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OFFSHORE DRILLIN ACTIVITIES IN BARENTS SEA: CHALLENGES AND CONSIDERATIONS

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ABSTRACT

The number of oil and gas activities in the arctic and sub-arctic regions has been increased during the last decades due to recent advances in technology, increasing demand for hydrocarbons, and the fact that conventional hydrocarbon resources in other regions are approaching their maturity.

Drilling is one of the most important activities in the oil and gas operations, which may be present from the early stages of a field discovery till the end of production phase. Like anywhere else, drilling in the arctic and sub-arctic seas involves a wide range of challenges, which can result in higher levels of uncertainties and risks. Therefore, these challenges need to be considered through the whole life cycle of a field. The specifics of these areas like remoteness, lack of infrastructure, icing events, and sea ice conditions, as well as their harsh climate conditions intensify these challenges, and the resulting uncertainties, and risks. To be able to identify and manage such risks, the first step is to know the associating challenges, which consequently needs a thorough knowledge about the location of the operation, its characteristics, and climate conditions.

This paper describes and discusses the main environmental characteristics of the Barents Sea. It further reviews some challenges in drilling activities in this area, and some general considerations, by which these challenges can be managed.

1 INTRODUCTION

The Arctic holds about 84 billion barrels of undiscovered conventional oil (16% of world's undiscovered conventional oil resources) and 1,400 trillion cubic feet of undiscovered natural gas (25% of worlds' undiscovered conventional gas resources), (Christopher, 2012, 2012), which makes this region a good candidate for hydrocarbon exploration and production activities. However, this is just one of the reasons that demand for oil and gas (O&G) activities in the Arctic have been growing up in the recent decades. The other important factors can be:

- Conventional hydrocarbon resources in the other regions are approaching their maturity
- Recent advances in offshore technology and ship design has made the development of previously discovered resources (but not developed yet) to be economically beneficial
- Using state-of-the-art technologies to have a better mapping, seismic activities and assessment of resources, has provided the companies more accurate information about the arctic climate conditions as well as the characteristics of its hydrocarbon bearing formations
- The trend of increasing temperature in the Arctic during the recent decades has resulted in thinner ice, ice sheet shrinkage, decrease in sea ice cover period, and consequently easier access to the Arctic Ocean and coastal areas (DNV/FNI, 2012)

The O&G industry has started operation in the arctic and sub-arctic areas since 1960s, when giant Prudhoe Bay field in Alaska was discovered (Matskevitch, 2007). Like in any other region, O&G activities in the Arctic are facing a wide range of challenges. In the Arctic, these challenges are arising from its harsh and divers climate conditions, society concerns, remoteness and lack of infrastructure.

Due to the diversity in the arctic climate conditions, some solutions that are applicable in one location, may not be suitable somewhere else. For instance annual climate changes in the Arctic are found to be more severe than anywhere else. In some places air temperature varies by 50°C from summer to winter, or amount of sea ice will reduce by 70% from winter to summer in some areas (DNV/FNI, 2012). While some places can have several months without sun or several months with midnight sun, some other areas experience darkness and midnight sun periods for only a couple of days or weeks. Hence, the solutions for arctic developments are different and in addition to the activity, they depend on the activity location and its climate conditions.

Several authors have described drilling and production challenges involved in some projects in the arctic and sub-arctic areas. Krieger, et al., (2003) have discussed development challenges in the Northstar field in Alaska's North Slope. Hamilton (2011) has described several challenges of deep-water offshore development in the arctic seas. Marsden et al. (2011) have studied feasibility of escape, evacuation and rescue for the arctic operating platforms, considering different situations of sea ice conditions and open water periods. Kipker and GmbH (2011) have studied rig winterization and human, safety and Environment (HSE) management as well as maintenance programs for a land rig on an artificial island in the arctic environment. Barnes (2011) has described some challenges of Russian onshore and offshore field developments in the arctic environment. Due to the differences in the arctic areas and their characteristics, the types of arising challenges may be different too. For example as British Petroleum (BP) developed Northstar field in Alaska's North Slope, one of the challenges was how to face with the danger of polar bears (Krieger, et al., 2003), while there is no polar bear at all in the western parts of the Barents Sea, where Statoil is operating Snøhvit gas field. As another example, while how to build an artificial spray-ice island to support onshore drilling rig may be a challenging task in the Canadian Beaufort Sea, offshore activities in the western parts of the Barents Sea are deep water drilling activities using floating drilling units (Weaver and Poplin, 1997). Therefore to manage these challenges, a comprehensive understanding and knowledge about the location is necessary.

