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Safety Aspects of Offshore Oil and Gas Operations in Arctic and Sub-Arctic Waters

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Executive Summary

This report prepared by the Joint Research Centre of the European Commission is the second part of a dilogy which aims to be a compendium for regulators in the offshore oil and gas sector and an informative reading for the community.

While the first report[1] of the dilogy describes the safety principles, the methods of risk assessment and a state-of-the-art of the technologies and procedures for the prevention of accidents and emergency response for offshore oil and gas exploration and exploitation activities in temperate climates, the present report reviews the extraordinary challenges that offshore oil and gas operators face in the extremely harsh and vulnerable areas of the Arctic and sub-Arctic waters.

Operations in extreme conditions require specialized technology, assets, management and procedures, including awareness of safety principles, preparedness to mitigate consequences of accidents and execution of emergency response plans. A crucial role is played by the human factor, in that extreme conditions require well-trained and well-equipped personnel for ensuring a successful implementation of the safety procedures. These aspects pose new challenges to the oil and gas industry when operating in Arctic waters.

The review is based on the retrieval and analysis of a large number of open source information, along with input from authorities, oil and gas operators and the Arctic Committee of IOGP, the International Association of Oil and Gas Producers. The information collected has been organised with the aim of offering the readers an overview of the required means and resources for operating in extreme conditions as well as addressing them to more specific and technical publications covering the same aspects.

In order to gather practical information on how operators respond to challenges likely to be encountered in the Arctic and sub-Arctic regions, a technical questionnaire was submitted to oil & gas companies operating in such areas thanks to the support of the Arctic Committee of IOGP, the International Organisation of oil and gas producers, which distributed the questionnaire to the operators and delivered a summary of the individual replies to the JRC.

The outcome of the questionnaire shows the approach adopted by operators in terms of health, safety and environmental risk management, emergency preparedness and response, and the initiatives taken by the industry to improve such approaches. The answers of the survey emphasized the commitment adopted by the industry in their operations in the Arctic and sub-Arctic waters.

The harsh environmental conditions and the fragile ecosystem of the Arctic and sub-Arctic regions compel the oil and gas industry to carry out offshore operations with the highest safety standards in order to prevent accidents that could have tremendous and irreversible consequences on this extremely vulnerable ecosystem.

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[1] Tarantola, S., Rossotti, A., Contini, P. and Contini, S., A guide to the equipment, methods and procedures for the prevention of risks, emergency response and mitigation of the consequences of accidents: Part I, EUR 29120 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-79922-8, doi:10.2760/204818, JRC110802

1 Introduction

The Arctic is a vast region that encompasses over one-sixth of the global landmass, and spans over thirty million square kilometres and twenty-four time zones. The global community has begun to give increasing attention to this northern expanse, as the warming temperatures are melting the polar ice caps.

As sea ice recedes, the Arctic gradually offers increased access to natural resources and longer navigation seasons, arising global expectations for future economic exploitation of the region. The oil and gas industry is also very much interested in carrying out explorations as it is estimated that the Arctic contains 20% of the World's undiscovered, yet recoverable, hydrocarbon reserves.

Exploiting natural resources in the Arctic and sub-Arctic areas involves managing a number of risks which become even more severe when operating in a highly sensitive environment and extreme weather conditions (cold, dark, wind, ice, etc.).

The Arctic remains the most expensive region on Earth for resource exploration and exploitation for a number of reasons. Assets must be specially designed to withstand the extremely rigid temperatures, transportation of materials and equipment is extremely expensive due to the remoteness of the operations' areas, higher salaries are required to induce highly qualified personnel to work in such inhospitable regions. Finally, following the Deep Water Horizon oil spill in the Gulf of Mexico in 2010, regulations on offshore drilling have been tightened, thereby limiting access and increasing costs further.

This report intends to be a compendium for regulators and an informative reading for the community about the risks of oil and gas exploration and exploitation in Arctic waters, the instruments that are needed to reduce as much as possible such risks as well as the emergency response and mitigation measures that have to be in place to minimise the consequences of accidents.

The report is structured as follows.

Chapter 2 identifies geographically the Arctic region offering a map of the distribution of oil and gas fields and recent drilling activities. The special features of the Arctic weather and climate are then described highlighting how they determine the safety measures to adopt and, consequently, the high production costs of the offshore Arctic oil. The Chapter concludes with an interesting list of both resolved and unresolved disputes between Countries on the Arctic continental shelf.

Chapter 3 explains the concept of winterization, namely the modifications that have to be made on an offshore asset for ensuring that this is suitable for working in cold climate conditions, and offers an overview of the main international standards in place for winterization.

Growing exploitation of the Arctic involves, nevertheless, major environmental risks. Chapter 4 offers a review on the vulnerability of the Arctic marine environment and the major consequences that oil spills may have in this area.

Chapter 5 expands on the need for ad-hoc assets, specialized technology, dedicated management and procedures for operating in the extremely delicate Arctic and sub-Arctic ecosystem. Besides claiming awareness of safety principles and adoption of appropriate resources and tools, the chapter focuses on the need to be prepared with the instruments for the mitigation of the consequences of major accidents, such as the means of containment, recovery and restoration, and with the execution of emergency response plans. The chapter provides a number of interesting links where the reader can find additional documentation.

Chapter 6 offers a glimpse of recent accidents which resulted in oil spills along with a summary of their environmental consequences. Links to public investigation reports are also provided for more details.

Chapter 7 provides an overview of available oil spill response technologies that could be used in the Arctic and summarises the most notable research activities of the last decade in this field.

Finally, in order to gather information on safety activities and emergency response preparedness in case of an accident, a questionnaire was submitted to a sample of oil and gas companies operating in Arctic areas, thanks to the support of the Arctic Committee of the International Association of Oil and Gas Producers (IOGP). A summary of the received answers is provided in Chapter 8.

2 The Arctic area

In the present Chapter, the geographical identification of the Arctic is given along with the spatial distribution of oil and gas fields and recent drilling activities. The special features of the Arctic weather and climate are then described highlighting how they determine the safety measures to adopt and, consequently, the high production costs of the offshore Arctic oil. The Chapter concludes with an interesting list of both resolved and unresolved disputes between Countries on the Arctic continental shelf.

2.1 Geographical description of the Arctic area

There is no common definition of exactly what area the Arctic encompasses. Out of the literature review, several definitions of the Arctic area can be given, depending on the application each definition is referred to (e.g. politics, maritime, fishing, agriculture). The most widely used geographical indicators of the Arctic region are the following:

- The **Arctic Circle**. This is the most widely used indicator to define the Arctic area but also the less accurate as it does not take into consideration any climatological or other geographical variations. According to this indicator, Arctic is defined as any land north of the Arctic Circle (above the latitude of 66° 33' 44"). Eight countries share the land within the Arctic Circle. These are Norway, Sweden, Finland, Russia, U.S.A. (Alaska), Canada, Denmark (Greenland) and Iceland. Nevertheless, only five countries border the Arctic Ocean and have exclusive rights to the sea bottom and resources below. The Arctic Five consists of Norway, Russia, U.S.A., Canada and Denmark.
- The **10°C July Isotherm**. This geographical indicator delimits Arctic areas according to climatological criteria. Subsequently, Arctic is defined as any land north of the regions where the average daily temperature in July doesn't rise above 10°C.
- The **Treeline**. This geographical indicator is based on vegetation criteria and subsequently can be applied only in terrestrial areas. According to this indicator, Arctic is defined as any land north of the treeline, a northern limit beyond which trees do not grow. The Arctic landmass north of the treeline is divided into the Low Arctic and the High Arctic. Additionally, south of the Low Arctic area there is a transition zone between the treeline and the continuous boreal forests which is called Sub Arctic.

The aforementioned geographical definitions of Arctic are respectively represented in Figure 2.1 by the dotted blue line (Arctic Circle), the red line (Isotherm) and the green one (Treeline). Source: https://simple.wikipedia.org/wiki/Arctic.

Figure 2 1. Map showing three different geographical definitions of the Arctic region. (Source: CIA World Factbook)

For the present study it is necessary to introduce another geographical indicator to define which seas around the North Pole are Arctic and sub-Arctic seas. This indicator, based on the seasonality of the sea ice, allows us to define:

- The **Arctic Seas** where a continuous sea ice cap is present all around the year.
- The **Sub Arctic Seas** where sea ice occurrence is always seasonal.

The delimitation of the Arctic and Sub Arctic seas is illustrated in Figure 2.2. The dark grey area represents the permanently frozen Arctic Seas whereas the lighter grey areas represent the Sub Arctic Seas where sea ice is formed only seasonally. (Source: Book titled “Sea Ice” published by John Wiley & Sons Ltd, 652pp, 2017).

It must be noticed that several water masses with very low latitude get frozen during the winter months like the Sea of Okhotsk or the Caspian Sea. This is attributed to the surrounding land masses with below freezing temperatures. For the purposes of the present report, these water masses will also be considered as sub-Arctic Seas. In Table 2.1 the basic features of the seasonal sea ice in some major sub-Arctic Seas are presented.

Figure 2 2 Map of sea ice extent in the northern hemisphere. Dark grey depicts the extent in the summer whereas lighter grey depicts the seasonal (winter) sea ice zone. (Source: Sea Ice, 2017)

Table 2 1 Basic features of the sea ice cover in some major sub-*Arctic Seas* (Source: Sea Ice, 2017)

Sub-Arctic Sea	**Total sea area ($x10^6$ km^2)**	**Maximum ice extent (% of the area)**	**Highest latitude (°N)**	**Maximum ice thickness range (m)**	**Average ice season length (days with ice)**
Sea of Okhotsk	1.530	50 - 90	62	0.5 – 1.5	180
Hudson Bay	0.830	95 - 100	64	1.0 – 2.0	275
Baltic Sea	0.377	10 - 100	66	0.1 – 1.2	180

The Arctic Ocean covers most of the Arctic area. It is the shallowest ocean (mean depth 1.361m) and has significantly larger continental shelves than other oceans. The Laptev and East Siberian Seas are the shallowest (mean depths 48m and 58m respectively). The Lincoln Sea and the adjacent area of the Northern Canadian Arctic Archipelago are the deepest portions of the Arctic Ocean shelve seas (mean depths 257m and 338m respectively). The Arctic Ocean is also the least salty, due to low evaporation and the huge influxes of freshwater from rivers and glaciers. The Arctic Ocean has only three connections to the other oceans:

1. Bering Strait (depth 45m);
2. Canadian Archipelago (depth 220m);
3. Fram Strait (depth 2.600m).

The following web site https://geology.com/world/arctic-ocean-map.shtml shows the Arctic map as well as the bathymetric chart of the Arctic Ocean, which is provided in Figure 2.3. The red dotted line indicates the limits of the Arctic Ocean. Abbreviations in Figure 2.3: NB – Nansen Basin, AB – Amundsen Basin, MB – Makarov Basin, CB – Canada Basin.

The Bathymetric Chart was produced by investigators representing the Intergovernmental Oceanographic Commission (IOC), the International Arctic Science Committee (IASC), the International Hydrographic Organization (IHO), the US Office of Naval Research (ONR), and the US National Geophysical Data Centre (NGDC).

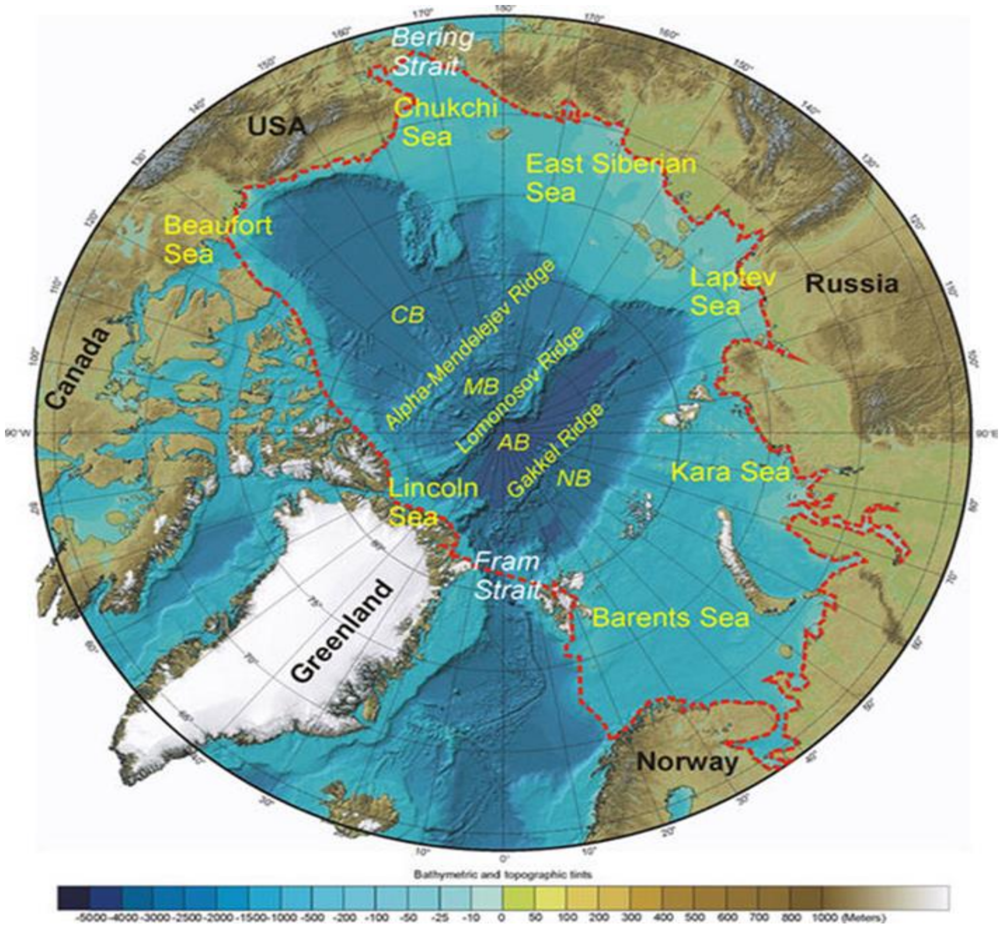

Figure 2 3 Bathymetric charts of the Arctic seas (Source: Geology.com)

2.2 The Arctic climate

The Arctic weather and climate are influenced by several factors, the most important of which is the solar radiation. The amount of solar radiation reaching the Earth varies with the latitude and the cloud cover. Since the incident solar radiation decreases from the Equator to the poles, temperature decreases with increasing latitude. An interesting plot showing the variation of the duration of the daylight with latitude over the year is provided in Figure 2.4, taken from: **https://en.wikipedia.org/wiki/Climate_of_the_Arctic**.

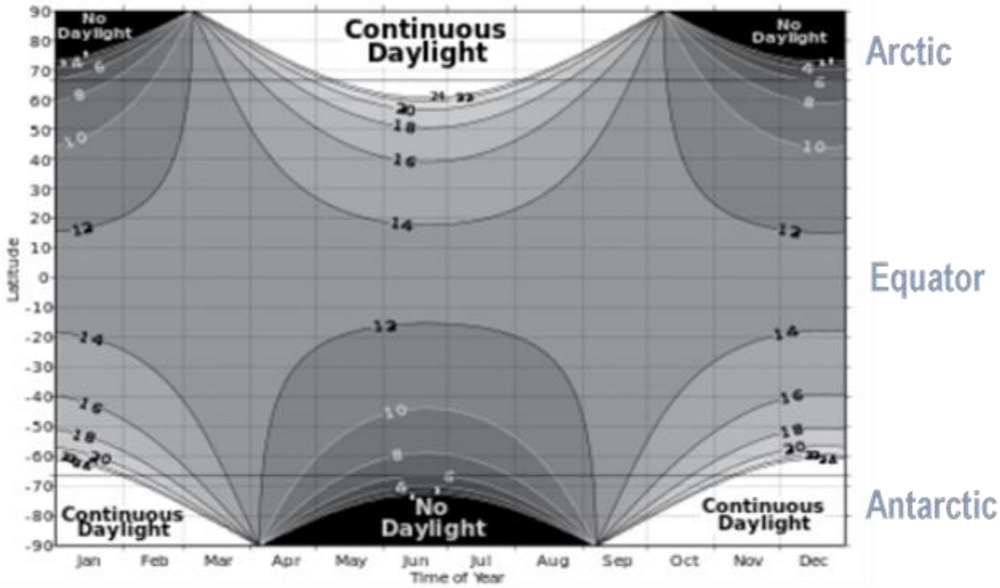

Figure 2 4 Variations in the duration of daylight with latitude and time of year (Source: Wikipedia)

This figure also shows the latitude of 66° 33’ of the Arctic Circle. Following this line, the number of daylight hours can be read for each month of the year.

The Arctic experiences the extremes of solar radiation. During the Northern Hemisphere’s winter months, the Arctic is one of the coldest and darkest places on Earth. Following sunset on the September equinox, the Earth’s tilted axis and its revolution around the sun reduce the light and heat reaching the Arctic until no sunlight penetrates the darkness at all. The sun rises again during the March equinox, and increases the light and heat reaching the Arctic. By the June solstice, the Arctic experiences 24-hour sunshine.

Therefore, the climate of the Arctic is characterized by long, cold winters and short, cool summers. Some parts of the Arctic are always covered by ice whereas others experience long periods with some forms of ice on the surface. In winter, temperatures can drop below −50 °C whereas in summer temperatures range from about −10 to +10 °C with some land areas occasionally exceeding 30 °C.

Comparing the two poles of the Earth, the Arctic and the Antarctic, it can be said that the former is mostly an ocean surrounded by land whereas the latter is mostly land surrounded by water. The Arctic's thin ice cover has water, not land, under it. Subsequently, there is always a small scale heat transfer from the warmer water mass under the ice to the Arctic air. From the other hand, Antarctica has mountains with an average elevation of about 7,500 feet (2.3 km) and stronger winds than the Arctic. As a consequence, Arctic clime is less cold than that of the Antarctic.

Wind speeds over the Arctic Basin and the western Canadian Archipelago average between 4 and 6 m/s (14.4 and 21.6 km/h) in all seasons. Stronger winds do occur in storms but they rarely exceed 25 m/s (90 km/h) in these areas. During all seasons, the strongest average winds are found in the North-Atlantic seas, Baffin Bay, and Bering and Chukchi Seas, where cyclone activity is most common. On the Atlantic side, the winds are strongest in winter, averaging 7 to 12 m/s (25 to 43 km/h, 16 to 27 mph), and weakest in summer, averaging 5 to 7 m/s (18 to 25 km/h, 11 to 16 mph). On the Pacific side they average 6 to 9 m/s (22 to 32 km/h, 13 to 20 mph) year round. Maximum wind speeds in the Atlantic region can approach 50 m/s (180 km/h, 110 mph) in winter (Przybylak et al., 2003).

Water is the Arctic's biggest resource. Twenty percent of all water of the Earth is tied up in Arctic ice and glaciers. The global warming is mostly responsible for the continuous reduction of the extent and thickness of the Arctic's sea ice.

See ice extent and thickness variation over time considering the end of the winter period (March) is provided in http://nsidc.org/arcticseaicenews/2016/04/march-ends-a-most-interesting-winter/ from which Figure 2.5 has been extracted, showing the linear rate of decline of 2.7 percent per decade, i.e. a decline of 42,100 square kilometres (16,200 square miles) per year.

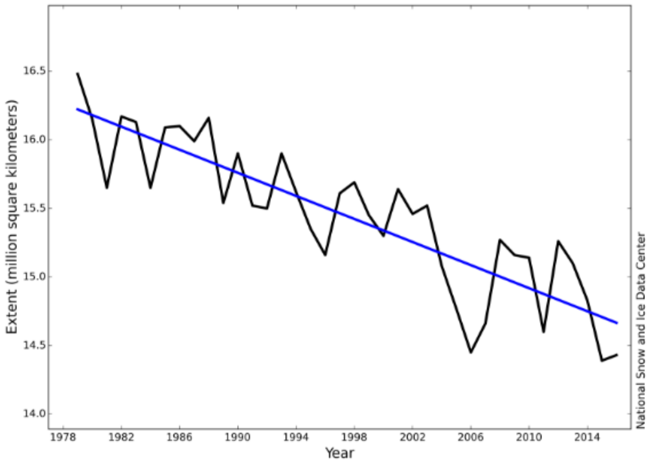

Figure 2 5 Average monthly Arctic sea ice extents in the period from 1979 to 2016 (Source: National Snow and Ice Data Center)

If the current trend continues, within the next couple of decades it will be possible, during summer, to open the Northwest Passage (from the Bearing Sea to the Atlantic Ocean through the Canadian Arctic Archipelago) to standard ships. More info and maps can be found in: https://geology.com/articles/northwest-passage.shtml.

In the Arctic region the ground is at or below 0 °C. This condition is called permafrost (Brown et al.). According to the Intergovernmental Panel on Climate Change (IPGC) there is high confidence that permafrost temperatures have increased in most regions since the early 1980s. Observed warming was up to 3 °C in parts of Northern Alaska (early 1980s to mid-2000s) and up to 2 °C in parts of the Russian European North (1971–2010). In the Yukon Territory of Canada the zone of continuous permafrost might have moved 100 kilometres poleward since 1899. A global temperature rise of 1.5 °C above current levels would be enough to start the thawing of permafrost in Siberia.

It is thought that permafrost thawing could release methane and other hydrocarbons the so called gas hydrates, which are powerful greenhouse gases. These gases may contribute to increasing global warming. Estimates vary on how many tons of greenhouse gases are emitted from thawed permafrost soils. One estimate suggests an average annual emission rate of 4–8 billion tons of CO2 equivalents in the period 2011–2040 and annually 10–16 billion tons of CO2 equivalents in the period 2011–2100 as a result of thawing permafrost. For comparison, the anthropogenic emission of all greenhouse gases in 2010 is approximately 48 billion tons of CO2 equivalents.

The thawed permafrost could also encourage erosion because permafrost lends stability to barren Arctic slopes.

An interesting app showing the weather forecast (with animation) for the next 10 days for the Arctic region can be found at https://www.weather-forecast.com/maps/Arctic. Considered parameters are: temperature, cloud cover, wind, precipitation, rain and snow.

The following site: http://nsidc.org/soac contains NASA satellite data displayed in the form of maps and bar charts. Data on Arctic change over time are explained and graphically displayed. Such data are related to:

- Near surface air temperature
- Water vapour
- Sea ice
- Snow cover
- Vegetation
- Frozen ground
- Annual minimum exposed snow and ice
- Sea ice age

Finally, it is interesting to mention particular phenomena that can be seen sometimes in the Arctic areas due to those particular environmental conditions. The Aurora Polar phenomenon (distinguishing it in Boreal or Austral depending on the hemisphere in which it occurs, North or South) is produced by solar particles, mostly made of electrons, which are pushed against the Earth's magnetic field at great speed. Since the Earth's magnetic field is weaker at either pole, some particles enter the Earth's atmosphere and collide with gas particles, thus producing energy generating, in our eyes, waves of light of various wavelengths at different high (Blue to violet – below 100 km; Green 100 – 240 km; Red – over 240 km).

Many Web sites provide very nice photographs about this phenomenon.

See e.g.: https://oceanwide-expeditions.com/to-do/experiences/aurora-borealis-northern-light

The description of several other phenomena, such as e.g. Coronas and anti-coronas, Halos, and Optical haze, can be seen at: https://nsidc.org/cryosphere/arctic-meteorology/phenomena.html.

2.3 Spatial distribution of Oil & Gas fields

It is a fact that even today most of the Arctic areas (especially offshore) remain unexplored with respect to hydrocarbon resources. Currently, the increasing meltdown of summer polar ice in the Arctic Ocean encourages the Arctic nations to perform offshore hydrocarbon exploration activities.

Generally, the area north of the Arctic Circle can be subdivided into three parts:

- 1/3 of the area is covered by land, the so called Arctic region.
- 1/3 of the area is covered by shallow waters, the so called continental shelves.
- 1/3 of the area is covered by deep waters of the Arctic Ocean (over 500 meters deep).

The Arctic region holds about 16% of the total Oil and Gas resources of the Arctic and until today is where most of the exploration activities have taken place. The Arctic continental shelves constitute the largest geographical area on Earth with enormous probable resources still unexplored. The Arctic Ocean remains also unexplored. Large Arctic oil and natural gas discoveries began in Russia in 1962, with the discovery of the Tazovskoye Field, followed in 1967 with the discovery of the US Alaskan Prudhoe Bay Field.

In 2008, the United States Geological Survey (USGS) released the first-ever wide-ranging assessment of Arctic oil and gas resources, estimating that the area north of the Arctic Circle contains 22% of the world's undiscovered but recoverable hydrocarbon reserves (30% of the gas and respectively 13% of the oil reserves). More than 87% of these resources are located in the following seven Arctic basins which are also illustrated in Figure 2.6: Amerasian, Arctic Alaska, East Barents, East Greenland Rift, West Greenland-East Canada, West Siberian, and Yenisey-Khatanga Basin. https://geology.com/articles/arctic-oil-and-gas/

Figure 2 6 Map of Arctic Oil and Natural Gas Provinces (Source: Geology.com)

According to the United States Geological Survey (USGS) assessment (2008) the estimated undiscovered but technically recoverable, conventional Oil & Gas resources in the aforementioned seven Arctic basins account for about 360 billion barrels of oil equivalent and their distribution is illustrated in Table 2.2.

