NTNU – Trondheim
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Proactive Emergency Preparedness in the Barents Sea

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Reliability, Availability, Maintainability and Safety (RAMS)
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Preface

This thesis is conducted as a part of the study program for Master of Science in RAMS studies at NTNU during the spring semester 2012. The thesis gives an insight into accidents and incidents in the Arctic Sea related to offshore petroleum exploration and production with respect to the emergency preparedness handling of these accidents and incidents. It further discusses the emergency preparedness challenges for petroleum exploration and production in arctic and sub-arctic areas.

This report is part of the project "Preparation of first line emergency strategy and dimensioning of the Goliat emergency preparedness" at SINTEF Safety Research in Trondheim.

Salma Basharat

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Summary

Today rise in oil and gas demand, energy crisis, issues concerning energy security and increase in oil prices in the world provoke further exploration and production of oil and gas. The Arctic Sea is the last frontier of abundant hydrocarbon reserves. Having effective regulations, innovative technologies and adequate safety norms, the world has still seen some major accidents such as Gulf of Mexico accident. Knowing that offshore petroleum industry is moving further north in Arctic poses additional challenges due to harsh climatic conditions and remoteness from existing oil and gas infrastructure.

The objective of this thesis is to provide an overview of offshore petroleum activity in arctic and sub-arctic areas as well as the accidents which took place in these areas. Furthermore, the accidents are analyzed with respect to the emergency preparedness handling of accidents using the NORSOK Z-013 standard as one basis. The thesis also discusses the anticipated emergency preparedness challenges for arctic and sub-arctic areas.

The Arctic Sea is the final destination in the north having enormous amount of hydrocarbons. The harsh weather conditions of the Arctic Sea characterized by polar lows, long nights, extreme fog and sub-zero temperatures have not prevented the countries bordering the Arctic Sea in exploiting the oil and gas resources. Russia, having extended pipeline infrastructure, has the most active part in the Arctic region followed by the US and Norway. The offshore exploration and production activities in the Canadian and Greenland Arctic Sea are gradually progressing.

Up to date, there have been very few accidents in the Arctic Sea thereby providing a limited knowledge base for emergency response in the Arctic Sea. The accidents which we have been able to account for are mainly related to blowout, pipeline leak, ship collision and capsize accidents. The accidents have occurred in the Russian Arctic Sea and the Alaskan Arctic Sea.

The NORSOK Z-013 standard refers to alert, danger limitation, rescue, evacuation, and normalization as the five emergency preparedness phases and their detailed description is

available in the Activities Regulation by the Petroleum Safety Authority in Norway (PSAN). It is stated in the NORSOK Z-013 standard that a set of Defined Situation of Hazard and Accident (DSHA) needs to be defined as part of the risk and emergency preparedness analysis. The set of DSHAs provided in the “Trends in risk level” project is used in this thesis for the classification and analysis of the accidents in the Arctic Sea.

The analysis of the accidents in the Arctic Sea shows that all the emergency operations went through the phases of alert and normalization while the oil spill related accidents did not pass through escape and evacuate operations as there were no personnel involved in these accidents. All the emergency operations were affected by bad and tough weather conditions. Advanced emergency preparedness tools, equipment and technology are needed for effective emergency operations under such conditions. Due to scarcity of accidents in the Arctic Sea, only four DSHAs (out of 12) have been experienced, or at least reported. It may be that some of the remaining DSHAs are not reported due to minor consequences.

In addition to the lessons learned from the emergency response operations for the accidents experienced in the Arctic Sea, there are also some emergency preparedness challenges which can be anticipated. The challenging weather conditions due to sudden polar lows, strong winds, spray icing, snowstorms and severe fog can hamper the emergency operations. Furthermore, long distances and lack of infrastructure can create communication and logistic problems and can result in delay of rescue and evacuation operations. Robust and reliable ice and weather data is a challenge due to global warming and may become a limiting factor for the adequate design of offshore equipment. The use and maintenance of emergency response equipment is also a challenge in sometimes dark, snowy and foggy areas of the Arctic Sea and the Barents Sea.

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1. Introduction

This chapter gives a background description about the need for dimensioning of emergency preparedness in the Arctic Sea. It also describes the objectives, scope and limitations, approach, and structure of the report.

1.1 Background

In the middle of the 21st century, the world will face doubling of energy use (Shell, 2011a). The overall utilization of natural gas and oil will increase by 25% and 20% respectively in the next 25 years (Harsem et al., 2011). Figure 1 shows a rise in the oil and gas demand for the upcoming years.

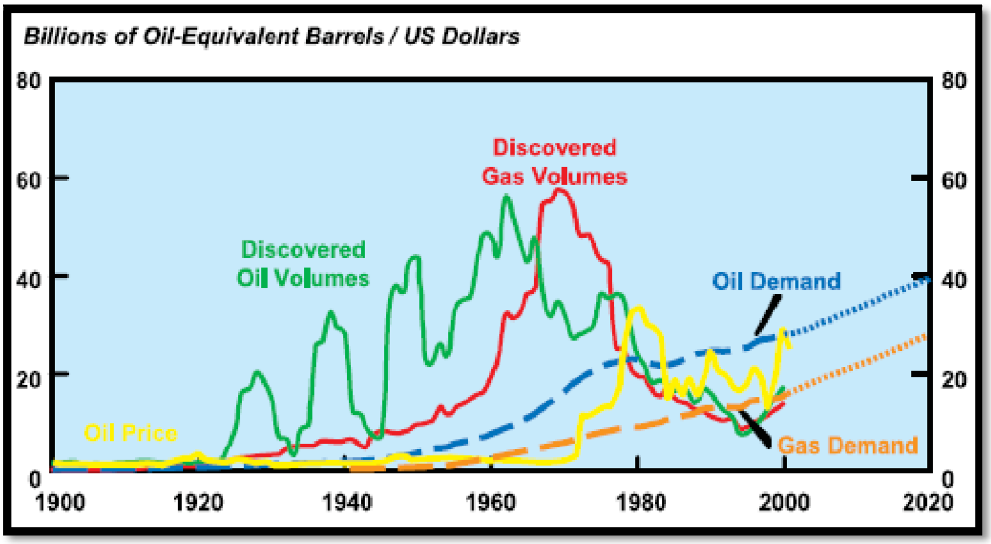

Figure 1 Trends in oil and gas demand (Longwell, 2002)

There is a dire need for the exploration of hydrocarbons due to the rising energy demands, high oil prices and concerns over energy security. In order to meet these demands successfully, the offshore petroleum industry is moving further north to the Arctic area. The Arctic Sea is a final destination for the hydrocarbon exploration and drilling. The Arctic Sea has enormous petroleum reserves amounting to almost 10% of the world's known conventional petroleum resources.

Onshore oil production in the Arctic Sea began in the 1940s while offshore production started in the 1960s, but still, most of the Arctic areas including the Barents Sea are unexplored. US, Norway, Russia, Greenland and Canada are the main oil producing countries in the Arctic area (Shell, 2011a). All these countries encounter problems during exploration and production due to challenging environment of Arctic. The arctic and sub-arctic areas including the Barents Sea pose risks to life, assets and environment. The risks are due to the following factors:

a) The harsh and extreme weather conditions such as icing, low temperature, darkness, polar lows
b) The extra remoteness and long distance from shore
c) Lack of infrastructure

Norway is an oil producing country in the North Sea and the Barents Sea (part of the Arctic Sea). Norway has experienced some accidents which have occurred in the North Sea. The worst accident on the Norwegian sector of the North Sea occurred in 1980 when the flotel Alexander L. Kielland capsized and 123 people lost their lives. Snorre Alpha in 2004 is another accident in the Norwegian Sea but without any fatalities (Vinnem, 2011). If we talk about the helicopter accidents, then the most serious helicopter accident in the Norwegian sector took place in 1978 when 18 people died. The last multi fatality accident in the North Sea occurred in July 1988 when Piper Alpha caught fire which was followed by uncontrolled release of gas causing 167 people to lose their lives (Tveit, 1994).

The 2010 study about the trends in risk level in the Norwegian petroleum activities (PSAN, 2010) has shown both positive and negative trends. The trends reveal a sharp increase in the well control and gas leaks incidents however there were no fatal accidents on the Norwegian Continental Shelf during the year. A positive trend has been shown for the helicopter accidents, ship collision accidents and the accidents resulting in serious personal injury. This shows that considerable attention is paid to the safety management and emergency preparedness in order to improve the trends in risk levels.

From the above facts and findings, it can be claimed that even if there have been offshore petroleum accidents in the past, the trends in the risk level on the Norwegian Continental Shelf have shown considerable improvement in the safety standards. This implies that the solutions to avoid and/or handle such accidents and emergency situations are in place and are continuously improving. Secondly, keeping in mind the harsh climatic conditions of the Arctic Sea as compared to the North Sea, the knowledge related to the past accidents in the North Sea do not provide a sufficient knowledge base in order to avoid future accidents in the Arctic Sea.

The dimensioning of the emergency preparedness for accidents and incidents in the arctic and sub-arctic areas needs to take the location specific factors of the area into account in order to cope with the particular challenges related to the operations in the Arctic Sea including the Barents Sea.

1.2 Objectives

The objectives of this thesis are as follows:

1. To provide an overview of offshore petroleum activity in arctic and sub-arctic areas around the world, emphasizing the areas comparable to the Barents Sea.
2. To provide an overview of accidents/incidents that has occurred in these areas.
3. To describe the main content of the emergency preparedness part of NORSOK Z-013 standard and discuss the relationship between risk analysis and emergency preparedness analysis. Both revision 2 from 2001 and revision 3 from 2010 will be considered.
4. To analyze the accidents/incidents with respect to the emergency preparedness handling of the accidents/incidents.
5. To describe the emergency preparedness challenges for arctic and sub-arctic areas, including operation and maintenance of emergency preparedness equipment.

1.3 Scope and Limitations

The scope of the thesis is to provide information related to proactive emergency preparedness for accidents/incident in the offshore petroleum activity in arctic and sub-arctic areas. By “proactive” we mean i) acting in advance to deal with an expected difficulty or ii) to be proactive by learning from the previous relevant experience. In this thesis, the latter meaning is used. The relevant emergency preparedness experience for the past accidents is analyzed in order to avoid accidents in the future. The thesis covers accidents/incidents in the arctic and sub-arctic areas including the Barents Sea which we have been able to account for. The accidents related to exploration and drilling of the hydrocarbons are covered in the thesis. The thesis also includes two major accidents in the Arctic Sea which does not fall under the umbrella of petroleum related accidents, but still may be useful for the dimensioning of emergency preparedness in the Arctic Sea.

The main limitations of the thesis are i) availability and access to information about accidents/incidents in arctic and sub-arctic areas, ii) accidents/incidents due to transportation and storage of the hydrocarbons are not included, and iii) occupational accidents/incidents are excluded.

1.4 Approach

The approach used to solve the different tasks in the project includes a) a literature review on accident/incidents in arctic and sub-arctic sea areas, b) thorough reading of the NORSOK standard Z-013, and c) an extensive internet search. A detailed description of the approach for each research task is provided in Chapter 2.

1.5 Report Structure

The structure of the thesis is as follows: Chapter 2 presents detailed information on the methods and approaches to solve each project task. Chapter 3 describes the normative reference for the analysis i.e. NORSOK Z-013 while Chapter 4 provides an overview of offshore petroleum activities and companies operating in arctic and sub-arctic area around the world. Chapter 5 describes the accidents/incidents that have occurred in these areas. Chapter 6 describes the analysis of the accidents/incidents in the light of the NORSOK Z-013 standard. Chapter 7 discusses the results of the analysis as well as the anticipated challenges for emergency preparedness in arctic and sub-arctic areas. Chapter 8 presents the conclusion for the dimensioning of emergency preparedness in the Arctic Sea and Barents Sea.

2. Methodology

This chapter describes the method and approach in order to meet the objectives mentioned in Section 1.2. Figure 2 shows the relationship among the project tasks (yellow numbers) as well as the structure of the thesis (chapter numbers).