This paper reviews the important environmental and climate characteristics of the Barents Sea, focusing on its western part, and then discusses the general difficulties and challenges, which may be faced during the drilling activities in this area. Further, looking from dependability point of view, it reviews some considerations given in the previous case studies and literature, which need to be planned in order to manage the encountering challenges.

2 BARENTS SEA

The Barents Sea is a marginal sea reaching the Arctic Ocean in the north, bordering the Greenland and the Norwegian Sea in the west, the Kara Sea in the east and the coast of Kola Peninsula in the south (see Figure 1). The Barents Sea average depth is around 230 m. It has a depth of less than 100 m at the central and southern parts as well as on Svalbard Archipelago coast, and a depth of 600 m at the deepest sections. Its total area and water volume is 1,420,000 km^2 and 316,000 km^3, respectively (ISO/FDIS 19906, 2010).

2.1 Hydrocarbon resources

The total undiscovered conventional hydrocarbon resources in this area is: 11 billion barrels of oil, 380 trillion cubic feet of natural gas, and 2.2 billion barrels of natural gas liquids

(NGL), of which 3.47 billion barrels of oil, 58.46 trillion cubic feet of gas, and 778 million barrels of NGL lie in the Norwegian sector of the Barents Sea (Klett and Gautier, 2009).

Goliat and Snøhvit are the only fields, currently being developed in the Norwegian sector of the Barents Sea. The Goliat oil and gas field with total recoverable reserves of 174 million barrel of oil and 282.5 billion standard cubic feet of gas is discovered in 2000. The production is planned to be started in the third quarter of 2014. The Snøhvit unit with recoverable reserves of 6.71 trillion cubic feet of gas and 636 million cubic feet of gas condensate consists of three fields: Snøhvit, Askeladd and Albatross. Snøhvit field is discovered in 1984, started production in 2007 and will continue for more than 30 years. The unprocessed produced gas stream is transported in pipeline 150 km to the onshore Melkøya LNG plant near Hammerfest (See Figure 2) (DNV, 2012). The Havis and Skrugard oil fields (7 km away from each other) were discovered in January 2012 and April 2011, respectively. Both of them are estimated to have 400-600 million barrels of oil. The production is to be started in 2018 (Buffagni et al., 2012). There are also some gas and gas condensate resources in the Russian sector of the Barents Sea, mainly in the eastern part and in the Kara Sea. However, in this paper it is tried to be focused on the Norwegian sector. See Moe and Rowe (2008) for detailed Russian petroleum activities in the Barents Sea.

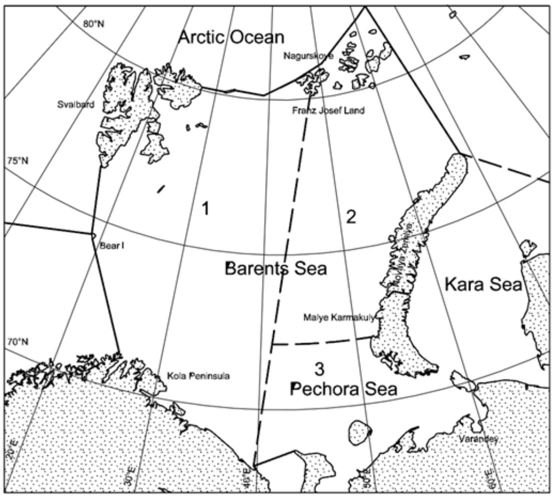

Figure 1. Barents Sea: 1-western region, 2-northeastern region, 3-southeastern region (ISO/FDIS 19906, 2010).

