed office furniture and poorly laid out workstations
H-25.09	Lighting		P	Pr	Work areas requiring intense light, glare, lack of contrast, insufficient light
H-25.10	Incompatible hand controls		E		Controls poorly positioned in workplace requiring workers to exert excessive force, lacking proper labels, hand-operated control valves, for example in driller house, heavy machinery, control rooms
H-25.11	Awkward location of workplaces and machinery		E		Machinery difficult to maintain regularly due to their awkward positioning, for example valves in an usually high or low position
H-25.12	Mismatch of work to physical abilities		E		Requiring older workers to maintain a high physical level of activity over the course of an 8/12 hour day, heavy construction work performed by slight individuals
H-25.13	Mismatch of work to cognitive abilities		E		Requiring individuals to monitor a process without trying to reduce their boredom by giving them a higher task load, asking a worker to supervise something he/she is not qualified
H-25.14	Long and irregular working hours/shifts		E		Offshore locations utilising long shift cycles, overtime, night shifts, rollover shifts
H-25.15	Poor organisation and job design		E		Ambiguity of job requirements, unclear reporting relationships, over/under supervision, poor operator/contractor interfaces
H-25.16	Work planning issues		E		Work overload, unrealistic targets, lack of clear planning, poor communications
H-25.17	Indoor climate (too hot/ cold/ dry/ humid, draughty)		E		Uncomfortable climate for permanently manned areas
H-26	**Psychological hazards**				
H-26.01	Living on the job/away from family		Psy		Homesickness, missing family and social events, unable to be involved in community, feeling of isolation and losing chunks of life. Drifting away from spouse and family, development of different interests and friends, threatened by spouse's independence, wind-down period at start of break. Inability to support spouse in domestic crisis. Difficult to turn off in leisure time
H-26.02	Working and living on a live plant		Psy		Awareness that mistakes can be catastrophic, vulnerable to the mistakes of others, responsible for the safety of others. Awareness of difficulty of escape in an emergency. Awareness of risks in helicopter travel, adverse weather.
H-26.03	Post traumatic stress		Psy		Serious incidents, injuries to self and others
H-27	**Security related Hazards**				
H-27.01	Piracy	Se			
H-27.02	Assault	Se			
H-27.03	Sabotage	Se			
H-27.04	Crisis (military action, civil disturbances, terrorism)	Se			
H-27.05	Theft, pilferage	Se			
H-28	**Use of Natural Resources**				
H-28.01	Land			R	Installation sites, drilling locations, seismic clearing, pipeline right-of-ways

Hazard Number	Hazard Description	Safety	Health	Env	Sources
H-28.02	Water			R	Cooling water
H-28.03	Air			R	Turbines, combustion engines (cars, trucks, pump and compressor drivers)
H-28.04	Trees, vegetation			R	Installation sites, seismic clearing, pipeline right-of-ways, drilling locations
H-28.05	Gravel			R	Borrow pits, road construction
H-29	**Medical**				
H-29.01	Medical unfitness		M		Medically unfit staff for the task
H-29.02	Motion sickness		M		Crew change on water, marine operations

HAZID

Universitetet
i Stavanger

Topic	Subsea Field Development in the Arctic and high North
Prepared By	Riad El-Wardani
Date	29 January 2013

Basis

Skrugard-type field, located North of Norway within the Southern Barents Sea.
Similar development concept to Goliat with buoy shaped FPSO host and subsea tie-backs.

File Summary

HAZID Process	Describes the HAZID process and a brief project description
Category 1	Natural & Environmental Hazards
Category 2	Facility
Category 3	Health Hazards
Category 4	Project Implementation Issues
Haz Ref	
RAM	Describes the RAM in particular the category definition.