Further information: https://pubs.usgs.gov/fs/2008/3049/fs2008-3049.pdf

Table 2 2 Estimated Oil & Gas resources in the seven largest Petroleum Provinces of the Arctic (Source: U.S. Geological Survey, May 2008)

Petroleum Province	Crude Oil (billion barrels)	Natural Gas (trillion cubic feet)	Natural Gas Liquids (billion barrels)	Total (billion barrels of oil equivalent)
West Siberian Basin	3.66	651.50	20.33	132.57
Arctic Alaska	29.96	221.40	5.90	72.77
East Barents Basin	7.41	317.56	1.42	61.76
East Greenland Rift Basin	8.90	86.18	8.12	31.39
Yenisey – Khatanga Basin	5.58	99.96	2.68	24.92
Amerasian Basin	9.72	56.89	0.54	19.75
West Greenland – East Canada	7.27	51.82	1.15	17.06
Total 7	72.5	1,485.31	40.14	360.22
Total Arctic	**90**	**1,669**	**44**	**412**

The USGS assessment concludes that 412 billion barrels of oil equivalent (boe) remain to be found in the Arctic out of which 84% are expected to occur offshore. Nevertheless, it should be mentioned that USGS's assessment didn't take into consideration the economic feasibility for the exploration and exploitation of the estimated Arctic oil & gas resources.

A distribution of the potential Arctic oil and gas resources among the Arctic countries is illustrated in Figure 2.7. It could be deducted that Russia is estimated to hold more than half of the total Arctic hydrocarbon resources. However, U.S.A. appears to be the country with the largest undiscovered Arctic oil reserves which gather the most of the probabilities for a possible development. The potentials and the perspectives of hydrocarbon development for each Arctic country are analysed in the following report:
http://www.safety4sea.com/wp-content/uploads/2014/09/pdf/EY-Arctic_oil_and_gas.pdf

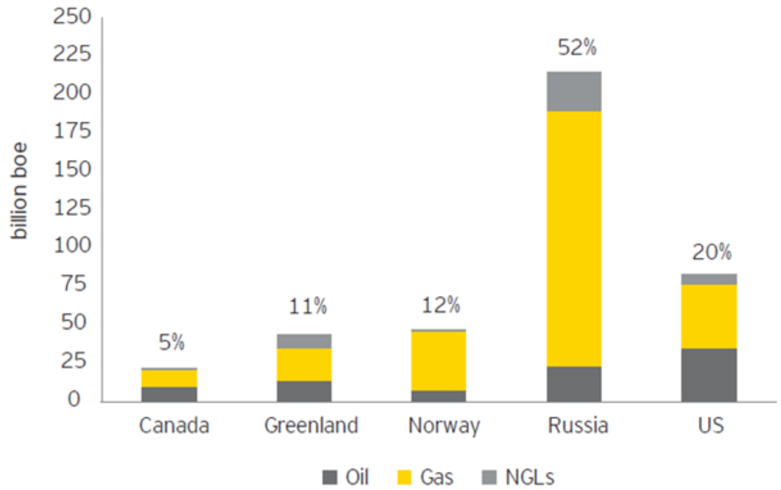

Figure 2 7 Distribution of potential Arctic Oil & Gas Resources (Source: EY calculations from US DOE and US GS data, 2013)

2.4 Arctic continental shelf claims

During the last decades, Arctic has been gradually evolving from a remote area to a strategic zone of global geopolitical relevance. The main reasons for the transformation of Arctic's geopolitical status are:

- The opening of the Arctic shipping routes. The rise of the global temperature has as a consequence the continuous reduction of the average Arctic sea ice extent and eventually the establishment of new shipping routes through the Arctic Sea. Nowadays, the North - West Passage (NWP) through the Canadian Arctic Archipelago and the Northern Sea Route (NSR) which follows the Russian and

Norwegian coasts are accessible by conventional vessels only during the summer months. The year round opening of the Arctic Sea routes is expected to make Arctic Oil and Gas resources much more accessible and to reduce significantly their transportation costs. In Figure 2.7 the green dotted line marks the Northeast Passage or Northern Sea Route (NSR) and the blue dotted line marks the North - West Passage (NWP) respectively.

- The high energy potential of the Arctic area. Recent assessments estimate that the area north of the Arctic Circle holds 22% of the Earth's undiscovered conventional Oil and Gas resources.
- The advancement of the Arctic technology. The technological developments of the last decades have made possible to extract hydrocarbons from deep sea waters and under extreme weather conditions. Significant technological developments have been also identified in the oil spill detection & response techniques. As years go by, the production of offshore Arctic hydrocarbons is gradually becoming economically more viable.
- Developments in the Arctic legal framework. The UN Convention of the Law of the Sea (UNCLOS) which is in force since 1994 allows the Arctic states to claim for extension of the limits of their exclusive economic zones (EEZ) in the Arctic Ocean.

Nowadays political tension in the Arctic is low. Arctic countries cooperate within the framework of international research programmes and several international institutions and non-state organizations were funded. Nevertheless, the opening of new shipping routes in the Arctic and the energy potential of the area are factors that could affect the geopolitical stability in the Arctic. A French expert on the Arctic, Richard Labévière, has outlined three alternative geopolitical scenarios in the area:

1. An Arctic dominated by the United States.
2. A new regional cold war between the United States and Russia.
3. An Arctic space with stable partition of national sovereignty, respect for the Law of the Sea and strong cooperative institutions.

An interesting geopolitical analysis of the Arctic area can be found here:

http://site.uit.no/arcticreview/files/2015/01/Geopolitics-International-Governance.pdf

The economic zone of every Arctic country in the Arctic Ocean is determined by the United Nations Convention on the Law of the Seas (UNCLOS). It must be underlined that up today, UNCLOS has been ratified by Russia, Norway, Denmark and Canada but not from U.S.A.

The full document of UNCLOS can be found here: http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

According to UNCLOS, each country's sovereign territorial waters extend to a maximum of 12 nautical miles (22 km). Every coastal country may establish an exclusive economic zone (EEZ) extending 200 nautical miles (370 km) from shore. UNCLOS allows States to extend their limits beyond 200 miles if they can provide scientific evidence that the continental shelf beyond their coastline extends that far. Upon ratification of UNCLOS, a country has a ten-year period to make claims to an extended continental shelf, by collecting and analysing data on the depth, shape, and geophysical characteristics of the seabed and sub-sea floor. If validated, the country receives exclusive rights to resources on or below the seabed of the relevant area.

Norway, Russia, Canada, and Denmark have all conducted scientific projects to provide a basis for seabed claims on extended continental shelves beyond their exclusive economic zones, and have subsequently submitted claims to the UN Commission. As the US has not ratified UNCLOS, it cannot submit claims to the Commission on the Limits of the Continental Shelf (CLCS). The CLCS review of the claims is expected to take years. It must be also added that the status of some territories in the Arctic sea region is disputed for various reasons.

A very interesting review on Arctic continental shelf claims has been recently (2017) published by the European Parliamentary Research Service and can be found here:

http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/595870/EPRS_BRI(2017)595870_EN.pdf

In 2008 the five Arctic coastal countries - Russia, Denmark, Norway, Canada and U.S.A., issued the so called Ilulissat Declaration which actually delimits national claims in the Arctic Ocean. More specifically, the Arctic Five through the Ilulissat Declaration have stated that jurisdiction and territorial claims should be solved by negotiations within the existing international legal framework (UNCLOS) and therefore there is no need to develop a new comprehensive international legal scheme to govern the Arctic Ocean. The document of the Ilulissat Declaration can be found here:

https://www.regjeringen.no/globalassets/upload/ud/080525_arctic_ocean_conference-_outcome.pdf

In Figure 2.8 a map of the Arctic territorial claims is illustrated. With the red line, the exclusive economic zones of each Arctic country are delimited. In 2001, Russia became the first country to file a claim, arguing that the underwater Lomonosov ridge was not merely a chain of mountains in international waters but was actually an extension of Siberia's continental shelf. Russia's claim is illustrated in Figure 2.7 with the orange area in the Arctic Ocean beyond the red line. It must also be stated that the UN Commission was not convinced and asked for seismology reports and sonar measurements to support Russia's submission.

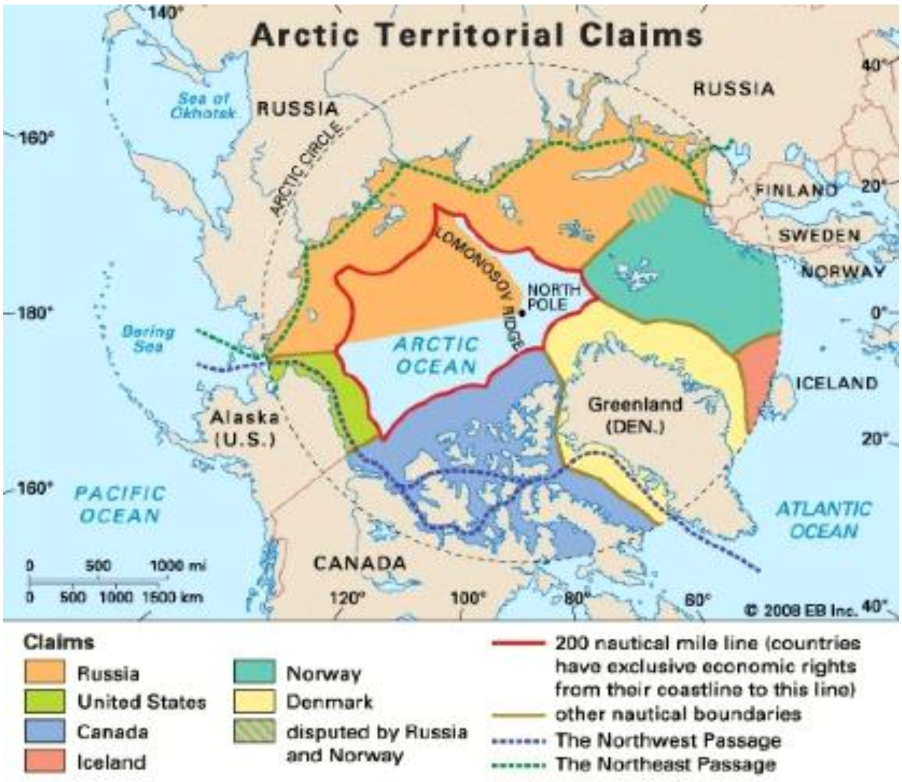

Figure 2 8 Map of Arctic Territorial Claims (Source: National Defense University Press)

2.4.1 Arctic Territorial or Maritime Disputes which have been resolved

United States - Canada

A long dispute between United States and Canada concerned the Northwest Passage. The USA claimed that it was international waters, whereas Canada considered it as Canadian, internal waters. The US and Canada had long disagreed on who had jurisdiction over the Northwest Passage, which is really a collection of routes navigating around the islands of the Canadian Arctic between Alaska and Greenland (Figure 2.8). In 1988, the two countries agreed that the US would always ask permission before sending icebreakers through the Northwest Passage, and the Canadians would always give it.

Further information: https://www.pri.org/stories/2017-09-04/who-controls-northwest-passage-its-debate

Norway - Russia

The Barents Sea controversy was a dispute between Norway and Russia, officially started in 1974 over the delimitation of Arctic sea boundaries in the Barents Sea. The conflict is historically characterised by both nations continuously presenting claims on the seabed, none of which are officially acknowledged or legally justified. The first known claims were presented by Norway in 1963 after which Russia followed suit in 1965. The Barents Sea dispute officially came to an end on 7th June 2011, the date on which the Barents Sea Treaty, signed on 15th September 2010, came into action after almost 40 years of negotiations.

Further information: http://www.inquiriesjournal.com/articles/758/3/the-barents-sea-conflict-russia-and-norway-competing-over-fossil-fuel-riches-in-the-arctic

United States - Russia

Since the purchase of Alaska from Russia in 1863, the United States and Russia have been trying to finalize marine boundaries. The most recent attempt was made in 1990 and became known as the Baker-Shevardnadze Treaty. With the fall of Soviet Union, the Russian Parliament refused to ratify the Treaty and Russian diplomats from time to time attempted to re-negotiate some of the agreements made in 1990. The Russian argument was largely based on the fact that Shevardnadze was not acting on behalf of the Country's interests. According to some experts, Russia cannot legally undermine the 1990 Treaty, even if it refuses to ratify it.

2.4.2 Arctic Territorial or Maritime Disputes which remain unresolved

Canada - Denmark

Far in the Arctic North lies the uninhabited, barren and desolate Hans Island. Since the early 1930s, Hans Island has been at the centre of an ongoing disagreement between Canada and Denmark as technically it is located in both Danish and Canadian waters. Currently, Canada and Denmark agree to disagree on who owns Hans Island. There have been talks and willingness to solve the hurdle, but nothing has been agreed so far. The militaries of both Countries periodically visit the island to remove the other Country's flag and leave a bottle of Danish schnapps or Canadian whisky.

Further information: https://www.cbc.ca/news/canada/north/canada-denmark-should-turn-hans-island-into-a-condominium-academics-1.3315640

Russia - Canada - Denmark

Russia, Denmark and Canada all are claiming that Lomonosov ridge is a continuation of their continental shelf, therefore allowing them to proclaim sovereignty over it and additional 200 miles adjacent to it. Denmark is using Greenland to proclaim that Lomonosov ridge is a natural continuation of the world's largest island. Canada has a slightly different point of view, stating that the massive ridge is part of North American continent. Russia, arguably spending the most time and money to conduct scientific research on the subject had launched several expeditions, including to the bottom of the Arctic Ocean right under the North Pole. Russia claims that Lomonosov Ridge is a continuation of Siberia (Northern Asia).

Further information: https://arctic.ru/analitic/20181115/804847.html

Russian Claims on the Arctic Continental Shelf

According to the UNCLOS, a coastal state has exclusive sovereign rights to explore and exploit the natural resources of its continental shelf up to 200 nautical miles from its shores. Beyond this limit, a coastal state has to provide scientific evidence to establish the extent of the legally defined continental shelf.

In its 2001 claim, Russia argued that the Lomonosov Ridge and the Alpha Mendeleev Ridge are both geological extensions of its continental Siberian shelf and, thus, that parts of the Central Arctic Ocean, as well as parts of the Barents Sea, the Bering Sea, and the Sea of Okhotsk, fall under its jurisdiction.

However, the CLCS found the substantiation of the Russian claim on the shelf insufficient and asked for more information. Since then a new submission has been under preparation.

International experts suggest several scenarios for the further developments if a second, revised submission be returned to the CLCS. One extreme would be for Moscow to withdraw from the UNCLOS and just declare unilaterally that its continental shelf reaches up to the North Pole. Russia would still retain the right to a continental shelf, and would find itself in the same position as the U.S., which remains outside the UNCLOS, and would have to rely on customary law to support its claim. However, this option is hardly acceptable for Moscow because it would provide a much less secure legal position than would a CLCS' decision which is considered as a final and binding rule.

2.5 Drilling activities

Drilling activities in the Arctic Basins started in the seventies. A map giving an idea about the location of such activities can be found at: http://2knowabout.blogspot.it/2014/12/shells-arctic-challenger-to-burn-oil.html

The map in Figure 2.9 shows another distribution of the oil and gas production wells (purple points) in the Arctic and Sub-Arctic areas until 2014. It can be seen that there are offshore production wells in the Beaufort Sea, in the north part the Canadian Archipelago, in the Barents Sea and in the Kara Sea. The North West Passage and the Northern Sea Route are also illustrated along with the military presence in the Arctic area. This map can be found at: https://www.theguardian.com/world/2012/jul/22/arctic-ice-melting-oil-drilling

The same map, with higher resolution, can be found at:

http://www.arcgis.com/home/webmap/viewer.html?url=https://services.arcgis.com/hRUr1F8lE8Jq2uJo/ArcGIS/rest/services/OpeningUpTheNorth/FeatureServer/2&source=sd

A very interesting report - dealing with the petroleum hydrocarbon issue in the Arctic area can be found at:

https://www.amap.no/documents/download/76

An interesting poster (from INTERSEA) providing the spatial distribution of oil and gas platforms operating in the Arctic Circle until 2014, along with their characteristics, can be found at:

https://www.offshore-mag.com/content/dam/offshore/print-articles/volume-74/02/0214ArcticPoster-012014Ads.pdf

According to the above source, all Arctic production facilities and terminals until January 2014 were in total 34.

The above poster has been extracted from a set of various maps, which may be of interest to readers, accessible from: https://www.offshore-mag.com/maps-posters.html

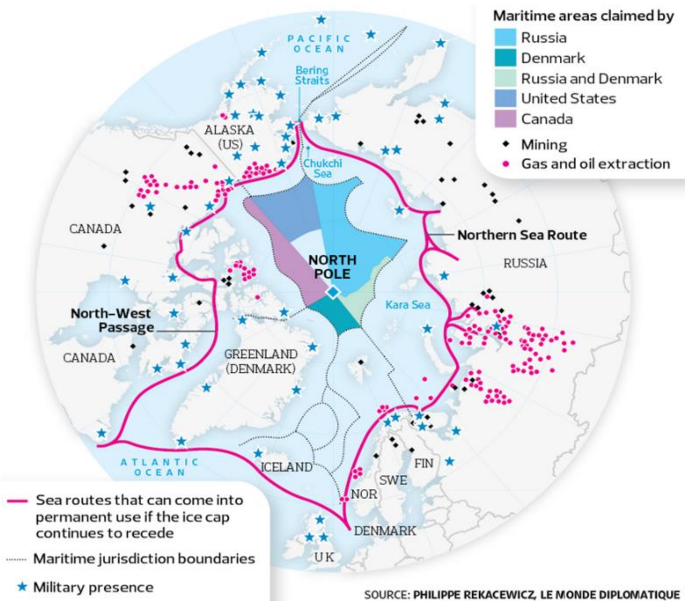

Figure 2 9 Map of oil and gas production wells in Arctic and Sub-Arctic areas (Source: Philippe Rekacewicz, Le monde Diplomatique)

The main challenges in the Arctic offshore development, from high costs to high environmental risk, are described in the report "Arctic oil and gas" (2013) prepared by EY. It is worth reporting EY's perspective on this important issue. "*There is huge potential as well as risks associated with operations in the Arctic and the industry must prove that the Arctic can be drilled and developed safely. These operations are clearly on the outer limits of the both safety and commercial viability for the industry and a spill or accident there would be catastrophic (….). Geopolitics will play a critical role, as countries with varying interests use control through jurisdiction and regulation as opposed to diplomatic cooperation. In such a political environment, the massive long-term investments and commitments that will be required to develop these resources are unlikely to be forthcoming, or at least more limited. On a more positive note, commercial collaboration and competition, primarily based on the technology and resources of the major players in the Arctic (such as ExxonMobil, Shell,* *BP, Statoil, Eni, Total SA, Chevron and ConocoPhillips), along with the Russian giants Rosneft and Gazprom and possibly a few of the larger independents, will truly lead us to pioneer this frontier".*

Further information: https://safety4sea.com/wp-content/uploads/2014/09/pdf/EY-Arctic_oil_and_gas.pdf.

The RIAC (Russian International Affair Council) web site describes the current and future perspectives for oil and gas resource development in five countries: Russia, Canada, Denmark, Norway and the United States, analyses main issues oil and gas companies face while assembling their projects as well as factors that influence their activity. Further information: http://russiancouncil.ru/en/arcticoil

The Offshore Energy Today web site dedicated to the Arctic contains continuously up-to-date information of various types: https://www.offshoreenergytoday.com/tag/arctic/

2.6 Costs of oil production in the Arctic Seas

The convenience of drilling in the Arctic Seas even today remains an issue under discussion as offshore operations in Arctic still remain costly and risky.

2.6.1 Factors that shape the prices of Arctic oil production

Despite the fact that most of the fields in Arctic were discovered in the 1970s and early 1980s, little development activity has been reported to date. The Arctic remains the most expensive region on Earth for resource exploration and development for a number of reasons:

- Extreme weather conditions - Installations, equipment and ships must be specially designed to withstand the extremely rigid temperatures.
- Remoteness - Transportation of materials and equipment is extremely expensive. The icepack can hinder shipment of personnel, materials, equipment, and oil for long time periods. Furthermore, long supply lines from the world's manufacturing centres require equipment redundancy and a larger inventory of spare parts to insure reliability.
- High operational costs - Higher wages and salaries are required to induce highly qualified personnel to work in the isolated and inhospitable Arctic.
- Environmental regulations - Following the Deep Water Horizon oil spill in the Gulf of Mexico in 2010, regulations on offshore drilling have been tightened, thereby limiting access and increasing costs further.

In Figure 2.10 the Global Liquids Cost Curve is illustrated according to Rystad Energy (2014). It is estimated that in 2020 the total world oil production will be around 100 million barrels per day to cover the global oil demand. The diagram illustrates every possible resource of oil with an upper and a lower production cost depending on several parameters. For this reason, an average break-even price is introduced for every resource of oil. From the Global Liquid Cost Curve it can be deducted that in 2020 Arctic oil production will remain the most expensive and will have the smallest contribution to the total oil production. It must be underlined that offshore Arctic oil production is more expensive than onshore and as a consequence the corresponding average break – even price must be above 78 $/bbl.

2.6.2 Market conditions

The relatively low prices that dominated the oil market the last years combined with other sources of supply that have appeared in the market, resulted in the postponement of large-scale, Arctic oil exploration and production to the future years. New extraction technologies for deep water drilling, secondary, and tertiary oil production along with Enhanced Oil Recovery (EOR) methods, which allow the extraction of unconventional oil reserves (oil from tar sands, tight oil, shale oil) have increased global potentials for oil production. From the other hand, the global decrease in the economic growth and the increase of renewable energy share in the global energy mix has decreased oil demand.

However, since Arctic holds approximately 22% of the world's undiscovered, conventional oil and gas resources from which only 16% is believed to be found on land, it is expected that offshore oil and gas production activity in the Arctic will be developed in the next decades. According to Figure 2.10 offshore Arctic oil extraction will be boosted when reserves of cheap oil get depleted and oil prices arise above 80 $/bbl.

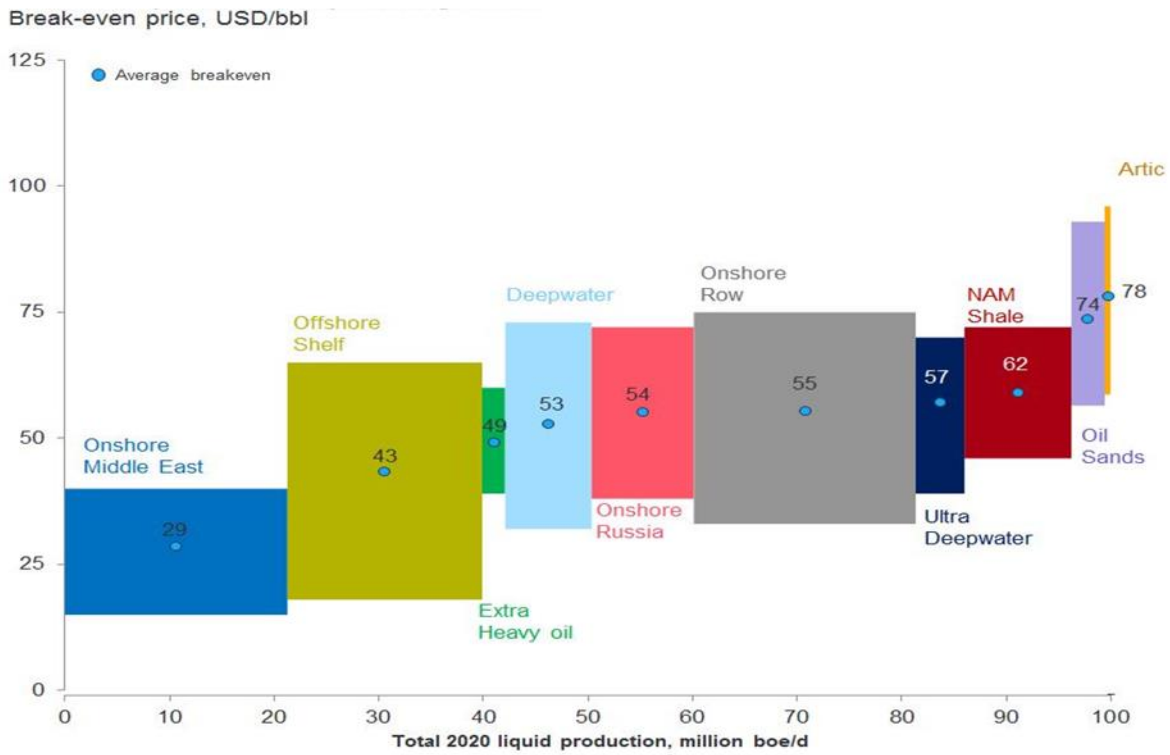

Figure 2 10 Global Liquids Cost Curve (Source: Rystad Energy, 2014)

3 Winterisation standards

Winterization is a process for ensuring that a system (i.e. equipment, installations or vessels) is suitable for working in cold climate conditions. Winterization includes e.g. mitigation of ice effects, prevention of ice accretion, de-icing, protection of operating conditions, piping arrangements, etc.