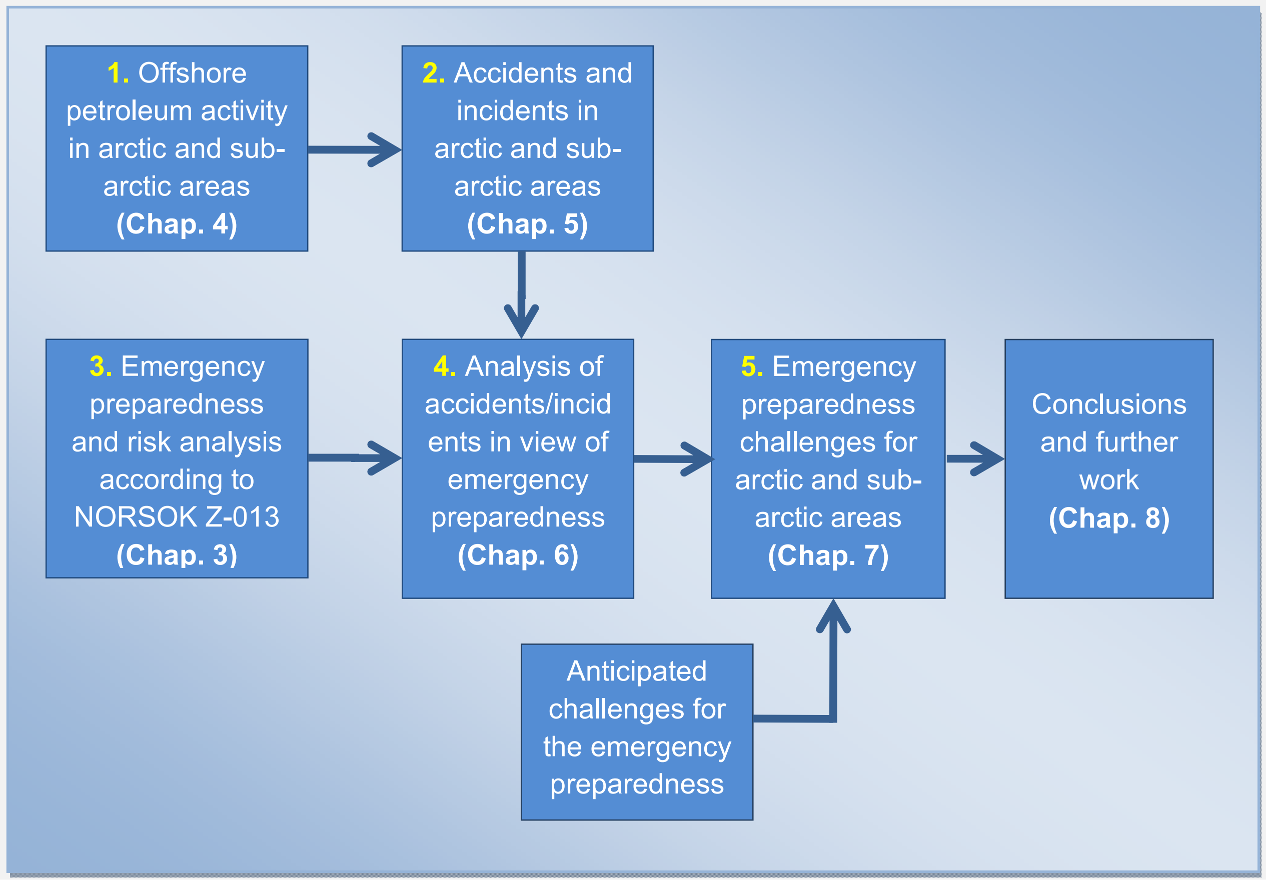

Figure 2 Relationship among the project tasks

The first project task about offshore petroleum activity in arctic and sub-arctic areas has been further divided into three sub tasks. The first sub task provides meteorological and geographical information about arctic and sub-arctic areas including the Barents Sea. The second sub task describes information about the offshore oil and gas companies operating in these areas. The last sub task describes the offshore petroleum activities in the countries having border with the Arctic Sea. For all three sub tasks, extensive internet search was conducted. The keywords and derivatives related to each sub task are listed in Table 2.

For the second project task related to overview of accidents/incidents in arctic and sub-arctic areas, extensive literature search was conducted. Most of the accident details relevant for the thesis were obtained from the internet. The websites of relevant oil and gas authorities were also reviewed in order to have in depth knowledge about the accidents/incidents. There might be other accidents taking place in the areas of arctic, but the accidents/incidents described in the thesis are the only ones which we have been able to find information about. The keywords and their derivatives for this task are listed in Table 2.

The two revisions (2 and 3) of NORSOK Z-013 standard were studied in order to understand the structure of risk and emergency preparedness analysis in the third task (Figure 2). Both revisions were compared and contrasted in order to discuss the relationship between risk analysis and emergency preparedness analysis.

The fourth task was related to the analysis of accidents/incidents with respect to the emergency preparedness handling of the accidents/incidents in arctic and sub-arctic areas. The input was taken from task two and three (Figure 2). The accidents/incidents were classified according to the defined situation of hazard and accident (DSHAs) and the phases of emergency preparedness mentioned in NORSOK Z-013. The emergency preparedness phases were only listed in the NORSOK Z-013 standard however the detailed description of the phases was obtained from the website of the Petroleum Safety Authority Norway (PSAN). For simplicity, the list of DSHAs was subdivided into “major DSHAs” and “other DSHAs” for the master thesis. The list of major DSHAs was used for the classification of accidents/incidents in the Arctic Sea. Table 1 shows the structure for accident/incident analysis which was used in the thesis.

Table 1 Structure for accident/incident analysis

EP Phases / Major DSHAs	Alert	Danger limitation	Rescue	Evacuation	Normalization
1.					
2.					
3.					
.....					

After analyzing the accidents/incidents in the light of the emergency preparedness concepts and methods in task 4, different challenges for the emergency preparedness in arctic and sub-arctic areas were summarized in task 5. In addition, anticipated challenges about offshore drilling and production in arctic areas have been included which are based on extensive reading of relevant articles, conference papers and reports. The keywords used for search of information on the anticipated challenges in arctic areas are listed in Table 2.

Table 2 Keywords and their derivatives for the project tasks

Project tasks	Keywords/search term	Derivatives
1. Offshore petroleum activity in arctic and sub-arctic areas.	The Arctic Sea, sub arctic areas, the Barents Sea, oil and gas companies in the Arctic, petroleum activity.	Climate, meteorological conditions, sea ice, Polar lows.
2. Accidents/incidents in the arctic and sub-arctic areas.	Accidents in the Arctic Sea, emergency preparedness reports for accidents in the	In White Sea, in Kara Sea, oil leakage accidents, oil rig accidents.
3. Emergency preparedness and risk analysis according to NORSOK Z-013.	NORSOK Z-013 standard revision 2 and revision 3.	Not applicable.
4. Analysis of accidents/incidents in view of emergency preparedness	Not applicable.	Not applicable.
5. Emergency preparedness challenges for arctic and sub-arctic areas.	Challenges for hydrocarbon drilling in the Arctic Sea.	Rescue resources in the Arctic Sea. Technology challenges.

3. Normative Reference for Analysis

The NORSOK standard Z-013, developed by the Norwegian petroleum industry, is about risk and emergency preparedness analysis. For this project, two revisions of the standard are considered. One is revision 2, 2001 while the other is revision 3, 2010. The standard contains requirements for effective planning, execution and use of qualitative risk analysis (QRA) and emergency preparedness analysis (EPA). It helps the industry by providing

a) guidelines for establishing risk acceptance criteria,
b) requirements to use QRA and EPA in different life cycle phases and
c) a procedure for the planning and execution of this analysis.

The QRA and EPA helps in the decision making process by selecting appropriate risk reducing measures and emergency preparedness plans for the safety of people, assets and environment. The standard does not cover occupational health, safety and environment aspects (NORSOK Z-013, 2001, 2010).

Revision 2 is only for offshore facilities (PNGIS.net, 2012a) while revision 3 is for both offshore and onshore production facilities of oil and gas (PNGIS.net, 2012b). Revision 3 has explicitly listed the normative and informative references while revision 2 has provided only a list of normative references. The most distinct difference between the two revisions is that revision 3 has made an attempt to adapt to the structure and model of ISO 31000 (Risk management, principles and guidelines) with some exceptions.

For the structuring and analysis of accidents/incidents in arctic and sub-arctic areas around the world, the different phases of emergency preparedness and DSHA used in the emergency preparedness analysis are presented and described in the following sections.

In this thesis, if there are differences in the two revisions, this is explicitly stated. If not, this means that both the revisions provide similar information.

3.1 Emergency Preparedness Phases

The NORSOK Z-013 standard list the following emergency preparedness phases:

- Alert
- Danger limitation (Combat)
- Rescue
- Evacuation
- Normalization

The NORSOK Z-013 standard does not elaborate the phases. However, Section 77 of the Activities Regulations and corresponding guidelines by the PSAN gives information about each phase. It says that, "in *alert* phase, the right notification is given immediately to the following organisations depending upon the situation:

a) the facility's central control room or other central function,
b) the Joint Rescue Coordination Centre
c) one or more parts of the operator's emergency preparedness organization,
d) the contractors' emergency preparedness organizations,
e) other licensees and partners in the event of an agreement relating to coordinated emergency preparedness resources, or in the event of joint use of production and/or transport systems.

The *danger limitation* phase describes the measures so that the hazardous situations should not develop into an accident situations. For the phase of *rescue*, personnel should be rescued during the accident situations by

a) locating missing personnel using personnel control systems,
b) bringing personnel to safe areas on vessels, facilities or land,
c) giving injured personnel lifesaving first aid and medical treatment on their own facilities, the standby vessel or other facilities.

The next phase of *evacuation* describes that the personnel on the facility should be evacuated quickly and efficiently at all times. The requirements relating to evacuation as mentioned in the standard entails that the evacuation measures shall be of a nature that provides the highest possible probability that personnel can be evacuated from an exposed area to a safe area on the facility and, if applicable, to safe areas on vessels, other facilities or on land. As regards sick and injured personnel, the requirement implies that transport to the land-based health service takes place in a safe and prudent manner. It must be noted that the rescue of the personnel can occur before and after the phase of evacuation.

The condition can be *normalised* when the development of a hazard and accident situation has been stopped, e.g. through monitoring and cleanup of the pollution and restoring the environment, thereby restoring the condition to its state before the hazard and accident situation. Criteria shall be set for normalisation of the external environment. The requirement relating to normalisation as mentioned in the standard also implies that

a) injured or sick personnel are given the necessary treatment and care, such as medical treatment on land and follow-up of physical and psychological delayed injuries, and that the next of kin are provided with the necessary information, care and follow-up after major accidents,
b) damage to the facility and reservoir is stabilized and corrected,
c) the operation of the facility is resumed.”

3.2 Defined Situations of Hazard and Accident

Defined situations of hazard and accident (DSHA) are those selected hazardous and accidental events which can be used for the dimensioning of the emergency preparedness for a particular activity. DSHAs are important terms in the regulations by PSAN. The Management Regulations, Section 15, mentions that the party responsible shall perform quantitative risk analysis associated with all sort of activities as well as identification of situations of hazards and accidents. The same requirements exist in relation to emergency preparedness. In the guidance document of the Management Regulations, it is compulsory for the parties to use NORSOK Z-013. According to NORSOK Z-013, DSHA should include three types of events/situations:

- Dimensioning accident event (DAE) usually defined on the basis of design accidental load (DAL) through quantitative risk assessment (QRA)
- Minor accidental events
- Situations associated with temporary increase of risk such as work over open sea, hot work, etc

DSHAs can also include events which are comparable to the activity of interest and accidental events identified in the QRA but not identified as DAE which represent separate challenges for the emergency preparedness (NORSOK Z-013, 2001, 2010).

The two revisions of NORSOK Z-013 describe almost the same DSHAs. In revision 2, we have a category of accident titled as “Hydrocarbon leaks, fire and explosion” which is similar to the accident category of “Process accidents” in revision 3. Revision 3 also lists utility systems and storage accidents while revision 2 does not discuss about them separately. In revision 3, the accidents due to ship collisions, falling and swinging loads and external impacts are merged into a category of “external impact” while in revision 2, each one of them are described in separate sections. The rest of the accidents are the same in both the revisions such as blowouts and helicopter accidents.

There also exists a company-independent set of DSHAs used by PSAN in a project titled as “Trends in risk level (RNNP)” (Skjerve et al., 2008). The main purpose of this set was to provide a basis for calculating data on incidents/accidents on the Norwegian Continental Shelf. This set is somehow a general set of DSHAs and different companies adopt it differently according to their particular installations. The list of the DSHAs in RNNP and Skjerve et al., (2008) is divided in two categories (Table 3 and 4). Table 3 shows a list of DSHAs which can be used for accidents having major potential while Table 4 shows the other DSHAs which can be used for the emergency preparedness of accidents normally not having major accident potential.