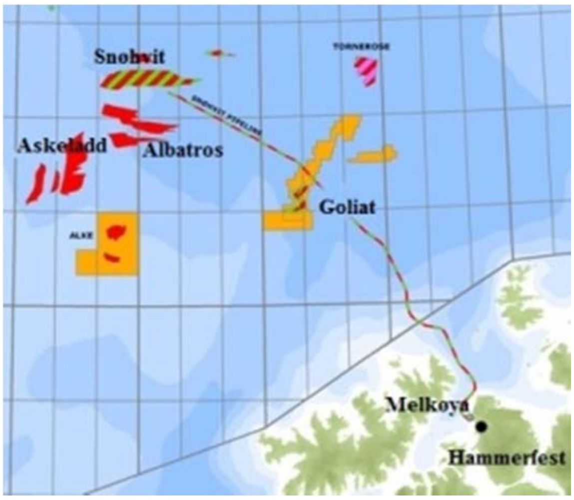

Figure 2. Snøhvit and Goliat fields in the Norwegian sector of the Barents Sea (EniNorge, 2013).

2.2 Climate Conditions

A proper understanding of the physical environment is required for a safe and reliable industrial activity. In this section major metocean and meteorological characteristics of western part of the Barents Sea, as well as darkness period and sea ice conditions are briefly reviewed.

Barents Sea has a diverse climate conditions. This diversity can be seen in air and water temperature, sea ice features, sea ice-covered and open-water periods, waves, winds, currents, and so on. As shown in Figure 1, the Barents Sea can be divided into three separate regions based on general climate conditions: Western, North-eastern, and South-eastern regions (ISO/FDIS 19906, 2010).

Another division, which is based on general physical-geographical features of the Barents Sea (seabed relief, atmospheric processes, system of currents, ice edge position, etc.), is shown in Figure 3 (DNV, 2012). Based on this grouping, all discovered Norwegian fields lie in subarea II. Based on the division by ISO/FDIS 19906 (2010), they will lie in subarea No. 1

(i.e. the western region). So to be more focused, the climate and sea conditions relating to only these parts will be discussed.

Air and Surface Temperature: The average air and water (surface) temperature in the western part of the Barents Sea generally varies between -9 to 7°C and 5 to 9°C, respectively (ISO/FDIS 19906, 2010). Figure 4 shows the highest and lowest air temperature in the Barents Sea with an annual probability of exceedance of 0.01.

Darkness and Visibility: Darkness period in the winter season and lack of enough visibility due to fog and snowstorm are the other specific factors of the arctic seas.

Decrease in visibility generally occurs due to snowstorms, fog and rain. In the western part of the Barents Sea, the annual number of days with the visibility of less than 1 km (due to fog) is between 50 to 80 days. For the visibility of less than 2 km (due to snowstorm) it will be between 100 to 130 days (ISO/FDIS 19906, 2010).

Darkness period (polar nights) in winter refers to the number of days, in which sun goes below the horizon. Going further towards north, the number of polar nights increases. Table 1 shows darkness period for some places in the Barents Sea and Svalbard Archipelago.

Table 1. Darkness period in some places in the Barents Sea (www.yr.no)

Place	Darkness Period	
Hammerfest	22 Nov.	20 Jan.
Bjornoya (Bear Island)	07 Nov.	04 Feb.
Hopen	31 Oct.	10 Feb.
Pyramiden, Svalbard and Jan Mayen	25 Oct.	17 Feb.
Nu-Alesund, Svalbard and Jan Mayen	24 Oct.	18 Feb.
Rossoya, Svalbard and Jan Mayen	19 Oct.	23 Feb.

Figure 3. Barents Sea subareas designed by AARI: I. Spitsbergen, II. Norwegian, III. Franz Josef Land, IV. NE Barents Sea, V. Novozemelsky, VI. Kola, VII. Pechora, VIII. White Sea (DNV, 2012)

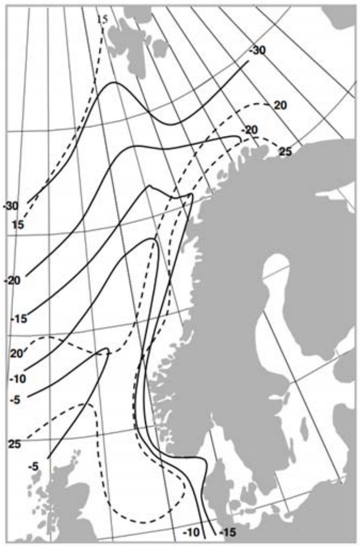

Figure 4. Highest (dotted line) and lowest (solid line) air temperature (°C) with an annual probability of exceedance of 0.01(Norsok N003, 2007).