Therefore, each vessel and installation working in the Arctic environment must be properly winterized or at least accomplish with the minimum requirements for all vessel types as established by norms and standards.

According to DNVGL-OS-A201 offshore standards "Winterization for cold climate operations" (see ed. July 2015 at: https://www.dnvgl.com/rules-standards/index.html) three different levels of winterization are considered, depending on the minimum temperature the structure will have to endeavour:

- A *basic winterization* should ensure the structure to withstand air temperature not below -15°C and water temperature of +4°C without ice class and -2°C with ice class;
- A *cold winterization* should ensure the structure to withstand air temperature not below -30°C and water temperature of +2°C without ice class and -2°C with ice class;
- A *polar winterization* should ensure a resistance down to -45°C with water never above -2°C.

To ensure a proper customized design and winterization to those installations planned to work in harsh climates, DNVGL proposed a set of rules and standards for managing the potential deterioration in functionality of equipment, installations and vessels as a result of cold climate operations. These rules and standards are described in Sections 3.1 and 3.2.

3.1 DNV GL rules for mobile offshore units

- DNVGL-RU-OU-0101 Offshore drilling and support units

https://rules.dnvgl.com/docs/pdf/dnvgl/ru-ou/2015-07/DNVGL-RU-OU-0101.pdf

This publication presents DNV GL's Rules for Classification of Offshore Drilling and Support Units, the terms and procedures for assigning and maintaining classification, including listing of the applicable technical references to be applied for classification.

- DNVGL-RU-OU-0102 Floating production, storage and loading units

https://rules.dnvgl.com/docs/pdf/dnvgl/ru-ou/2015-07/DNVGL-RU-OU-0102.pdf

This publication presents DNV GL's Rules for Classification of Floating Production and Storage Units or Installations, stating the terms and procedures for assigning and maintaining classification, including listing of the applicable technical references to be applied for classification.

- DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units

https://rules.dnvgl.com/docs/pdf/dnvgl/ru-ou/2015-07/DNVGL-RU-OU-0103.pdf

Although this document refers primarily to Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG), the principles herein may also be used for other offshore gas installations such as those involving primarily Compressed Natural Gas (CNG), and Gas To Liquid (GTL) products. A floating offshore installation which processes hydrocarbons and refrigerates gas to produce LNG will be termed here an LNG FPSO (LNG Floating Production, Storage and Offloading unit). LNG FPSOs are also commonly termed FLNG. An offshore installation which receives and degasifies LNG is termed an FSRU (Floating Storage and Regasification Unit).

- DNVGL-RU-OU-0104 Self-elevating units

https://rules.dnvgl.com/docs/pdf/dnvgl/ru-ou/2015-07/DNVGL-RU-OU-0104.pdf

The objective of this publication is to give a complete but concise overview of the relevant technical standards and DNV GL's involvement for building and classing a conventional self-elevating unit. In this objective, the book is to be used in conjunction with DNV GL-RU-OU-0101 and the relevant technical standards as referred to therein.

This publication covers the involvement of class for a unit's different phases during life time, i.e. design, construction, commissioning, delivery and operation. The publication does not cover the requirements for separate additional class notations, or the requirements for units of an unconventional design. These are detailed in the Rules for drilling units (ref. DNVGL-RU-OU-0101). This publication does not cover the requirements applicable for units drilling on a fixed platform.

3.2 DNV GL offshore Arctic standards

- DNVGL-OS-A101 Safety principals and arrangements
  https://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-A101.pdf

  The objectives of these standards are to:

  - provide an internationally acceptable standard of safety for offshore units and installations by defining requirements for design loads, arrangements, area classification, shut down logic, alarms, escape ways and communication;
  - serve as a contractual reference document between suppliers and purchasers;
  - serve as a guideline for designers, suppliers, purchasers and regulators;
  - specify procedures and requirements for units or installations subject to DNV GL certification and classification services.

- DNVGL-OS-B101 Metallic materials
  https://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-B101.pdf

  - A material specification shall be prepared referring to the relevant section of this standard and stating possible additional requirements and/or modifications to materials, manufacture and testing.
  - The specified properties shall be consistent with the specific application and operational requirements of the structure or equipment. Suitable allowances shall be included for possible degradation of the mechanical properties resulting from subsequent fabrication and installation activities.
  - The specification should include specific requirements in places where this standard gives options, e.g. chemical composition, testing, requirements subject to agreement, etc.

- DNVGL-OS-C101 Design of offshore steel structures
  https://rules.dnvgl.com/docs/pdf/dnvgl/os/2015-07/DNVGL-OS-C101.pdf

  - DNVGL-OS-C101 is the general part of the DNV GL Offshore Standards for structures. The design principles and overall requirements are defined in this standard. The standard is primarily intended to be used in design of a structure where a supporting object standard exists, but may also be used as a stand-alone document for objects where no object standard exist.
  - When designing a unit where an object standard exists, the object standard (DNVGL-OS-C10x) for the specific type of unit shall be applied. The object standard gives references to this standard when appropriate.
  - In case of deviating requirements between this standard and the object standard, requirements of this standard shall be overruled by specific requirements given in the object standard.
  - This standard has been written for general world-wide application. Governmental regulations may include requirements in excess of the provisions by this standard depending on size, type, location and intended service of the offshore unit or installation

- DNVGL-OS-C301 Stability and watertight integrity
  https://rules.dnvgl.com/docs/pdf/DNVGL/OS/2017-01/DNVGL-OS-C301.pdf

This offshore standard provides principles, technical requirements and guidance related to stability, watertight integrity, freeboard and weathertight closing appliances for mobile offshore units and floating offshore installations.

The types of units that are covered by this standard include:

- ship shaped units
- column stabilised units
- self-elevating units
- cylindrical units
- tension leg units
    - Deep draught units

The objectives of this standard are to:

- provide an internationally acceptable standard of safety by defining minimum requirements for stability, watertight integrity, freeboard and weathertight closing appliances
- serve as a contractual reference document between suppliers and purchasers
- serve as a guideline for designers, suppliers, purchasers and regulators
- specify procedures and requirements for units or installations subject to DNV GL certification and classification.

- DNVGL-OS-D101 Marine and machinery systems and equipment
  https://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-D101.pdf

  The requirements in this standard cover marine piping systems, machinery piping systems and marine machinery systems, which are defined as systems serving the marine systems on an offshore unit or installation and not primarily intended for operation in drilling or hydrocarbon production service or dedicated auxiliary systems. Interfaces between such systems and marine systems should be identified and a specification break defined.

- DNVGL-OS-D201 Electrical installations (2017)
  https://rules.dnvgl.com/docs/pdf/DNVGL/OS/2017-01/DNVGL-OS-D201.pdf

  The objectives of this standard are to:

    - provide an internationally acceptable standard of safety by defining minimum requirements for offshore electrical installations
    - serve as a contractual reference document between suppliers and purchasers serve as a guideline for designers, suppliers, purchasers and regulators
    - specify procedures and requirements for offshore units or installations subject to DNV GL certification and classification

- DNVGL-OS-D202 Automation, safety, and telecommunication systems
  http://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-D202.pdf

  The requirements of this standard, shall apply to all safety, automation, and telecommunication systems required by the DNV GL Offshore Standards.

  All safety, automation, and telecommunication systems installed, but not necessarily required by the DNV GL Offshore Standards, that may have an impact on the safety of main functions (see DNVGL-OS-A101), shall meet the requirements of this standard.

  The requirements of this standard are considered to meet the regulations of the MODU Code, with regard to safety, automation, and telecommunication systems.

- DNVGL-OS-D301 Fire protection
  https://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-D301.pdf

This standard is applicable to drilling/well intervention, storage, production, accommodation and other types of mobile units and offshore installations.

The standard covers the following systems and arrangements, including relevant equipment and structures:

- passive fire protection
- active fire protection of specific areas
- fire-fighting systems
- fire and gas detection and alarm systems
- miscellaneous items

- DNVGL-OS-E101 Drilling facilities (2018)
https://rules.dnvgl.com/docs/pdf/DNVGL/OS/2018-01/DNVGL-OS-E101.pdf

The standard covers drilling systems and equipment located both surface and subsea, including wellhead connectors, but not wellhead or elements located below wellhead.

The prescriptive requirements in the standard are the results of generic hazard identification and barrier analysis based on existing technology and operations.

Prescriptive requirements are not intended to inhibit the development and application of new technology and operations, and available technological and technical improvements at the time of application should be taken into account.

Introduction of novel technology or designs shall be preceded by a recognized qualification process. Alternative solutions, if clearly proven to provide an equivalent or higher safety level than required in this standard, may be considered to comply with this standard.

- DNVGL-OS-E201 Oil and gas processing systems
http://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-E201.pdf

This offshore standard contains criteria, technical requirements and guidance on design, construction and commissioning of offshore hydrocarbon production plants and associated equipment. The standard also covers liquefaction of natural gas and regasification of liquefied natural gas and also associated gas processing.

The standard is applicable to plants located on floating offshore units and on fixed offshore structures of various types. Offshore installations include fixed and floating terminals for export or import of LNG

- DNVGL-OS-E301 Position mooring
https://rules.dnvgl.com/docs/pdf/dnvgl/os/2015-07/DNVGL-OS-E301.pdf

The standard is applicable for and limited to column-stabilised units, ship-shaped units single point moorings, loading buoys and deep draught floaters (DDF) or other floating bodies relying on catenary mooring, semi-taut and taut leg mooring system. The standard is also applicable for soft yoke systems. The objective shall give a uniform level of safety for mooring systems, consisting of chain, steel wire ropes and fiber ropes.

The standard has been written in order to:

- give a uniform level of safety for mooring systems
- serve as a reference document in contractual matters between purchaser and contractor
- serve as a guideline for designers, purchasers and contractors
- specify procedures and requirements for mooring systems subject to DNV GL certification and classification services

- DNVGL-OS-E401 Helicopter decks (2017)
https://rules.dnvgl.com/docs/pdf/DNVGL/OS/2017-01/DNVGL-OS-E401.pdf

This standard is intended to provide requirements and guidance to the design of helicopter decks constructed in steel or aluminium, for mobile offshore units and offshore installations.

The objectives of this standard shall:

- provide an internationally acceptable standard of safety for helicopter decks by defining minimum requirements for the design, materials and construction
- serve as a contractual reference document
- serve as a guideline for designers, suppliers, purchasers, contractors and regulators
- specify procedures and requirements for helicopter decks subject to DNV GL certification and classification.

3.3 Anti-icing and anti-freezing measures

These measures are required for exposed areas, systems and equipment. The following are examples of generally suitable solutions:

- Equipment and areas that require anti-icing measures should, as far as possible, be situated in protected locations, so that sea spray and weather cannot reach them. A shielded location will normally be the simplest and most reliable solution for anti-icing, wherever it is possible. However, this implies the increase of energy consumption due to the installation's heating-ventilation and air conditioning (HVAC) systems. Moreover, congestion of equipment increases the damages in case of (confined) explosion; hence specific ATEX design and passive blast protections solutions (explosion proof walls, explosion hatches, etc.) are to be considered.
- Hard removable covers may also be applicable for some types of equipment.
- The use of electric heating blankets or heat tracing can be a solution for the protection of equipment on open decks or unheated spaces.
- The use of anti-freeze additives or use of low temperature fluids in liquid systems alone or in combination with supplementary heating of either the piping or the circulating fluid.

Anti-freezing arrangements using heating should be able to maintain the subject liquid to at least +3°C above its nominal freezing temperature and the heating capacity for anti-icing arrangements shall be sufficient to prevent surface ice forming. Anti-icing arrangements using heating should be able to maintain a surface temperature of at least +3°C. The heating capacity should be established by a heat balance calculation and should be maintained at a range from +3°C to +10°C in order to minimize the potential effect of corrosion under the insulation. https://en.wikipedia.org/wiki/Deicing

Anti-icing of offshore structures can be accomplished by applying a protective layer, using a viscous fluid called anti-ice fluid, over a surface to absorb the contaminant. All anti-ice fluids offer only limited protection, dependent upon frozen contaminant type and prevailing weather conditions. A fluid has failed when it no longer can absorb the contaminant and it essentially becomes a contaminant itself. Even water can be a contaminant in this sense, as it dilutes the anti-icing agent until it is no longer effective.

3.4 De-icing measures

De-icing must be carried out by fixed heating arrangements or by use of portable equipment such as:

- High pressure blowing steam hoses and hot water hoses: The location and number of the steam/hot water outlets and equipment shall be appropriate to the local layout and to the time scale in which the de-icing is required to be achieved.
- Mallets (wooden, rubber or plastic hammers) shovels and hand held tools: De-icing equipment shall be located in areas where it is readily available and shall be protected from icing and other adverse conditions.

Chemical de-icing fluids: consisting of propylene glycol (PG) and additives applied on metallic structures. However, since most of the de-icing fluid does not adhere to the structure surfaces, and falls to the ground or into the sea, operators typically use containment systems to capture the used liquid, so that it cannot seep into the ground and water. Even though PG is classified as non-toxic, it pollutes waterways since it consumes large amounts of oxygen as it decomposes, causing aquatic life to suffocate

Several types of chemical de-icers are available on the market, although they share a common working mechanism: they prevent water molecules from binding above a certain temperature that depends on the concentration. This temperature is below 0 °C, the freezing point of pure water. Sometimes, there is an exothermic dissolution reaction that allows for an even stronger melting power (https://en.wikipedia.org/wiki/Deicing).

Some examples of chemical de-icers can be:

Inorganic salts such as:

- Sodium chloride (NaCl or table salt; the most common chemical de-icing);
- Magnesium chloride (MgCl2, often added to salt to lower its working temperature);
- Calcium chloride (CaCl2, often added to salt to lower its working temperature);
- Potassium chloride (KCl).

Organic compounds such as:

- Calcium magnesium acetate (CaMg2(CH3COO)6);
- Potassium acetate (CH3COOK);
- Potassium formate (CHO2K);
- Sodium formate (HCOONa);
- Calcium formate (Ca(HCOO)2);
- Urea (CO(NH2)2), a common fertilizer.

Alcohols, diols and polyols such as:

- Methanol (CH4O);
- Ethylene glycol (C2H6O2);
- Propylene glycol (C3H8O2);
- Glycerol (C3H8O3).

Such chemical methods can be quite impacting on the Arctic environment. In fact, the chemicals could also reach water bodies in concentrations that are toxic to the ecosystems.

Organic compounds are biodegraded and may cause oxygen-depletion issues. Small creeks and ponds with long turnover time are especially vulnerable.

Ethylene glycol and propylene glycol are known to exert high levels of biochemical oxygen demand (BOD) during degradation in surface waters. This process can adversely affect aquatic life by consuming oxygen needed by aquatic organisms for survival. Large quantities of dissolved oxygen (DO) in the water column are consumed when microbial populations decompose propylene glycol.

Sufficient dissolved oxygen levels in surface waters are critical for the survival of fish, macroinvertebrates, and other aquatic organisms. If oxygen concentrations drop below a minimum level, organisms emigrate, if able and possible, to areas with higher oxygen levels or eventually die. This effect can drastically reduce the amount of usable aquatic habitat.

Reductions in DO levels can reduce or eliminate bottom feeder populations, create conditions that favour a change in a community's species profile, or alter critical food-web interactions.

Direct infrared heating has also been developed as de-icing technique. This heat transfer mechanism is substantially faster than conventional heat transfer modes used by conventional de-icing (convection and conduction) due to the cooling effect of the air on the de-icing fluid spray. One infrared de-icing system requires that the heating process take place inside a specially-constructed installation. This system has had limited interest among Operators, due to the space and related logistical requirements for the enclosed location (https://en.wikipedia.org/wiki/Deicing).

3.5 Selection of metallic material

All metallic materials used in structure, equipment or systems considered important for safety or otherwise addressed in DNVGL-OS-A201 standard, and located in open or unheated spaces, shall have mechanical properties appropriate for the winterization temperatures (WT).

The methodology for the selection of the metallic materials shall be consistent with the design code applied for the item under consideration. Design codes with material selection based on the extreme low temperature methodology (typically pressure vessels, drilling equipment, etc.) should apply WT as appropriate.

Aluminium and Austenitic Stainless Steels are considered suitable to all levels of winterization, without need for further demonstration as shown at the following link: https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2013-10/OS-A201.pdf.

3.6 Selection of non-metallic material and electronic components

All non-metallic materials (polymers, seals, ceramics, flexible hoses, fenders, etc.) and electronic components used in equipment/systems and located in open or unheated spaces shall function normally in cold-climate conditions. Therefore, they shall be confirmed to retain their relevant functional properties to ambient air temperature.

Further information: https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2013-10/OS-A201.pdf.

3.7 Other technical issues and solutions

Throughout personal discussion with Operators, other technical issues and solutions to be adopted in extreme weather (also in sub-arctic areas) are hereafter highlighted:

High winds and waves

DNV-GL states that the mechanisms of rogue waves and their detailed dynamic properties are becoming clearer with recent research and through a growing consistency between numerical models and the experimental data documented by many studies. Several different mechanisms may be responsible for generating these waves such as linear focusing of energy, wave-current interactions (e.g. observed in the Agulhas current alongside the southeast coast of South Africa), crossing seas (Wind Sea and swell or two swell systems), quasi-resonant nonlinear interactions (modulation instability), shallow water effects and wind.

Several rogue wave-related accidents involving ships and offshore structures have been reported, and yet, as of today, rogue waves are not explicitly included in classification society rules and offshore standards. This is understandable, due to a lack of consensus on the precise definition of rogue waves. Without a specific definition, there is also no agreement either on the probability of occurrence of such waves, being still a subject of research. More information on rogue waves can be found at: https://www.dnvgl.com/feature/rogue-waves.html#start.

On a jack-up rig, the legs are extremely exposed, and need to withstand relatively high impacts. Therefore the design must take high wind and spray into account in accordance, for instance to the DNV GL standard for impact resistance which stipulates 14/11 MJ.

Due to possible high waves, the jack-up leg length needs to increase up to over 100 m (some rigs reach over 200 m high), as it needs to be possible to jack up the structure to a very significant air gap to keep the hull out of the way of slamming impact by extreme waves.

Storage capabilities

Due to the remoteness of the Arctic environments, large quantities of spares and consumables will require storage, as such items cannot be easily sourced in a remote area with limited infrastructure. This can either add to the requirements for sizing of the unit, but could also add to the congestion issue. Alternative storage options may have to be explored by the operator.

Waste storage capabilities

Storage of waste products in remote and environmentally sensitive regions, waiting for the supply vessel to take care of them, must be carefully taken into account. Therefore, a complete "zero discharge" philosophy should be adopted, even for low risk disposal (such as cleaned cuttings with no oily residue), which may require processing and storage either on board or on a "floating shore base".

DNV-GL states that waste management is still far from being considered a mission accomplished. Key issues include:

- The lack of adequate Reception Facilities in many ports and terminals.
- Difficulties in the handling of certain hazardous waste streams.
- The shortage of storage means on board.
- The rather slack use of shipboard treatment technology.
- The different priorities given by some port states to the disposal of some types of garbage.

It is now clear that the Garbage Management Plans developed according to the IMO Guidelines MEPC.220 (63) need to address additional procedures and/or kinds of waste that fall into the operational or domestic origin categories and respond to new challenges or real situations. A few questions that still need answers are:

- Can food waste be incinerated, where it is not permitted to be discharged into the sea and its long storage on board might create health hazards to the crew?
- What kinds of waste should not be mixed and remain separated till their final disposal, to prevent risks to the seafarers and environmental damage by the dispersal of hazardous substances?
- How can the minimum waste storage capacity of the ship be better calculated?
- Is biological waste originated by various cleaning machinery considered as garbage?
- How to deal with empty containers that initially held a hazardous substance?

Environmentally-sound management of ship-generated garbage means taking all practicable steps to ensure that all potential waste streams are managed in a manner that will ensure the protection of human health and the environment against any adverse effects.

An integrated approach with the Garbage Management Plan is considered necessary to help promote pragmatic garbage management and allow for capacity or resources to be optimized and fully utilized. It should be noted that a well implemented waste management plan is also dependent on the interaction between the vessel and a number of external factors such as ship suppliers, operators of reception facilities, port authorities, etc. Further information can be found at this link:

https://www.dnvgl.com/news/the-challenge-of-optimizing-onboard-waste-management-56507

4 Pollution in the Arctic environment from offshore Oil & Gas activities

The Arctic ecosystem equilibrium is both perfect and extremely vulnerable. It is perfect because of its extreme wilderness and almost complete lack of human interference; it is vulnerable because the minimum interference from outside may cause a great disturbance with negative effects that can last years or even centuries.

These conditions are likely to change very rapidly as the formal economy of the Arctic is largely based on resource extraction. The Arctic area could contain as much as 22 percent of the world's hydrocarbon deposits, with some 29 billion barrels of oil and more than 200 trillion cubic feet of natural gas thought to lie off the Alaska coast alone. North America's largest oil field, Prudhoe Bay, in comparison, holds an estimated 25 billion barrels.

Future development is expected to attract approximately a trillion dollars of new investment during the next 25 years. The current trend of development in the Arctic is a shift from sporadic development to larger-scale development, including new infrastructure, a trend fed both by climate change and global demand for resources. Further information:

http://wwf-ap.org/apps/site/templates/downloads/wwf-arctic-council-conservation-scorecard-WEB.pdf

Until recently the abovementioned offshore deposits have been locked up by thick Arctic ice that no drill rig could withstand. But with the Arctic Ocean now projected to be ice-free during the summer by mid-century and the price of oil stabilizing at about $100 a barrel, nearly every Arctic nation is prospecting for black gold in its rapidly warming Arctic waters. Further information:

https://news.nationalgeographic.com/news/energy/2012/09/120910-shell-begins-arctic-drilling/

Growing exploitation of the Arctic involves, nevertheless, major environmental risks.

A report released by the National Research Council (NRC) has taken a comprehensive look at the impact of oil and gas exploration in the Arctic. According to NRC, rapid climate change is leading to retreat and thinning of Arctic sea ice, potentially increasing the accessibility of U.S. Arctic marine waters for commercial activities. With this projected rise in activity come additional concerns about the risk of oil spills. Recent interest in developing the rich oil and gas resources in federal waters offshore of Alaska has led to planning, environmental assessments, and preliminary drilling for oil and gas exploration. Further information:

https://news.nationalgeographic.com/news/energy/2014/04/140423-national-research-council-on-oil-spills-in-arctic/

In October 2016, the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS) has released an Environmental Impact Statement (EIS) to describe the effects of offshore oil and gas exploration activities in the U.S. Beaufort and Chukchi seas, Alaska. Given the widespread presence of several species of marine mammals in the above mentioned areas, it is likely that some amounts of seismic and exploratory drilling activities will result in the disturbance of marine mammals through sound, discharge of pollutants, and/or the physical presence of vessels. Further information:

https://www.fisheries.noaa.gov/resource/document/effects-oil-and-gas-activities-arctic-ocean-final-environmental-impact

Yet, researchers don't know how vulnerable Arctic species would be to a spill, and which species would be affected more than others. Due to lack of sufficient data on the number of species in the region as well as that on migratory population, it is difficult to predict future scenarios in case of an accident: depending on the extent of the spill and the ecosystem in the nearing areas, a spill can lead to anything from an unfortunate incident to a terrible disaster. Further information:

http://blog.iiasa.ac.at/2017/08/16/what-would-an-oil-spill-mean-for-the-arctic/

A research published on American journal Environmental Science and Technology shows that an oil spill – in this case in the winter – can have more serious consequences for food chains in the Arctic than previously assumed: "*the most surprising finding is that it takes a lot less of the toxic substance pyrene from crude oil to kill zooplankton than we have seen in previous experiments. At doses 300 times smaller than what we have seen so far, half of the copepod species Calanus glacialis in our experiment died*," says PhD Kirstine Toxværd (*Impact of Pyrene Exposure during Overwintering of the Arctic Copepod Calanus glacialis)*. Further information:

https://pubs.acs.org/doi/10.1021/acs.est.8b03327

Generally speaking, the Arctic environment is more vulnerable to oil spills than warmer environments because oil breaks down more slowly under cold conditions and because Arctic plants and animals need a longer time to recover from damage. In addition, remedial measures are difficult due to the extreme conditions of cold, ice cover, and winter darkness.

Knowledge of ice thickness, concentration, and extent is essential for anticipating the likely behaviour of oil in, under, and on ice and determining applicable response strategies, while high-quality bathymetry, nautical charting, and shoreline mapping data are needed for marine traffic management and oil spill response. From a biological perspective, understanding population dynamics and interconnections within the Arctic food web will enable the determination of key species that are most important for monitoring in the case of an oil spill.