Table 3 Major accident potential DSHAs

1. Non-ignited hydrocarbon leaks
2. Ignited hydrocarbon leaks
3. Well kicks/loss of well control
4. Fire/explosion in other areas, not hydrocarbons
5. Vessel on collision course
6. Drifting object
7. Collision with field-related vessel/installation/shuttle tanker
8. Structural damage to platform/stability/anchoring/ positioning failure
9. Leaking from subsea production systems/pipelines/risers/flow lines/loading buoys/loading hoses
10. Damage to subsea production equipment/pipeline systems/diving equipment caused by fishing gear
11. Evacuation
12. Helicopter crash/emergency landing on/near installation

Table 4 Other DSHAs

13. Man overboard
14. Serious injury to personnel
15. Occupational illness
16. Total power failure
17. Control room out of service
18. Diving accident
19. H2S emissions
20. Lost control of radio-active source
21. Falling object
22. Acute pollution
23. Production halt
24. Transport system halt

The list of DSHAs in Table 3 is simple and precise. Therefore, it is used in this thesis for the analysis of the accidents in arctic and sub-arctic sea around the world.

3.3 Relationship between Risk Analysis and Emergency Preparedness Analysis

Risk analysis (for example QRA) identifies the hazards and estimates the risk through quantification of probability and consequence of accidental events in such a way that the outcomes of the risk analysis can be compared to the risk acceptance criteria.

The EPA process consists of the establishment of DSHAs, including major DAEs, establishment of performance requirements, and effectiveness analysis of identified measures, selection of solutions and establishment of an emergency preparedness plan (NORSOK Z-013, 2001, 2010).

The two revisions of NORSOK Z-013 (revision 2 and 3) have different descriptions of the process of risk and emergency preparedness analysis. Therefore both the revisions of the standard will be described and discussed in the following sections.

3.3.1 NORSOK Z-013 Revision 2 (2001)

Figure 3 shows the relationship between risk analysis and emergency preparedness analysis in revision 2 of NORSOK Z-013.

The information from the quantitative risk analysis provides input to the emergency preparedness analysis process. The information helps to establish a set of DSHAs and also includes assumptions which should be used when establishing the performance requirements. The performance requirements are established for each DSHA and structured according to the phases mentioned in Section 3.1. The next step in the EPA analysis identifies technical, operational and organizational measures to handle the DSHAs. This step is followed by the effectiveness analysis where the identified measures are recursively analyzed until a final solution is selected. The last two steps (Figure 3) of the emergency preparedness analysis process, “Select solution” and “Emergency preparedness action plan”, are not part of the EPA.

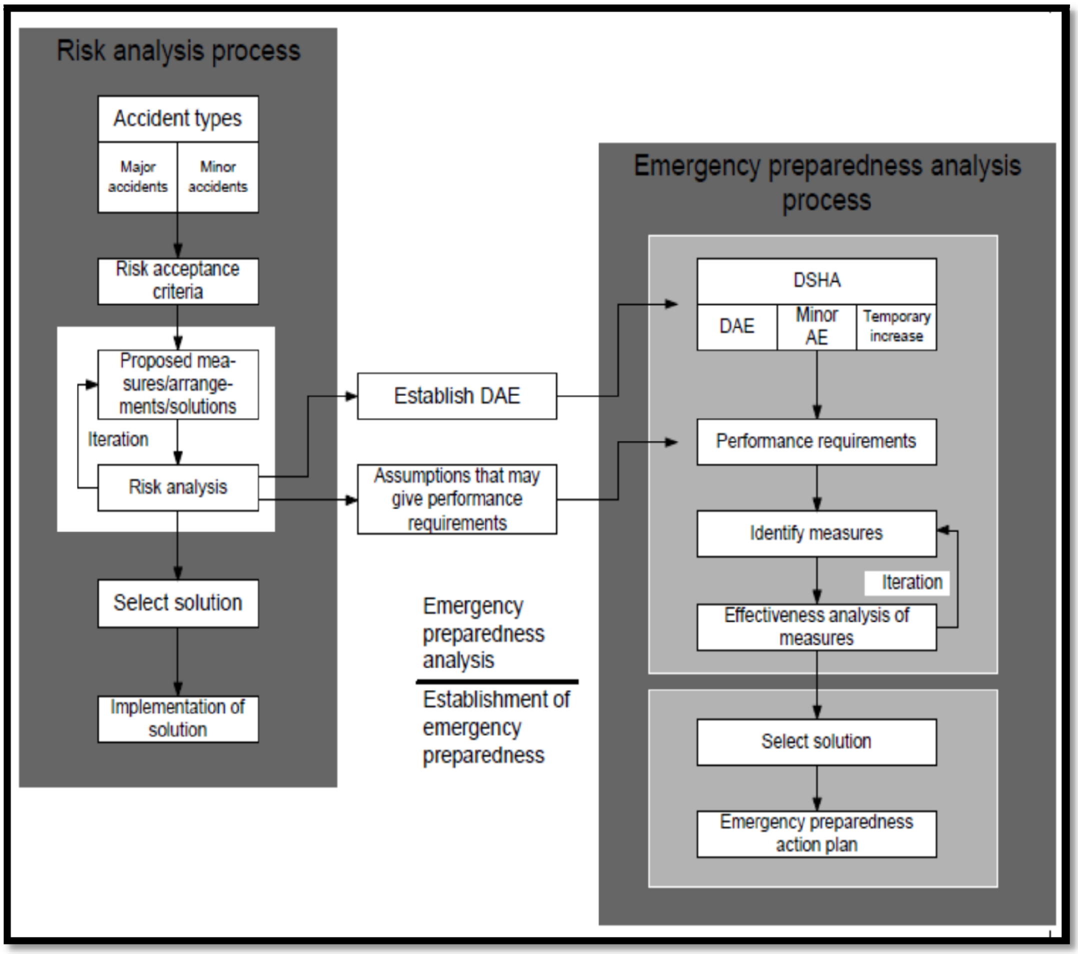

Figure 3 Risk analysis and emergency preparedness analysis (NORSOK standard Z-013, Revision 2 page 15)

3.3.2 NORSOK Z-013 Revision 3 (2010)

Figure 4 shows the relationship between risk analysis and emergency preparedness analysis in revision 3 of NORSOK Z-013.

The most important aspect of revision 3 is that it has used almost the same structure, principles and model as used in ISO 31000. ISO 31000 is a risk assessment standard having elements of risk identification, risk analysis, risk evaluation and risk treatment. Further, it explicitly emphasizes on establishing a context prior to the risk assessment process. Besides this, the ISO 31000 has two separate processes which are conducted through out the entire process. The first process is the process of monitoring, review and update while the second is communication and consultation (ISO 31000, 2009).

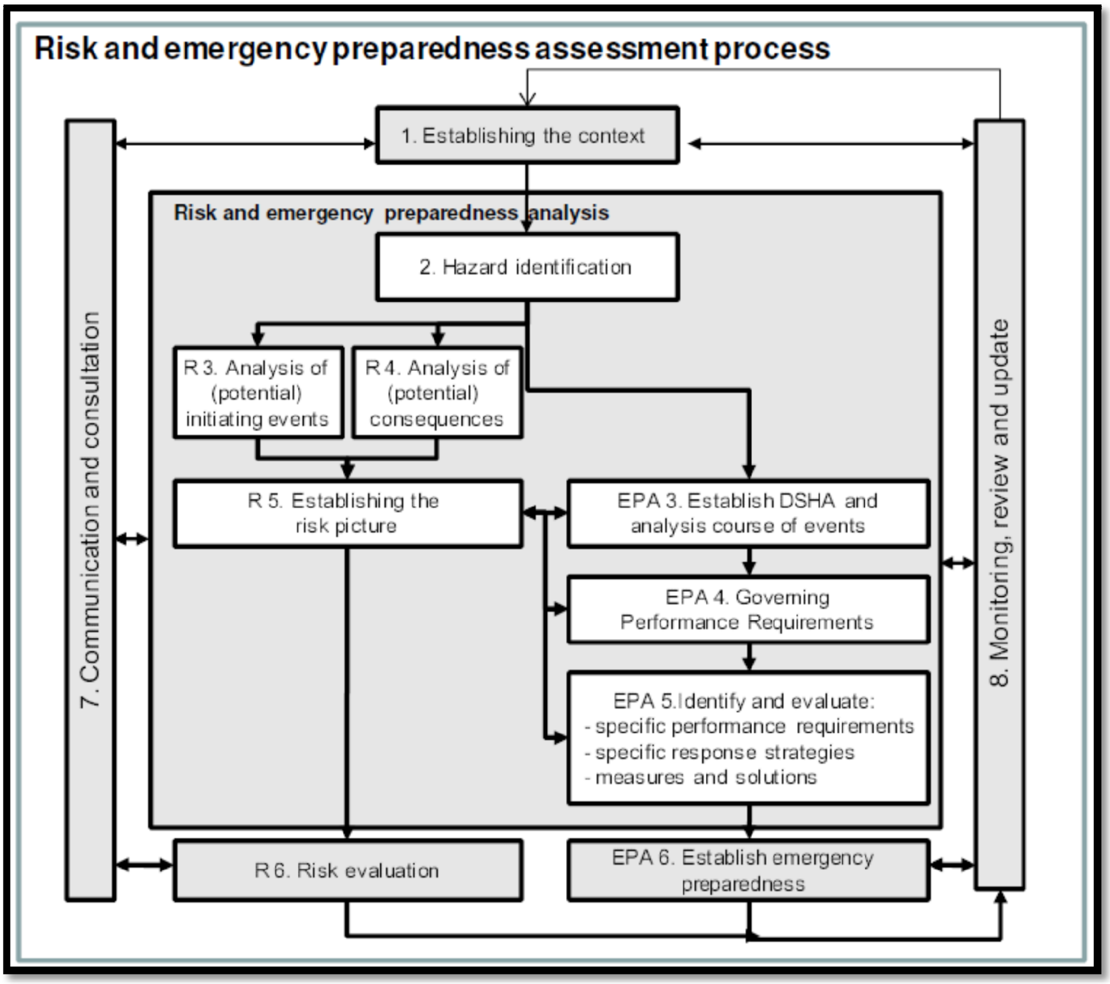

Figure 4 Risk analysis and emergency preparedness analysis (NORSOK standard Z-013, Revision 3 page 17)

The NORSOK Z-013, revision 3 structure is similar to the ISO 31000 with a difference of the "risk treatment" element. The NORSOK standard does not include this element in the risk and emergency preparedness analysis process. It might be due to the fact that this risk element is part of the risk management process in the ISO 31000 and not part of the risk assessment process. For both the risk and emergency preparedness assessment processes, it is necessary to establish the context of the assessment.

The scope and criteria is defined to make both the processes suitable with respect to the intended objectives and purpose. In order to establish the DSHAs, the EPA takes information from the risk assessment process as well as the hazard identification process. Step 7 of communication and consultation intend to involve relevant stakeholders in order to improve the quality of the risk assessment process. Step 8 involves continuous monitoring of established context and updating of context and risk assessment process if required (Figure 4).

The NORSOK Z-013 standard provides an adequate basis for the risk analysis and emergency preparedness analysis. Both the revisions (2 and 3) have unique structure for risk analysis and EPA which can be useful in different contexts. Revision 2 is more detailed and explicit about the risk analysis as well as emergency preparedness analysis while revision 3 is less exact with respect to input from QRA.

If we compare Figure 3 and 4, we can find some differences between revision 2 and 3. In revision 2, both risk and emergency preparedness assessment are two independent processes and emergency preparedness analysis process takes the input from the risk analysis process. In revision 3, the two processes are integrated and yet independent so that any one of them can be used when required.

When both of the assessments have to be performed simultaneously, then risk and emergency preparedness analysis has to be coordinated because inputs and results from one process will be used for the other process. It can also be noted that revision 2 is explicit on DAEs and clearly depicts the composition of a DSHA while revision 3 does not elaborate the composition of DSHA. Furthermore, revision 2 is more exact on assumptions that might give performance requirements, whereas in revision 3, the assumptions and the DAEs are hidden in the process of establishing the risk picture.