Polar Lows: A polar low (See Figure 5), which forms only over ice-free sea and mainly from September to early summer, arises when a system of cold polar air moves over a relatively warmer area. While the flowing cold air, coming from ice-covered ocean, has a temperature of around -40 to -20 °C, every open sea can be a source of heat, even if its temperature is in the range of -1.9 to 5 °C (Carstens, 1985; Kristiansen, et al., 2010). The European Arctic (like the Greenland Sea and the Barents Sea) and the North Sea, where the North Atlantic currents pushes warm water up towards the ice and enhances the heat flux with surface temperature up to 5°C, are a common area for polar lows to happen (Hamilton, 2004; Kristiansen et al., 2010). Some of the Polar lows' characteristics are listed below (Gudmestad and Karunakaran, 2012; Bulakh, et al., **2011**; Carstens, 1985; Hamilton, 2004; Kristiansen, et al., 2010; Baller, 1983):

- Diameter of 400 to 800
- Life span of 6 to 46 hours from initiation to decay
- Difficult to predict, due to the lack of appropriate models
- Rapid development from zero to storm in about 15 minutes
- Strong winds, up to 50 to 70 knots (25 to 35 m/s)
- Associated with gale or storm force winds, seldom hurricane
- Associated with heavy snow showers, icing, and wind direction change
- Associated with decreased visibility due to snowstorms

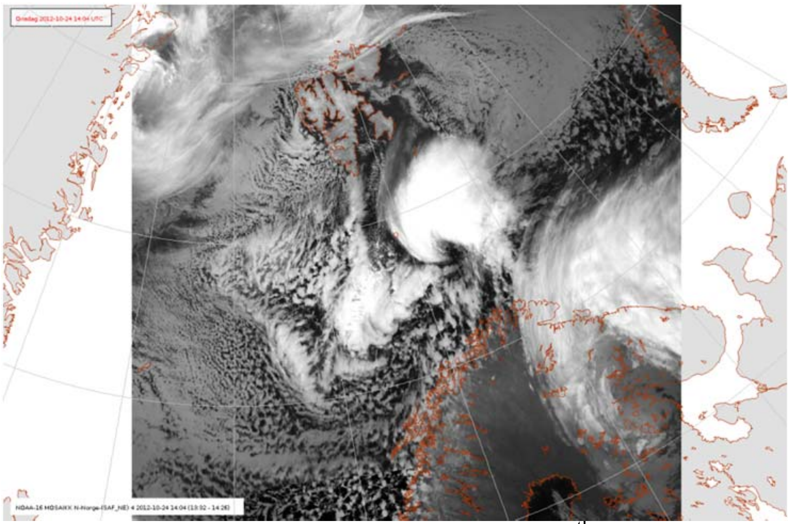

Figure 5. A polar low in the middle of the Barents Sea on 24th October 2012, associated with the maximum snow depth of 82 cm, lasted for about 24 hours (Meteorologisk Institutt, 2013a)

Wind: Generally strong winds and cyclones, forming in the North Atlantic and moving into the central part of the Barents Sea or southward to the Kola Peninsula, determine the meteorological conditions in the Barents Sea. In winter, the most common wind patterns are southwesterly and southerly, which are predominant in the southern parts, and northeasterly winds, which are predominant in the northern areas. In summer, cyclones are moving northwards. Their probability of occurrence decreases to two per month. Most regions are associated with weak winds with variable directions (ISO/FDIS 19906, 2010). Generally, the highest wind speed appears around Bjornoya (Bear Island) and decreases towards east and north, while equally distributed (Gudmestad, 1999).

It should be noted that, apart from the regular winds, polar low phenomenon creates high speed cyclonical shape winds and storms, which as stated earlier, they are unfortunately hard to predict. For example a polar low on 6th February 2012, created strong winds with maximum speed of 20 m/s (Meteorologisk Institutt, 2013b), while the average wind speed in January is about 9.6 m/s (Gudmestad, 1999).

Wave: There is little variation in the mean significant wave height and wave period in the western Barents Sea; however the wave height and period decreases eastward (Norsok N003, 2007). Figure 8, shows significant wave height, in meter (solid line), and related maximum peak period, in second (dotted line). While there is no enough data for wave heights and their peak period, or a limited number of measurements have been carried out, conservative values (such as those shown in Figure 8) should be considered (Norsok N003, 2007).