Monitoring approaches will need to take advantage of benchmarks, or reference points over time, rather than static baselines. Critical types of benchmark data for oil spill response in the Arctic include:

- Spatial and temporal distributions and abundances for fishes, birds, and marine mammals;
- Subsistence and cultural use of living marine resources;
- Identification and monitoring of areas of biological significance;
- Rates of change for key species;
- Sensitivity of key Arctic species to hydrocarbons;
- High-resolution coastal topography and shelf bathymetry;
- Measurements of ice cover, thickness, and distribution.

Additional research and development needs to include meteorological-ocean-ice forecast model systems at high temporal and spatial resolutions and better assimilation of traditional knowledge of sea state and ice behaviour into forecasting models. Releasing proprietary monitoring data from exploration activities would increase knowledge of Arctic benchmark conditions. When appropriate, Arctic communities could also release data that they hold regarding important sites for fishing, hunting, and cultural activities.

Recent spills demonstrate the concrete risks for the region.

In December 2004, a Malaysian cargo vessel traveling through Alaska's Aleutian Islands lost engine power and ran aground. Six crew members died. Poor weather conditions prevented any response for several days. Within two weeks, nearby response equipment supplies were depleted and continued bad weather kept dispersant supplies from arriving for three weeks. The spill killed more than 1,600 birds, closed a local crab fishery and contaminated local beaches. This accident discharged 335,000 gallons of heavy fuel as cargo. Following the spill the fishing industry had to implement extreme and costly measures to ensure that oil did not contaminate their harvested product.

In March 2006, a Dominican cargo ship collided with another vessel off the coast of Estonia, where it sank. Because Estonia lacked the resources to mount an effective response in icy conditions, a week passed before response vessels could be brought in from Finland. By then, much of the oil had spread to shallow areas inaccessible to these boats, further hampering clean-up efforts.

A spill a month earlier near Estonia resulted in the deaths of 35,000 birds.

In March 2006, a fuel oil spill was discovered when the ice began to break up near a chemical plant in south-eastern Norway. The oil had already travelled down the Glomma River to an ocean inlet near a bird sanctuary and vacation area before it was detected. Strong currents, ice and cold prevented the use of the available response equipment, resulting in the oiling of 200 ducks and 80 swans.

In December 2007, approximately 250,000 barrels of oil poured into the North Sea as it was being piped from an offshore platform to a loading buoy operated by Norwegian oil giant Statoil-Hydro. Weather including near-gale conditions and wave heights of 7 meters prevented the use of the available response equipment.

Shell's attempt to drill in 2012 ended with the drilling rig, the Kulluk, running around and needing to be rescued.

The Arctic Challenger is the vessel proposed by Shell to flaring off oil and gas recovered from underwater hydrocarbon spill in the Arctic. The vessel represents the multinational energy corporation's hopes for demonstrating its technical know-how for cleaning up underwater Arctic oil spills. A 2012 executive presentation by Shell Oil's President Marvin Odum suggests the *Arctic Challenger* is a key part of the company's "cap and contain" plans to mitigate against major spills: in what the company says is an "unlikely" event of an underwater oil and gas blow out from its drilling operations, the ship would flare off the recovered hydrocarbons into the air. Shell and other companies have suspended Arctic drilling plans for 2014, but there is little doubt the push to develop the region's energy resources will continue. Further information:

http://2knowabout.blogspot.it/2014/12/shells-arctic-challenger-to-burn-oil.html

The remoteness of the area and the lack of basic infrastructure (roads, ports, airports, accommodation facilities) make operations for oil spill containment and response in Arctic extremely difficult and expensive. In addition, there is still significant undergoing research on very crucial questions regarding oil spill response in the Arctic which have not yet clearly answered, such as: how chemical dispersants and oil collection agents might work in a cold climate, how ice conditions and ocean currents will influence the fate of spilled oil, and how well microbes in the Arctic are able to degrade the hydrocarbons, as they tend to do in warmer climates.

Arctic oil spill response is challenging because of:

- Extreme weather and environmental conditions.
- The lack of existing or sustained communications, logistical, and information infrastructure; significant geographic distances.
- Vulnerability of Arctic species, ecosystems, and cultures.

A fundamental understanding of the dynamic Arctic region is needed to help guide oil spill response and recovery efforts. Information on physical processes—including ocean circulation, ice cover, marine weather, and coastal processes—is important to frame the environmental context for the Arctic ecosystem and can help responders predict where oil will spread and how weathering might change its properties. Parameters such as air and water temperature, wind velocity, and hours of daylight are important considerations in choosing an effective and safe response strategy.

Key response countermeasures and tools for oil removal in Arctic conditions include biodegradation (including oil treated with dispersants), in situ burning, chemical herders, mechanical containment and recovery, detection and tracking, and oil spill trajectory modelling.

These are joined by the "no response" option of natural recovery, which is a viable alternative in some situations. No single technique applies in all situations. The oil spill response toolbox requires flexibility to evaluate and apply multiple response options, if necessary. Well-defined and well-tested decision processes are critical to expedite review and approval of countermeasure options in emergency situations.

Timely and effective response to oil spills requires containment, recovery and restoration.

Oil spills in polar seas are especially damaging because the natural conditions severely constrain an effective response. As a part of normal operations, ships produce a range of substances that must eventually be eliminated from the ship through discharge into the ocean, incineration or transfer to port-based reception facilities. Further information:

http://www.arctis-search.com/Effects+of+Oil+Spills+in+Arctic+Waters

There are currently inadequate techniques for recovering spilled oil in ice-covered environments. The solutions that today are available for oil spill recovery in the Arctic include mechanical methods, bio-remediation, in-situ burning and dispersants. The severity of contamination is not only dependent on the type of organisms exposed to oil, but also on the type and volumes of spilled oil, weathering processes, oil combating measures taken, and the location of the spill. Whether large oil spills require more time than smaller spills, the use of oil dispersants has usually more severe consequences on organisms than the mechanical and/or biological oil combating. On the basis of the extreme conditions of the environment in the Arctic, responding to oil spills is a key challenge along the various sailing routes, especially where ice is present.

State-of-the-art information on Arctic activities can be found in the archive of the Arctic Council: https://oaarchive.arctic-council.org/

The Arctic Council was established in 1966 with the aim of promoting cooperation, coordination and interaction among the Arctic States on sustainable development and environmental protection in the Arctic. This is carried out through the organization of Working Groups on different programmes (e.g. Arctic Contaminants, Arctic Monitoring, Conservation of Arctic Flora and Fauna, Emergency Prevention, Preparedness and Response, Protection of the Arctic Marine Environment) whose activities are publicly available.

Within these activities a very interesting and comprehensive report was made available by the task force on Pollution Prevention, in 2016; it was prepared by Proactima for the Norwegian Petroleum Authority acting on behalf of the Norwegian Ministry of Foreign Affairs. The purpose of this report was to establish an overview of what has been done and what activities are in progress regarding technical and operational measures, specifically designed to prevent or contain the escape of fluids into the marine environment from offshore petroleum activities in Arctic and cold climate regions.

This report titled "*Overview of measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activities"* can be downloaded from:

https://oaarchive.arctic-council.org/bitstream/handle/11374/1738/EDOCS-3194-v1-ACSAOUS202_Fairbanks_2016_71a_Overview_Measures_OPP_Norway_report.pdf?sequence=1&isAllowed=y

In this report the following undesirable events were considered as they may result in acute pollution from offshore installations in the Arctic:

- Process leak;
- Blowout;
- Riser / pipeline / subsea structure leak;
- Object on collision course;
- Damage to structure;
- Leak during loading / offloading.

Based on the list of undesirable events a set of themes to be studied have been identified, i.e.:

- Meteocean and ice conditions;
- Ice management;
- Drilling technology, well integrity and well control;
- Pipelines and subsea structures;
- Facility design;
- Loading and offloading;
- Communication solutions;
- Human resources and competence;
- Management;
- Oil spill detection;
- Development of new concepts for exploration and production activities.

For each theme the information of interest was collected from industry and research institutions, as well as from open sources.

A risk-based approach was considered to identify all measures (i.e. preventive and mitigating barriers, including the human dimension) available to avoid/contain the oil spill.

The state of the art on technological and operational measures to prevent oil pollution, including on-going research projects and programs, is well described.

The study concludes by providing some observations, recommendations and suggestions for further work.

It may be also useful to mention that there are serious arguments against the exploitation of the Arctic:

Greenpeace has started in 2012 the "*Save the Arctic*" campaign to protect the Arctic from oil drilling and industrial fishing. The campaign aims at prompting a United Nations resolution on protection for the Arctic. Further information:

https://en.wikipedia.org/wiki/Save_the_Arctic

According to WWF, despite the efforts on prevention and safety measures, the lack of experience of deploying and operating spill response equipment in the Arctic makes it exceedingly difficult to predict or understand the response capabilities and limitations of current spill response systems. (See: '*Lessons Not learned. 20 Years*

After the Exxon Valdez Disaster Little Has Changed in How We Respond to Oil Spills in the Arctic). Further information: https://wwf.fi/mediabank/983.pdf

Several videos, dealing with the problem of risk of oil spill in the Arctic environment can easily be found on YouTube. Some of them are provided below:

https://www.youtube.com/watch?v=JwCbWPR7VK8

This video (6' 30'') highlights the point of views of the scientific community about the lack of knowledge in this area, and the perspectives of those who depend on the Arctic Ocean for their livelihood.

https://www.youtube.com/watch?v=Xyn4dAcP-Mc

On the same subject is the content of the above video (6' 14''): Battle for the Arctic: Drill or Not to Drill.

https://www.youtube.com/watch?v=mxN1yc_DikU

Finally, this video (22' 59'') describes the organizational work on board of the Russian Prirazlomnaya platform operating on the Russian Shelf above the Arctic Circle. The "Kirill Lavrov" is the tanker that ferries the oil to land.

5 Safety and contingency plans in the Arctic

5.1 The safety issue

An accident scenario is a chain of events originated by a triggering event or threat and ending into a set of consequences depending on the behaviour of *prevention*, *control* and *mitigation* systems.

Accident sequences are graphically represented in a “Bow-Tie” (BT) diagram in which the causes are placed on the left and the consequences on the right (Tarantola et al., 2018).

The central element of a bow-tie is an undesirable event (UE) with the potential to cause harm, whose causes (on the left-hand side) and consequences (on the right-hand side) are determined. UEs are particular plant conditions describing an accidental situation in which the integrity of the installation is threatened.

Three types of systems can be found in a Bow-Tie diagram. Prevention systems aim to avoid the occurrence of UEs or to reduce their occurrence frequency; the role of Control systems is to limit as much as possible the extent and/or the duration of undesirable events; and Mitigation systems aim at reducing the magnitude of damages when event evolve into accidents. All these safety-related systems and procedures are referred to as Safety Barriers.

A threat is an event (simple or complex) which is able to cause the occurrence of an UE when all preventive measures fail, i.e. these events are the root causes or initiators of accident scenarios.

<u>Examples of simple threats</u>: valve rupture; human error; mud pump failure; etc.

<u>Examples of complex threats</u>: well kick; riser failure; drilling into shallow gas pockets; etc.

Complex threats can be further decomposed into a set of simpler threats up to their root causes (e.g., by fault tree analysis).

Triggering events can be subdivided into Natural (e.g. extreme weather conditions, earthquake, geological seabed instability) and anthropogenic (human/mechanical technical events).

In the Arctic region natural events are mainly represented by the harsh environment and extreme weather conditions (e.g. extreme cold, ice on board, ice pack and icebergs on the sea, high winds, and darkness). Such harsh conditions can affect both equipment, leading to structural failure, and human psychology, challenging personnel often to the limit.

Although in Tarantola et al. (2018) the aim was on general accidents occurring on board of offshore installations, in the present report the focus is on those accidents specifically related to mechanical or human failure stressed by extreme weather conditions, such as those in the Arctic area.

As described in section 3, drilling and production platforms operating in the Arctic area must be properly winterized; systems installed for this purpose (e.g. anti-icing, anti-freezing**,** de-icing), will appear into the Bow-Tie diagram since their failure implies the failure of the related winterized components. Moreover, the failure of these systems may also act as initiating events of accident sequences.

The (probabilistic) safety analysis of a platform operating in the Arctic area can be performed by applying the classic procedure based on fault tree and event tree methodologies, whereas the assessment of the accident consequences may require the adaptation of dispersion models, especially on water. It seems that fire and explosion models do not require any modification, whereas specific models are needed for evaluating the dispersion of oil.

The results of the analysis of all significant accident scenario are finally used for risk-assessment purposes to demonstrate that risks have been reduced to an “as low as reasonably practicable” (ALARP) level or that the plant design / management needs to be improved.

Operations in offshore waters of the Member States of the European Union are mainly regulated by the offshore safety Directive 2013/30/EU with the objective to “… *reduce as far as possible the occurrence of major accidents relating to offshore oil and gas operations and to limit their consequences, thus increasing the protection of the marine environment and coastal economies against pollution, establishing minimum conditions for safe offshore exploration and exploitation of oil and gas and limiting possible disruptions to Union indigenous energy production, and to improve the response mechanisms in case of an accident.*”

With reference to the Arctic waters, the offshore safety Directive recognises that “… *Arctic waters are a neighbouring marine environment of particular importance for the Union, and play an important role in* *mitigating climate change. The serious environmental concerns relating to the Arctic waters require special attention to ensure the environmental protection of the Arctic in relation to any offshore oil and gas operation, including exploration, taking into account the risk of major accidents and the need for effective response. Member States who are members of the Arctic Council are encouraged to actively promote the highest standards with regard to environmental safety in this vulnerable and unique ecosystem, such as through the creation of international instruments on prevention, preparedness and response to Arctic marine oil pollution, and through building, inter alia, on the work of the Task Force established by the Arctic Council and the existing Arctic Council Offshore Oil and Gas Guidelines.*"

Regulations for drilling and production, including transportation, of oil and gas in the Arctic are based on safety principles. For instance, the regulations for the Norwegian petroleum industry apply for the entire continental shelf and the functional requirements are the same for the entire area. This means that any requirement related to health, safety or the environment must be met regardless of where the operation takes place. This also includes the Barents Sea (Personal communication with Sigve Knudsen, Norwegian Petroleum Safety Authority).

There are some important principles in the regulations (cf. frame regulation § 10) requiring that:

- The activities shall be prudent, based both on an individual and an overall assessment of all factors of relevance for planning and implementation of the activities as regards health, safety and the environment.
- Consideration shall also be given to the specific nature of the activities, local conditions and operational assumptions.
- A high level for health, safety and the environment shall be established, maintained and further developed.

The regulations stipulate therefore a clear requirement that the nature of the activity and the local conditions shall be considered. Based on this, the requirement to fulfil a function may lead to different solutions (technical, operational or organizational) at varying locations on the continental shelf under the local conditions. This means that one may find different technical solutions in the North Sea, Norwegian Sea and the Barents Sea that fulfil the same requirement that applies to the entire continental shelf. The difference in solutions will be a direct response to the specific conditions at the location where the operation is to be performed. This is particularly the case for the need to perform winterization and the level of winterization of a facility or installation depending on the specific conditions at the location of the operation.

State of the art solutions are developed by many stakeholders in the petroleum industry. The solutions evolve and improve as new experience and knowledge is applied. To enable industry to continuously improve and develop the solutions they apply, regulations describe a function rather than prescribing a solution. This is important as it gives the responsible party or the operator, the option to apply new technology as it is proven and becomes available. The responsibility to ensure prudent activities and the application of technological solutions that meet the regulations lie with the responsible party/operator.

Norwegian regulations refer to standards that, when applied, are considered to specify a solution that meets or exceeds the functional requirement. Where the guidelines to the regulations specify a standard, the safety level described in the standard must be met or exceeded by the responsible party for the operation. An alternative to the standard may be used if this also meets or exceeds the safety level achieved by applying the standard. The development of standards is a responsibility that is taken by, amongst others, the petroleum industry. Typically, standards for the oil industry may be developed by organizations like International Organization for Standardization (ISO), International Association of Oil and Gas Producers (IOGP), Norwegian Oil and Gas and other relevant organizations. A detailed description of the development of standards within the petroleum industry has been documented in a report developed within the Arctic Council. The report is titled "*Standardization as a tool for prevention of oil spills in the Arctic*". The report describes the organizations and processes involved in developing, maintaining and revising standards for the petroleum industry. The report and the related summary can be found at the following links on the Arctic Council website:

https://oaarchive.arctic-council.org/bitstream/handle/11374/1951/2017-05-04-EPPR-Standardization-to-prevent-oil-spills-long-version-report-complete-A4-size-DIGITAL.pdf?sequence=1&isAllowed=y

From the open source investigation, a lot of other documents have been found, some of the more interesting ones are listed herewith.

A very interesting thesis on RAM (Reliability Availability Maintainability) problems and solution methods for the analysis of safety barriers of oil and gas drilling and production installation in the Arctic can be downloaded from:

https://munin.uit.no/bitstream/handle/10037/9972/thesis.pdf?sequence=6

The *Artificial Gravel Island* of the *Liberty Project*, is a proposal to drill in Arctic waters from an artificial island. Further information:

https://phys.org/news/2017-10-oil-company-arctic-drilling-artificial.html

The paper "*Effects of Cold Environments on Human Reliability Assessment in Offshore Oil and Gas Facilities*" (The Journal of Human factors, November 26, 2013) proposes a new methodology that focuses on the effects of cold and harsh environments on the reliability of human performance. Further information:

http://journals.sagepub.com/doi/pdf/10.1177/0018720813512328

In the article "*Risk analysis of offshore transportation accident in Arctic waters*" (The International Journal of Maritime Engineering, R. Abbassi et al, 2017) a methodology for risk analysis applicable to shipping in Arctic waters is introduced. Further information:

https://www.researchgate.net/publication/320347524_Risk_analysis_of_offshore_transportation_accident_in_Arctic_waters

"*Risk Management in the Arctic Offshore: Wicked Problems Require New Paradigms*", ISER WP 2011.3. This research examines how various groups with interests in the Arctic offshore define risks. Further information:

http://www.iser.uaa.alaska.edu/Publications/2011_10-riskmanagement.pdf

"*Oil spill risks assessed for offshore Arctic pipeline*". A. Dinovitzer et al, Offshore Mechanics and Arctic Engineering Conference, 2004, Vancouver.

https://www.ogj.com/articles/print/volume-102/issue-40/transportation/oil-spill-risks-assessed-for-offshore-arctic-pipeline.html

X. Gao et al., "*An approach for prediction of petroleum production facility performance considering Arctic influence factors*", Reliability Engineering and System Safety, Vol. 95 (8), 2010.

https://www.sciencedirect.com/science/article/pii/S0951832010000773

5.2 Contingency plans

The final output of the Bow-Tie model is a list of accident consequences resulting from the foreseen behaviour of the mitigation barriers. The emergency response plan is the ultimate measure of mitigation. A proper emergency plan, drafted with knowledge and taking into account the actual possible threats existing in each particular offshore installation is the leading key for the safest and easiest solution to an emergency. Indeed, a well-designed emergency response plan should be able to guide personnel to act not following their instincts but in a proper way, following pre-defined procedures.

As described in Tarantola et al. (2018), the requirements of an emergency response plan can be summarized as follow:

- Cooperation with contractors, authorities, and communication of the respective information available.
- Capping systems (different techniques).
- Clear definition of the chain of command and responsibility.
- Temporary refuge details.
- Details of evacuation and escape equipment.
- Means of recovery to a safety place.

More particularly, a contingency plan should:

- be readily available in case of emergency.

- clearly identify the hierarchy of the emergency command structure for both the onshore and offshore bits and ensure a prior identification of competent and acknowledged personnel.
- include the details of the emergency control room facilities and all the existing equipment and documentation.
- include the periodical verification of the whole communication system.
- verify that the key personnel have the proper knowledge and experience to make the communication system working.

The above listed requirements are generally applicable also to activities carried out in the Arctic area. The open source offers a huge amount of documents dealing with the problem of emergency planning and response for drilling and production activities in warmer than Arctic environments. In the Arctic region the low temperature, darkness, polar low, long distances, etc., make the problem more difficult. Moreover, the presence of icebergs or ice pack on the sea, call for strong interaction and information sharing between ice surveillance and navigation crews; hence, new organizational command and control solutions need development for reducing reaction times. Also, novel hull shapes require investigation, to minimize ice impact on operations as described in Section 3.

From the open source investigation performed on the emergency planning and response problems, many interesting documents, especially from the stakeholders' point of view have been found. Some of these documents are herewith listed:

The paper "*Emergency response and environment restoration. Perspectives on emergency response in the Canadian Arctic*" is one of a three-part series focused on a hypothetical sinking of the MS Arctic Sun in Cumberland Sound, Nunavut, Canada. The series is part of a larger project on Emergency Management Preparedness in the Arctic being undertaken by the Munk-Gordon Arctic Security Program. Further information:

https://www.researchgate.net/profile/Joice_K_joseph/post/Hello_Can_anyone_suggest_some_disaster_management_aspects_for_the_Arctic_region/attachment/59d6353879197b8077992d15/AS%3A383454068920320%401468433982276/download/MS+Arctic+Sun+Case+Study+-+Part+B.pdf

The project "*Oil Spill Preparedness in Small Communities*" was approved by the Emergency Prevention, Preparedness and Response (EPPR) Working Group of the Arctic Council in June 2015. The project co-leads Norway, U.S., Canada and Aleut International Association developed a community self-assessment tool that will help EPPR better understand community preparedness and risk exposure. Further information:

https://oaarchive.arctic-council.org/bitstream/handle/11374/2079/2017_03_15_PPR_Oil-Spill-Response-report-%20FINAL.pdf?sequence=1&isAllowed=y

"*Arctic: Emergency response - Offshore operations in the Barents Sea*". This position paper from DNV GL aims to provide insight into the feasibility of emergency preparedness solutions for the Barents Sea, and highlights where existing technology might be applicable and where new concepts need to be developed. The DNV report is available on request at the following address:

https://www.dnvgl.com/oilgas/arctic/arctic-emergency-response.html

Schmied J. et al. (2017), "*Maritime Operations and Emergency Preparedness in the Arctic–Competence Standards for Search and Rescue Operations Contingencies in Polar Waters*". In: Latola K., Savela H. (eds), The Interconnected Arctic — UArctic Congress 2016. Springer Polar Sciences, Springer, Cham.

This paper elaborates on the operational competence requirements for key personnel involved in large scale SAR (Search And Rescue) operations. Findings from real SAR incidents and exercises provide in-depth understanding on the operational challenges. From the list of references, the reader is addressed to other interesting papers on the subject. Further information:

https://link.springer.com/chapter/10.1007/978-3-319-57532-2_25

The Arctic Council Working Group on Emergency Prevention, Preparedness and Response (EPPR) addresses prevention, preparedness and response to environmental emergencies in the Arctic. The working group will increase emergency response capacity with people who live and work in the Arctic. Prevention and safety are also focus areas. Safety systems and guidelines for worker health and safety are planned. Further information:

http://www.arctic-council.org/index.php/en/about-us/working-groups/eppr

The Arctic Environmental Protection Strategy (AEPS) is a multilateral, non-binding agreement among Arctic states on environmental protection in the Arctic. It was adopted in 1991 by Canada, Denmark, Finland, Iceland, Norway, Sweden, the Soviet Union, and the United States. The AEPS deals with monitoring, assessment, protection, emergency preparedness/response, and conservation of the Arctic zone. Further information: https://en.wikipedia.org/wiki/Arctic_Environmental_Protection_Strategy

6 Accidents on Arctic and sub-Arctic offshore installations

6.1 Introduction

A common feature of all offshore Oil & Gas operations is that they always entail the risk of a major accident which may have severe and multifaceted consequences to many recipients. The risk of a major accident becomes even higher as Oil & Gas companies move their drilling rigs into deeper waters and harsher marine environments driven by the depletion of the easily accessible hydrocarbon reserves.

An accident in an offshore Oil & Gas installation has the potential to cause a large scale of human, economic, and environmental disaster. The resulting impacts may involve loss of human lives, injuries, environmental pollution of the surrounding marine and coastal areas, direct and indirect economic losses for the affected population and the involved companies, deterioration of the energy supply security and fluctuations in the oil production rates & prices. From all the above, it becomes clear that the negative impacts of an accident in an offshore installation may be very hard to quantify precisely. In order to illustrate the severity and the wide range of impacts that may result from an accident in an offshore installation it was found necessary to introduce *Annex 1* & *Annex 2*.

In *Annex 1* the blowout of the Macondo well (20 April 2010, Gulf of Mexico) was selected as a case study because it is a recent, landmark accident which is recognised as one of the world's biggest offshore disasters. Since then, there has been sufficient time to assess the impacts of the accident at their full extent. Moreover, the technological status of the modern offshore installations which are in operation nowadays, do not differ much from that of the Deepwater Horizon drilling rig.