EPA 5 in Figure 4 is actually the combination of two processes; identify measures and effective analysis of measures, in Figure 3. Also, EPA 6 (Figure 4) is also combination of select solution and emergency preparedness action plan in Figure 3. Another difference between the two revisions is that Steps 3 (Establish DSHA and analysis course of events), Step 7 (Communication and consultation) and Step 8 (Monitoring, review and update) of revision 3 (Figure 4) are not present in revision 2 (Figure 3).

4. Offshore Petroleum Activity in Arctic and Sub-Arctic Areas

This chapter briefly explains the geographical and meteorological information about arctic and sub-arctic areas on the globe. Further, the information of oil and gas companies operating in this region is also recognized along with the exploration and production activities of oil and gas companies in the arctic and sub-arctic areas around the world. The information serves as a necessary input for the analysis and understanding of the accidents in these areas.

4.1 Geographical and Meteorological Information about Arctic and Sub-Arctic Areas

The Arctic Sea (also known as the Arctic Ocean) located in the Northern Hemisphere (75° 00° N latitude and 00° 00° longitude) of the globe and partly covered by sea ice throughout the year, is the smallest and shallowest ocean as compared to the world's five major oceans. The sea ice, formed when the sea water freezes, of the Arctic sea varies in thickness depending on the wind and ocean currents which can also compress the ice to form pack ice. The size of the sea is almost equal to the size of Russia having roughly a circular basin. The Arctic Sea is surrounded by the lands of North America, Greenland, and Eurasia and by a number of islands. The Arctic Sea includes the seas of Barents, Beaufort, Chukchi, East Siberian, Greenland, Kara, Laptev, White and Bays of Hudson and Baffin (ArcticOcean, 2012). The geographical location of the Arctic Ocean and its seas is shown in Figure 5.

The general climatic condition of the Arctic Sea is characterized by dark nights, cold and stable weather conditions during winter time, and foggy weather and weak snow with cyclones in summer time. Maximum snow is normally encountered during the months of March or April making snow cover (20-50 cm) over the frozen ocean. Due to global warming, the average annual temperature of the Arctic region is 10-20 °C. Petroleum and gas are a few resources out of many which are abundant in this region (ArcticOcean, 2012).

Figure 5 Geographical location of the Arctic Sea (ArcticOcean, 2012)

The sub-arctic area is a geographical area just south of the Arctic Circle. It covers most of Canada, Alaska, Siberia, northern Mongolia and Scandinavia (includes kingdom of Denmark, Norway and Sweden). The sub-arctic region (50°N and 70°N latitude) is characterized by very cold winters (below -30°C) and short and warm summers (30°C) (SubArctic, 2012).

4.1.1 The Barents Sea

The Barents Sea is located between 70 and 80ºN. It is connected with the Norwegian Sea from the west and to the Arctic Sea from the north (Figure 5). The average depth of the sea is 230 m. The sea is located north of Russia and Norway (Barents, 2012a).

The general conditions of the weather in the Barents Sea are more stable throughout the year as compared to the weather conditions in the North Sea. The sea is dominated by the cyclones and strong wind storms that occur in the North Atlantic and then move into the Barents Sea. Strong winter winds usually strike the sea from the southwest. The wind speed in the Barents Sea decreases towards the east and north. Atmospheric lows and highs can affect the wind speeds and eventually change the iceberg drifts (Barents, 2012b; Røsnes, 2011). The average maximum wind speed at 10m above sea level is 26.6 m/s (Jacobsen, 2010).

All Norwegian coastal areas are affected by polar lows ("a low pressure phenomenon which is normally generated during situations with outbreaks of cold arctic air over the sea"). The polar lows in the Barents Sea can develop rapidly within 12 to 24 hours of the time of formation and often vanish quickly. With the outbreak of a polar low, heavy snowfall occurs and the visibility becomes very poor.

The ice condition varies in the Barents Sea. Most of the ice fields have thickness of 1 m. In the center of the sea, the ice may appear once every 4 years however pack ice can be seen more often in the northern part of the Barents Sea. The Barents Sea is also characterized by icing which is "a phenomenon where water or moisture at subfreezing temperatures freezes onto surfaces above sea level". The icing on the vessels can occur from October to May. There are two types of icing in the sea. *Sea spray* icing is most common and can result in significant amount of ice on the vessels. The sea spray icing can occur when the temperature is below -2 °C and wind speed is greater than 11 m/s. *Atmospheric* icing occurs through snow, rain or super cooled droplets. The metrological conditions for atmospheric icing to occur are a) temperature between 0 and -20 °C and b) wind speed less than 10 m/s. Atmospheric icing is harmless as compared to sea spray icing (Røsnes, 2011).

The maximum and minimum average air temperatures in the Barents Sea are +4.4 °C and -7.7 °C respectively. In addition, the maximum air temperature near Goliat and Snøhvit (southwest) can be between 20 °C and 25 °C while the minimum range can be -15 °C to -20 °C. With regards to sea temperatures, then the maximum and minimum ranges in the southwest of the Barents Sea are 10 °C to 12.5 °C and 2 °C to 4 °C respectively (Jacobsen, 2010).

Currents are very local in the Barents Sea. There are two main current directions in the Barents Sea. In the southern part of the Barents Sea, the current moves towards east while in the northern part, it moves westward and southwards (Røsnes, 2011). Some of the currents in the Barents Sea are (Barents, 2012b):

a) The North Cape current
b) West Spitsbergen current
c) Bear Island current
d) East Spitsbergen current

If we talk particularly about the Norwegian part of the Barents Sea, then there are some important results and findings by Det Norske Veritas (DNV), a global provider of services for managing risk. The Barents 2020 project by DNV has divided the Norwegian part of the Barents Sea in eight sub-areas according to the ice conditions (Figure 6). According to Rysst (2010):

- ice and Metocean conditions vary in the Barents Sea, but are uniform within each numbered sub-area shown in Figure 6,
- waves and winds are lower than in the North Sea and
- the main difference from the North Sea is ice and icing.

Figure 6 Divisions of the Norwegian Barents Sea (Rysst, 2010)

Sea ice, polar lows, wind chill and ice bergs are some of the key characteristics of the Barents Sea in Norway. The main characteristics of the Barents Sea (DNV, 2008) are summarized in Table 5.

Table 5 Main characteristics of the Barents Sea (based on DNV, 2008)

Category	Characteristics	Description
Physical Environment	Sea spray ice	Ice created from sea water having different types thereby generating different ice loads.
	Wind chill	Common in Barents sea when strong winds combine with low temperatures.
	Icebergs	Mostly tabular icebergs (steep sides with a flat top), iceberg mass may exceed 2 million tons; a number of icebergs just off the coasts of Finnmark in Northern Norway were observed in 1881 and 1929.
	Light/dark climate	Limited visibility and difficult working conditions especially in winter.
	Cold	Extremely low temperatures creating polar lows in the area. Polar lows can have implications of heavy snowfall, rise of wind speed and wave heights and low visibility due to heavy snowfall.
Human Environment	Remote and limited access	Difficult in situations when there is heavy precipitation and fog.
	Lack of improved infrastructure	New area for hydrocarbons resources therefore shortage of resources and infrastructure in the area.

4.2 Oil and Gas Companies Operating in Arctic and Sub-Arctic Areas

There are a number of oil and gas companies operating in the respective areas of the Arctic Sea. This section gives a brief overview of those companies which we have been able to account for. Furthermore, the Norwegian Petroleum Directorate (NPD) has also awarded licenses to particular companies for the exploration and production of oil and gas in the Norwegian side of the Barents Sea. The awards given in the 21st licensing round (MPE, 2011) are shown in Figure 7. Figure 7 shows the information about the companies and their share in different zones of the Barents Sea. The description about these companies is also provided in Section 4.2.

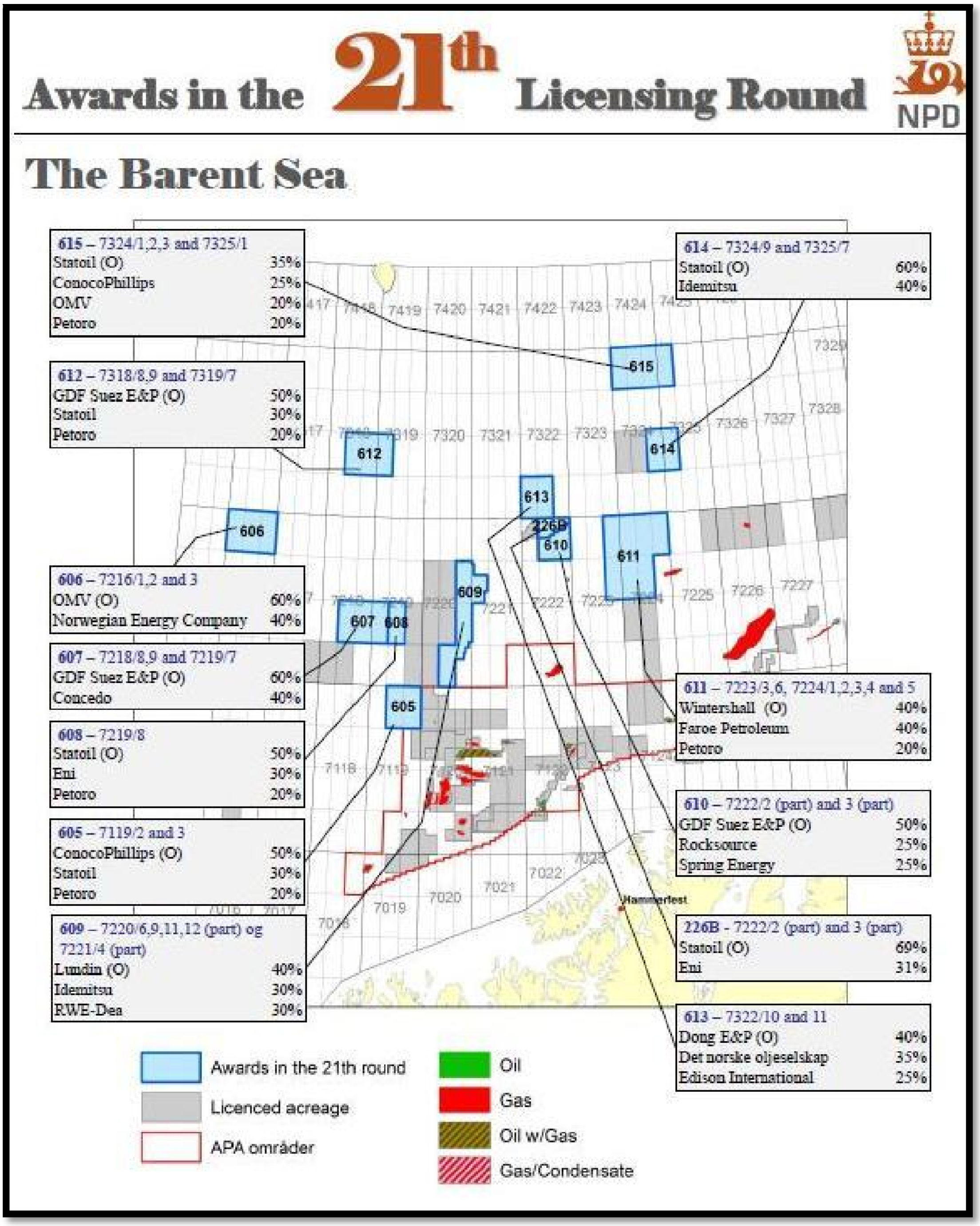

Figure 7 Licenses awarded to the companies in the Norwegian part of the Barents Sea (MPE, 2011)

4.2.1 Statoil

Statoil (a Norwegian state-owned company) has been involved in the exploration of hydrocarbons in the Barents Sea since 1980, the same year when the Norwegian government opened the sea for exploration. The company has almost 40 years of offshore experience in the exploration of oil and gas in the severe weather conditions of Norway. Statoil having strong competence, new technologies and strong values is capable to have strong hold even in other Arctic regions of Russia, Canada, Greenland and USA (Nygård, 2011). Statoil has been the operator for more than 60 out of 80 wells drilled in the southern Barents Sea (Statoil, 2011).