Workshop Date 29 January 2013

No	Attendees	Role
1	Riad El-Wardani	Shell, Subsea Systems Engineer
2	Ilya Sizov	AkerSolutions, HSE Engineer
3	Kourosh Mashayekh	Aibel, Project Engineer
4	Alejandro Bencomo	Technip, Senior Project Engineer
5	Ahmed Mahran	Subsea 7, Pipeline Design Engineer
6		
7		
8		
9		

ARCTIC FIELD DEVELOPMENT HAZID Register Section 1: EXTERNAL & ENVIRONMENTAL HAZARDS												
							Risk					
Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	People	Environment	Asset	Reputation	Recommendation/Action	Timing (Project Phase)
1.01	Natural and Environmental Hazards	Physical Environment Extremes	Adverse weather (temperature, waves, wind, dust, flooding, sandstorms, ice, blizzards, fog, clouds)	The possibility of ship collision due to low visibility (fog, snow, rain, etc.)	Position of host facilities to be verified for shipping route and the requirement for Radar Beacon to be confirmed. 500m exclusion zone around host facility. Halt marine operations during low visibility, bad weather.	L	B3		B3	B2	Geomatics and marine confirmed requirement for Radar Beacon as per IALA Recommendation R-101.	FEE
				Vessels or equipment damage due to **polar lows** or **north atlantic hurricanes** during construction, intervention or installation	Special risk during subsea construction campaigns. Companies to have the required patience and due dilligence to wait for suitable weather windows to carry out campaigns without risking assets and safety. Back up vessels and procedures to be in place in case need arises for prompt evacuation.	L	C1		B1		Use of vessel mounted meteorological radars to improve forecasting. Update models to gain higher accuracy in predicting weather windows. Budget for downtime and contingency when planning offshore campaigns. Design equipment for good instalability. "Kulluk" example.	Design
				Late detection of approaching ice features, late mobilization of iceberg management vessels due to lack of visibility or incorrect programming of radar.	Make use of iceberg radar, scouting vessels or other means. Limitation with image resolution of radar.	L	B2	B3	B3	A4		Design
				Bad sea state will hinder vessel transfer and increase risk of vessel transport.	Due to bad weather, travel to the host facility by boat will not be allowed. If crew are already on the platform, boat transfer will not be allowed for swell >2m.	L	C1				Clear Boat Transfter Procedures and following protocol.	Operation
				Bad weather condition which disallows transfer by boat/helicopter.	Normal and scheduled outdoor activities will incur higher risk. To meet the MHMS minimal requirement for tiered response, Tier-2 requirement states the need for an Advanced Paramedic and response of 1hour anywhere on the Norwegian sector (FalckNutec)	M	B4				To provide training and adequate equipment as recommended by the MHMS to meet Tier 2 response.	Design
			Iceberg and ice features drift	Failure to identify correct drift direction, speed and characteristic behaviours of different ice features may lead to collision	Experienced personnel and use of various tracking tools for continuous monitoring.	L	B3	B3	B2		Trajectory for different ice feautures change significanlty, icebergs may break down and change trajectory and behaviour	Design
			Iceberg and ice features drift	Lack of understanding of ice feature behaviour such as scouring leading to insufficient design	Experienced design engineers and applying generous design factors to avoid "near misses", ref. Hibernia designed for 6million ton iceberg whereas largest iceberg witnessed I the area has not come anywhere near this magnitude.	L	A0	A3	A3	A4		Design
			Iceberg and ice features drift	Dangerous ice coming through facilities area and no/wrong decision being made regarding disconnection or leaving location	Procedures, responsibilities and decision criteria to be established and clearly communicated.	L	A3	A3	A3	A4		Operation
1.02		Lightning	Lightning	Lightning strikes at elevated points i.e. crane	Offshore platforms and vessels are prone to lightning strikes on high points. Arrestors and proper earthing to be incorporated as part of the design to avoid such incidents.	M	B4		B2		To confirm that lightning strikes hazards is addressed in design and ensure adequate earthing as per industry standards.	Design
1.03		Earthquakes	Earthquake	Possible impact is personnel fatality, damage to structures and facilities.	Designed to latest metocean data.	M	B5	B3	B3		Investigate credibility of occurance and design accordingly. Review design premise accordingly.	FEE
1.04		Erosion	Ground slide, coastal, riverine	Possible ground slide / soil instability. Norwegian sector commonly encounters unconsolidated layers over hard clay. Could lead to ground slide due to increased loads from rock dump / seabed preparations for equipment.	Carry out bore hole anaylsis at installation site to determine soil conditions.	L						Design

Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	People	Environment	Asset	Reputation	Recommendation/Action	Timing (Project Phase)
1.05		Subsidence	Ground structure, foundations, reservoir depletion	Potential damage of risers, submergence of boat landing and facilities located close to mudline.	Design considerations through foundation design, mudmats on subsea equipment etc. and annual monitoring.	**L**	**B0**	**B0**	**B0**		Design to cater for uncertainties and adequate subsidence allowances for sub-structure.Incorporate lessons learnt from Ekofisk Complex if available and latest prediction into design.	Design
1.06		Physical Environment Models	Lack of or limited environmental models	Incorrect planning and execution of offshore marine activities, overload in mooring and riser systems if unexpected conditions are met resulting in permanent damage or unnecessary disconnection of operating facilities.	Make use of iceberg radars, scouting vessels, air petrol and other means so as to provide multiple sources of data gathering. Continuously monitor changing parameters and update models	**L**	**B1**	**B2**	**B2**	**B2**		Design
2.01	Created (Man-made) Hazards	Security Hazards	Internal and external security threats	Trespassing of fishermen on to platform and interfering with platform facilities.	Installation of monitored trespassing gate on host facility, possibly add spikes on riser guards to detract offenders from climbing on risers.	**L**	**B0**		**B1**			Operation
2.02		Fishing	Trawlboard impact damaging subsea infrastructure, snagging on pipelines, flowlines and umbilicals.	Fishermen activities (trawling, fishing) posing danger of rupturing pipelines, flowlines or umbilicals or leaving entangled fishing lines/hooks. Potential interference with offloading operations and collision risks.	Complex is manned and current established security procedures (patrolling standby vessels, liason with government securities, etc.) will be incorporated to deter such events.	**L**	**C0**	**B1**	**C1**	**C1**	Install trawl board protection, GRP covers on hardware and well approaches. Include pipeline routes on fishing charts and exclusion zones on maritime maps for high risk areas.	Design
2.03		Terrorist Activity	Riots, civil disturbance, strikes, military action, political unrest	None reported in Norway to date	Liaison with governmental authorities	**L**	**B0**		**B1**			Operation
3.01	Effect of the Facility on the Surroundings	Geographical - Infrastructure	Plant location, plant layout, pipeline routing, area minimisation	Pipeline tie-ins are not expected to cross over any reefs/coral outcrops. Pipeline may cross through special breeding grounds for different fish species, king crab or whale migration routes.	Carry out thorough route mapping and planning to avoid detremental effects on surrounding environment. Take environmental survey before, during and after carrying out significant activity in the area.	**M**		**C3**		**D3**	Close and open communication with NGOs and local groups to discuss plans and avoid encroaching on sensitive areas, take necessary measures to reduce or eliminate activities during breeding or migration seasons, be visible with efforts being made.	Design
				Collision risks from plying vessels at proximity.	Complex is gazetted on sealine map. Navigational aids are provided. Beacon on host facility	**L**			**B3**			Operation
3.02		Proximity to Transport Corridors	Shipping lanes, air routes, roads, etc	North East shipping lane close-by in this area and opening up for more traffic in recent years; no threats recorded to date		**L**						Operation
3.03		Environmental Issues	Vulnerable fauna and flora, visual impact	Leaks from facility or subsea infrastructure damage to the sea and for offshore loading station.	Leaks on platforms will be contained by drip trays and careful containment of hydraulic fluid systems. Leak detection system implemented for subsea infrastructure, pipelines and risers.	**L**	**B3**	**C2**		**B3**	Close communication with authorities in reporting all leaks and discharges. Careful monitoring of detection systems and regular inspection of hydraulic fluid areas.	Design
				Pollution and limited possibility to recover due to ice and detection of the containment	Additional barriers and leak detection on leak sources.	**L**	**B3**	**C2**		**B3**		Operation
				Standby vessels, rigs and work barges contaminated effluent discharges overboard.	Standard contract requirements will ensure compliance to maritime & environmental regulations.	**L**		**C2**		**B3**	Legal Compliance to be checked whilst preparing Compliance Register document during invitation to tender (ITT)	FEE
				Migratory paths of birds and mammals affected.	Migration paths for whales and other birds and mammals in the area to be reviewed and reflected in installation, intervention and contruction schedules. Locals to be consulted.	**L**		**C2**		**B3**	Detailed design and installation procedure to comply with EIA recommendations, comply with Minimum Environmental Standards (MES).	Design
				Emission of gas with H2S, Co2 under process upset conditions.	(1) Monitoring program in place (2) Control and shutdown procedures.	**M**	**B4**	**B1**		**B3**	Monitoring programme and training for H2S handling and disposal. Carbon capture scheme to be investigated.	FEE
3.04		Social Issues	Local population, local attitude, social/cultural areas of significance	Arctic is a sensitive political arena with a lot of interest, local and global communities do not want industry to interfere with prestine arctic environment	Careful, fit for purpose design and rigirous qualification testing of all equipment before use in arctic conditions. Open and transparent communication with communities and NGOs	**M**	**E0**			**E2**	Involvment of local communities, open dialogue with government and communities, careful consideration in resolving social and environmental concerns without dismissing them.	FEE

Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	People	Environment	Asset	Reputation	Recommendation/Action	Timing (Project Phase)
4.01	Infrastructure	Normal Communications	Air links and water links	Night flying will be required, so helideck needs to to equiped for night flying. Due to lack of infrastructure in the area, re-fueling for extended trips might be difficult and emergency response slow.	Helideck will be equiped for night flying. Some fueling capacity to be included on host facility. Dedicated north / arctic helicopter base required in high north to service future development in region.	L	B3					FEE
				Increased logistic support (air & sea) in the movement of people and supplies.	Implement strict safety regulations as per North Sea	M	C4	C1	C3	C3	Conduct incremental coarse qualitative risk assessment (QRA) in a timely manner for early implementation into design.	FEE
4.03		Supply Support	Consumables/spares holding	Preservation and storage of spares and consumables	Early identification and planning for storage and handling of capital spares and consumables. Dedicated protected storage facilities to be implemented on host.							FEE
4.04		Satellite	Lack of or limited satellite coverage, meteorological and oceanographic data and ice information.	Difficult to detect and evaluate different weather features coming into the area such as polar lows, hurricanes, ice cover and adverse weather conditions.		L	B1		B3	B3	Making use of several different sources such as statistical models, onshore stations and offshore vessel based solutions must be evaluated.	FEE
5.01	Environmental Damage	Continuous Plant Discharges to Air	Flares, vents, fugitive emissions, energy efficiency	Design will be in compliance to Norwegian regulations and specifically high north and arctic requirements of no continuous flaring under normal operations.	Design will be in compliance to regulations	L		C1			Norwegian rules and regulations to be strictly adhered to and implemented	Design
				Emission of gas with H2S, CO2 under process upset conditions.	(1) Monitoring program in place (2) Control and shutdown procedures.	M	B4	B1		B3	Monitoring programme and training for H2S handling and disposal	Design
5.02		Continuous Plant Discharges to Water	Target/legislative requirements, drainage facilities, oil/water separation	All produced water must be routed for treatment and storage or reinjection, no discharge to sea. Failure of pump or process equipments, leak of storage vessels or rupture of pipe.	Implement treatment facilities on host, include water reinjection capacity or treatment according to regulations.	L		B3		C2	Include water treatment and reinjection facilities as part of host facility and subsea infrastructure design.	FEE
5.03		Facility Impact	Area minimisation, pipeline routing, environmental impact assessment	Refer 3.01		L						FEE
5.04		Waste Disposal Options		Disposal falls under scheduled (toxic) waste disposal guidelines, risk of discharges / leakages to sea	Guidelines on proper waste storage and management to be developed and implemented	M	B5	B3		B3	Waste management procedures to be strictly adhered to and implemented	FEE
5.05		Timing of Construction	Seasons, periods of environmental significance	Working during winter periods with extreme cold climate and icing risk	Planning and scheduling of construction activities	M	C3		B3	B3		Design