In *Annex 2* a list of the most catastrophic accidents in the offshore Oil & Gas industry (in terms of human casualties and volume of oil spilled) is presented. All the above data, constitute valuable information for every future attempt to produce hydrocarbons in the Arctic or sub-Arctic Seas.

A recently published study (Ismail et al. 2014) provides an evaluation of the accidents that occurred in offshore Oil & Gas installations operating all over the world over the last 56 years (1956 – 2012). From the analysis of 219 major accidents in jack-ups, drill ships, semi-submersible and platforms it was observed that most of the accidents are attributed to human error or failure of equipment. It was also noticed that most of the accidents were routine accidents meaning that similar accidents have happened elsewhere sometime in the past. Finally, it was remarked that vast majority of accidents are not attributed to only one cause but to a synergy of multiple failures – causes. In *Figure 6.1* the percentage distribution of the basic causes of accidents in offshore installations is illustrated. It becomes clear that the most frequent causes of accidents in an offshore installation are the blowouts (46,1%) followed by storms (15,1%) and structural failures (11,4%). **[27]**

Apart from being the most frequent cause of accident, offshore blowouts also carry the biggest risk in terms of the extent and the cost of the induced damage. In case of a blowout accident, large quantities of crude oil may be released uncontrollably for weeks, or even months with severe economic and environmental impacts. As it is illustrated in *Annex 1,* most of the economic damage from the Macondo well blowout was not attributed to the loss of the Deepwater Horizon platform but to clean up costs, fines and court-ordered compensations to oil spill victims. According to the SINTEF Offshore Blowout Database, 642 offshore blowouts / well releases have occurred world-wide since 1955. **[28]**

According to an impact assessment which was published (2011) by the European Commission, the direct, tangible costs for offshore accidents in Europe are estimated to range from €205 to €915 million annually.

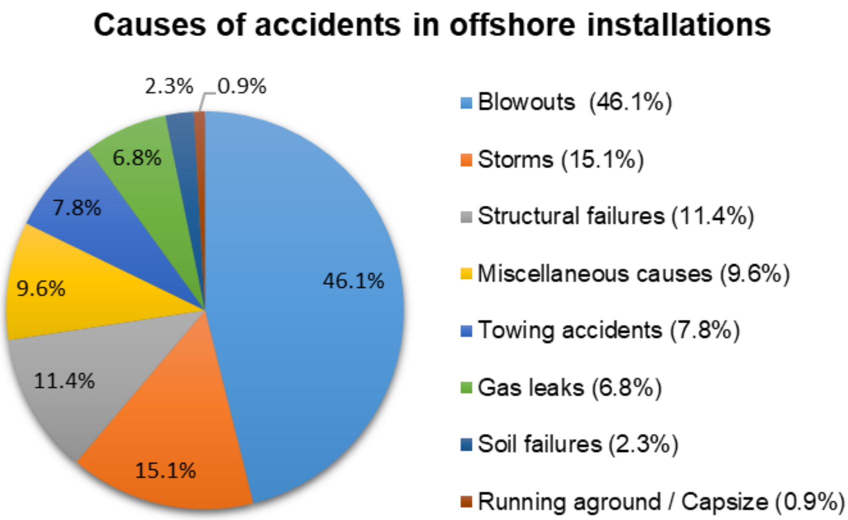

Figure 6.1. Distribution of main causes of accidents in offshore installations (Source: Ismail et al., 2014) **[27]**

Up today, there is no adequate, recorded number of accidents in offshore installations in the Arctic, which could be used for statistical analysis, since operating durations (exposure times) of the Arctic offshore installations have been very limited. Nevertheless, in future field developments, accidents triggered by harsh environmental conditions are expected to be more frequent in Arctic than in other parts of the world. Strong winds, high waves, low temperatures, icing, icebergs and poor visibility are significant promoters and triggers of accidents.

A recent study conducted by the Joint Research Centre (2017) gives an overview of the incidents triggered by natural hazards at offshore installations in harsh environments. According to the paper, the most frequently damaged offshore installations are the semi-submersible units and the highest likelihood for an accident to occur is during exploration drilling or transfer operations. Moreover, the paper raises safety concerns for the offshore operations as there are indications for a future rougher maritime climate and global worsening of extreme metocean conditions due to climate change. **[26]**

Past accident analysis is of fundamental importance for the prevention of their reoccurrence in the future. For this reason, a database of accidents in the Arctic Seas along with lessons learnt from landmark accidents are presented in the following paragraphs of the Chapter.

6.2 Accident Database

Transparency and exchange of information on past offshore incidents and accidents is of paramount importance for preventing the recurrence of similar accidents in the future. The availability of accurate data on past offshore accidents provides the basis for their statistical analysis and the overall risk management of offshore Oil & Gas operations. More specifically, through accident statistics it becomes possible to identify:

- The associated risk of different types of offshore operations;
- The associated risk of different types of offshore installations;
- Any trends or cycles in the occurrence of offshore accidents;
- The safety performance of Oil & Gas operators.

In that context, several databases on past offshore accidents have been developed at national or international level. Accident databases at national level are developed by Regulatory Authorities in accordance to legislative requirements and the corresponding data refer to accidents in the continental shelf of a specific country whereas accident databases at international level are developed by International Associations and the corresponding data refer to accidents anywhere in the world or in a group of countries. In *Table 6.1* accident databases which contain (not exclusively) data on accidents in offshore Oil & Gas installations in the Arctic are presented. It must be mentioned that up today there is no a common database for Arctic countries to collect and share data on accidents and other incident events that occurred in the Arctic Seas. However, an effort to gather accident data from all the Arctic countries is made by the Arctic Council via the Arctic Offshore Oil and Gas Regulatory Resource (AOOGRR). Further information: https://www.pame.is/index.php/aoogrr-by-topic/accident-and-incident-reporting

Table 6 1 Offshore accident databases which contain data from operations in the Arctic Seas

Regulatory Authorities which maintain Accident Databases at National level	
Petroleum Safety Authority (PSA) - Norway	
Danish Energy Agency (DEA) - Denmark	
Danish Working Environment Authority (DWEA) - Denmark	
Bureau of Safety and Environmental Enforcement (BSEE) - USA	
National Energy Board (NEB) - Canada	
Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) - Canada	
Accident Databases at International level	**International Associations**
SINTEF Offshore Blowout Database	SINTEF
Well Control Incident Database (WCID)	IOGP
Worldwide Offshore Accident Databank (WOAD)	DNV
Performance Measurement Project (PMP)	International Regulators' Forum (IRF)

A common feature of all offshore accident databases is that they are not directly available to the public as there is a need to protect sensitive and confidential information. A very comprehensive source of offshore accident information for public use is the Worldwide Offshore Accident Databank (WOAD) operated by Det Norske Veritas (DNV). WOAD data are not publicly available but can be accessible through a database subscription (with charge). For the purposes of the present report and in order to extract data related to accidents in the Arctic Seas the WOAD database has been used as the main source of information.

Regulation gaps

Offshore accidents and incidents, especially occupational safety events are being reported to national Regulatory Authorities according to national legislations. An existing regulation gap is that **Arctic countries have different labour and environmental legislations** and as a consequence the definition of what constitutes a reportable accident varies among each country. In some countries one or more days of absence from work following an incident is considered as a reportable event, whereas others require the absence for at least three subsequent days as the necessary condition. Another example worth citing is that in Russia, oil leaks which are less than eight tons are classified as incidents and therefore remain unreported and carry no penalty under the existent laws. It should also be mentioned that in Russia the regulatory framework is not so strict over the established National Oil Companies, especially in cases where there is a conflict with Russian economic or geopolitical interests. **[30] [32] [33]**

Furthermore, the existing legislative framework for occupational health and safety focuses on serious accidents resulting in fatalities, injuries or damages to the installations. As a result, **near misses are not always reported** by the operators because it is not a legal requirement. However, it has been identified from lessons learnt, that the inclusion of near misses in the accident databases is of fundamental importance. It is worth mentioning that Transocean drilling company had an incident (23 Dec 2009) on one of its North Sea rigs similar to that which caused Deepwater Horizon disaster a few months later (20 Apr 2010). Unfortunately, information about this near miss was not disclosed, not even to Transocean employees of the installations operating in the Gulf of Mexico. Should Transocean have learned from the near-miss in the North Sea, the Macondo accident could have been avoided. **[31]**

Another regulation gap which must be underlined is the fact that **the Regulatory Authorities and the involved International Associations do not have a common format of reporting** the accidents and incidents in their databases. As a result, the exchange of information between different databases is hindered.

Finally, it must be highlighted that the accidents in all existing databases are recorded without making any reference to the **operating durations** (exposure times) of the corresponding installations. The reporting of the time interval within which accidents take place could determine the rate in every offshore platform and therefore generate a clearer image of the differences in the safety performance between offshore installations in the Arctic and offshore installations in the rest of the world.

The Worldwide Offshore Accident Databank (WOAD)

One of the most reliable sources of information on accidents occurring in the offshore oil and gas industry is the Worldwide Offshore Accident Databank (WOAD) operated by Det Norske Veritas (DNV). WOAD comprises information of 6451 events (accidents, incidents and failures) occurring to 3795 operating units from 1970 to 2013. The databank is continuously being updated with the latest information available from authorities, official publications, reports, newspapers, databases, rig owners, and operators globally. The data of WOAD are not publicly available but are accessible through a database subscription (with charge).

It must be underlined that WOAD is composed of worldwide data, collected and compiled by DNV which is an International Association and not a Regulatory Authority. This implies that the completeness of the accident database depends on the availability of the data and not on compulsory data registration from the operators. As a consequence, most of the records in WOAD database, refer to accidents which occurred in countries willing to share accident related information. From all the above, the following deductions could be made:

- The geographical distribution of the recorded accidents is not representative of the offshore safety performance of the countries mentioned.
- Since not all of the offshore accidents are reported, the WOAD constitutes an underestimation of the real situation.

Within the WOAD database, the records are classified into the following 4 categories:

1. **Accidents** for all the hazardous situations which have caused fatalities or severe injuries.
2. **Incidents** for all the hazardous situations which have caused minor injuries to personnel or low degree of damages to the installation which require repairs or replacements.
3. **Near-misses** for all the situations that might have or could have developed into an accident. No damages to the installation occurred and no repairs were required.
4. **Insignificant events** for all the situations with minor consequences. No damages to the installation occurred and no repairs were required. This category also includes minor personnel injuries and small spills of crude oil or chemicals.

Generally, there is a relationship between the numbers of different types of accidents, the distribution of which could be depicted as an accident triangle. Every recorded major accident, implies the occurrence of many more, less serious or near miss incidents which most of the times remain unreported. As a consequence, the accident distribution in the WOAD database could be characterised as more oriented to the major accidents and deviates from the real, triangular accident distribution which is illustrated in Figure 6.2.

Figure 6.2. Accident Triangle (Source: DNV GL) [34]

Method used

In order to retrieve data of accidents in Arctic or sub-Arctic installations, the Worldwide Offshore Accident Databank (WOAD) was found to be the most suitable database. In the WOAD 2013 update, there was a record of 6415 events on offshore installations globally, covering the period 1970 - 2013. A subset of accidents that occurred only in the Arctic or sub-Arctic Seas was isolated. In total, 36 events were identified which are depicted in Table 6.2 & Table 6.3 (light grey indication). Concerning offshore accidents occurred after 2013, 11 events were identified through publicly available information, which are depicted in Table 6.3 (dark grey indication). The combined data collection from the WOAD and other publicly available sources resulted in the registration of 47 accidents in Arctic or sub-Arctic offshore installations during the period 1980 – 2019. It must be noted that the resulted statistical sample of accidents (47 accidents) is too small to be used for further statistical analysis where general accident trends could be defined. For this reason, all identified accidents are just presented in chronological order in Table 6.2 & Table 6.3.

Table 6 2 List of accidents in offshore installations in Arctic & sub-Arctic Seas (1980 -2019) - Part A

Nr	Accident Date	Accident Category	Name of unit	Field / Block	Country	Fatalities	Injuries
1	10/15/1980	Accident	Okha (Jack-up)	Sea of Okhotsk (Sakhalin)	Russia		
2	4/23/1981	Incident	Ross (Semi-submersible)	Barents Sea (7119/12-2)	Norway		
3	9/28/1981	Incident	Canmar Explorer (Drill ship)	Beaufort Sea	Canada		
4	9/20/1982	Accident	Key Singapore (Jack-up)	Bering Sea (Nuniwak)	U.S.A.		
5	1/24/1983	Accident	Valentin Shashin (Drill ship)	Pechora Sea (KOLA-1)	Russia		
6	9/14/1983	Accident	CBIR No 2 (Drill barge)	Beaufort Sea	United States		
7	12/15/1983	Accident	Kulluk (Submersible)	Beaufort Sea	Canada		
8	5/12/1985	Incident	John Shaw (Semi-submersible)	Labrador Sea	Canada		
9	5/23/1985	Accident	Grayling (Jacket)	Gulf of Alaska (Cook Inlet)	United States		
10	12/1/1987	Insignificant	Polar Pioneer (Semi-submersible)	Barents Sea (7219/9-1)	Norway		
11	12/20/1987	Accident	Steelhead (Jacket)	Gulf of Alaska (Cook Inlet)	United States		
12	12/24/1988	Accident	Kulluk (Submersible)	Beaufort Sea	United States		
13	9/22/1993	Incident	Canmar Explorer (Drill ship)	Beaufort Sea	United States		
14	9/29/1994	Incident	Endicott (Jacket)	Beaufort Sea (Endicott)	United States		
15	4/25/1997	Accident	Ocean Alliance (Semi-submersible)	Norwegian Sea (6707/10-1)	Norway		
16	1/21/1998	Incident	Ocean Alliance (Semi-submersible)	Norwegian Sea (6706/11-1)	Norway		
17	2/26/1998	Near miss	Ocean Alliance (Semi-submersible)	Norwegian Sea (6706/11-1)	Norway		
18	9/27/1999	Incident	SAKHALIN 2 (FPSO/FSU)	Sea of Okhotsk (Sakhalin)	Russia		
19	1/18/2001	Incident	Tyonek (Jacket)	Gulf of Alaska (Tyonek)	United States		
20	1/18/2001	Accident	Bell 206L-1 (Helicopter)	Gulf of Alaska (Tyonek)	United States		
21	4/21/2002	Accident	King Salmon (Jacket)	Gulf of Alaska (Cook Inlet)	United States		4
22	8/21/2002	Incident	Cook Inlet (Pipeline)	Gulf of Alaska (Cook Inlet)	United States		
23	2/1/2004	Insignificant	Alaska North Star (Jacket)	Beaufort Sea (North Star)	United States		

Table 6 3 List of accidents in offshore installations in Arctic & sub-Arctic Seas (1980 -2019) - Part B

Nr	Accident Date	Accident Category	Name of unit	Field / Block	Country	Fatalities	Injuries
24	2/8/2005	Insignificant	Eirik Raude (Semi-submersible)	Barents Sea	Norway		
25	2/16/2005	Insignificant	Eirik Raude (Semi-submersible)	Barents Sea	Norway		
26	4/12/2005	Incident	Eirik Raude (Semi-submersible)	Barents Sea	Norway		
27	12/13/2005	Near miss	Polar Pioneer (Semi-submersible)	Norwegian Sea (Snøhvit)	Norway		
28	2/12/2006	Near miss	Polar Pioneer (Semi-submersible)	Norwegian Sea (Snøhvit)	Norway		
29	2/16/2007	Incident	Northstar (Artificial Island)	Beaufort Sea (North Star)	United States		
30	11/24/2007	Incident	SAKHALIN 2 (FPSO/FSU)	Sea of Okhotsk (Sakhalin)	Russia		
31	11/29/2009	Accident	Lisburne (Pipeline)	Beaufort Sea (Prudhoe Bay)	United States		
32	12/17/2011	Accident	Kolskaya (Jack-up)	Sea of Okhotsk (Sakhalin)	Russia	53	3
33	4/9/2012	Accident	Nikaitchuq (Artificial Island)	Beaufort Sea (Nikaitchuq)	United States	1	
34	7/14/2012	Incident	Noble Discoverer (Drill ship)	Alaska (Dutch Harbor)	United States		
35	9/4/2012	Incident	Scarabeo 8 (Semi-submersible)	Barents Sea (7220/10-1)	Norway		
36	12/31/2012	Accident	Canmar Kulluk (Drill barge)	Gulf of Alaska (Sitkalidak)	United States		
37	10/2/2014	Accident	Baker platform **[13]**	Gulf of Alaska (Cook Inlet)	U.S.A.		
38	11/8/2014	Accident	GSP Saturn (Jack-up) **[4]**	Pechora Sea	Russia		
39	6/3/2015	Incident	Fennica (Ice management vessel) **[12]**	Alaska (Dutch Harbor)	U.S.A.		
40	4/17/2016	Near miss	Goliat (FPSO) **[6]**	Barents Sea	Norway		
41	6/25/2016	Accident	Goliat (FPSO) **[10]**	Barents Sea	Norway		1
42	2/7/2017	Accident	Hilcorp Energy (Pipeline) **[3]**	Gulf of Alaska (Cook Inlet)	United States		
43	3/29/2017	Near miss	SeaRose (FPSO) **[11]**	Labrador Sea (White Rose)	Canada		
44	4/13/2018	Incident	Goliat (FPSO) **[7]**	Barents Sea	Norway		
45	6/17/2018	Near miss	Melkøya (Industrial Island) **[8]**	Norwegian Sea (Snøhvit)	Norway		
46	9/16/2018	Near miss	Goliat (FPSO) **[5]**	Barents Sea	Norway		
47	1/16/2019	Near miss	West Hercules (Semi-submersible) **[9]**	Barents Sea (7132/2-1)	Norway		

6.3 Landmark Accidents

6.3.1 Kolskaya jack-up drilling rig (Sea of Okhotsk, 17 Dec 2011)

Figure 6.3. The Kolskaya drilling rig under tow shortly before it sunk [1]

General description of the accident

Report of the Investigative Committee of the Russian Federation

According to investigators, in April 2011, OAO AMNGR and OOO Gazflot concluded a contract on construction of prospecting borehole Pervoocherednaya-1. Under the contract the Kolskaya oil rig drilled the borehole in the West section of Kamchatka offshore in the period between August and December of 2011. On finishing the drilling, OAO Far Eastern Marine Steamship Line and OAO AMNGR agreed on towing the Kolskaya oil rig from the drilling site to the port of Korsakov, Sakhalin Region. The Magadan icebreaker and the Neftegaz-55 towing vessel were employed to do the job.

Under the agreement the route of the towing went along the west shore of Kamchatka and Kuril Islands. The towing distance amounted to 917 miles. Under the requirements of Safe Towing Regulations the maximum towing speed should not be over 3.2 knots and if the waves are over 4 meters high and wind speed is over 17.1 m/s the pillars have to be lowered by two flights (about 13.12 m lower than the level of the main deck) and drift should be started. Head of OAO AMNGR Fleet Operation and Navigation Safety Service was appointed responsible for the towing.

On the order of deputy general director for safety of navigation Boris Likhvan the Kolskaya oil rig with 67crew members aboard started to be towed away on 11 December 2011. Acting chief engineer Bordzilovsky ignored repeated demands of chief of the Kolskaya oil rig that it was necessary to evacuate 28 people not involved in towing and forbade the evacuation by an oral order. During 5 days the towing went on normally. Then the weather suddenly worsened. The responsible for the towing operation, wanted to outrun the cyclone and made an unauthorized decision to raise the speed up to 4.8 knots, which he reported to Likhvan (acting deputy general director) and Bordzilovsky (acting chief engineer). The latter did not give orders to drop the speed to the allowed limits. As a result of the excess of the maximum speed allowed for towing the plating of the oil rig got deformed and then got cracks in it. Water started coming inside the platform and sometime later the oil rig was brought down by the bow. The accused received several reports through satellite communication that it was necessary to lower the leg chords to make the rig drift. The two men, however, hoping on the favourable outcome, ignored these alarming signals and did not take any timely measures to lower the leg chords. Up to 25 m/sec squalls of wind and 4-5m high waves tore away the pod of the bow. The damaged plating started to let the water in ballast tanks and the oil rig got a trim. Leaktightness of water-proof shutoffs at the top deck was broken. The water kept going into the machine room, while the pumps could not manage, which caused further draught and trim and subsequent progressing flooding of not damaged compartments of the oil rig. Almost 24 hours later the accused gave a belated order to lower the leg chords, but the trim (list) made it impossible.

Realizing that the situation was critical with the trim getting bigger and bigger and foreseeing unavoidable wreck of the rig and death of people aboard, the accused did nothing to organize a rescue operation in order to save some money. They ignored recommendations of the duty officer of Yuzhno-Sakhalinsk Marine Rescue Center to timely send SOS signal and did not dispatch rescue helicopters. Despite the prohibition and inaction of the leadership, at 9:45 AM, on 18 December 2011, due to the critical situation the captain sent an SOS, but, unfortunately, it was too late. At 12:46 PM, the same day, the Kolskaya oil rig capsized and sank in the Sea of Okhotsk at the depth of over 1.000 meters killing 53 crew members and injuring 3. **[2]**

Lessons learned

The sinking of Kolskaya oil rig, which led to the death of 53 people, is attributed to the synergy of multiple violations of safety rules and requirements, as listed below:

1. **Nonessential personnel were exposed to unnecessary risk**. From the total 67 crew members, 28 people should have evacuated the platform before the start of the towing.

2. **The safety standards set by the manufacturer were violated.** More specifically, in the determination of the limitations for sea towing, the platform's manufacturer (Rauma-Repola) explicitly stated: ***Towing is prohibited in the winter, in winter seasonal zones.*** **[35]**

3. **The safety regulations set by the national authorities were violated.** More specifically, it has been clearly regulated by the Russian authorities that in the Sea of Okhotsk towing of jack-up rigs with operating limits for a Class 6 sea state must be completed by 10th of October. Towing of all other jack-up rigs should must be completed before 15th of October. Other safe towing regulations were violated as well. The maximum towing speed should not be over 3.2 knots but instead, a decision to raise the speed up to 4.8 knots was taken. Moreover, in the prevailing weather conditions, the pillars of the platform should have been lowered by two flights which never happened. **[36]**

4. **Escape, Evacuation, and Rescue (EER) operations never occurred.** The crew members did not follow any procedure to evacuate the platform in a systematic manner. Furthermore, the SOS signal was sent too late, only 3 hours before the sinking of the rig, making impossible the successful implementation of any external emergency response plan.

6.3.2 Kulluk conical drilling rig (Gulf of Alaska, 31 Dec 2017)

Figure 6.4. Shell's drilling rig Kulluk, off Sitkalidak Island in Alaska (Source: United States Coast Guard)

General description of the accident

The Kulluk oil rig was an ice-class, Mobile Offshore Drilling Unit (MODU) owned by Shell and operated by Noble Drilling. In October 2012 Kulluk had finished the Arctic drilling season in Camden Bay in the Beaufort Sea and a towing operation was prepared to reach the port of Seattle for the necessary offseason repairs. The first part of the plan involved the towing of the Kulluk oil rig from Camden Bay to Dutch Harbor (Unalaska Island) using the ice-class tow supply vessel Aiviq and it was carried out successfully.

On December 21, the second part of the towing plan was launched which involved the towing of the Kulluk oil rig from the Dutch Harbor to the Port of Seattle a 2.000-mile trip which was expected to last three to four weeks with Aiviq to be the sole towing vessel.

On December 27, the two vessels were approximately 50 miles southeast of Sitkalidak Island. The prevailing weather conditions corresponded to winds of 15-20 knots and sea swells of 20-25 feet. Based on historical data, winds and waves of that size are not unusual during winter months in the Gulf of Alaska and should have been expected. As a consequence of the tow overload, the shackle connecting the tow line to the monkey's face failed, the tow was lost and Kulluk was set adrift. Nevertheless, the emergency tow line (with less tensile load capacity) was connected to the Kulluk. In the same day, all four engines of Aiviq failed which was attributed to seawater contamination of the fuel tanks. With no propulsion, Kulluk and Aiviq were set adrift in heavy seas.

On December 28, two more support vessels arrived on the scene, the Alex Haley and the Guardsman but without being able to contribute substantially to the towing operation despite all the efforts. An unsuccessful attempt was also made to evacuate the 18 crew members of Kulluk with helicopters but due to the prevailing high winds, safe evacuation was precluded.

On December 29, new fuel injectors were delivered to Aiviq and as a result all four engines were restored. Moreover, two helicopters managed to evacuate all the personnel of Kulluk oil rig. In the meanwhile, Alex Haley was instructed to depart for repairs and Nanuq support vessel arrived on the scene.

On December 30, the tow line connecting the Nanuq vessel with the Kulluk parted, whereas shortly after the same happened with the emergency tow line of the Aiviq vessel. Kulluk was set adrift at prevailing winds of 35-45 knots and sea swells of 20-25 feet. The support vessel Tug Alert arrived on the scene but it was impossible to set connection with the Kulluk due to the intense weather phenomena.