In Norway, Statoil has recently discovered both oil and gas in the Havis prospect with an estimate of 200-300 million of oil equivalents. This is Statoil's second discovery in less than a year (Adams, 2012). Another discovery of oil field in 2011 on the Skrugard prospect in the Barents Sea is also done by Statoil along with other companies. There are estimates of 150–250 million recoverable oil equivalents from this field (Statoil, 2011). In addition, Statoil has found the reserves of oil and gas in the Obesum area of the Barents Sea in 2008 and 2009 (Statoil, 2008, 2009). Further, the first offshore development of Snøhvit gas field in the Barents Sea was also conducted by Statoil. Statoil is a major operator of Snøhvit gas field with a share of 33.53% (Statoil, 2007).

In the Russian sector of the Barents Sea, Statoil has participated in exploration drilling activity in the 1990s, and is taking part in the development of the gigantic Stockman gas field in the Barents Sea along with other oil and gas companies.

In Canada, Statoil is mostly active in the sub-arctic areas offshore Newfoundland (a Canadian province in the eastern part of Canada). Statoil is involved in the fields of Terra Nova, Hibernia and Hebron as well as the Southern extension of Hibernia. The company also made a discovery of its own in the Mizzen prospect in 2009 (Statoil, 2012).

Finally, Statoil is considering participation in Greenland as well as in Alaska. The authorities of these two countries plan to conduct exploration of hydrocarbons and other resources in their respective Arctic part with the help of Statoil (Norheim, 2010).

4.2.2 Eni Norge

Eni Norge is part of the Italian energy company Eni. The company has exploration and production activities in all three parts of the Norwegian Continental Shelf including the Barents Sea since 1965 (Eni, 2012a). The company discovered the important field of Goliat in 2000 and has recently received the operator license for this oil field. The operator of the Goliat field is Eni Norway AS (65%) together with partner Statoil (35%). The development of Goliat, whose production will start in 2013, will be the first development of an oil field in the Norwegian sector of the Barents Sea. The Goliat FPSO (Floating Production Storage and Off-loading vessel) is currently under construction while the drilling of 22 wells will start in the autumn of 2012 (Eni, 2012b). Besides this, Eni Norge has an interest share in the Havis well of 30% and Statoil is the operator in this field. Eni Norge plans to explore the Barents Sea further in year 2012. So far, Eni Norge has Havis, Goliat and Skrugard in their portfolio making it their 30 year perspective on the Barents Sea (Eni, 2012c). Another achievement of Eni Norge as an operator is in the Norwegian Sea at the field of Marulk. The production drilling has started at this gas field with the help of Statoil and will continue till first quarter of 2012 (Eni, 2012d).

4.2.3 Gazprom

Gazprom, mainly a gas company having 50,002% stake in the hands of the Russian government, is the world's largest gas company doing all sort of activities ranging from exploration to marketing (RussianInfoCentre, 2007). The company controls 16% of the world's gas reserves and is operating in different regions of the world including the Arctic Continental Shelf. Apart from other countries around the globe, the European Union is also getting almost 25% of the gas from this largest Russian company (Lesikhina et al., 2007).

Sevmorneftegaz, a subsidiary company of Gazprom, is an operator involved in the exploration of oil and gas fields on the continental shelf of the Arctic Ocean. Sevmorneftegaz owns the licenses to develop the Prirazlomnoe oil field in the Pechora Sea and the Stockman gas condensate field in the Barents Sea (Bellona, 2007). Gazprom along with Total (a French company) and Statoil has created the Stockman Development AG Company for the development of the Stockman gas field (Gazprom, 2012a). In addition, Gazprom also holds the entire gas pipeline infrastructure in Russia. In February 2012, the federal government of Russia approved another license to Gazprom for the area located to the west of the Stockman field (Gazprom, 2012b).

4.2.4 Rosneft

Rosneft is another Russian oil company, allowed to operate in the waters of the Arctic Continental Shelf on the Russian side. It also operates in different locations of Russia. Rosneft holds in total proved hydrocarbon reserves of 22.8 billion barrels of oil equivalents (RussianInfoCentre, 2007). Rosneft signed an alliance project with BP in 2011 where the companies decided to build an Arctic technology center to investigate the safe exploration and production of hydrocarbons in the Arctic Continental Shelf. Rosneft have signed a joint venture with ExxonMobil (a US Company) for the exploration of hydrocarbons in the Kara Sea (Rosneft, 2012).

4.2.5 Chevron

Chevron is one of the world's leading integrated energy companies, with subsidiaries that conduct business worldwide (Chevron, 2011a). This company has substantial business activities of the oil, gas and geothermal exploration, production, refining, marketing and sales etc in different countries including Norway (Chevron, 2011b). Most of the crude oil production by Chevron comes from the offshore Hibernia Field in Canada. Chevron has extended its exploration opportunities in northern, western and eastern Canada (Chevron, 2011c).

4.2.6 Shell

Shell is a global oil and gas company operating in over 90 countries and producing around 3.1 million barrels of oil equivalents per day (Shell, 2012). Shell has been involved in the Arctic part of USA and Canada for almost 50 years. Shell has been very active in the exploration activities in the Beaufort Sea and the Chukchi Sea in USA. Further, Shell is mostly involved in gas projects in the Canadian part of the Arctic Sea. In Russia, Shell is involved in a massive integrated oil and liquefied natural gas (LNG) project of Sakhalin II. Sakhalin II has increased Shell's global LNG production drastically. The Salym project is another developing oil field project in the sub-arctic area of Western Siberia. 160,000 barrels of oil production a day was achieved from this field in April 2009. In Norway, Shell is involved in oil and gas fields south of Arctic Circle. Shell is in the assessment phase of oil and gas development in the Arctic region (Shell, 2011a).

4.2.7 Total

Total is a French multinational oil company whose business ranges from oil and gas exploration to marketing and trading of oil and gas products. Considering the exploration activities by Total, different reserves of oil and gas are discovered in the countries of Europe, Africa, America and Middle East. In Europe, most of the reserves are found in Norway and UK (Total, 2010). Total partnered with Statoil is involved in the Kharyaga field and Stockman gas field in the Russian part of the Barents Sea (Norheim, 2010).

4.2.8 ConocoPhillips

It is an American multinational oil and gas company ranked as fifth largest private sector energy cooperation in the entire world. After Gazprom, this US owned company is second largest Arctic producer (Nelder, 2009). In the Canadian part of the Barents Sea, ConocoPhillips is involved in the Mackenzie Delta, the Beaufort Sea and the Arctic Islands (ConocoPhillips, 2011). ConocoPhillips started operating in Norway in the 1960s. The company discovered Ekofisk oil field in the Norwegian North Sea in 1969. With the passage of time, the company expanded its business in different areas of Norway. The company is also taking part in the offshore petroleum activities in the Barents Sea. The company has received the license in the Barents Sea that holds the Caliente and Borch prospect. ConocoPhillips in a major operator with a share of 50% in the Caliente prospect (MPE, 2011).

4.2.9 Lundin Petroleum

Lundin Petroleum is a Swedish oil exploration and production company with its projects running in different geographical locations around the globe. The company has proven and probable reserves of 211 million barrels of oil equivalent (Lundin, 2012a). Lundin Norway AS is a subsidiary company of Lundin Petroleum. The company has been awarded 10 exploration licenses in the North Sea, Norwegian Sea and Barents Sea. Two out of ten licenses are awarded in the Barents Sea during the 21st Norwegian Licensing Round (Lundin, 2012b). In one of the licenses, Lundin is a major operator with a share of 40% while in the second, the interest share is 20% (Lundin, 2011a). Lundin Norway AS has also completed drilling of Skalle well which is a gas discovery in the south western part of the Barents Sea (Lundin, 2011b).

4.2.10 GDF Suez E&P

GDF Suez E&P Norge is an affiliate of GDF Suez. The company is present in Norway for the last 11 years. The company asset portfolio is expanding as the company is involved in the Norwegian Continental Shelf and the Barents Sea. The company, after Statoil, has the most awarded operatorship in the Barents Sea (Suez, 2011). The company has recently drilled an exploration well (Heilo) in the area of the Barents Sea while it also had an appraisal well in 2006 on Tornerose in the Barents Sea (Suez, 2012). As a result of the 21st licensing round, the company is awarded three operator licenses in the Barents Sea (Figure 7).

4.2.11 Dong E&P

Dong E&P is part of Dong Energy group headquartered in Denmark. Dong energy group is involved in the activities of procurement, production, and distribution and trading of energy in Northern Europe. Dong E&P is only involved in the exploration and production of hydrocarbons on the Norwegian Continental Shelf. The company is major operator in two sub sea projects (Trym and Oselvar) and partner in five producing fields on the Norwegian Continental Shelf (Dong, 2012). The company has been recently awarded a production license in the Barents Sea (Figure 7).

4.2.12 Arktikmorneftegazrazvedka

The Russian company Arktikmorneftegazrazvedka (AMNGR) started oil and gas exploration activities on the Pechora Sea shelf in 1981. So far, the company has discovered 15 oil and gas fields on the Barents, Kara and Pechora Sea shelf. AMNGR also produces hydrocarbons raw materials on the Peschanoozerskoye field at Kolguev Island in the Barents Sea. The company has extended the hydrocarbon related activities in Europe, Africa and South- East Asia (AMNGR, 2012a).

The above mentioned companies are operating nowadays in Norway, US, Russia and Canada. However, in Greenland, the offshore petroleum production in the Barents Sea has not started yet therefore information about operating companies in Greenland is not provided in Section 4.2.

The information about the operating oil and gas companies in the Barents Sea is summarized in Table 6.

Table 6 List of companies operating in the Arctic Sea

Company Name	Project/Prospect	Norway	Russia	Canada	USA
Statoil	Havis, Skrugard, Snøhvit, Obesum	X			
	Stockman field		X		
	Terra Nova, Hibernia, Hebron fields and Mizzen prospect			X	
Eni Norge	Goliat, Havis, Skrugard	X			
Gazprom	Pririazlomnoe and Stockman		X		
Rosneft	Exploration in the Kara Sea, Arctic Technology Centre (project)		X		
Chevron	Hibernia field (Canada)			X	
Shell	The Beaufort and Chukchi Sea				X
	Sakhalin II, Salym		X		
Total	Kharyaga and Stockman		X		
Conoco Phillips	Caliente and Borch prospect	X			
	The Mackenzie Delta, the Beaufort			X	

	Sea and Arctic Islands				
Lundin Petroleum	PL 609 (Figure 5) and Skalle well	X			
GDF Suez E&P	Heilo and Tornerose well PL 607, 610, 612 (Figure 5)	X			
Dong E&P	PL 613 (Figure 5)	X			
Arktikmorneftegazrazvedka	Peschanoozerskoye field and 15 fields of hydrocarbons in different areas.		X		

4.3 Offshore Petroleum Activities in Different Countries

Arctic Monitoring and Assessment Programme (AMAP) has presented the estimates of Arctic proved hydrocarbon reserves (Table 7) in different countries (AMAP, 1998).

Table 7 Estimates of the Arctic proved hydrocarbon reserves

Country	Proved reserves (x 10^6 m^3)	Yearly production (x 10^6 m^3)	Undiscovered, recoverable oil (x 10^6 m^3)
Canada	21	1.3	1701
United States	915	90	3630
Russia (Tyumen Oblast only)	15700	274	-------
Nordic countries	440	2	695

Offshore oil and gas exploration and production in arctic and sub-arctic areas started in the 1920 but the activities were slow. Nowadays, the exploration and production of hydrocarbons is at much faster pace in the Arctic Sea as compared to the past. Figure 8 shows major areas of oil and gas development and potential developments in the Arctic Sea (AMAP, 1998).