Sea Ice: Sea ice conditions in the Barents Sea are quite divers. While the southwestern parts are always ice-free from November to May, sea is generally covered by ice in the northern parts to the east of Bjornoya (Bear Island) (DNV, 2012; Gudmestad, 1999). Among the 8 sections of the Barents Sea, shown in Figure 3, while subarea II (Southwestern Barents Sea) is generally ice free, subareas I, III, IV, VII, and VIII have usually ice every winter. Regions V and VI are in between (DNV, 2012). The reason why the whole Barents Sea is never completely covered by ice is because of heat influx driven by the Atlantic Ocean waters (Bulakh et al., 2011).

Ice in the Barents Sea is a combination of multi-year (thickness of up to 3 m) and first-year (thickness of up to 1.5 m) ice as well as icebergs, in which multi-year ice is generally spread along the eastern coast of Svalbard Archipelago and Franz Josef Land (ISO/FDIS 19906, 2010).

Icebergs are coming from Svalbard Archipelago, Franz Josef Land, and Novaya Zemlya, and will be drifted by the dominant wind and ocean currents (ISO/FDIS 19906, 2010). Limit of first-year ice and limits of collision with icebergs are shown in Figures 7 and 8, respectively.

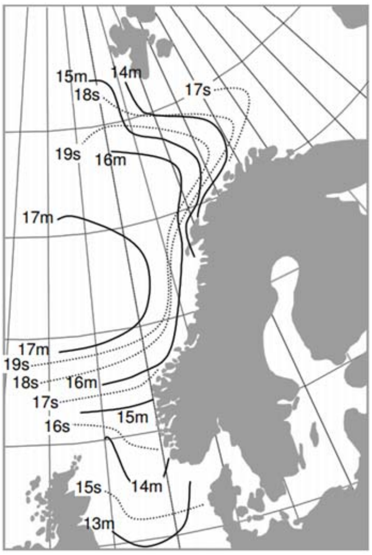

Figure 6. Significant wave height (solid line), in meter, and related maximum peak period (dotted line), in second, with annual probability of exceedance of 10^{-2} (Norsok N003, 2007)

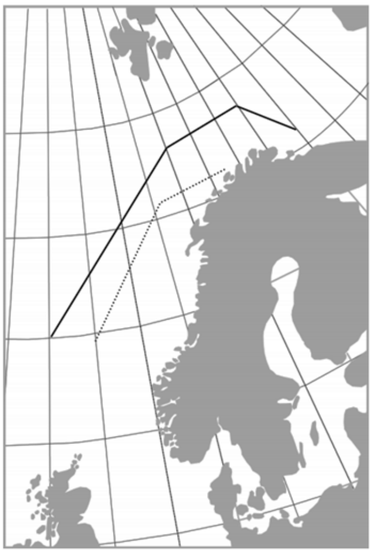

Figure 7. Barents Sea ice limit – Annual probability of exceedance of 10^{-2} (solid line) and 10^{-4} (dotted line) (Norsok N003, 2007).

Figure 8. Iceberg collision limit in the Barents Sea – Annual probability of exceedance of 10^{-2} (solid line) and 10^{-4} (dotted line) (Norsok N003, 2007).

Sea-Spray Icing: Sea-spray ice forms within an especial range of air temperature and wind speed, when wind-blown water droplets, generated from whitecaps on the ocean surface, strike a structure. Since wind spreads the spray droplets, it is highly expected to see the accreted ice on the windward sides of the structures.

It should be noted that generally due to washing effects of waves there is no spray ice near the waterline. The two most important factors affecting the intensity of sea-spray icing are wind speed and air temperature. Wind increases the heat loss rate of airborne droplets and accelerates icing process. The intensity of icing will steadily increase as temperature decreases below -2 °C (Ryerson, 2008). Figure 9 shows the possible places of atmospheric icing and sea-spray icing on a platform.

Atmospheric Icing: ISO 12494, (2001) defines atmospheric icing as "all processes, where drifting or falling water droplets, rain, drizzle or wet snow in the atmosphere freeze or stick to any object exposed to the weather". Therefore atmospheric icing is classified as types of ice, based upon methods of deposition and characteristics of deposits. This classification includes: glaze from precipitating freezing rain or freezing drizzle, snow, rime ice resulting from super-cooled cloud or fog droplets, and hoar frost resulting from the deposition of water vapor directly as ice crystals. Sleet and sea-spray, are not included in atmospheric ice category (Ryerson, 2011). While atmospheric icing can form anywhere, lower parts of the platforms are the main sea-spray ice accretion areas (See Figure 9).