On December 31, the Tug Alert vessel was successfully connected with the emergency tow line (previously used by Aiviq) and started towing Kulluk away from the shore. In the same day, the Aiviq vessel re-established tow of the Kulluk by using the rig's anchor wire. The two vessels had the intention to tow Kulluk towards a safe harbor on the Northeast side of Sitkalidak Island approximately 74 miles away. In prevailing winds of 40-50 knots the Aiviq's tow parted and Kulluk started pulling Tug Alert backwards towards Sitkalidak Island. Since there wasn't any possibility for the Aiviq vessel to reconnect with Kulluk, there was no other option for the Tug Alert vessel but to release the tow. Less than an hour later, Kulluk grounded on a beach on Sitkalidak Island.

At the time of the accident, the Kulluk oil rig was carrying around 143.000 gallons of low-sulfur diesel oil and 12.000 gallons of other petroleum products. It must be stated that no environmental damage was reported as a result of the grounding. All personnel were successfully evacuated without any casualties or injuries. As far as the Kulluk oil rig is concerned, inspections after the accident revealed substantial damages in the underwater portions of the hull, the electrical equipment, the lifesaving and safety equipment and several interior and engineering spaces. Nevertheless, the watertight integrity was retained. When the rig was recovered, the repairs were not deemed feasible and Shell decided to scrap the unit in 2014.

The developed towing plan had been complied with all the established standards and procedures of that time. It was of fundamental importance the fact that it was not selected the shortest route but a coastal route always within 200 miles from land so as to remain within the range of SAR helicopters. Furthermore, despite of the fact that the Kulluk could accommodate 108 persons, during the towing operation only a basic crew of 18 people was on board. These two key points facilitated the rescue operation and prevented any casualties. **[37] [38] [39] [40]**

Lessons learned

1. **People without the adequate expertise, found in charge for the final approval of the towing plan.** More specifically, the Alaska Venture Operations Manager was initially considered as the final approval authority but as he was on holiday at the time, the final approval was given by a deputy who had never reviewed a tow plan within Shell, had not participated in any of the planning meetings, and had not received any related training or even guidance about the process. **[37]**
2. **The weather phenomena were underestimated.** The towing plan that was approved for the transit of December 2012 was exactly the same with the towing plans that had been used for the transits of June, August and November of 2012 (same towing vessel and towing configuration). The particularities of the winter weather conditions in the Alaskan waters were not taken into consideration in the December towing plan. In addition, none of the ships deck officers had worked before in Alaskan waters during wintertime. The general lack of experience in adverse weather that characterized the crew, was displayed by several actions during the towing operation. **[37]**
3. **The tow plan was designed with an insufficient margin of safety.** Redundancy is a necessary element in all operations which involve high risk like towing in Alaskan waters during winter months. In order to provide an order of magnitude it could be mentioned that according to the technical studies of that time, the required towing power (bollard pull) for the towing of the Kulluk oil rig, was estimated to be 200 tons whereas the maximum towing power of the tow vessel (Aiviq) was 208 tons. If the plan had involved additional towing vessels, the consequences of the mechanical failures that came up could have been mitigated. **[37] [38]**
4. **There are regulation gaps in the inspection regime.** The 120 t SWL shackle which was the source of the original loss of tow, was not examined thoroughly prior to the commencement of the voyage as there wasn't such a regulatory requirement. The shackle was only undergone a visual inspection which is insufficient for the determination of its suitability or the detection of hidden defects. Moreover, the history of the shackle could not be ascertained, as it was installed without

knowledge of where or how it was used. Similarly, for other crucial mechanical parts of the towing operation, like the tow line and the tow gear. [39]

5. **It was given greater value to the maximization of profit against safety.** Although not officially declared by Shell, it seems that the real reason for which the towing operation started at 21 of December, despite the very bad weather forecast, was to bring the Kulluk rig out of the Alaskan waters before the turn of the year so as to avoid being charged several million dollars in tax.

Generally, it should be mentioned that the time window for drilling in the Arctic Seas is very short and it is a common practice for oil companies to tow their drilling platforms in southern regions before the start of the winter months. Since the towing of drilling rigs is extremely vulnerable to bad weather and storms there should be greater oversight of the frequent towing operations in the Arctic and sub-Arctic Seas.

7 Recent research activities

7.1 Introduction

As conventional oil is getting depleted worldwide, reserves in the less accessible Arctic waters will increasingly receive the attention of the involved countries and the oil & gas industry. A key parameter which determines the future of exploration and production of hydrocarbons in the Arctic is the capability of the available technologies to prevent and respond successfully to an accidental oil spill in the Arctic waters. The objective of Chapter 7 of this report, is to provide a brief overview of the available Oil Spill Response Technologies that could be used in the Arctic, to identify any possible knowledge gaps and to summarise the most notable research activities of the last decade.

Oil Spill Prevention, Control and Response in Arctic areas, include the same general suite of countermeasures applied elsewhere in the world. Nevertheless, oil spill response strategy for Arctic seas must additionally take into consideration the following determinant parameters:

- Periods of extended darkness complicate any type of offshore response operation. During winter months there is no possibility for visual oil spill detection and for aircrafts to operate.
- Remoteness, great distances and lack of shore – based infrastructure (ports, airports) make the support of any offshore response operation much more complicated. Operators should be entirely self-sufficient.
- The harsh operating environment (extreme cold and ice) undermines safety of the personnel and operability of the equipment.
- The ice cover in the Arctic seas is dynamic and unpredictable. Growing or moving ice can undermine oil detection (oil can be trapped on or under ice) and the effectiveness of clean-up activities.

Over the last decades the oil & gas industry made significant research efforts to develop robust technology to prevent and respond effectively to accidental oil spills in Arctic waters. It must be pointed out that most of the research was carried out in U.S.A and Canada. Indicatively, according to USARC, in 11 years (from 2000 to 2010) over $164 million were funded by the U.S. Federal Government and 248 research projects were compiled. The most notable research effort of the oil & gas industry in the last decade, is the Arctic Oil Spill Response Technology Joint Industry Programme (JIP) which was initiated in 2012 and completed in 2017 and its predecessor Oil in Ice Joint Industry Programme (JIP) which was initiated in 2006 and completed in 2009. **[12] [13] [14]**

It is true that after the tragedy of Deepwater Horizon oil spill (April 2010) global research activity has given special importance in the upgrading of all Oil Spill Response Technologies: In Situ Burning, Dispersants, Mechanical Oil Recovery and Detection - Monitoring of oil spills. Finally, it should be added that during the last decade significant research activities have been observed in the technological upgrading of robotic inspection tools for offshore oil & gas facilities. All these topics will be addressed briefly in the following paragraphs.

Annex III lists a considerable number of Oil Spill Prevention & Response Research Projects, including links to their web-sites.

7.2 In Situ Burning (ISB)

Figure 7 1 In situ burning of crude oil collected in a fire resistant boom, Norway 2009 (Source: Arctic Council, 2015) **[1]**

General description of the technique

In situ burning (ISB) is the term used for controlled burning of oil in the original place and refers to a technique where accidentally spilled oil is ignited and burned directly on the water surface. It was used for the first time in 1958 during a pipeline spill in the Mackenzie River, Northwest Territories, Canada and since then several research activities and test burns have been conducted. Nowadays, it can be considered that ISB is a proven and environmentally acceptable response countermeasure technique with an overall removal rate ranging from 65 to over 90%. The Alaska Department of Environmental Conservation (2001) stated that "*The environmental advantages of in situ burning outweigh the potential environmental drawbacks of burn residue, including the possible environmental harm if the burn residue sinks*''. Among the three available response options, ISB is especially suited for use in the Arctic, where ice often provides a natural barrier to maintain the necessary oil thicknesses for ignition without the need for containment booms, and oil remains fresh and unemulsified for a longer period of time. [1]

Advantages of ISB	Disadvantages of ISB
Rapid removal of large amounts of oil	A large black smoke plume is created
Reduced volume of oil requiring collection and disposal	Burn residue sometimes requires collection and disposal
High efficiency rates	Risk of fire spreading
Less equipment and labor required	Oil on water must have at least 3 mm of thickness for the ignition & combustion to be successful. Oil usually must be contained to achieve this thickness

Knowledge gaps – Recent research activities

The **Helitorch** is an aerial ignition device which is hanged from or mounted on a helicopter to disperse ignited lumps of gelled gasoline. The Helitorch is a proven technology as it is used as an operational Arctic spill response tool from the mid-1990s. New Helitorch fuel formulations have already been developed in order to demonstrate an increased ignitability of emulsified and hard -to- ignite oil spills. Despite of the proven safety record, the Helitorch system still has some limitations as helicopters with sling loads have low speed, limited operational range and are susceptible to icing. Recent research activities focus on the development of **new aerial ignition systems** for Arctic offshore which do not require a sling load under a helicopter like fixed wing aircrafts. Unmanned Air Vehicles (UAVs – drones) are also being considered as possible ignition devices. **[1] [2]**

Chemical herders are surfactants which are applied to the water surface around the edge of oil spills and cause the oil slicks to contract and thicken to ignitable thicknesses. They could be applied in ice-free waters or in waters with limited ice cover (0/10 to 6/10 ice cover). Generally, chemical herders have been available for several decades but they haven't been used extensively to date as they are effective only under largely calm conditions. Furthermore, most of the available chemical herders demonstrate poor effectiveness in cold waters. Finally, it must be pointed out that currently, the best-known chemical herders are chemically stable and no biodegradable, and hence remain in the marine ecosystem for years. **[1] [8]**

Recent research efforts have already introduced **new types of cold – water chemical herder formulations** which have proved their effectiveness in laboratory experiments and in small – scale experimental releases. Two types of cold - water chemical herders (ThickSlick 6535 and OP-40) are already commercially available. Nowadays, research is being conducted in order to expand the response window of the chemical herders by investigating new formulations and their effectiveness in a range of different type of crude oils which are submitted to different weathering conditions. Research is also performed in the identification of the environmental impacts of chemical herders in the Arctic seas and in the development of eco-friendly, **biodegradable chemical herders** from naturally occurring molecules that could meet the hallmarks of commerciality. [4] Finally, another area which gathers significant research efforts is the development of rapid and reliable response aerial systems, where fixed wing aircrafts or helicopters (manned or remotely controlled) could be used for **aerial spraying of chemical herders**. **[3] [5] [6] [7]**

Significant research was also performed the last decade in order to improve the designs of **fire resistant containment booms**. Their operability and their effectiveness in broken ice conditions have been also investigated. Recent field tests have proved that it is feasible to use fire-resistant booms in light drift ice to collect oil and ice for In Situ Burning. The use of fire resistant booms is recommended for oil spills in open sea or in limited ice concentration (0/10 to 3/10 ice cover). **[9]**

7.3 Dispersants

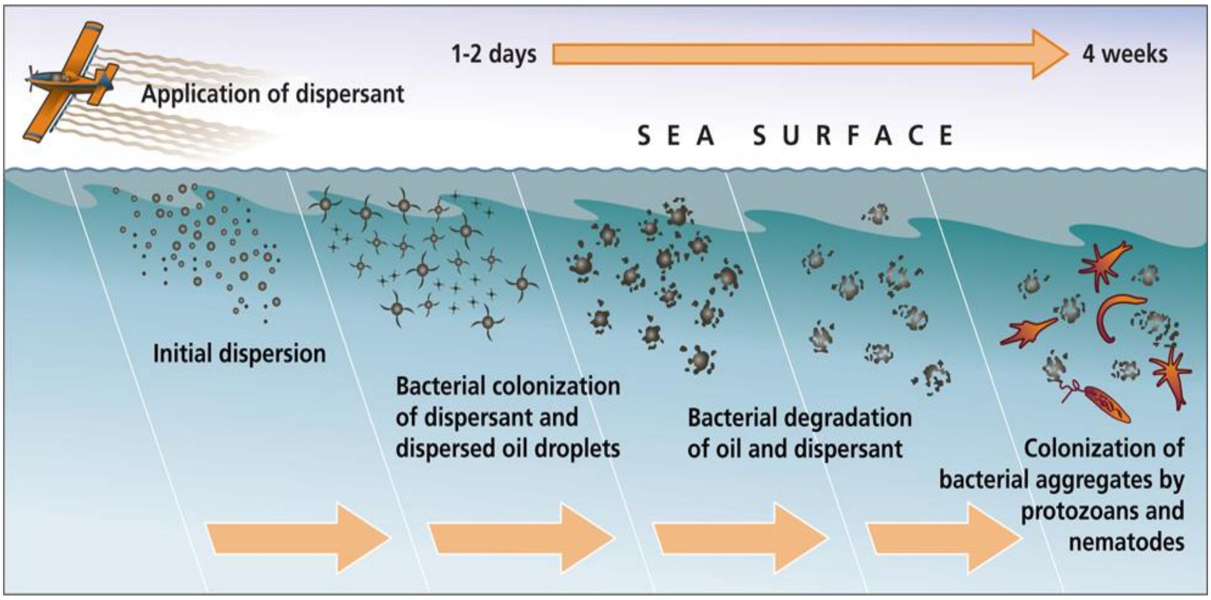

Figure 7 2 Biodegradation of spilled oil enhanced by aerial application of dispersants (Image Credit: Medscape)

General description of the technique

All commercially available chemical dispersants (e.g. Corexit 9500A or Corexit 9527A) are blends of surfactants in solvents. Surfactants reduce the surface tension at the oil / water interface enabling the two phases to mix. Solvents are needed to dissolve the surfactants so that the dispersants become liquids of uniform consistency and low viscosity. When dispersants are sprayed onto a sea surface oil slick then with the synergy of the wave energy, the lowered surface tension causes the oil spill to break up into small oil droplets (smaller than 100 μm). Subsequently, the subsurface currents dilute the small oil droplets in the water column where they are colonised and biodegraded by 'oil eating' bacteria naturally existing in the oceans. Generally, dispersants can be sprayed in the sea surface by vessels or aircrafts with dispersant to oil ratios of around 1:20 but lower ratios can be achieved in the case of direct subsea injection in a wellhead blowout.

The effectiveness of the dispersants and the subsequent microbial degradation of oil droplets in Arctic environments has been verified by recent laboratory and field experiments. More specifically, lab tests conducted in 2007 by U.S. Environmental Protection Agency (EPA) reported that greater than 80% of the alkanes of the dispersed Alaska North Slope (ANS) crude oil were biodegraded in 40 days. Similarly, lab tests conducted by the University of Alaska in 2014 reported chemical losses due to biodegradation of ANS crude oil ranging from 46% to 61% over 60 days. **[17] [18]**

Advantages of Dispersants	Disadvantages of Dispersants
Indicated for very large oil spills	Need for sufficient - accessible stockpiles
Indicated to mitigate a wellhead blowout via subsea injection of dispersants	Need for daylight and good weather conditions for aircrafts / vessels to operate
Can be deployed rapidly by aircrafts	Dispersed oil in shallow depths may involve toxicity dangers
Can be effective in high sea states	Dispersants are not effective in viscous oils

Knowledge gaps – Recent research activities

The technique of **subsea injection** of chemical dispersants was firstly applied in the Macondo Well Blowout during the Deepwater Horizon oil spill (April 2010). Approximately 771.000 gallons of dispersants were injected directly at the site of the wellhead using a remotely operating, underwater vehicle. The continuous injection of dispersants directly at the discharge point, under highly turbulent conditions proved to be very effective. Subsea injection may require 5 times less the volume of dispersants which is needed for surface operations with the same results. Furthermore, the technique provides operability under any weather conditions, presence of ice or long periods of darkness and minimizes human contact with the dispersants. Nevertheless, the optimization of the system design, the environmental impacts and the effectiveness of subsea injection of chemical dispersants in the presence of ice cover, could be considered as topics for future research. **[15]**

As it was already mentioned, conventional dispersants demonstrate poor performance when applied in viscous oils. Recent research efforts conducted by ExxonMobil have already developed a **new gel type dispersant** with higher concentration of active ingredients which could be effective in oils currently considered too viscous either because of naturally high viscosity (e.g. IFO, HFO), or because of weathering, emulsification and cold temperatures. Furthermore, lab tests have proved that this new gel type dispersant results in a decreased toxicity of the dispersant –oil mixture due to reduced solvent concentrations. It could be used in light or medium crude oils as well, with dispersant to oil ratios (DOR) as low as 1:60 (compared to 1:20 typically used for dispersants) which means that the load capacity of a plane could be tripled. **[10] [11]**

Oil particles can interact with the particulate matter which is naturally found in suspension in the water column and form **Oil-Mineral Aggregates (OMA)**. The formation of OMA stabilises oil droplets, prevents droplet coalescing and subsequently enhances the dispersion and biodegradation of oil in the water column. A new promising Oil Spill Response technique involves the increase of the rate OMA are formed by injecting clay mineral particles to the oil spill in conjunction with supplementary mixing energy from a propeller. The efficacy of oil dispersion through promoting formation of OMA was field tested for the first time in 2008, in Canada, by spraying calcite mineral fines to an oil spill. Laboratory tests in field samples revealed that 60% of the Total Petroleum Hydro-carbons had been degraded after 56 days of incubation at 0,5°C. **[16]**

As it was already mentioned, the mixing energy provided by the waves, promotes significantly dilution and dispersion of the oil droplets into the water column. Generally, the greater the mixing energy provided, the less dispersant is required. In Arctic areas where increased ice concentrations are encountered, waves are non-existent and supplementary mixing energy must be applied. Field tests have confirmed that the use of **azimuthal-drive icebreakers** can be very effective in providing the necessary turbulence. **[17]**

Another key parameter for the successful implementation of the technique is the precise targeting of the oil spill so as not to waste dispersant. In the frames of the Joint Industry Programme on Oil Spill Recovery in Ice, an **articulated spray arm** was developed making it possible to provide accurate delivery of the dispersant, several meters from the side of the application ship. **[17]**

Finally, a new developed and environmentally friendly technique, involves spraying sea water into an oil spill without any use of unnatural chemicals. Lab tests have shown that the **injection of sea water under high pressure** disperses an oil spill into smaller oil droplets than chemicals dispersants do, making biodegradation of oil faster. **[21]**

7.4 Mechanical Containment & Recovery (C&R)

Figure 7 3 Skimmer deployed in icy water (Source: Pew Research Center) **[22]**

General description of the technique

Mechanical Containment & Recovery (C&R) is a three stage process. The first stage aims at limiting the spread of spilled oil in the sea surface, usually by containing the oil spill in a boom towed by vessels. In the Arctic seas, the presence of ice cover can also lead to natural containment of oil as it is illustrated in Figure 7.3. The second stage of the process involves the recovery of the already contained oil from the sea surface by using a skimming or a direct suction device or a sorbent material. Finally, the last stage includes all the necessary actions for the offshore storage and the subsequent transfer, disposal or recycling of the recovered mix of oil and water.

Mechanical Containment & Recovery (C&R) systems are strongly relied on supportive coastal infrastructure. Furthermore, they are characterised by very low oil encounter and recovery rates which are largely exacerbated by the presence of ice. As a consequence, this technique can have only a supplementary role in the mitigation of large oil spills but can be more effective in small to medium sized spills. Indicatively, in the Macondo spill (2010), Mechanical C&R systems accounted for only 2-4% of the total 780.000 m^3 of discharged oil, whereas in the Godafoss incident (2011) where only 112 m^3 of oil were released, the technique managed to recover around 50% of the discharged volume. **[1]**

Advantages of Mechanical C&R	Disadvantages of Mechanical C&R
Indicated for small oil spills	Slow process with low oil recovery rates. Insufficient to respond to large oil spills
Indicated for shallow or biologically productive waters	Need for offshore & coastal infrastructure like storage, disposal and recycling facilities
	Ineffective in high sea states
	Ineffective in the presence of ice

Knowledge gaps - Recent research activities

The technological level of Mechanical Containment & Recovery (C&R) systems could be characterised as rather mature. Their effectiveness is limited by the fundamental constrain of Encounter Rate which refers to the amount of oil that comes into contact with the recovery device. As a consequence, any further technological improvement is expected to be incremental and have little effect on the overall effectiveness.

Over the last decades, continuous research is being conducted to develop new vessel design concepts that could increase oil spill response capability in ice covered waters. Multipurpose, ice strengthened vessels with special features like azimuth driving, advanced oil spill detection systems and increased storage capacity for the recovered oil and the necessary mechanical equipment have been constructed. The state of the art should include the following oil spill response vessels: Aker ARC 131 (Finland), Louhi (Finland), Multipurpose Vessel 8116 (Sweden), Andrey Vilkitsky (Russia), Polaris (Finland), Gennadiy Nevelskoy (Russia), Esvagt Aurora (Denmark), Stril Barents (Norway) and Baltika (Russia).

As it is already mentioned, the main drawback of all mechanical Containment & Recovery systems is their low Encounter Rate making them insufficient for big, rapidly spreading oil spills. Spilled oil may spread faster in the sea surface than it can be contained and recovered by mechanical devices. With existent technology, conventional containment booms can be towed in open water, at speeds around one knot since higher speeds could result in loss of oil under the boom. Recent research activities have developed innovative designs of ice boom systems which promise successful containment of oil at speeds up to three knots. Generally, ice booms are more reinforced than conventional booms in order to withstand the strains of ice being captured within the towed boom systems. [19]

Another limiting factor of all mechanical C&R systems is that they become extremely ineffective even in small ice concentrations as ice interferes with boom operation. The pneumatic boom is a new small – scale, mechanical containment device that has been developed recently and involves the release of air bubbles through a perforated grate which is submerged in a depth of a couple of metres beneath an oil spill. Field tests have shown that the generated curtain of air bubbles can limit effectively the spread of an oil spill even in areas of strong currents. Another approach is the recently developed foam filled oil boom which has also demonstrated good performance in ice covered waters as it can be easily inserted between cracked ice blocks to contain an oil spill. [20] [23]

Significant research has also been conducted to develop reliable ice management systems which are absolutely necessary for deflecting ice and making oil volumes accessible for recovery. Generally, there are three different approaches for separating oil from ice with the latest two to gather the biggest perspectives for field applications: [19]

Oil contaminated ice can be lifted from the water surface to be processed on board. An example of the above technique is the MORICE prototype unit.

Oil contaminated ice can be submerged. Buoyancy separates naturally oil which floats up to the surface. The OilWhale prototype, the LORI Ice Cleaner and the Lamor Oil Ice Separator (LOIS) are innovative systems which follow this principle.

Oil contaminated ice can be cleaned at the water surface. Examples of this approach are the Lamor Arctic Skimmer (LAS) and the Lamor Sternmax, the world’s largest skimmer which is deployed at the stern of the response vessel.

The backbone of all mechanical recovery operations is the skimming unit. Recent research activities have developed innovative skimming systems in order to increase their resistance to arctic conditions and their capability to handle cold viscous oils and mixtures of oil and ice. Skimmers capable of independent propulsion have also been developed which allow remote recovery of oil that is not accessible by the mother ship. An example of self-propelled skimmer is the Framo Polaris Skimmer. Generally, for ice – covered waters two types of skimmers are recommended, the rope mop (oleophilic) skimmers and the brush skimmers. Innovative skimming systems that should be mentioned are the Desmi Helix skimmer, the Desmi Polar Bear skimmer, the Lamor Oil Recovery Bucket (LRB) and the Hendriksen FoxTail rope skimmer. [19]

Area of recent research activities has also been the development of on board concepts for separation of the recovered fluids (oil, water, ice) and for incineration of the recovered oil. Till today there is no proven technology for on-board separation of the recovered fluids fast enough, to maintain reasonable response operations. Concerning the development of on board combustion systems of the recovered oil there are three main concepts which are still under development: The Pneumatic Flare, the Rotary Cup Burner and the Augmented Burner concept. [19]

7.5 Selection of Oil Spill Response Strategy

The selection of the appropriate response strategy to deal with an oil spill in Arctic, includes the identification of the appropriate response technique which is going to be used, along with the level of intensity and the duration of its implementation. The weathering and the movement of spilled oil in the sea surface, gives a dynamic nature to oil spills which usually leads to the simultaneous implementation of various OSR techniques that complement each other. The selection of the appropriate response strategy is determined by the following parameters:

- Type and quantity of spilled oil;
- Environmental resources and habitats threatened;
- Local weather, sea state and presence of ice;
- Proximity to supportive infrastructure.

The most comprehensive approach to define the appropriate response strategy for a particular oil spill is the Net Environmental Benefit Analysis. NEBA is a decision making process which assesses the long-term effects on an ecosystem in order to ensure that the selected response strategy leads to the best overall minimization of environmental damage. NEBA is performed during the planning stage and it includes a range of potential oil spill scenarios in order to reduce the time it would take for decision making during a real oil spill where decisions are taken rapidly. In order to strengthen the NEBA approach in Arctic operations, significant research is being conducted in the following topics: [24]

- Arctic ecosystem and valuable resources;
- Transport and fate of oil spills in the Arctic marine environment;
- Environmental impacts of every Oil Spill Response technology;
- Biodegradation of oil in the Arctic marine environment;
- Ecotoxicology of oil and treated oil;
- Population effects modelling;
- Ecosystem recovery.