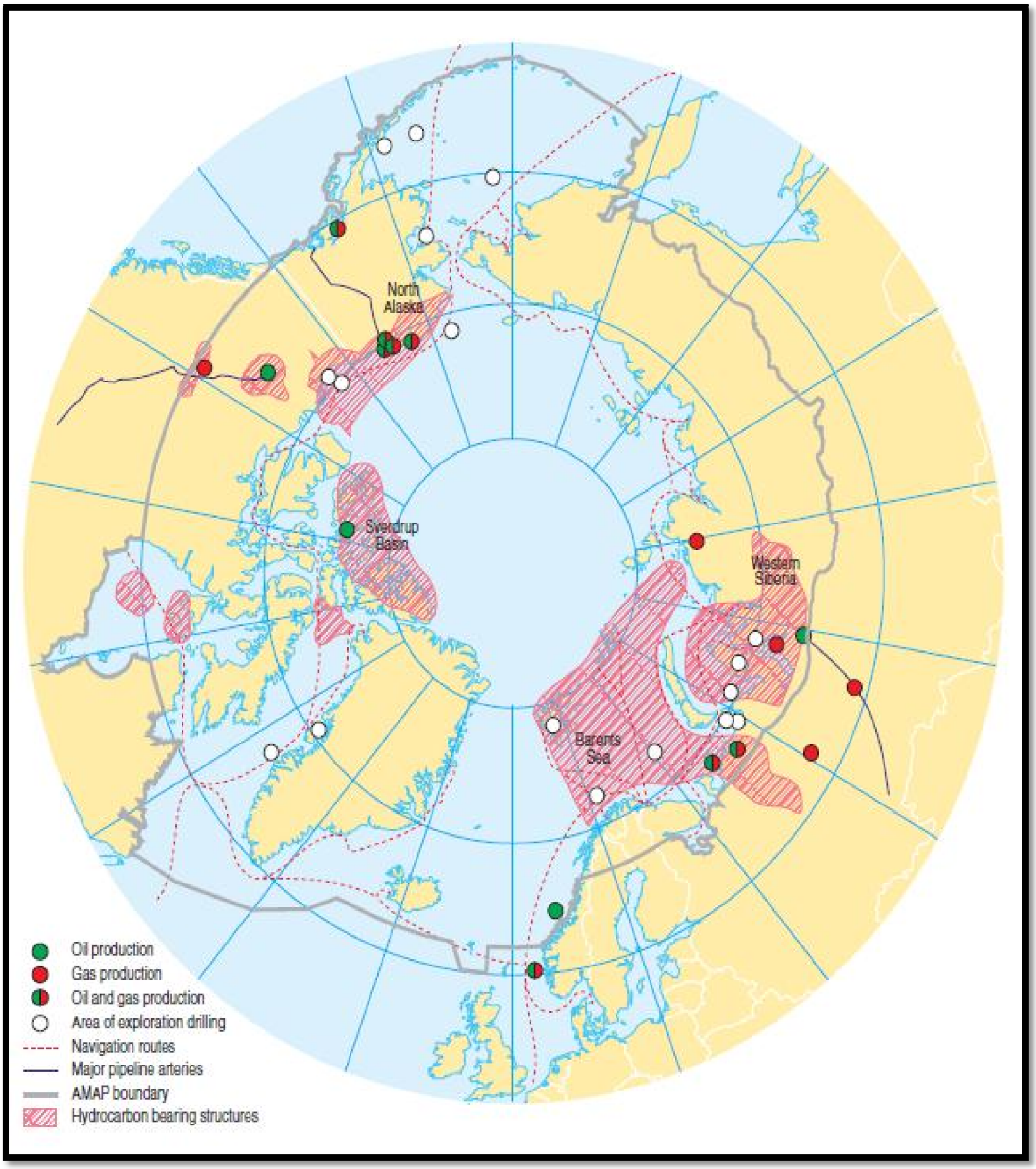

Figure 8 Major areas of oil and gas development and potential development in the Arctic Sea (AMAP, 1998)

The following sub section describes the offshore hydrocarbon activities in the Arctic Sea of Russia, Norway, Canada, Greenland and US.

4.3.1 Offshore Petroleum Activity in Russia

According to Koivurova and Hossain (2008), abundant oil and gas reserves (equivalent to 100 billion tons of oil) for Russia are located in the Arctic Sea. About 70 trillion cubic feet of gas is estimated to be buried under the soils of the Barents, Pechora and Kara Seas. The Barents Sea, alone accounts for 22.7 billion tons of oil and gas. The oil and gas activities in Russia may start in the Prirazlomnoe oil field, the Medynsko-Varandey area, and the Kolokolmor and Pomor area. Prirazlomnoe oil field, located in the Russian Arctic Continental shelf, is the pilot oil field and is a source of attraction for oil and gas companies who intend to operate in the Arctic Sea. The Medynsko-Varandey area is located in the south-eastern part of the Barents Sea while the Kolokolmor and Pomor area are located in the southern part of the Pechora Sea. An estimate of 300 million tons of oil is made which can be extracted from the Kolokolmor and Pomor area (Koivurova & Hossain, 2008). According to AMNGR (2012a), fifteen different fields on the Barents, Pechora and Kara Sea shelf are:

1. Four oil fields (Prirazlomnoye, Varandey-more, Medynskoye-more and Dolginskoye)
2. One oil and gas-condensate (Severo-Gulyaevskoye)
3. Five gas condensate (Pomorskoye, Shtokmanovskoye, Rusanovskoye, Leningradskoye and Ledovoye)
4. Five gas fields (Murmanskoye, Severo-Kildinskoye, Ludlovskoye, Severo-Kamennomysskoye and Kamennomysskoye- more)

4.3.2 Offshore Petroleum Activity in Norway

Norway has abundant reserves of oil (10.2 billion barrels) and gas while on average approximately 3 million barrels of oil is produced every day and is exported to the markets of UK, France, Germany, the Netherlands and the US. When it comes to the Norwegian Arctic Sea, oil and gas activities are only limited to the Barents Sea (Koivurova & Hossain, 2008). It is estimated that 7 billion barrels of oil equivalents are present in the Norwegian part of the Barents Sea which is almost equal to the sale value of NOK 3000 billion (Norheim, 2010). The Barents Sea has so far 90 exploration and appraisal wells and most of them are in the Hammerfest Basin

(Nygård, 2011). 39 production licenses and 61 exploration wells have been awarded in the Norwegian Arctic sector since 1980. The first gas field of Snøhvit (by Statoil) was discovered in 1984 while in 2000 the oil field of Goliat (by Eni Norge) was discovered. It is said that Goliat field has reserves of 240 million barrels in oil equivalent (CTV, 2011). Reserves of oil has also been found in the Havis prospect with an estimate of 200-300 million of oil equivalents as well as in the Skrugard prospect of the Barents Sea with an estimate of 250 million recoverable oil equivalents in this field (Adams, 2012). The reserves of oil and gas in the Obesum area of the Norwegian Barents Sea were also discovered in 2008 and 2009 (Statoil, 2008, 2009).

4.3.3 Offshore Petroleum Activity in Canada

According to the estimates made in January 2008 by Oil and Gas Journal (OGJ), 179 billion barrels of oil reserves are present in Canada. The first Arctic well in Canada was drilled in 1961-62 and the oil exploration and production continued till date. Currently, three oil fields namely Terra Nova (300-400 million barrels oil), White Rose (250 million barrels oil) and Hibernia (615 million barrels oil) are in operation in the part of the Arctic belonging to Canada (Koivurova & Hossain, 2008).

4.3.4 Offshore Petroleum Activity in Greenland

Some of the Greenland Basins and provinces have more than 50 trillion cubic feet of natural gas (Harsem et al., 2011). The exploration of hydrocarbons in Greenland started in the beginning of the 1970s in Greenland. Different areas were drilled in the following years but oil was found only in the well of Kangâmiut – 1 and on the peninsula of Nuuussuaq by a Canadian company. The offshore petroleum activity in Greenland is moving forward gradually and it is hoped that hydrocarbons will be found in the area (Koivurova & Hossain, 2008).

4.3.5 Offshore Petroleum Activity in US

Most of the hydrocarbon production in Alaska (US) is in the Prudhoe Bay area. Three major oil fields in this area are Endicott, Point McIntyre and Northstar oil fields. The Endicott oil field is connected to onshore Prudhoe Bay oil field while the Point Macintyre oil field produces oil from the East Dock off the Prudhoe Bay oil field. The Endicott oil field contained 582 million barrels which is greater than the containment of oil (400 million barrels) in the Point McIntyre oil field. The Northstar oil field started production in 2001 presently producing 65,000 barrels a day. The oil from this field is transported through pipelines which are buried very deep to minimize the effects of ice (Koivurova & Hossain, 2008).

5. Accidents in Arctic and Sub-Arctic Areas

This chapter describes briefly the accidents/incidents in the arctic and sub-arctic areas which we have been able to account for. The section includes two categories of accidents. The first category includes accidents related to offshore petroleum operations whereas the second category includes the accidents which are not related to the oil and gas industry. Table 8 shows the list of offshore petroleum related accidents/incidents.

Table 8 List of accidents/incidents in arctic and sub-arctic areas

Name	Location	Type	Year
Qugruk 2 Well Blowout Accident	USA (Alaska)	Blowout	2012
Kolskaya Rig Accident	Russia	Capsize	2011
Alaska Oil Spill Accident	USA (Alaska)	Pipeline leak	2006
Nefterudovoz-57 Accident	Russia	Ship collision	2003
Usinsk Accident	Russia	Pipeline leak	1994

5.1 Qugruk 2 Well Blowout Accident

A North Slope (a region of Alaska bordering with the Arctic Circle) oil well blew in the Alaska Arctic oil fields on 15th February 2012. The well hit a natural gas pocket at about 2,500 feet and the blowout resulted in the release of high pressurized gas and caused 42,000 gallons of drilling mud to set on ice pad and rig. The gas was vented through a gas diverter.

It is said that the gas pocket at Qugruk 2 was overlooked by operating company (Repsol), and lead to this unwanted event (DeMarban, A., 2012a, 2012b).

Luckily there were no injuries, explosion or oil spill. The Alaska Oil and Gas Conservation Commission withdrew drilling permits from Respol for the other two wells, Qugruk 1 and 4. Repsol was asked to reapply for the permits.

Figure 9 South end of the well pad where Qugruk 2 well blowout took place (DeMarban, A., 2012b**)**

During the emergency operation, all the ignition sources were shut down and the workers were evacuated safely. The responsible company, Respol, followed its contingency plans accurately. The sudden release of gas from Qugruk 2 stopped flowing within a day and half because the underground gas pocket was small. The well was cemented and closed on 17th March 2012. Respol has cleaned and removed 2,189 barrels of liquid from the site while the cleanup work on the rig and well pad continued for several weeks. The cold weather hampered the cleaning process. Furthermore, 2363 cubic yards of solid waste is also removed from the accident location (DeMarban, A., 2012a, 2012b).

5.2 Kolskaya Rig Accident

A Russian drilling rig named Kolskaya capsized on 18th December 2011 and sank within 20 minutes in the Okhotsk Sea. The accident took place at around 2:00 GMT, at the temperature of -17 °C. The rig sank in the sea while it was being towed to a new location during a storm. The platform capsized before the crew could get to their rescue rafts (Wade, 2011).

Figure 10 Kolskaya rig sank in December 2011 (Wade, 2011)

Ice and waves damaged the rig and caused water to enter in the vessel thereby causing the rig to sink (Kireeva & Kaminskaya, 2011). The oil and gas company AMNGR was responsible for the rig and according to Kireeva and Kaminskaya (2011) most of the victims were drilling specialists and not ordinary workers. The company's higher officials claim that the people on board were highly experienced as well as trained for the rescue drills. Further, the technical condition of the rig was also adequate. It is also said that the staff was forced to take the rig to the desired location even though it was bad weather. The company would have faced a loss if the towing process had to be delayed till February 2012.

The accident caused confirmed deaths of 16 people and 37 people could not be found. It is also believed that since the rig was towed and was not involved in drilling operations there cannot have been any major oil spill as a result of the accident (Kireeva & Kaminskaya, 2011).

During the emergency operation, the first distress signal was sent to the rescue organization. The rescue workers saved the lives of 14 people on board with the help of planes, helicopters, and rescue vessel while the search for missing people was hampered due to sub-zero temperatures. The area was searched by the helicopters and planes (Ponomareva, 2011).

5.3 BP Alaska Oil Spill Accident

The largest oil spill on Alaska's North Slope occurred in February 2006 and was discovered in March 2006 at a pipeline owned by BP Exploration, Alaska (BPXA) in western Prudhoe Bay. Almost 653 tons of oil spilled over an area of 1.9 acres from a hole corroded in a pipeline.

Figure 11 A worker cleaning up after Alaska oil spill (Barringer, 2006)

Less budget allocation for corrosion-fighting, ignorance to four leak detection alarms, too few corrosion monitoring staff and insufficient level of corrosion inhibitor were some of the causes which resulted in the massive oil spill (Wikipedia, 2012).

As a result of this accident, thick black crude oil seeped into the snow and spread across two acres. Due to negligence for the discharge of the oil, BP Exploration was also fined US 20 million dollars. BP suffered major image and financial loss. Further, the discovery of 10 km of corroded pipeline also caused shutdown of Prudhoe Bay oil field (Alaska, 2012).