Figure 9. Potential ice accretion areas by ice type on a platform (Paulin, 2008)

3 OPERATIONAL CHALLENGES

There is a variety of technical challenges and problems while operation in normal climate conditions, such as wellbore problems, and surface and downhole equipment corrosion and failure, etc. Dealing with these challenges in the arctic regions, has its own difficulties and concerns, for example: difficulties in doing preventive and corrective maintenance activities because of storms, winds, ice, and very cold temperature; or delays in providing spar part and technical services and teams because of bad weather conditions and lack of infrastructure. Therefor after specifying the climate conditions and physical environmental characterises of the operation location, their effects, on the operations should be known too. The following sections describe these effects form dependability point of view.

3.1 Dependability

Dependability is defined as "the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance" (IEV 191, 2013). Availability performance is then defined as "the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided" (IEV 191, 2013).

Before discussing dependability elements, "item" is needed to be defined. IEV 191, (2013) defines item as "any part, component, device, subsystem, functional unit, equipment or system that can be individually considered". It further describes "An item may consist of hardware, software or both, and may also in particular cases, include people". Therefore in drilling operation, in addition to mechanical or electrical equipment, a variety of activities (such as tripping, making connections, platform disconnection, etc.) and drilling operation systems (such as rotating, circulating, hoisting, etc.) can be considered as an "item".

Dependability elements are defined as:

- *Reliability performance:* the ability of an item to perform required function under given conditions for a given time interval (IEV 191, 2013).
- *Maintainability performance*: the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources (IEV 191, 2013).
- *Maintenance support performance:* the ability of a maintenance organization, under given conditions, to provide upon demand the resources required to maintain an item, under a given maintenance policy (IEV 191, 2013).

3.2 Reliability performance challenges

Arctic harsh climate conditions can affect the reliability performance of an item by increasing its failure frequency. Therefore it is necessary to study how these conditions may result in the failure of an item.

One of the most important challenges in the cold climate operation is icing, due to either sea-spray or atmospheric icing. Low air temperature, combined with winds, and sea-spray, can lead to marine icing events (Ryerson, 2009). Though some part of the drilling platform is covered as a winterization policy; however, there are still some areas that spray icing can occur. Additionally atmospheric icing cannot be avoided in helicopter deck or high elevation places like drilling derrick. Icing can create a number of challenges and difficulties in the operations such as (Ryerson, 2011):

- Decrease in crew safety, operational tempo and productivity
- Stability issues of support vessels
- Issues regarding firefighting operations
- Inaccessibility to ice-covered equipment, which is required for an activity
- Decrease in crew performance efficiency because of slippery surfaces and safety issues

The other climate conditions and arctic specifics can also have effects on the reliability of activities or systems such as:

- Low temperature coupled with winds can increase human errors due to wind chill effect (the felt temperature by humans).
- Darkness and working in harsh climate conditions can make team and crew selection difficult.
- Cold weather, snow, and atmospheric and sea-spray icing needs the drilling platform to be winterized. However working in a closed area will have its own difficulties like large energy requirements and ergonometric designs, danger of slips and falls (Gudmestad, 2010)
- Any gas release from the wellbore or surface facilities will cause severe safety problems in the case of not having adequate ventilation.
- Bad weather condition may cause delays in regular transportation of drilling crew, providing emergency needs, and transferring the injured people by helicopter.
- Steel and plastic materials are brittle in very low temperature. Cold air also can affect the efficiency of sealants, lubricant and welding joints.
- Lighter components of natural gas can form gas hydrates in the presence of water, under high pressure and low temperature conditions. Formation of gas hydrates can cause corrosion and blockage in the tankers, pipelines and pumps.
- Rig energy can be provided by fuel combustion or by electricity cables from the shore. Providing electricity from the shore may be challenging due to long distance to the

shore. Although combustion of natural gas to provide the required energy is environmentally friendlier than other coal fuels, it needs its special safety concerns.
- Strong winds, which can happen during polar lows, can be a threat to the stability of drilling derrick or other structures.
- The possibility of having iceberg in the western and southwestern parts of the Barents Sea is quite low. However, going further to the places with higher probability of having iceberg, needs platform towing facilities and ice management.