ARCTIC FIELD DEVELOPMENT HAZID Register
Section 2: FACILITY HAZARDS

							Risk					
Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	P	E	A	R	Recommendation	Timing (Project Phase)
6.01	Control Methods/ Philosophy	Manning/operations Philosophy	Effect on design, effect on locality (Manned, unmanned, visited)	Insufficient resource and training. Insufficient marine resources (Fast Crew Boat) to support operation. Cold climate and icing	The overall Manning Study and Operations Philosophy to include risk assessment of personnel working in harsh climate. Winterization to be assessed including all ventilation requirements.	M	C3		B3			FEE
6.02		Operations Concept	Amount of processessing on host facility vs. export philosophy	Processing facilities within winterized installation, proximity of personnel to processing facilities	Layout design to take into consideration need for winterization and location of plant.	L	B2		B3			FEE
6.03		Maintenance Philosophy	Plant/train/equipment item, heavy lifting, access, override, bypass, commonality of equipment, transport	Personnel working in harsh environment, equipment freezing and lack of infrastructure - limited supply vessel traffic	These items are to be included in the Maintenance Management Plan. Training to be carried out sufficiently and correct PPE to be provided	L	B2		B2			FEE
6.04		Control Philosophy	Appropriate technology, (DCS/local panels)	Hydrocarbons on board, limited mobility on host facility and supply boat traffic	Control philosophy to implement as many automated functions as practicable, shut down philosophy to take into account harsh conditions and possibility for delayed reaction.	M	C3		B2		Shut Down Philosophy and BoD to confirm requirement.	FEE
6.05		Manning Levels	Accommodation, travel, support requirements. Consistency with operations and maintenance, etc philosophies	Refer above 6.01		M	C3		B3			FEE
6.06		Emergency Response	Delayed ER due to remoteness and environmental conditions, ER during winter months, isolation, ESD philosophy, blowdown, flaring requirements	Refer above 6.01. If there is hydrates, then a blow down is needed.	Hydrate assessment study to be carried out, ER plan to be implemented taking into account difficulty in accessing host facility and subsea infrastructure during winter months.	L	C2					FEE
6.07		Concurrent Operations	Production, maintenance requirements	Tie-in of subsea wells and satelites.	Platform to be designed for limited SIMOPS (i.e. excluding drilling).	L			C2		To confirm potential tie-ins and design platform for limited SIMOPS (excluding drilling campaign).	Design
6.08		Start-up / Shutdown	Modular or plant wide	The mode of start-up shutdown is captured in the Operations Philosophy.	Remote start-up. Only fire and gas detection will shut down the platform in ESD.	L			C2		To confirm the mode for start-up in the Operating Philosophy.	Design
7.01		Stored Flammables	Improper storage, operator error (release), defect, impact, fire (mitigation measures include: substitute non flammable, minimise and separate inventory)	Hydrocarbons, diesel, jet fuels, chemicals for scale inhibition and methanol or MEG present on host facility.	Covered by design layout and operations procedures. Increased attention due to winterization	L	C2				To address in the design layout and operations procedures.	FEE

Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	P	E	A	R	Recommendation	Timing (Project Phase)
7.02	Fire and Explosion Hazards	Sources of Ignition	Electricity, flares, sparks, hot surfaces (mitigation measures include: identify, remove, separate)	Potential fire and sparks from equipment.	EX equipment and hazaraous area classification. Adequate purging systems to be implemented to route escaped gases to safe area.	L	C2				Proper selection of EX equipment and hazardousarea classification.	FEE
7.03		Equipment Layout	Confinement, escalation following release of explosive or flammable fluid (operator error, defect, impact process control failure, corrosion), module layout/proximity, orientation of equipment, predominant wind direction	Reduce degree of confinement, spacing based on consequence assessment, escalation barriers.	Plant Layout study to be carried out in design phase.	L	B3	B3	B3			FEE
7.04		Fire Protection and Response	Active/passive insulation, fire/gas detection, blowdown/relief system philosophy, firefighting facilities	Need for AFP and/or PFP as per burn down philosophy.		L	B3		B3			FEE
7.05		Operator Protection	Means of escape, PPE, communications, emergency response, plant evacuation	Emergency Response in light of H2S and other toxic gases and fire scenario needs to be reviewed.	Adequate Evacuation, Escape plans and emergency response to be implemented.	M	C4					FEE
8.01	Process Hazards	Inventory	Excess hazardous material	Refer 7.01								Design
8.02		Release of inventory	Excessive process stress, impact (penetration by foreign object), process control failure, structural failure, erosion or corrosion	Hydrocarbon or dangerous gases release	Recognise and minimise process hazards during design, inherently safe plant, containment and recovery measures	M	C3	C3	B3			Design
8.03		Over Pressure	Offsite sources, process blockage, thermal expansion/contraction, connection of process to utility systems, chemical reaction, material fit for purpose for cold climate	Overpressure and hydrocarbon / hazardous gases release	All equipment will be design to maximum Closed In Tubing Head Pressure (CITHP).	L	C2		C2		To confirm in the BoD that all up stream facilities including pipelines will be design for maximum CITHP.	FEE
8.04		Over/under Temperature	Atmospheric conditions, blowdown, fire, hot / cold surfaces, chemical reaction	High temperature of process equipment from flowline, headers to coolers and vs. cold temperatures of topsides surfaces due to atmospheric conditions	Insulation and/or cage to be provided for PPE. Trace heating for critical equipment to avoid ice build up and jamming of equipment	M	C3				To review the piping insulation requirementand PPE requirement to operate.	Design

Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	P	E	A	R	Recommendation	Timing (Project Phase)
8.06		Wrong Composition/Phase	Offsite contamination, failure of separation process, build-up of wrong phase (sand, hydrates, etc), toxic substances	Higher than expected H2S	Sour service requirements to be identified as per well fluid properties. Well stream to be tested for accurate measures.	M	C3					Design
9.01	Utility Systems	Firewater Systems	Freezing of fire water intake piping / penetrations / pumps / equipment	Inability to use fire water system when required	Heat tracing and adequate location planning, regular maintenance and inspection	M	B3	B4	B3			FEE
9.02		Fuel Gas	Availability of and addition of ignition source of fuel gases.	Refer 7.02								Operations
9.03		Heating Medium	Need for heating medium to combat harsh weather conditions and maintain adequate working environment conditions.	Loss of heating medium, material safety data sheet for heating medium	Adequate selection of heating philosophy and regular monitoring of heating system	L	B2					FEE
9.04		Diesel Fuel	Availability of and addition of ignition source of fuel gases.	Refer 7.02								Operations
9.05		Power Supply	Remoteness of facilities	Loss of power supply especially during winter months where maintenance and repairs campaigns are limited	Implement robust preventative maintenance and inspection routines.	L						FEE
9.07		Drains	Integrity loss of drain system	Leaks / discharges of hazardous waste drains to sea or within enclosed environment.	Robust design and regular inspection and maintenance of hazardous waste drains. Open drain systems to be implemented to avoid increased number of valve stations and introduction of blockage sources	L	B2	C2		B2		FEE
9.08		Inert Gas	Possible need for inert gas for AFP.	Personnel exposure to hazardous inert gas	Operating Procedures to clearly specify impact of including inert gas for AFP and mitigate against risk by avoiding personnel exposure	L	B2					FEE
9.09		Waste Storage and Treatment	Due to remote location some storage of hazardous waste will be necessary	Exposure of personnel to hazardous waste, incorrect lablelling / storage of hazardous waste, discharge to sea	Operating Procedures to clearly specify impact of including hazardous waste storage, correct labeling, handling and marking to be implemented	L	B2	B2				Operations
9.10		Chemical/fuel Storage		Refer 9.04 and 9.09								Operations
9.11		Potable Water	Due to remoteness of location, need for potable water production necessary	Contamination of potable water system	Adequate design and redundancy in potable water system, clear segragation from service water and other sources. Implement robust measures and labeling to avoid contamination of potable water, monitoring equipment to be implemented and routine checks.	L	B3			B3		FEE
9.12		Sewerage	Contamination of other systems such as service and potable water, discharge to sea not in accordance with regulations		Adequate design and redundancy in sewage system, clear segragation from service and potable water. Sewage handling facilities (macerator) to be included in design according to local legislation and health guidelines	L	B3	B2		B2		FEE

Code	Category	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	P	E	A	R	Recommendation	Timing (Project Phase)
10.01	Maintenance Hazards	Access Requirements	Cold climate and environmental coditions complicate access for maintenance especially during winter months.	Greater clearances required for cold climate operations, special attention to subsea maintenance and intervention especially during winter months where access to area is limited due to weather conditions.	Clear and robust Maintenance Management Plan and fall back procedures in case of corrective maintenance required during winter months.	L	B2		B3			Design
10.04		Commonality of Equipment	With implementation of new technology specifically suited to arctic climate, increased risk of human error and unfamiliarity with equipment	Human error, lack of possibilty for interchangeability especially during maintenance in winter months where supply traffic is limited	Implement adequate capital sparing philosophy, promote repeatability and standardization in design for maintenance.	L		B2	B3			Design
10.05		Heavy Lifting Requirements		Crane requirement for lifting of modules, both subsea and on host. Size and weights of equipment to be optimized to avoid use of heavy lift vessels and suitability for using Construction Vessels.	The frequency of lift will depend on the extent of infrastructure to be installed, weights, sizes, hook heights and crane reach.	L	C2					Design
10.06		Transport		Harsh climate and rapidly changing environmental conditions	Campaign based maintenance with support barge. Careful planning of logistics and robust supply chain management plan.							Design