BPXA immediately activated the response contractor and incident management team. Two EPA coordinators were mobilized to the Prudhoe Bay. A committee was also formed to handle the media. The clean up operation was completed in May, 2006 with the help of vacuum trucks and the contaminated snow and oiled tundra was also removed (ARRT, 2006). The site was further covered with frozen tundra taken from some other site (Alaska, 2008). The emergency and rescue teams faced difficulties in the cleaning of the oil due to very cold weather and therefore it took considerable time for the clean up. The corroded pipeline was later replaced with a new flow line (Roach, 2006).

5.4 Nefterudovoz-57 Accident

In 2003, a storage tanker (Nefterudovoz-57) in the White Sea was dented by another boat while it was trying to moor to the other storage tanker. As a result of this collision, the oil started to leak and it was noticed on the fourth day by local population.

The causes of the accident are not known. However, the fishermen and the birds were the immediate victims of the oil leakage. The responsible company, Volgotanker, was also fined to pay 12 million rubles but the company is fighting its case in the court.

There was lack of coordination in the plan for cleaning the oil spill. The false information about the spill and clean up operation by the company misled the emergency services and caused a huge damage to the animals at the coast (Lesikhina et al., 2007).

5.5 Usinsk Accident

An oil leakage accident (1994) in Russia caused almost 100,000-120,000 tones of oil leakage in the Vozey-Golovnie pipeline which is south of the Arctic Circle. The oil spread across vast areas of tundra and marshland. The spill was much larger as compared to the 37,000 tones of oil spilled in Exxon Valdez accident (Wikipedia, 2012).

The pipeline was brought in use for the first time in 1975 and was never maintained and repaired until the time when the accident happened.

Figure 12 Usinsk Accident (Francis, 1994)

Almost 115 hectares of tundra were contaminated effecting fishery as well as local people. The number of fish sharply declined in the area while inhabitants developed problems in their immune systems. Further, the oil was discarded in the areas where the cattle grazed thereby causing plague in the animals after some time. The responsible company, Komineft, was also fined 600,000 USD.

The clean-up operation in Usinsk covered in excess of 400 hectares of oil. The emergency response teams had set fire to the spilled oil in order to avoid further spread (Lesikhina et al., 2007).

5.6 Other Accidents

There are a few other accidents in the Arctic Sea which are not related to oil and gas activities but still can be useful in terms of emergency preparedness dimensioning in the Arctic Sea. It includes Maxim Gorky accident (1989) and the Kursk explosion (2000).

a) Maxim Gorky Accident

One of the accidents was on 19th June 1989 when a vessel in the Arctic Sea hit an iceberg in the Greenland Sea, north of Norway. The accident took place at 23:05 and the Maxim Gorky (Soviet cruise ship) had 953 people out of which 378 were crew members. The weather conditions were good. There were no wind and major wave swells when the crew discovered ice and wanted to show it to the passengers. As the vessel moved closer, the Maxim Gorky collided with the iceberg resulting in rips in the hull and the bow of the ship.

A rescue vessel, Senja, arrived next day at 4:15 while the accident occurred at 23:05. The call for assistance as well as the ongoing situation on Maxim Gorky was received through radio communication by the rescue team. All the passengers were rescued but some of the rescue workers got small injuries (Lohr, 1989).

b) Kursk Explosion

Another famous accident was on 12th August 2000 when a Russian nuclear submarine, Kursk, exploded and sank in the Russian Barents Sea. The accident took place north-east of Murmansk about 250 km from Norway. The two explosions took place with a difference of three minutes causing 118 men on board to die along with the sinking of the submarine.

The first message from the rescue centre of northern Norway in Bodø was received by Norwegian Radiation Protection Authority (NPRA) on 14th August 2000 at 09:50. NPRA declared emergency preparedness at 10:40 and the crisis committee for nuclear accidents was activated. On the same day at about 16:30 NPRA received a confirmation from Russian authorities about the accident. The reactors in the submarine were shut down immediately. An expedition consisting of Norwegian and Russian personnel was sent from 17th to 22nd August 2000 to open the rescue hatches in the submarine compartment. The main aim of the expedition was to rescue the workers if they were still alive. However, none of the crew on board was alive. Further, there was no radioactive leakage after the accident (Amundsen et al., 2001).

6. Accident Analysis and Results

This chapter describes the results of the analysis of the petroleum accidents and the related emergency preparedness experience using the NORSOK Z-013 standard for structuring and classification of information.

Table 9 presents the classification of the accidents (described in Section 5.1 – 5.5) according to the emergency preparedness phases described in Section 3.1 and the DSHAs introduced in Section 3.2 (Table 3).

The main findings and results are as follows:

1. The number of accidents in arctic and sub-arctic areas is quite small, i.e. only *5 accidents in 18 years*. This limited number of accidents eventually provides a scarce knowledge base with respect to emergency response.

2. The accidents in the Arctic Sea are scattered both with respect to time period and location. The most recent accident took place this year (2012) in the Alaskan Arctic oil fields while the first accident (in 1994) occurred in the Russian Arctic Sea.

3. Most of the accidents (3 out of 5) took place in the *Russian Arctic Sea* while two of the accidents took place in *Alaska*. There were no accidents in the Norwegian, Canadian or Greenland Arctic Sea.

4. Only the Kolskaya Rig accident (2011) resulted in the loss of human lives as the rig capsized due to stability failure and rough weather. The Alaska oil spill accident (2006) and Usinsk accident (1994) were of type *pipeline leak* and resulted in oil spills. Similarly the Qugruk 2 *blowout* accident (2012) and Nefterudovoz-57 *ship collision* accident (2003) also had environmental related consequences.

5. There are single accidents related to DSHA 3 (*well kick*), DSHA 7 (*vessel collision*) and DSHA 8 (*structural damage*) while two accidents are related to DSHA 9 (*leaking from pipeline*). None of the accidents were related to DSHA 1-2, 4-6 and 10-12.

6. All of the five accidents provide information about the emergency preparedness phase *alert* and *normalization*.

7. The emergency phase *rescue* and *evacuation* are not applicable to three of the accidents (Alaska oil spill, Nefterudovoz-57, Usinsk accident). These accidents resulted mainly in oil spills with no need for rescue or evacuation of people.

8. Most of the emergency operations conducted in relation to the accidents faced challenges due to the *harsh climatic conditions* in the areas of the Arctic Sea.

Table 9 Classification of accidents according to major DSHAs

EP Phases **Major DSHAs**	**Alert**	**Danger limitation**	**Rescue**	**Evacua-tion**	**Normal-ization**
1. Non-ignited hydrocarbon leaks					
2. Ignited hydrocarbon leaks					
3. Well kicks/loss of well control	🟥 Qugruk 2 (5.1)	🟥 Qugruk 2 (5.1)	🟥 Qugruk 2 (5.1)	🟥 Qugruk 2 (5.1)	🟥 Qugruk 2 (5.1)
4. Fire/explosion in other areas, not hydrocarbons					
5. Vessel on collision course					
6. Drifting object					
7. Collision with field-related vessel/installation/shuttle tanker	🟥 Nefterudovoz-57 (5.4)	🟧 Not known	🟨 Not applicable	🟨 Not applicable	🟥 Nefterudovoz-57 (5.4)
8. Structural damage to platform/stability/anchoring/ positioning failure	🟥 Kolskaya Rig (5.2)	🟧 Not known	🟥 Kolskaya Rig (5.2)	🟥 Kolskaya Rig (5.2)	🟥 Kolskaya Rig (5.2)
9. Leaking from subsea production systems/pipelines/ risers/flow lines/loading buoys/loading hoses	🟥 BP Alaska Oil Spill (5.3) Usinsk (5.5)	🟧 Not known	🟨 Not applicable	🟨 Not applicable	🟥 BP Alaska Oil Spill (5.3) Usinsk (5.5)
10. Damage to subsea production equipment/pipeline systems/diving equipment caused by fishing gear					
11. Evacuation					
12. Helicopter crash/ emergency landing on/near installation					

🟥 Emergency preparedness phases covered

🟧 Not applicable

🟨 Not known

7. Discussion

The chapter is divided in two parts. The first part is based on the eight specific results/findings (in Chapter 6) obtained after analyzing the five accidents that have taken place in arctic and sub-arctic areas (at least to our knowledge; there may be others not known to us). The second part of this chapter discusses *anticipated* (not experienced) challenges for emergency preparedness in arctic and sub-arctic areas, based on knowledge from other areas.

7.1 Discussion of Results

This section separately discusses the eight results/findings obtained after the analysis of accidents which have occurred in arctic and sub-arctic areas.

1. Limited number of accidents

Since there have been rather few accidents (that we have information about) in the Arctic Sea, the relevant experience data on emergency preparedness is scarce and the analysis is correspondingly uncertain or incomplete. There may be a degree of non-reporting of accidents which have contributed to the limited number of (known) accidents. It should be noted that detailed information about the accidents and related emergency information in the Russian Arctic Sea was devoid on the websites. This could imply that the Russian authorities are “less eager” to report accidents or admit that accidents have occurred.

2. Accidents scattered in time and space

The accidents have occurred in quite different locations, although only the Russian Arctic Sea and US Arctic Sea are represented. Only five accidents have occurred since 1994; however four of the five accidents occurred in the last ten years, whereas just one occurred in the ten years before that. This seemingly increasing trend is likely a result of increased offshore petroleum activity in this northern region. For example, the Russian government has increased the exploration activities due to rise in oil prices and nationalization of the oil and gas companies (Harsem et al., 2011).

3. Russia and USA (Alaska); the hosts of the accidents

Most of the accidents (3 out of 5) have occurred in the Russian Arctic Sea, which is not surprising since Russia is the most active country operating in the Arctic Sea. Russia has well developed infrastructure along with 25 ice breakers and record breaking lengths of pipeline structures as compared to all other Arctic countries (Harsem et al., 2011). Similarly, the other two accidents, which occurred in the Alaskan Arctic Sea, can be due to the fact that offshore petroleum activity started quite early in this region and is progressing at a fast pace. It is also reasonable to have more accidents and activities in Russia as it has more of the hydrocarbon reserves as compared to the other countries bordering the Arctic Sea.

The hydrocarbons reserves in Norway, Canada and Greenland are considerably smaller than in Russia and Alaska. Therefore, the offshore activities in these countries have either not started or is growing at a gradual pace. The Greenland authorities will launch the licensing rounds in 2012 and 2013 which might be a proper start of offshore petroleum exploration and production in the Greenland Arctic Sea. Although Canada is involved in important petroleum projects in the Arctic Sea but further exploration is heavily dependent on its regulations and energy demands from USA (Harsem et al., 2011). The somewhat gradual pace of exploration activities in Norway, Canada and Greenland may be a good strategy to avoid accidents.

4. Types of accidents and their consequences

The five accidents which occurred in the Arctic region were two pipeline leaks, one blowout, one ship collision, and one rig capsize. Only the latter resulted in loss of lives while all the other accidents resulted in oil spills which, however, is of great concern in this region. The response to oil spills in icy and remote areas is challenging. The response measures can span over months and can be less effective. However, Shell claims to have an adequate system for the coping of acute oil spills in the Alaskan Arctic region using advanced response strategies and equipment (Shell, 2011b).

The accidents of Kolskya (capsize) and Nefterudovoz-57 (ship collision) can imply that the Russian companies might face challenges in the Arctic Sea which they have never experienced before. This combined with the “so what” attitudes of the Russian authorities after oil spill accidents such as the Usinsk accident is a source of concern. According to environmentalists, every year one percent of Russian’s annual oil production is spilled, which is almost equivalent to one Deepwater Horizon accident leak every two months. It is said that “leaks of less than 8 tons are classified only as incidents and carry no penalties”. Having more than hundred environmental degraded hot spots in the Arctic zone of the Russian Federation reflects an alarming situation (Vasilyeva, 2011b). Different resources claim different estimates of oil spills; however, it can be assumed that oil spills and unwanted incidents in the Russian Arctic Sea are numerous and extensive.