3.3 Maintainability performance challenges
Arctic harsh climate conditions and its other specifics can increase downtime in the operation by decreasing maintenance team capabilities, and accessibility to the failed components; specifically:
- Wind and snowdrifts reduces accessibility as well as personnel capabilities. Snowstorm decreases the visibility and makes the maintenance jobs even more difficult.
- Formation of atmospheric and sea-spray icing on the equipment reduces accessibility. Slippery surfaces and falling ice are other hazards, which decrease the maintenance team capabilities.
- Wind chill phenomenon affects the maintenance team efficiency.
- Fog can decrease the visibility and affect the inspection and maintenance jobs.
- Darkness may cause some emotional/health problems for the maintenance team
- Polar lows can stop maintenance activities and increase downtime due to their associated strong winds and snowstorms.
- Low air temperature and sea-spray or atmospheric icing may affect some maintenance, inspection and condition monitoring tools and equipment, like alarms and gauges.

3.4 Maintenance support performance challenges
Defining and developing maintenance procedures, procurement of maintenance tools and facilities, logistics and administration, documentation, and development and training programs for maintenance personnel are some of the essential features of a maintenance support system (Barabady, 2007). Working in the arctic areas, can cause some challenges in any of these features, which consequently affects the whole maintenance programs and activities, especially due to delays in providing well-trained maintenance team and spare part. In this regard, the cost of unplanned maintenance activities may be quite high because appropriate support may take a number of days or weeks in the case of unpredicted harsh weather conditions. Additionally:
- Remoteness and lack of infrastructure increase down time, if an expert maintenance team or technical services are needed.
- Very cold temperature, snow, icing events and long periods of darkness requires well-trained maintenance crew, capable of working in such harsh conditions.

Fortunately the western part of the Barents Sea is never covered by ice. However, going towards north and northeast in the future, this would cause additional challenges in providing spare part and technical services.

4 DEALING WITH CHALLENGES
To be able to work under harsh climate conditions, drilling rigs must be modified to guarantee reliable and safe operations. These modifications include rig winterization as well as applying some changes to the rig structure (like enclosed rig floor) in order to meet the safety and environmental regulations. To implement these challenges use of qualified technology and experience, and implementing risk analyses are recommended (Gudmestad, 2010). In this

regards, there are several standards that must be met by the companies and operators. For example, the Norwegian standard, NORSOK N003 specifies general principles and guidelines for determination of actions and action effects for the structural design and design verifications of all types of offshore structures used in petroleum activities. NORSOK D series include several standards, describing drilling activities' regulations and requirements for the operations in the Norwegian Continental Shelf. For offshore activities, in addition to some local standards like DNV-OS series, which include offshore activities' regulations in Norway, there are some International standards that must be met too, such as ISO 19906:2010 which describes the requirements for offshore operations in the arctic and subarctic areas.

To implement rig modifications, a good solution can be looking at the previous similar cases, and consider them as a benchmark for the further operations. For instance the experiences and lessons learnt in Snøhvit development drilling operations can be used for further drilling activities in Goliat or the newly discovered fields of Skrugard and Havis, because they are located in areas with to some extent, similar climate conditions.

One of the main parts of rig modification is winterization, which makes the drilling platform be able to work under arctic climate conditions. For example Statoil sheltered and enclosed rig's exposed areas such as drilling floor, derrick, muster stations, pipe and riser deck, etc., to provide a tolerable working area for the crew (Eikill and Oftedal, 2007). Figure 10 and 11 show two semisubmersible platforms in the North Sea, Norway (not winterized) and Okhotsk Sea, Russia (winterized). While the North Sea climate conditions do not require rig winterization, Polar Star semisubmersible rig has been winterized to be able to work under harsh climate conditions in the Okhotsk Sea.

Figure 10. Semisubmersible Transocean Arctic platform in the North Sea, Norway (Offshore-mag, 2013).

Figure 11. Polar Star semisubmersible platform, in the Okhotsk Sea, Russia (Vyborgshipyard, 2012) .