ARCTIC FIELD DEVELOPMENT HAZID Register
Section 3: HEALTH HAZARDS

Code	Category - Guide Word	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk	Risk				Recommendation	Timing (Project Phase)
						H/M/L	P	E	A	R		
11.01	Health Hazards	Disease Hazards	Endemic diseases, infection, malarial mosquitoes, hygiene - personal and/or catering, contaminated water or foodstuff, social, e.g. AIDS, VD, etc stagnant water, poor living conditions	Food poisoning, personal and catering hygiene as well as bird flu (lots of birds on offshore facilities) could cause illness, low productivity, wide spread disease etc. although the cold temperatures are a good sedation for bacteria	Hygiene, catering tender , personal hygiene, material handling procedures in place	L	C1				Ensure continuous monitoring & awareness	Operation
11.02		Asphyxiation hazards	Asphyxiating atmospheres, failure to use appropriate PPE, vessel entry, winterization risk, working in confined spaces, smoke, exhaust	Confinement effects may potentially be an issue especially for winterized facilities where most of the equipment will be within confined spaces and exhaut routed to safe areas	Plant Layout Methodology study at early stage of project will define risks and mitigations associated with each of the plant areas	L	C1				Plant Layout Methodology (PLM) required	Operation
11.03		Carcinogenic	Chemicals in use	Methanol, MEG and diesel have potential to be carcinogenic	Material Handling and Management Strategy should address safe handling and disposal of chemicals	L	C2					Operation
11.04		Toxic	Hazardous atmosphere, asphyxiating atmosphere, chemicals in use	H2S, Hg, CO2 levels in process fluids could be harmful to the environment and to personnel.	H2S awareness, guidelines and standards adherence, ensure continuous monitoring and detection in place. Robust evacuation procedures and fail safe mechanisms.	M	B4				(1) Ensure that adequate barrier or control measures are in place to detect and isolate leak areas (2) Training and certification of personnel (3) Facilities to be designed to cater for H2S environment	Operation
11.05		Physical	Noise, radiation (ionising, gamma source e.g. radioactive scale or non-ionising, e.g. flares, UV, sunlight), ergonomics	Inadvertent exposure of personnel to radiation from NDT isotopes during construction / installation period.	Permit to Work (PtW) control and governance established.	L	B3			B3		Operation
				Prolonged exposure of high noise under normal operation, from HVAC, coolers, turbines and generators.	Limit personnel time exposure on platform and acoustic induced vibration (AIV) and noise study and noise contour mapping study for platform to identify noisy/hot spots where isolation and ear protection is required.	M	E2				Noise Monitoring to be implemented during operation and equipment degradation to be closely monitored.	Design
11.06		Mental	Shift patterns	Potential worries related to distance from shore, isolated environment with limited infrastructure around, evacuation procedures in high north not as robust as rest of Norwegian sector, potential sour gas production, increased health and safety risks due to cold climate and environmental conditions	Robust training program for evacuation and rescue from high north, training and reassurance to staff of potential risks and mitigations, training for sour gas facilities, suppling crew with thoroughly tested and trialled PPE fit for purpose	L	C2					Operation
11.07		Working Hazards	Diving, working in water, working at heights, hazardous equipment, hazardous surfaces, electricity, confined spaces, colc clmate	Platform installation and riser tie-ins., mooring activities, Man Overboard (MOB), maintenance in winter months	PtW in place, estabilsed procedure in place, fit for purpose PPE, protected and heated work environments where suitable with adequate ventilation	M	C4				Ensure specific measures are recorded as part of the Critical Activities Catalogue and Hazards and Effects Management Process (HEMP), ensure boat landing is away from risers	Design

Code	Category - Guide Word	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	P	E	A	R	Recommendation	Timing (Project Phase)
11.08		Transport	Excessive journeys, extreme weather	Mental and physical stress due to helicopter and seafairing traffic	Optimise crew change pattern to limit travel , ensure adequate equipment, evacuation, search and rescue plans and procedures are in place and that crew are trained sufficiently to deal with emergency situations. Implement and follow Journey Management Plans (JMP)	L	C1				Crew boat transport and intra-field personnel transfers to be reviewed as part of the Manning Philosophy and LIRA (Logistics and Infrastructure Risk Assessment), Detailed Field Development Transport Risk Assessment to be undertaken at decision gate 2 (Concept Design to Detailed Design)	FEE