7.6 Detection & Monitoring of Oil Spills

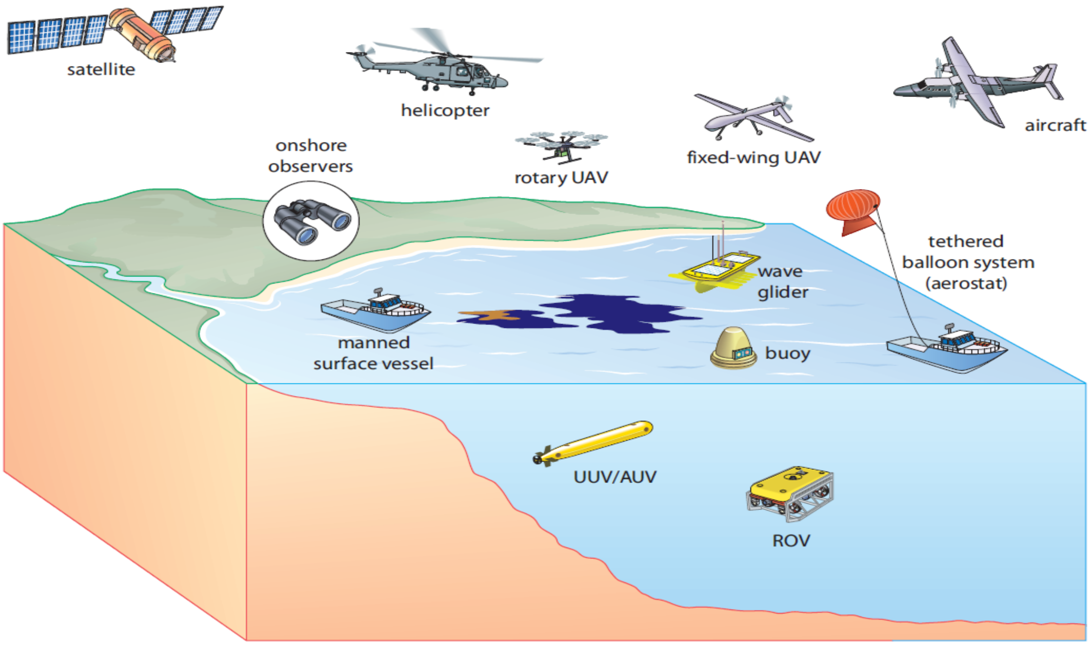

Figure 7 4 Surveillance tools that may be used in a response operation (Source: IOGP – Report 549) [25]

General description of the technique

The successful implementation of any OSR strategy is relied on the timely detection and accurate monitoring of the oil spill as it expands in the sea surface. Detection & monitoring of oil spills in the Arctic waters has many particularities and even today is considered as a technological challenge. The lack of waves due to the presence of ice impedes the use of any conventional marine or satellite radar system. In addition, long periods of darkness, high wind speeds and cloud cover, decrease significantly the operability of current airborne detection & monitoring systems. Potential oil spills in Arctic are required to be detected in various ice conditions: on, under or encapsulated within the sea ice, between ice floes or buried under snow. In all the aforementioned parameters, it should be added that natural weathering of oil influences negatively its detectability by the remote sensing systems. From all the above, it becomes obvious that advanced detection & monitoring systems need to be developed for the special Arctic conditions, capable to provide an accurate and real time image of the oil spill to the response personnel.

Knowledge gaps – Recent research activities

Over the last decade, significant advances in the field of remote sensing and surveillance have been recorded. The research activity is expected to continue in the following years and lead to the development of new sensor technologies and deployment platforms. Figure 7.5 illustrates a distribution of peer – reviewed papers related to remote sensing that were published between the years 2000 and 2012. After a global search, 75 relative papers were identified and they were classified according to the type of platform each sensor is integrated to. It is obvious that most research activities are oriented towards sensors mounted from satellite platforms. **[26]**

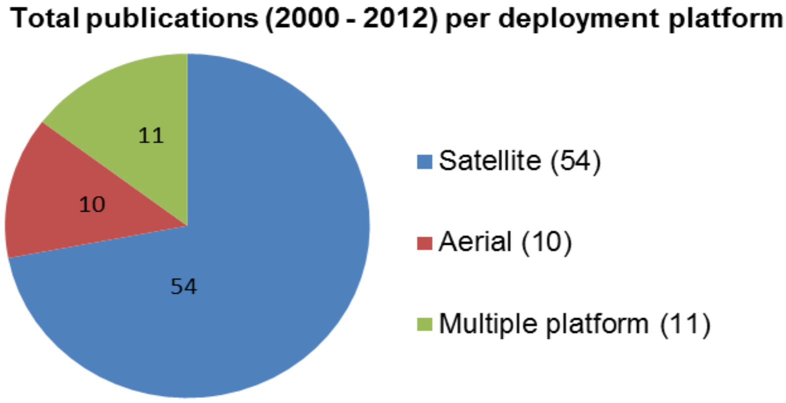

Figure 7 5 Distribution of peer reviewed remote sensing papers per used platform (Source: API – Report 1144) **[26]**

The current state of the art for oil spill detection technologies in ice covered waters is illustrated in Table 7.1 where the performance of the commercially available combinations of platforms and sensors are evaluated for every possible oil-in-ice distribution. In cases where the sensors have proved their performance and can be considered as reliable for the specific oil in ice distribution, Green colour is used as indication. Red colour is used where technological limitations that cannot be overcome, make oil spill detection improbable. Finally, in cases where a sensor's performance is not yet proved but there are possibilities of successful implementation, the Orange indication is used. Consequently, the Orange areas in the Table could be characterized as areas of scientific interest where further research needs to be conducted. **[27]**

Emerging trends in the area of remote sensing involve the development of data fusion algorithms that will enable **multi sensor integration** to the surveillance systems. Generally, multiple data streams can lead to more comprehensive datasets and more accurate depictions of the oil spills. The need for multi sensor integration is also depicted in Table 7.1 where it becomes obvious that in order to detect oil spills in all the possible oil in ice distributions encountered in the Arctic seas, data streams from multiple sensors are required.

As it is already mentioned, the research activity in remote sensing systems for oil spill detection is focused mostly on satellite sensors. This is attributed to the fact that active microwave sensors mounted on satellites can cover quickly wide areas without being affected by weather conditions, cloud cover or absence of sunlight. Synthetic Aperture Radar (SAR) is the most applicable space born sensor and its performance in detecting oil spills in open water and in very open drift ice (till 3/10 ice concentration) can be considered as proven. Nevertheless, SAR's detection capability is hindered in ice concentrations higher than 4/10ths as both oil and newly formed thin sea ice have the same SAR signature resulting in false positives. Research efforts in progress, investigate the use of **multi-polarization SAR systems** in order to discriminate oil spills from newly formed sea ice and expand the operating range of satellite sensors. **[28]**

Another very promising area of research in satellite remote sensing is the development of classification algorithms that will allow automatic, real time detection and continuous monitoring of an oil spill. **Automatic detection** of oil spills is of fundamental importance for responding to unknown - accidental incidents or illegal discharges. Several innovative techniques are under development. A recently developed approach based on the Robust Satellite Technique (RST) involves the combination of data acquired from optical sensors mounted on meteorological satellites with radar acquisitions from SAR systems resulting in a multiplatform system. **[29]**

Nowadays, detection of oil spills under or within sea ice, remains a technological challenge beyond the technological capabilities of airborne and space-borne sensors. There are few available technologies, which can be applied on or near ice, the most promising of which is the **Ground Penetrating Radar**. GPR is a surface carried unit which emits electromagnetic pulses in the microwave region (500 MHz to 1 GHz). By analysing the collected reflection signal, information can be obtained about the structure of the subsurface. The technique is based on the fact that the dielectric permittivity ratio between sea ice and sea water is much larger than the corresponding ratio between sea ice and oil resulting to different reflected signals. Generally, the range of GPR systems is very short, and their detection capabilities are limited to oil spills which are thicker than 2 cm and located in a maximum depth of 210 cm below ice. The most important drawback of the technique is the need of personnel on ice to operate the device which arises safety issues and makes the process time consuming. To address the above issue, the operability of a GPR system mounted from a low flying helicopter is being investigated after some encouraging experimental tests. Another weak point of the technique is the fact that variations in the snow and ice structure may result in the same reflection signals as with oil spills resulting in false positives. Therefore, recent research activities aim to the development of semi – automated classification algorithms which will improve the reliability of GPR systems. **[30]**

Detection of oil spills located under or within sea ice is being investigated through other helicopter - mounted sensors which are still not commercially available. The **Frequency Modulated Continuous Wave** (FMCW) radar is a recently designed prototype, which has demonstrated several benefits over the pulse type radars (GPR). It should be referred that both GPR and FMCW radar systems are unlikely to provide reliable detection of oil in or under ice once the internal temperatures are close to the melting point. In the same context, a full scale **Nuclear Magnetic Resonance** (NMR) prototype has recently (2016) undergone a feasibility testing and proved ability to detect an oil spill 1 cm thick located in a depth of 110 cm below the simulated ice. **[31] [32]**

Undersea robots consist an attractive approach for detecting oil spills located under or within sea ice as they can operate independently of weather conditions and without the need of personnel on ice. There are two types of underwater robots: Remotely Operated Vehicles (ROVs) which are controlled from the surface over a tether and Autonomous Operated Vehicles (AOVs). ROVs are considered a reliable, mature technology but the tether limits their range and a vessel is always required to support their operation. From the other hand, AOVs can cover much larger search areas making them more suitable for big oil spills and they can be launched from the shore or from a helicopter. Recent research activities have focused on the advancement of AOVs under ice capabilities as their range is limited by their battery capacity and the absence of a tether complicates accurate navigation and real time data rates. A recently developed Long Range AUV prototype has demonstrated capability to rove for 15 days continuously without recharging batteries, covering in total 373 miles. The AOVs' sensor suite performance is also an area of research. Recent experiments have demonstrated the ability of a multi sensor system which is consisted of digital cameras, a laser fluorosensor and a high-frequency narrowband sonar to detect oil efissiently under various sea ice conditions, or encapsulated within the ice to a thickness of up to 15 cm. **[33] [34]**

Table 7 1 Remote Sensing Capabilities versus Oil in Ice Distribution Categories (Source: Arctic Oil Spill Response Technology, 2016)

Oil in ice Distibution	Platforms / Sensors															
	Stable Ice Surface			AUV / ROV			Offshore Platform / Vessel / Aerostat			Airctaft / UAV						Satellite
	VIS / OPT	TIR	GPR	OPT	LFS	Sonar	VIS / OPT	TIR / FLIR	Marine Radar	VIS / OPT	TIR / FLIR	UV	LFS / LIDAR	SLAR	GPR	SAR
Oil on water with ice																
Oil falling on slush ice					P	P	Y	Y	N	Y	Y	N	Y	N		N
Oil rising below slush ice				P	P	P	P	P	N	P	P	N	P	N		N
1/10 - 3/10 ice concentration							Y	Y	Y	Y	Y	Y	Y	Y		Y
4/10 - 6/10 ice concentration							Y	Y	P	Y	Y	Y	P	P		P
7/10 - 9/10 ice concentration	P	P					Y	Y	N	Y	Y	N	P	N		N
Oil on ice																
Exposed on solid ice surface	Y	Y								Y	Y	N	Y	N		N
Under snow cover	P	N	Y							N	N	N	N	N	Y	N
Exposed in spring melt pools	Y	Y								Y	Y	P	N	N		N
Oil under / in ice																
Smooth ice	P		Y	Y	Y	Y								N	P	N
Deformed ice			N	P	P									N	N	N
Encapsulated layer	P		Y	P	P									N	P	N
Disperced vertical migration			P	P	N									N	P	N

Abbreviations

AUV	Autonomous Underwater Vehicle	VIS	Visual Observation		**Expected Performance**
FLIR	Forward-looking infrared sensor	UAV	Unmanned Aerial Vehicle		
GPR	Ground Penetrating Radar	UV	Airborne Ultraviolet reflectance scanner	Y	Yes (likely)
LFS	Laser fluorosensor	ROV	Remotely Operated (underwater) Vehicle	P	Potential (may be possible)
LIDAR	Light detecting and ranging system	SAR	Synthetic Aperture Radar	N	No (not likely)
OPT	High definition cameras	SLAR	Side – Looking Airborne Radar		Not applicable
TIR	Thermal Infrared Sensor				

8 Questionnaire on safety aspects for offshore Oil & Gas operations in the Arctic

The authors of this report have prepared a questionnaire for oil and gas companies operating in the Arctic in order to gather information from the offshore industry on the state of the art of safety measures and emergency response in case of accident and the particular precautions that are taken into consideration when operating in the Arctic and sub-Arctic environments.

The seven questions included in the survey are reported below. The authors thank the Arctic Committee of the International Association of Oil and Gas Producers (IOGP) for the help offered in distributing the questionnaire to the individual companies and the subsequent collection of their replies. The compiled answers are presented in this chapter.

1. How does your safety management system for activity in an Arctic/sub-Arctic environment differ from that in more benign areas?
2. How do you assess physical and psychological suitability of personnel for additional challenges of work in an Arctic/Sub-Arctic environment? Please list any specific additional psycho-physical requirements.
3. What are the additional challenges associated with emergency response in Arctic/sub-Arctic, and how do you address these challenges in your emergency response planning? Examples of emergency response plans are welcomed.
4. How do you mitigate risk to personnel in case of Arctic/sub-Arctic environmental conditions which hinder safe evacuation and rescue?
5. How do you plan for oil spill response in areas with ice compared to open water? What different or additional tools and procedures do you use?
6. How do you learn from incidents or near misses, particularly in Arctic / sub-Arctic waters? What tools do you use for sharing and learning? Specific examples of learning from events are welcomed.
7. Do you have any ongoing initiatives relating to improving safety of operation of activities in Arctic / sub-Arctic waters? Information on initiatives is welcomed.

QUESTION 1: How does your safety management system for activity in an Arctic/sub-Arctic environment differ from that in more benign areas?

The oil and gas industry uses comprehensive management systems and processes to avoid incidents that could negatively impact health, safety or the environment. These systems are in place to manage risks so that all onshore and offshore facilities are operated in a safe, reliable and responsible manner. Elements of the safety management system include: commitment and accountability; policies, standards and objectives; organizational planning and procedures; risk management; asset design and integrity; monitoring, reporting and learning; assurance review; and, continuous improvement. These generic aspects are applicable for activities worldwide, whilst driving focus to manage location and operation specific challenges.

The specific conditions associated with operations in a given Arctic location provide context and inputs to ensure a fit-for-purpose and effective risk management program. The very broad spread of operational and environmental conditions across the Arctic, is well suited to a safety management system approach that allows tailored safety management for actual activities and local challenges whilst drawing on available knowledge and best practices.

For a specific Arctic project, challenges to be managed can include presence of sea ice, icebergs, cold temperatures, operational remoteness, periods of full darkness and light, and ecological and social sensitivities. These are addressed through competent and trained staff, corporate guidelines and standards, Arctic specific guidelines and standards, non-Arctic specific guidelines and standards having Arctic applicability and supported by scientific data. As in all frontier areas where industry operates, uncertainty is addressed through prudent design practice and operational mitigations, and all identified risks are mitigated to meet local rules and regulations and to ensure the risk is "As Low As Reasonably Practicable", as per the ALARP principle.

Overall, a strong safety management system is equally applicable in the Arctic as in other regions and companies generally apply the same system across all locations. However, as delivery of a safety management system for Arctic areas is based on a thorough risk-based approach, this relies on having competent resources, including experienced Arctic specialists, who can identify, assess and mitigate the risks. Arctic specific requirements are not necessary, but companies may choose to reference appropriate good practices that are built up based on accumulated experience.

Additional notes

Asset integrity is managed via a disciplined risk management process including risk identification, risk analysis and assessment, risk review and control. Industry risk management process is based on *ISO 31000: 2018, Risk management – Principles and guidelines*, which is tailored to the Arctic through context setting and by site specific parameters including intended activity, location, time and activity duration, environmental conditions, social considerations, supporting capability such as assets and people and supporting scientific data.

The international oil and gas industry develops recognized technical standards which are used worldwide. Accumulated experience of the industry is continually included in these standards through systematic updating and issuance of new revisions. Recognized technical standards are normally valid also for use in cold climate areas, i.e. Arctic specific standards are generally not required but should be covered by the functional requirements of global standard. Functional standards are important as Arctic projects are typically highly tailored and location specific, and prescriptive "standardization" can introduce new risks and/or limit innovation. Most regulatory regimes encourage the use of new technology to enhance safety; and provide controls to ensure that any risks with the introduction of the new technology are fully managed

In some cases, Arctic specific standards and good practices have been identified as appropriate from developed experience, including e.g. ISO 19906: Petroleum and natural gas industries - Arctic offshore structures, OGP Reports, IACs Polar Class and individual Class Society codes. Selected new ISO standards have been developed where identified as priorities in the industry-government Barents 2020 study. These standards are soon complete.

The issue of standardization is often misunderstood, misused or – in some cases - mixed up with the role of regulations. Standards are developed by industry experts to represent consensus of proven best practices to provide reliable outcomes. Standards are voluntary. In cases where stakeholders are skeptical to industry ability or performance in the Arctic as an unfamiliar region, and wish to see mandatory requirements enforced, then that is the role of regulations. Regulations are mandatory and do not require consensus.

Question 2: How do you assess physical and psychological suitability of personnel for additional challenges of work in an Arctic/Sub-Arctic environment? Please list any specific additional psycho-physical requirements.

Companies in general have standardized requirements for working offshore. Given the significant variability in location and activities within the Arctic and sub-Arctic, the need for tailored requirements will be assessed on a project or activity specific basis according to the local environmental conditions.

The specific personnel safety challenges in the Arctic during routine operations are often related to the physical and psychological effects of cold and darkness. Industry guidelines regarding additional assessment of suitability for cold climate are available, e.g. IPIECA, IOGP, ISO.

As an example, Shell requires that special training and information is normally provided for all personnel travelling offshore to Arctic/Sub-Arctic environments and also requires HAZWOPER certification and additional training for responders expected to work in cold weather conditions. Several training courses for field personnel have been developed, such as the OSRL Extreme Cold Weather Spill Response Course to prepare responders and let them practice in controlled environment.

Fitness to Work took on an added dimension of importance during our operations in the Arctic. It was necessary to involve medical professionals (doctors, PA, and nurses) who had cold weather and Arctic experience to help assess the people involved in Arctic operations.

Personnel expected to fly on helicopters offshore must have current Arctic/Cold weather HUET training to ensure they are prepared to emergency evacuation in this climate.

For further details, please refer to:

- ISO 15743:2008 Ergonomics of the thermal environment -Cold workplaces
- ISO 35101:2017 Petroleum and natural gas industries -- Arctic operations -- Working environment
- IOGP Report 398 Health aspects of work in extreme climates
- IOGP Report 447 HSE guidelines for metocean surveys including Arctic areas

And also:

- ISO 12894: 2001 Ergonomics of the thermal environment
- NORSOK S-002 (2018): Working Environment

Industry has contributed significantly to develop ISO 35101:2017 and NORSOK S-002 (2018) over the past several years, and requirements of these standards are based around a large collective of research knowledge as well as many years of experience. ISO 35101 was developed as a specific recommendation of the Barents 2020 report and includes e.g. psychosocial stress etc. So these are the key standards that I recommend you read, supported by the various IOGP guidelines etc.

Generally, companies will specify the standards / embed requirements for use via internal specifications etc. IOGP would expect that risk processes would pick up any project specific factors that should be a requirement. To support continuous improvement, companies also undertake research activities to follow up specific needs or niche requirements. IOGP has undertaken a number of reports over several years which include various aspects of cold working, including psycho-social, and so the relevant learning is captured into standards.

Question 3: What are the additional challenges associated with emergency response in Arctic/sub-Arctic, and how do you address these challenges in your emergency response planning? Examples of emergency response plans are welcomed.

Specific Arctic challenges will vary by region, but could be related to presence of sea ice, icebergs, cold temperatures, icing, operational remoteness, periods of full darkness and light, and ecological and social sensitivities. These factors could potentially cause or exacerbate the consequences of incidents, e.g. ice/iceberg causes structural damage, cold water reduces survival time for personnel exposure. The primary focus of industry is to prevent incidents by accounting for these conditions in safe design and operations. However, Arctic stakeholders are also prepared with comprehensive plans to mitigate consequences to life and the environment in case an accident occurs.

Accounting for "Arctic" factors in emergency response can introduce additional considerations in solutions compared to similar operations in other regions. In general, actual needs are identified through a disciplined use of risk management practices that consider detailed specifics of the region and activity in order to provide a robust response strategy, whilst allowing for technology innovation. ISO 19906 provides additional design information that reflects current best practices accumulated for the Arctic. Whilst Barents 2020 judged ISO 19906 to provide appropriate guidance for EER operations for Arctic Conditions; it also identified an opportunity to enhance the standard. This is being addressed under ISO DIS 35102. Overall, the general view is that it is important to have deep involvement of experts with knowledge of Arctic environment, challenges and technologies.

Logistics challenges of operating in remote areas may be based around existing facilities in the region, or emergency response resources must be brought where needed. In addition to well-recognized emergency response resources, it is important to check sufficient connectivity and redundant communications e.g. satellite and aerial monitoring, advanced communications networks to support SAR, medical evaluation/evacuation, oil spill monitoring and response etc.

Question 4: How do you mitigate risk to personnel in case of Arctic/sub-Arctic environmental conditions which hinder safe evacuation and rescue?

Arctic stakeholders mitigate risk in the first incidence by prevention of incidents, and multiple barriers that are in place to avoid the need for personnel to evacuate in an emergency. By applying the risk based methodology, they work to identify the situations where ensuring safe emergency evacuation and rescue may be appropriate, and to establish the effectiveness of methods in potential conditions. Effective evacuation and rescue relates to being able to leave the installation and move to a safe distance, and to survive until rescue to a safe haven is completed.

With respect to the local challenges that could be present at an Arctic or sub-Arctic location, there has been technology development regarding potential EER technologies e.g. evacuation bridges to supply vessels, ice strengthened winterized lifeboats, special craft for operations in / on ice, PPE for cold environment survival, personnel location equipment. In some locations (e.g. Norwegian and Barents Sea), relatively standard EER solutions can work throughout the year or part of the year. In other locations e.g. (Chukchi Sea, North Caspian Sea) the variability of environmental conditions from summer to winter may mean that there is no single evacuation method suitable for abandonment in all credible incident scenarios. Until year round solutions are developed, then a suite of different evacuation facilities may be necessary to cover seasonal operating environments.

It is important to remember that risk mitigation may also be through operating philosophy, i.e. Arctic stakeholders do not operate if they cannot provide safe and reliable evacuation. Consistent with offshore operations in other remote or harsh regions, if they identify potential conditions where evacuation cannot be safely performed, then the management system will require precautionary shutdown and down-manning of the facility. This thereby avoids the need for emergency evacuation in unsuitable environmental conditions. There are numerous examples of precautionary evacuation.

Generally they consider that approaches used for the offshore industry in remote and cold regions may be transferable to tourism and merchant maritime industries who increasingly operate in these areas.

Question 5: How do you plan for oil spill response in areas with ice compared to open water? What different or additional tools and procedures do you use?

The oil and gas industry is committed to operating safely and responsibly in environmental and social terms. Prevention of oil spills from occurring is the top priority to manage risk. Prevention is based on identifying initiators and causes of hazards that could lead to a spill, and a disciplined use of reliable and redundant controls and barriers that manage or avoid hazards, to ensure a very low likelihood of a spill occurring. For example, primary controls and barriers to prevent well control incidents while drilling include well design, use of trained competent personnel to construct the well, and remote monitoring of critical well parameters by well control experts. For drilling, a secondary barrier would be provided by the Blowout Preventer (BOP). In the unlikely event that these primary and secondary barriers fail, the use of a Capping Stack or Subsea Isolation Device would provide further controls stopping or limiting spills.

While risk is most effectively managed by prevention, industry is continually improving spill response capabilities as a key priority to mitigate risk even further. The overall goal of oil spill response (OSR) is to minimize the potential damage caused by an accidental release and employ the most effective response tools for a given incident in the unlikely event that all preventative barriers and controls fail. Preparedness is important in order to ensure that appropriate plans, people and equipment are in place and available. Giving responders the flexibility to apply the most effective "tools in the toolbox" to suit the prevailing conditions is the key to mounting a successful response and minimizing impacts.

The breadth of environmental conditions across the Arctic means that it is important that response preparedness plans are carefully tuned to be specific to the actual activity and location. The choice of response options can vary greatly depending on e.g. the source of the spill, location, timing, ice conditions, ice season duration, environmental sensitivities and oil properties. An appropriate toolbox of latest technologies must be available for the potential conditions in which a spill might occur, and the response team must have full flexibility to apply these. In this respect, industry invests in research and development for continuous improvement, develops and maintains various best practices and guidelines, and supports local clean seas organizations to that are trained and updated to provide the best available emergency response planning and execution. There are currently initiatives within IPIECA and IOGP to summarize Arctic specific OSRP considerations and to map tools and resources to make these more clearly available to other interested parties.