However, there are still some uncovered places, where anti-icing and de-icing solutions should be applied there (Ryerson, 2011). Some of the common and important considerations, regarding rig winterization are listed below (Ryerson, 2009):

- Design considerations for the hull, crane pedestals, helideck, and derrick
- Wind force considerations for the enclosed areas
- Design considerations of ballast, ventilation and firefighting systems
- Platform stability considerations with respect to sea-spray and atmospheric icing
- Means to ensure availability of escape ways, lifesaving, and evacuation equipment

- Insulation and heat tracing of critical equipment, escape ways, and the places which need to be reached during operation
- Providing heating systems for the enclosed areas
- Ensuring that safety systems and blowout preventers (BOPs) are highly reliable
- Availability of different methods of anti-icing and de-icing such as: use of chemicals, coating, thermal, mechanical
- Material design, regarding the extremely low temperature of the arctic, such as sealants, plastics, metals, and lubricants

In addition to winterization, there are also other parameters need to be considered. These items can be related to the environmental regulations or arctic environmental challenges. In this regard, some of the important considerations are described below.

Drilling Waste Management: Due to zero discharge policy in the Norwegian sector of the Barents Sea, drilling wastes should be either barged to the shore for eternal disposal or re-injected into the subsurface (Camus and Dahle, 2007). Regardless of different waste disposal methods, there should be some special containers on the platform to store the drilling wastes, in the case of delays in transferring cuttings to the shore or until the waste-disposal well is ready for waste re-injection (Krieger et al., 2003). Additionally, in the case of waste transport to the shore, making sure of vessel stability and preventing accidental discharge to the sea are the main concerns from environment point of view. Waste re-injection needs special onboard facilities to prepare the waste slurry and re-inject it into the subsurface. It should be noted that stoppage in the re-injection process can consequently cause the stoppage of drilling operation.

Air Emission Regulations: Regulations of air-emission requirements should be considered while rig modification. Use of natural gas for power generation and electrification of engines are the common ways to meet the air-quality requirements (Krieger et al., 2003). Additionally, regular air-quality measurements are needed to assure that emission level meets the environmental regulations.

Well Control System Improvements: To ensure rigorous prevention against or preparation for well-control incidents, detailed risk analyses as well as modifications to related systems like BOP, stripping equipment, and drillpipe tool-joint should be done (Krieger et al., 2003). Installing redundant safety valves, implementing regular inspection and preventive maintenance activities are recommended to reduce the failure probability.

Personnel Training: Drilling crew should know about and understand the possible challenges in, and circumstances of their working conditions. For instance they should be taught what to do in the case of polar lows and extreme snowstorms and winds. Emergency actions like escape and evacuation plans should be clearly described for the people on board too.

Emergency Preparedness: Before starting any operation in the arctic offshore, a reliable, safe and whole-year plan for Escape, Evacuation and Rescue (EER) and oil spill removal, must be developed. All drilling crew members should be aware of their responsibilities in these emergency cases (ISO/FDIS 19906, 2010). These plans should consider some factors such as sea ice and climate conditions, wind, and sea wave characteristics, polar nights' periods, limited visibility periods due to fog and snowstorms as well as distance to the shore (Marsden et al, 2011).

Service and Spare Part Support Program: At present, Polarbasen warehouse in Hammerfest is the only main hub in Northern Norway, which provides logistic supports and operational needs the Norwegian sector of Barents Sea. Due to increase in the number of offshore O&G activities in this area, maybe the needs for expanding this hub will arise in the future. Preparing a reliable and year-around available spare part and service support program is a requirement to prevent or reduce the delays and resulting stoppage in the operation. This plan should be prepared according to the specifics of the area, sea state, and climate conditions.

5 DISCUSSION AND CONCLUSION

Harsh climate conditions, society concerns, remoteness, and lack of infrastructure and data add a wide range of challenges to the offshore O&G operations in the arctic seas. Therefore design for operation, needs to consider such special conditions to mitigate the arising challenges and resulting risks and hazards. This must be done taking into account, local and international regulations and standards.

As the Barents Sea is known to have large amounts of discovered and undiscovered oil and gas resources in Norway, it has become an area of focus for O&G industries. To design for a drilling activity in the Barents Sea, after recognizing and analyzing the climate conditions and other physical environmental characteristics, drilling platforms must be modified to be able to work under such circumstances. These modifications include rig winterizations as well as improving the reliability of critical systems like well control system.

Additionally, emergency preparedness for EER and oil spill removal plays a crucial role in managing health, safety and environment (HSE) risks. Moreover having an available plan for spar part and service provision will reduce delays in operations considerably. Establishing more collaboration between Russia and Norway can help to manage these emergency situations.

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