ARCTIC FIELD DEVELOPMENT HAZID Register
Section 4: PROJECT IMPLEMENTATION ISSUES

Code	Category - Guide Word	Guideword	Hazard/Event (Expanders)	Threat	Controls, Barriers	Potential Risk H/M/L	Risk P	E	A	R	Recommendation	Timing (Project Phase)
12.01	Contracting Strategy	Prevailing influence	Stability and contractual conditions, contractor selection constraints	Risks related to schedule and quality of work depending on familiarity with contractor (e.g. if new contractor selected, time needed for familiarisation with company codes, standards, contractual requirements etc.)	Develop pre-approved vendor list and invest in front end familiarization of the contractors with company requirements to ensure a smooth detailed design phase.	M	C3	C1	C3	C3		FEE
12.02		Legislation	Governmental contracting requirements	Procuring equipment and materials from international vendors increases risk of compliance with local legislation and contracting requirements. Hiring foreign skilled workers also adds to this risk.	Develop pre-approved vendor list and invest in front end familiarization of the contractors with company requirements to ensure a smooth detailed design phase.	M	C3	C1	C3	C3	Secure ample competent workforce and provide training early to new crew via contractual obligations. Raise concerns regarding resources and equipment early in project	FEE
12.03		External Environmental Constraints	Governmental environmental requirements	New environmental requirements and compliance monitoring are always being introduced and may increase the risk for project delivery	Maintain close contact with government agencies and NGO to be able to foresee changes and react appropriately in due time	M				B4	Review all requirements before each decision gate and project phase.	FEE
13.01	Hazards Recognition and Management	Hazard Studies	HAZOP, SAFOP, QRA, FIREPRAN, PHR, EA, HRA, etc	Insufficient time and resources to implement suitable recommendations and actions from studies.	Dedicated HSE Engineer for project and suitable manhour planning to allow resources to handle unforeseen work tasks	M				C4		FEE
13.02		Project Controls	Quality assurance (change control, interdepartmental involvement and interfaces)	Improper QA/planning from FEE stage will affect project at later stage	Thorough Front End loading to be adapted on project and preliminary Project Execution Plan to be complete	M			C4	C4		FEE
14.01	Competency	Level of Indigenous Training	Quality of local workforce and contractors	Eager but unskilled and inexperienced work force specifically within Oil and Gas.	Setup training centres in local operating area to facilitate training of local workforce. Hire local workforce early and assign to other projects as trainees to build up required skills and knowledge.	L	C2	C2	C2	C1		Design
14.02		Training Requirements		Unfamiliar operation due to insufficient training for handling H2S, mercury and subsea operations	Operations Readiness Plan (ORA) includes competence and training requirements	M	C4	C0	C4	C3	Early training needs and strategy to be captured in ORP.	Design
14.03		Level of Technology	Necessary introduction of technology to tackle local challenges	Lack of familiarization of workforce with technology implemented, high life cycle cost due to training and errors during operation and maintenance.	Integration between design team and operations teams during design, fabrication and testing of new technology to build up competence and familiarization. Clear procedures and routines.	L	C2	C1	C2			Design
14.04		In-house vs. external resources	Not being able to fill core roles with internal skilled and competent resources	Insufficient internal resourcing could result in: (1) Project delays (2) Non-continuity of projects personnel (3) Increased project costs	Manpower plan to be developed where resource gaps are identified and recruitment campaign planned. Incentives to working in the high north to be considered vs. local content	M				C4	Direct interface between Projects and HR to discuss way forward I.e. cross -resourcing within company or external recruitment plans	Design
14.05		Specialized Skills	Lack of specilized arctic training and experience in the high north	Inexperienced crew working facility, scouting vessels, support vessels and other key roles where decisions are critical to operations. Misidentifying dangerous situations due to lack of understanding, training or experience.	Crew with high north and arctic experience, training schemes. Experienced personnel used in roles where decisions are critical to overall operations, i.e. ice scouting vessels.	M				C4	Underwater autonomous vehicles (UAV) are expected to take over many of the functions currently left to humans such as scouting and monitoring activities.	Operation