5. Only a few types of accidents (DSHAs) have occurred

The results shows that the accidents related to DSHA 3, 7, 8 and 9 have occurred while most of the other major DSHAs, DSHA 1-2, 4-6, and 10-12, have not occurred. Amongst these DSHAs, it may be the case that the accidents related to DSHA 1, 5, 6 and 11 have not been reported even though they may have occurred (due to minor consequences). For example, DSHA 5 and 6 can be considered “only” as threats that is, the threat of vessel on collision course (DSHA 5) or drifting object (DSHA 6) that may result in a collision.

6. Emergency phases: Alert and normalization

The analysis of the accidents shows that the first (alert) and last (normalization) phase of emergency response were present in all the accidents, which is not surprising. The alert or notification phase is necessary to initiate the emergency preparedness operation, unless one attempts to conceal the facts about the accident. Similarly, the normalization phase is a natural and final step in the emergency preparedness operation, although it is not unusual that the information about this phase is scarce (except for the cases of oil spills which can result in a long lasting normalization phase).

It might be possible that some of the petroleum related accidents only required the alert and normalization phases as part of the emergency response, since they were mainly related to oil spills and not to the rescue and evacuation of personnel. It is also possible that the emergency response information was missing for the other phases.

An important lesson learned from the past emergency responses is that the normalization phase lasts longer due to harsh weather conditions in the Arctic Sea. For the *Qugruk 2 well blow out* accident, the cleaning process during the normalization phase was prolonged while the other contingency plans were adequate. Furthermore, communication of adequate information during the normalization phase is important in order to avoid delays.

7. Emergency phases: Rescue and evacuation

The immediate consequences of most of the accidents (Alaska oil spill, Nefterudovoz-57, Usinsk accident) did not affect the personnel, so there was no need for rescue and evacuation operations. This will probably be the case also in the future for minor oil spills. However, accidents with large oil spills may affect the community living nearby which means that rescue or evacuation may have to be executed subsequently.

The information about rescue and evacuation operations for one of the accidents shows that these two phases can be prolonged due to large distances from onshore as well as due to cold weather. The search of missing people after *Kolskaya rig capsize* took a quite long time. In order to avoid such mishaps in the future, effective search and rescue equipment capable of operating in the Arctic Sea should be considered.

8. Experienced challenges due to harsh environment

The causes of the accidents and the delay in the emergency operations, at least in part, can be ascribed to the climatic conditions in the Arctic Sea. The *Kolskya rig* sank in the sea as ice and waves damaged it while the *Maxim Gorky* cruise ship collided with an iceberg. Similarly the cold weather hindered the emergency operation for the Alaska oil spill, Kolskaya rig accident and Qugruk 2 well blowout.

According to Harsem et al. (2011), the frequency of polar storms and hurricanes in the Arctic Sea is likely to increase in the future. This can affect the offshore drilling, production and emergency operation in case of an oil spill. Further, shallow water of the Arctic Sea can enlarge the huge waves thereby resulting in the sinking of offshore platforms. The largest uncertainty arises when we know that the Arctic ice is melting and therefore can bring climatic changes for the companies operating in arctic and their capacity of handling emergency situations.

According to Harsem et al. (2011), the Hibernia platform is able to resist damage by one million tons of iceberg while the Newfoundland field has ice berg tracking radars. The new cargo ships by Aker have the capacity to detect and break ice in the polar region (Harsem et al., 2011) while Goliat vessels have infra red cameras and oil detecting radars (Eni, 2012b).

However, the oil spill behavior and clean up operations in the harsh and challenging weather of the Arctic Sea is dominated by unknowns. Therefore, the oil and gas companies and the concerned authorities in all of the arctic countries should prepare for the worst case scenarios and for the handling of emergency situations in these areas.

7.2 Challenges for Emergency Preparedness in Arctic and Sub-Arctic Areas

The challenges for emergency preparedness in arctic and sub-arctic areas are first of all due to rough weather conditions, but they are also related to communication challenges, unreliable meteorological data, improper emergency equipment and lack of infrastructure.

Rough weather conditions

The information about the meteorological conditions of the Arctic Sea and the Barents Sea (Section 4.1) reveals that the offshore petroleum companies can encounter various challenges for the EER operations. The sudden formation of the polar lows can be a significant threat to all types of activities, while the combination of strong winds, snow and spray icing can result in icing on the vessels making the gravity load higher. Long polar nights in the middle of the winter season and limited periods of twilight during the day until the sun returns pose further challenges for EER operations. Snowstorms, which are also a key characteristic of the Barents Sea, can temporarily disable the detectors, radars and radio communication thereby making rescue operations more difficult. Operational issues also arise due to poor visibility. Extreme fog conditions from May to August can delay the helicopters operations, which can be involved in the rescue operations.

Information and communication challenges

The challenge due to long distances from onshore and harsh conditions makes the information availability difficult. The Electronic Navigation Charts for the Arctic Sea are not very accurate due to ice covering the sea and land. This makes the navigation of ships very difficult thereby making EER operations challenging (Kvamstad et al., 2009). Extensive maritime services may be required in order to meet information and communication challenges.

Reliable ice and metrological data

The need for reliable ice data is also identified by the industry and the petroleum companies to develop reasonable criteria for the design of offshore equipment. The historical data about the ice movement and storm frequencies in the Arctic Sea becomes useless or less effective due to global warming (Harsem et al., 2011). Therefore, new and improved technologies for ice navigation become vital in order to avoid accidents.

Emergency equipment and tools

The use of proper evacuation and rescue equipment also becomes an important factor during the EER operations. Helicopters, for example, are the best means of dry evacuation operations; however, in adverse weather conditions the success of the operation depends on wind speed, fog and competence of the pilots. Having just a few hours of operational time, helicopters can also need refueling if the accident occurs very far from the onshore base.

Polar lows and severe winter conditions can limit the use of escape chutes, survival suits and life rafts in the Barents Sea. Also, the lifeboats stability is highly affected by severe ice accretion.

The drift ice can also limit the vessel operations during some parts of the year. In that case, monitoring and understanding of ice conditions becomes very important. Navigation tools like GPS have operation limitation at 75 degree north. In that case, positioning of standby vessels becomes more challenging if the incident occurs beyond 75 degree north (Gudmestad & Quale, 2011; Jacobsen, 2010).

Information related to maintenance of the EER equipment is lacking; however, according to MarSafe (2010), the existing EER equipment is often not suitable for the situations in the Arctic Sea. It can become challenging to clean the accumulated ice on the emergency equipment frequently. In the case of an accident, heavy snow on life boats, escape chutes or any other emergency equipment can delay the emergency operations. It is also vital to design appropriate survival suits which can keep the crew warm for a longer period of time.

Long distances and lack of infrastructure

Apart from all these challenges, remoteness and long distances from the onshore facilities can complicate the recue and clean up operation in case of an accident. Inaccessible and inhospitable terrain can make the rescue operations very complicated.

8. Conclusions

The Arctic Sea is the final resort in the north having abundant petroleum reserves. With the increase in oil demand and oil prices, the countries bordering the Arctic Sea are actively involved in the exploration and production of hydrocarbons. However, the climatic conditions of the Arctic Sea are very harsh. They are characterized by polar lows, long nights, extreme fog, sub-zero temperatures and snow storms. Similarly, the weather conditions of the Barents Sea (located between Norway and Russia) are also very tough and are characterized by cyclones, wind storms and spray/ atmospheric icing.

The challenging weather conditions and ability to handle the emergency situations successfully in the arctic and sub-arctic areas have not placed any limitations on the petroleum companies operating in the Arctic Sea. Russia, having well developed infrastructure of pipelines, has the most active part in the Barents, Pechora and Kara Sea. A large number of companies have already started the explorations and production in the Russian Arctic Sea. Norway is highly active in the Barents Sea (part of the Arctic Sea). The Norwegian authorities have given 12 awards in the 21st licensing round to 18 international and local companies for the offshore exploration and production in the Barents Sea. The Canadian companies are operating in three oil fields (Terra Nova, White Rose and Hibernia) in the Canadian Arctic Sea while hydrocarbon production in Alaska (USA) is in the Prudhoe Bay area. The offshore petroleum activity in the Arctic Sea belonging to Greenland has already started but is slowly progressing.

There have been rather few accidents in the past twenty years in the Arctic Sea. The accidents, which we have been able to account for, were of different types. They include blowout, pipeline leak, ship collision and capsize related accidents. Three of the accidents took place in the Russian Arctic Sea while two of them took place in USA (Alaska). The most recent accident was the Qugruk 2 well blowout accident in 2012 resulting in no major loss.

The NORSOK Z-013 standard lists five phases of emergency preparedness. The phases are alert, danger limitation, rescue, evacuation, and normalization. More detailed descriptions of these phases are available in the Activities Regulation by PSAN. In the process of risk and emergency preparedness analysis, the party responsible has to prepare a list of Defined Situation of Hazard and Accident (DSHA). A company independent set of DSHAs used by PSAN in the "Trends in risk level" project (Skjerve et al., 2008) is used in this thesis for the classification of offshore petroleum related accidents in the Arctic Sea. Due to scarcity of accidents in the arctic region only four DSHAs (out of twelve) have been experienced. It might be possible that some of the remaining eight DSHAs have not been reported due to minor consequences.

The accident analysis, structured according to the NORSOK Z-013 emergency preparedness phases and the PSAN list of DSHAs, gives an insight about the emergency measures taken and provide lessons learned for future offshore petroleum activities in the Arctic Sea. All the emergency operations went through the phases of alert and normalization (which is not surprising).

For the *pipeline leak accident* (2006) in Alaska which resulted in oil spill, the emergency response was also adequate. Since there were no personnel which were affected, rescue and evacuation were not executed. For the *Kolskaya rig accident* (2011) resulting in capsize and the ship collision accident (1994) in the Russian Arctic Sea, the information about the alert and normalization phases were available. For the *Kolskaya rig accident*, the information on rescue and evacuation was also available.

The incomplete knowledge about all the phases of emergency response may be due to the fact that either the phases were not required or the information about them is missing on the relevant sources. It should also be noted that very few accidents in the Arctic Sea provides a scarce knowledge base and therefore the analysis of the accidents provides somewhat limited information.

One important finding is that the emergency operations were hampered due to harsh weather conditions of the Arctic Sea. Therefore, the adequacy of the emergency operations and their effectiveness in the harsh and challenging environment of the Arctic Sea has to be ensured in future operations. For efficient and successful emergency operations, information about meteorological data, increased situational awareness, improved emergency preparedness tools, improved electronic navigation charts and status to/from fairway objects will be required.

Besides the experiences gained from real accidents in the Arctic Sea, some additional emergency preparedness challenges for arctic and sub-arctic areas can be anticipated. The harsh weather situation due to long polar nights, sub-zero temperatures, heavy snow and fog poses constraints on the effectiveness of emergency operations in the Arctic Sea. Furthermore, lack of infrastructure and communications, remoteness and unreliable ice data may complicate the emergency preparedness.

The availability and maintenance of traditional emergency response equipment can also be challenging. Specific requirements for the survival suits, lifeboats, escape chutes and rescue vessels for use in the Arctic Sea as well as the Barents Sea need to be defined and implemented. In case of severe ice conditions, alternatives to lifeboats should be suggested. Specially designed helicopters adapted to darkness, long distances and climatic variations should be considered for rescue and evacuation operations.

New emergency preparedness regulations, safety standards and advanced technology should be incorporated in order to avoid unwanted accidents and oil spills in the arctic areas. All countries operating in arctic and sub-arctic areas should be able to comply with all arctic related regulations, standards and requirements. The companies should incorporate adequate technology and methods based on proactive and continuous learning from previous accidents in order to handle the accidents and emergency situations in the Arctic Sea including the Barents Sea successfully.

Appendix A

Acronyms

AMAP	Arctic Monitoring and Assessment Programme
AMNGR	Arktikmorneftegazrazvedka
BPXA	BP Exploration Alaska
DAE	Dimensioning Accident Event
DAL	Design Accidental Load
DSHA	Defined Situation of Hazard and Accident
DNV	Det Norske Veritas
EER	Emergency, Escape and Rescue
EPA	Emergency Preparedness Analysis
FPSO	Floating Production Storage and Off -Loading vessel
LNG	Liquefied Natural Gas
NPD	Norwegian petroleum Directorate
NPRA	Norwegian Radiation Protection Authority
OGJ	Oil and Gas Journal
PSAN	Petroleum Safety Authority Norway
QRA	Qualitative Risk Analysis
RNNP	Risikonivå i Norsk petroleumsvirksomhet (Risk in Norwegian Petroleum Industry)

Appendix B

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