There is a wealth of more detailed technical information on assessment, tools and methods available within the “toolbox”. Some specific points are noted below.

- A sub-sea capping system can be installed at the sea floor in the event of a loss of well control and in the event of BOP failure. It can be operated in open water, or in some ice concentrations with additional ice management.
- Presence of ice can pose a challenge for spill response, however experience has shown, that low temperatures and ice also can enhance spill response and reduce environmental impacts under certain conditions. For example:
    a. Low air and water temperatures generally lead to greater oil equilibrium thicknesses that result in reduced spreading rates and smaller contaminated area. These beneficial effects greatly reduce the potential for direct oil impact with natural resources while providing an opportunity for much higher oil encounter/removal rates using mechanical recovery and burning operations.
    b. Evaporation rates are reduced in cold temperatures and ice. As a result, the lighter and more volatile components remain for a longer time, thereby enhancing the ease with which the oil can be burned on water in controlled fashion.
    c. When ice concentrations preclude the use of booms, the ice serves as a natural barrier to the spread of oil and help concentrate the oil for recovery with stationary skimmers dipped into discrete pockets of oil. The natural containment of oil against ice edges leads to thicker oil films that enhance the effectiveness of burning.
    d. Oil that was released under stationary ice will rapidly become immobilized and encapsulated within the ice. This oil is then effectively isolated from any direct contact with biological resources (marine or bird life).
    e. Oil encapsulated within the ice is also isolated from any weathering processes (evaporation, dispersion, emulsification). The fresh condition of the oil when exposed (e.g., through ice management or natural melt processes) enhances the chances for effective combustion and dispersion.
    f. Landfast ice protects shorelines from the oil spilled offshore during freezing season and allows recovery or burning at its edge rather than on the shoreline as it would be in other regions.
    g. Oil spilled on frozen ground and in snow doesn’t spread to uncontaminated areas and doesn’t penetrate soil. It can be safely removed when safe to do so.

Numerous responses, experiments and field tests demonstrated that all 3 response options (mechanical recovery, in-situ burning and dispersants use) can work effectively in Arctic and ice-covered waters. In some cases, they can be more effective in Arctic than in temperate regions.

There is ongoing work across regions to operationalize methods, as well as testing of innovative solutions (e.g. pyrodrones for remote ignition). Exercises are an important part of preparedness for equipment, personnel and procedures. These activities are often beneficially undertaken collaboratively through national Clean Seas organizations funded by the industry, e.g. Norwegian Clean Seas Association https://www.nofo.no/en/

Question 6: How do you learn from incidents or near misses, particularly in Arctic / sub-Arctic waters? What tools do you use for sharing and learning? Specific examples of learning from events are welcomed.

There are many conferences on the Arctic, the majority of which are commercial (for money) and have limited value. The most relevant ones are those from technical organisations such as SPE, OTC/ATC, ISOPE, POAC etc. Many of these include very detailed assessment of technical factors related to safety of operations.

Arctic Stakeholders learn from ALL incidents, noting that many of the incidents that occur in the Arctic are caused by non-Arctic factors. The rather surface level of analysis found in newspaper reports and commercially available incident databases do not give deep assessment of causes.

National regulators all maintain their own general databases of incidents, as do trade orgs e.g. NOROG, IOGP. Key / urgent learnings will be communicated through regulators and industry organizations, and these are directed towards the relevant subject experts or responsible company personnel to deal with them. Standards will then be updated to address the issue. In most Western countries (e.g. UK and Norway) and some companies (e.g. Equinor) there is very strong culture for reporting and learning, but it's not global across all countries and companies. There are always opportunities to build safety cultures that recognize the value and benefit from reporting, rather than to fear punishment. (This is a global need across many industries so not Arctic or O&G specific.)

In addition, it must be noted that Arctic specific incidents will provide discussion into the trade organization fora e.g. IOGP, NOROG, CAPP, API (these last 3 are members of IOGP), and into the International Regulators Forum (IRF), and Arctic Offshore Regulators Forum (AORF). These organizations can then raise the need for regulations, guidelines, standards or notices etc. to address the issue.

Looking at Norway's PSA as an example: all investigation reports are openly available to everyone as are audit reports. These provide useful information regarding both lessons learned (investigations) and issues to be aware of in prevention of incidents (audits). The website is searchable to find audit and investigation reports, enforcement notices etc such as in: http://www.ptil.no/about-supervision/category888.html. The Norwegian PSA has its own Safety Forum http://www.ptil.no/safety-forum/category917.html and Regulatory forum http://www.ptil.no/regulations/regulatory-forum-article9524-216.html . Other countries have similar.

Question 7: Do you have any ongoing initiatives relating to improving safety of operation of activities in Arctic / sub- Arctic waters? Information on initiatives is welcomed.

Learning from incidents is an important part of company safety management at top level. The systems apply irrespective of where or what environment in which an incident or near miss occurred. Some companies have identified benefit in requiring that teams understood challenges and learnings from previous Arctic incidents as part of preparation and risk assessments for future operations.

Two companies have identified learning related to seabed topography in the Arctic. In some cases (Pacific and Bering Strait) the seabed is constantly changing, particularly in shallow waters. In others (Atlantic Greenland), real measurements in areas of sparse data have shown that conventional maps may be unreliable.

A recent learning related to iceberg management at the Sea Rose field offshore Newfoundland can be found at https://www.cnlopb.ca/wp-content/uploads/iceier.pdf

It has to be noted that some incidents that occurred in the Arctic are not related to Arctic environment specific issues, but e.g. maritime issues for transit of rigs, safety management for dropped objects.

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At the light of the answers published above, Oil & Gas companies apply equally a strong Safety Management System (SMS) in the Arctic as in the other regions. There is not a specific mandatory regulatory regime for oil and gas operators in Arctic areas but companies follow optionally, standards and good practices built up on their accumulated experience. Up today, the most comprehensive study in Arctic specific standards was conducted via the Barents 2020 project which resulted in Phase 3 report (2010) and Phase 4 report (2012): https://www.dnvgl.com/oilgas/arctic/barents-2020-reports.html

Furthermore, Oil & Gas companies have standardized physical and psychological requirements for all the personnel working offshore and apply additional, project - tailored training for those involved in operations in Arctic / sub-Arctic environments. Some indicative training requirements for personnel of Oil & Gas industry who is exposed to offshore, Arctic environments, are presented below:

- HUET - Helicopter Underwater Escape Training;
- HAZWOPER - Hazardous Waste Operations and Emergency Response Training;
- OSRL - Extreme Cold Weather Spill Response Course.

As previously stated, offshore operations in Arctic waters are more challenging than in less harsh environments due to ecological and social sensitiveness, prolonged periods of darkness (winter) and light (summer), operational remoteness, cold ambient air temperatures, dense fog, cold water temperatures, sea ice in varying concentrations and thickness, and icebergs. These Arctic factors result in a shorter "window" for emergency response. Similar conditions are also present in other sub-Arctic regions e.g. Sea of Okhotsk, North Caspian Sea. The overall Escape, Evacuation and Rescue (EER) system design and operational aspects for offshore installations in Arctic areas is being addressed under ISO/DIS 35102 which is still under development. https://www.iso.org/standard/75741.html

Risk mitigation concerning safe evacuation and rescue of personnel operating offshore in Arctic areas is ensured at first degree via a risk based approach for prevention of any possible incidents and at second degree, via development of suitable EER technologies. In cases where safe evacuation and rescue cannot be ensured due to remoteness or harsh environmental conditions then precautionary shutdown of the facility is imposed.

Finally, it has been proved that all of the 3 available Oil Spill Response (OSR) techniques (mechanical recovery, in-situ burning and use of dispersants) can be implemented as effectively in Arctic environments as in more temperate regions. The most extensive research effort to date, was conducted via the Arctic Response Technology (ART) Joint Industry Program (JIP 2012 - 2017) which included 34 research projects and resulted in very comprehensive reports covering the following six fundamental elements of Oil Spill Response in Arctic areas: http://arcticresponse.wpengine.com/reports/

- Mechanical recovery;
- In situ burning;
- Dispersants;
- Trajectory modelling;
- Remote sensing;
- Environmental effects.

9 Conclusions

In 2008, the United States Geological Survey (USGS) released the first-ever wide-ranging assessment of Arctic oil and gas resources, estimating that about 30% of the world's undiscovered gas and 13% of the world's undiscovered oil are found north of the Arctic Circle. Although until present, few fields have entered into production, the big perspectives for extensive offshore hydrocarbon development have established Arctic as a major player in the global oil & gas market.

It is a fact, that Arctic resource development remains extremely risky and costly. Over the last decades there has been a continuous research activity in order to make Oil & Gas operations in the Arctic safer and economically viable. The present report, as a part of this research effort, aims to provide an overview of the state-of-the-art innovative safety systems and most recent technologies and procedures for the prevention, mitigation and emergency response in case of accidents during offshore operations in the Arctic. As an outcome of all the topics that were analysed in the Chapters of this report, the following conclusions can be made:

- The Arctic offers geopolitical stability which is essential for the development of the Oil & Gas industry. Any territorial disputes that have arisen in the past were resolved peacefully between the Arctic countries.
- Despite the undeniable technological advancements of the last decades, oil spill response techniques in the remote and ice covered Arctic waters, cannot be as effective as in more temperate waters. Oil spill response capability in the Arctic is a major issue.
- The available detection and monitoring systems are not capable yet to provide an accurate and real time image of a possible oil spill over the wide range of ice conditions that may be encountered in the Arctic.
- Ice covered waters, and the relatively short food chain, make the Arctic ecosystem more vulnerable to oil pollution than other ecosystems in more temperate waters. The environmental consequences of a possible large oil spill to the Arctic ecosystem would be dramatic.
- Despite the fact that oil & gas industry applies a strong safety and environmental management system, accidents in offshore installations in Arctic are still occurring.

Ultimately, the present report highlights the imperative need for a close collaboration between the Arctic counties (and the industry) in order to overcome the existing regulation (and knowledge) gaps which characterize modern oil & gas operations in the Arctic seas.

The survey reports that oil & gas companies apply the same Safety Management System (SMS) in offshore operations in the Arctic as in other more temperate areas. There is not a specific mandatory regime for oil & gas operators in the Arctic seas but companies follow standards and good practices built up on their accumulated experience.

Taking into consideration that a number of accidents have occurred in the past years, and that, in the near future, offshore oil & gas exploration and production activities in the Arctic are very likely to become more intense (and smaller and less experienced companies may get involved in Arctic operations), it becomes obvious that the **set-up of a Pan-Arctic Competent Authority**, able to regulate every offshore operation in the Arctic, would be strongly recommended as it would lead to the implementation of a common legislative framework. By this way, international standards will be adopted by all operators in the Arctic ensuring that the safety level of all oil & gas activities is in accordance with the special Arctic conditions.

It is also crucial that oil & gas personnel that deal with the demanding working environment of the Arctic has the appropriate preparation. At present, the necessary training of the personnel involved in operations in Arctic and sub – Arctic areas is directed by each company separately and according to the specifications of each project. The **establishment of a Centralised Training Centre** would contribute largely in the accumulation of valuable knowledge and experiences from different sources and to the spread of this knowledge to everyone operating in the Arctic. By this way it could be ensured that all personnel have acquired all the necessary physical, psychological and cognitive qualifications to work safely in the Arctic.

Finally, the study underlines the **need for an Internationally Coordinated Arctic Research effort**. The technology that needs to be developed in order to create a reliable oil spill response mechanism for the Arctic seas requires the economic and scientific contribution of all the Arctic nations. Moreover, since the Arctic is an inherently connected environment, an accident would have impacts in several bordering countries. The ocean circulation, the slower oil biodegradation and the sea ice drift make oil spills a serious environmental issue beyond the jurisdiction of a single country.

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https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research/1000aa.pdf

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Annex 1. Potential impacts of an accident in an offshore Oil & Gas installation

Case study: Deepwater Horizon Explosion (20 April 2010, Gulf of Mexico)

Casualties: 11 crew members

Non-fatal injuries: 17 crew members

Public health impacts: Several studies have identified long-term toxic health effects in the workers who have been involved in the oil spill clean-up operations. More specifically, persistent alterations in their hematological, hepatic, pulmonary, and cardiac functions have been reported, even 7 years after the initial exposure. The psychological impacts of the oil spill in the coastal communities should also be referred. Several studies have identified that people with spill-related income loss had experienced increased levels of tension, anxiety, depression, fatigue, confusion, and total mood disturbance. **[20] [21]**

Environmental impacts: It is estimated that nearly 5 million barrels (666.400 tonnes) of crude oil were released in the waters of the Gulf of Mexico before the well was capped (87 days later), which is considered to be the largest marine oil spill in the history of the petroleum industry. The oil spill resulted in an oil slick ultimately covering more than 112.000 km^2 on the ocean's surface leading to various degrees of oiling along 2.100 km of shoreline in four U.S. states: Louisiana, Mississippi, Alabama and Florida. Effects-oriented studies demonstrated that the oil was toxic to a wide range of organisms like plankton, invertebrates, fish, birds, and sea mammals, causing a wide array of adverse effects such as reduced growth, disease, impaired reproduction, impaired physiological health, and mortality. **[19]**

Security of energy supply: After Deepwater Horizon accident, several countries introduced restrictions on offshore oil and gas activities affecting the security of energy supply and the oil prices. For example, in Italy a restriction was introduced in 2016 which bans any exploration activity within 12 miles from the coasts of Italy. **[16]**

Regional economic impacts: The regional fishery industry, has been severely hit. Federal agencies put into force fisheries closures and banned fishing for several months in areas of the Gulf which have been affected by the oil spill and the applied dispersants. The tourism industry was also impacted heavily by the oil spill. Estimates of lost tourism and "brand damage" due to the oil spill were projected to cost the Gulf coastal economy up to $22.7 billion through 2013. **[18] [22]**

Direct economic losses for the operator (BP): Obviously, the first direct loss for the operator was the total loss of a state-of-the-art drilling rig, valued at $560 million. Nevertheless, the biggest economic losses for the operator were attributed to settlement of civil damages claims. In an eight-year period (till January 2018) BP had paid around $65 billion in court-ordered compensations to oil spill victims. **[15]**

Indirect economic losses for the operator (BP): The accident resulted in significant reduction of the operator's shareholder wealth. The BP's share price has fallen up to 55% just two months after the accident - from $59.48 a share (19 April 2010) to $27 a share (25 June 2010). Moreover, in November 2012 the U.S. government banned BP from new federal contracts. As a result, BP could not supply military fuel or participate in new contracts for drilling tracts. The ban was lifted 2 years later in March 2014. **[23] [24]**

Economic losses for the Oil & Gas industry: The U.S. Department of the Interior enacted the Deepwater Moratorium on 30 May 2010, effectively halting all deep-water exploratory drilling in the Gulf of Mexico. The ban was lifted in 12 October 2010, but by February 2011 no one had received a permit to drill because those applying had to prove the ability to contain a spill. A study conducted by the Louisiana State University (July 2010) assessed that the Deepwater Moratorium would result in the loss of 12.000 oil related jobs and in total economic loss of $2.7 billion for the U.S.A. over the first six months. **[25]**

<u>It is worth to be mentioned:</u>

''As a result of our investigation, we conclude: The explosive loss of the Macondo well could have been prevented.'' (Report to the President - January 2011) **[14]**

Annex 2. Landmark accidents in offshore Oil & Gas installations

Highest casualties recorded

Accident Date	Name of unit	Location	Cause of accident	Fatalitie s
6 Jul 1988	Piper Alpha	North Sea, UK	Human Error	167
Reports				
http://www.hse.gov.uk/offshore/piper-alpha-public-inquiry-volume1.pdf http://www.hse.gov.uk/offshore/piper-alpha-public-inquiry-volume2.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
27 Mar 1980	Alexander L. Kielland	North Sea, Norway	Structural Failure	123
Reports				
https://officerofthewatch.com/2013/04/29/alexander-l-kielland-platform-capsize-accident/				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
3 Nov 1989	Seacrest Drillship	Gulf of Thailand	Storm	91
Reports				
http://journals.library.mun.ca/ojs/index.php/prototype/article/download/410/508				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
15 Feb 1982	Ocean Ranger	Grand Banks Canada	Storm	84
Reports				
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.822.9073&rep=rep1&type=pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
25 Oct 1983	Glomar Java Sea	South China Sea	Storm	81
Reports				
https://www.shipsandoil.co.uk/accident-reports-introduction/the-glomar-java-sea-accident				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
25 Nov 1979	Bohai 2	Gulf of Bohai, China	Storm	72
Reports				
http://members.home.nl/the_sims/rig/bohai2.htm				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
6 Nov 1986	Chinook Helicopter	North Sea, UK	Mechanical Failure	45
Reports				
https://assets.publishing.service.gov.uk/media/5422fdb840f0b61342000861/2-1988_G-BWFC.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
16 Aug 1984	Enchova Central	Campos Basin, Brazil	Blowout	42
Reports				
http://members.home.nl/the_sims/rig/enchova.htm				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
30 Jun 1964	C.P. Baker	Gulf of Mexico	Blowout	22
Reports				
http://members.home.nl/the_sims/rig/cpbaker.htm				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
27 Jul 2005	Mumbai High North	Mumbai High, India	Human Error	22
Reports				
https://journals.library.mun.ca/ojs/index.php/prototype/article/viewFile/468/536				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
23 Oct 2007	Usumacinta	Gulf of Mexico	Storm	22
Reports				
https://www.academia.edu/1981028/Usumacinta_Accident_Report				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
2 Oct 1980	Hasbah Platform	Persian Gulf	Blowout	19
Reports				
https://incidentnews.noaa.gov/incident/6258#!				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
1996	Ubit Platform	Nigeria	Fire	18
Reports				
http://energykavan.ir/images/DL/Evaluating-accidents-in-the-offshore-drilling-of-petroleum.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
9 Oct 1974	Gemini jack-up	Nigeria	Leg failure	18
Reports				
http://energykavan.ir/images/DL/Evaluating-accidents-in-the-offshore-drilling-of-petroleum.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
27 Dec 1965	Sea Gem	North Sea, UK	Fatigue - Collapse	13
Reports				
http://members.home.nl/the_sims/rig/seagem.htm				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
20 April 2010	Deepwater Horizon	Gulf of Mexico	Blowout	11
Reports				
https://www.nrt.org/sites/2/files/GPO-OILCOMMISSION.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
20 Mar 2001	Petrobas P36	Campos Basin, Brazil	Human Error	11
Reports				
https://journals.library.mun.ca/ojs/index.php/prototype/article/download/499/554 http://www.scielo.br/pdf/csp/v34n4/en_1678-4464-csp-34-04-e00034617.pdf				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
10 May 1979	Ranger I	Gulf of Mexico	Fatigue - Collapse	8
Reports				
http://members.home.nl/the_sims/rig/ranger1.htm				

Accident Date	Name of unit	Location	Cause of accident	Fatalities
1 Mar 1976	Deep Sea Driller	North Sea, Norway	Storm	6
Reports				
http://members.home.nl/the_sims/rig/dsd.htm				

Biggest oil spills recorded

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
20 April 2010	Deepwater Horizon	Gulf of Mexico	Blowout	666.400
Reports				
https://www.nrt.org/sites/2/files/GPO-OILCOMMISSION.pdf				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
3 Jun 1979	Sedco 135F (Ixtoc 1)	Gulf of Mexico	Blowout	476.000
Reports				
https://digitalcommons.uri.edu/cgi/viewcontent.cgi?article=1136&context=ma_etds https://www.marine.usf.edu/documents/Jernlov1981IXTOC.pdf				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
10 Feb 1983	Nowruz field platform	Persian Gulf	1. Collision 2. Act of war	272.000
Reports				
https://response.restoration.noaa.gov/sites/default/files/Oil_Spill_Case_Histories.pdf				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
16 Sep 2004	Taylor Energy platform	Gulf of Mexico	Hurricane Ivan	Active
Reports				
https://nypost.com/2018/10/23/14-year-long-gulf-of-mexico-oil-spill-to-become-worst-in-us-history/				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
6 Jul 1979	Shell Storage Tank 6	Forcados, Nigeria	Accidental rupture	79.000
Reports				
https://royaldutchshellplc.com/2011/12/22/when-shell-flushed-100000-tonnes-of-forcados-crude-into-the-sea/				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
17 Jan1980	Funiwa No.5	Niger Delta, Nigeria	Blowout	26.000
Reports				
http://krepublishers.com/02-Journals/JHE/JHE-28-0-000-09-Web/JHE-28-3-000-09-Abst-PDF/JHE-28-03-177-09-1964-Aghalino-S-O/JHE-28-03-177-09-1964-Aghalino-S-O-Tt.pdf				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
21 Aug 2009	West Atlas	Timor Sea - Austalia	Well head leak	23.630
Reports				
https://www.lawyersalliance.com.au/documents/item/412				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
22 Apr 1977	Ekofisk Bravo	North Sea	Blowout	15.000
Reports				
http://members.home.nl/the_sims/rig/ekofiskb.htm				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
28 Jan 1969	Platform Alpha	Santa Barbara, U.S.A	Blowout	13.600
Reports				
http://www.geog.ucsb.edu/~kclarke/Papers/SBOilSpill1969.pdf				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
2 Oct 1980	Hasbah Platform	Persian Gulf	Blowout	13.000
Reports				
https://incidentnews.noaa.gov/incident/6258#!				

Accident Date	Name of unit	Location	Cause of accident	Oil Spill (tonnes)
12 Jan 1998	Mobil - Idoho	Akwa Ibom, Nigeria	Pipeline leak	6.000
Reports				
https://www.researchgate.net/publication/286408739_Analysis_of_potential_effects_of_the_Idoho-QIT_oil_spill_on_river-estuarine_fisheries_in_Nigeria				

Annex 3. List of Oil Spill Prevention & Response Research Projects

Program name:	Arctic Oil Spill Response Technology - Joint Industry Program (JIP)
Start date – End date:	2012 – 2017
Coordinator	International Association of Oil and Gas Producers (IOGP)
Reports:	http://arcticresponse.wpengine.com/reports/
Objectives:	1. To improve Arctic oil spill response capabilities focusing on the following key areas: Dispersants, Environmental Effects, Trajectory Modelling, Remote Sensing, Mechanical Recovery, In-Situ Burning. 2. To better understand the environmental issues involved in selecting and implementing the most effective response strategies.

Program name:	Oil in Ice - Joint Industry Program (JIP)
Start date – End date:	2006 – 2009
Coordinator	Sintef
Reports:	https://www.sintef.no/projectweb/jip-oil-in-ice/publications/
Objectives:	To develop knowledge, tools and technologies for environmental beneficial oil spill response strategies for ice-covered waters.

Program name:	Oil Spill Response Research (OSRR) – Arctic
Start date – End date:	On going
Coordinator	Bureau of Safety and Environmental Enforcement (BSEE - U.S.A.)
Reports:	https://www.bsee.gov/site-page/arctic-oil-spill-response-research
Objectives:	For more than 25 years, BSEE (and former organizations) have aggressively maintained a comprehensive, long-term research program dedicated to improving oil spill response options. The major focus of the program is to improve the methods and technologies used for oil spill detection, containment, treatment, recovery and cleanup.

Program name:	Gulf of Mexico Research Initiative (GoMRI) Research Program
Start date – End date:	2010 - Ongoing
Coordinator	Gulf of Mexico Research Initiative
Reports:	http://research.gulfresearchinitiative.org/research-awards/
Objectives:	Shortly after the Deepwater Horizon tragedy, BP announced a commitment of up to $500 million over ten years to fund an independent research program designed to study the impact of the oil spills on the environment and public health in the Gulf of Mexico.

Program name:	**Oil Spill Response Science (OSRS)**
Start date – End date:	2017 -2019
Coordinator	Government of Canada
Reports:	https://www.nrcan.gc.ca/energy/funding/21146
Objectives:	1. Development of an Integrated Mechanical Recovery and Oil Spill Response System for Heavy Oil in Cold and Ice Prone Marine Environments. 2. Development of In-Situ Foam Filtration System for Oil Spill Recovery. 3. Advanced Membrane-Based Hybrid Process for Oil Spill Removal in Marine Environments. 4. The Development of Hybrid Rapid Response Agents to Mitigate the Impact of Oil Spills in Marine Environments.

Program name:	**Joint Industry Oil Spill Preparedness & Response Task Force (OSPR JITF)**
Start date – End date:	2010 - 2015
Coordinator	American Petroleum Institute (API)
Reports:	http://www.oilspillprevention.org/oil-spill-research-and-development-cente
Objectives:	To identify potential opportunities for improvement to the oil spill response system. The program consists of the following seven work-streams, the first five of which are relevant to Arctic offshore operations: Spill Response Planning, Oil Sensing and Tracking, Dispersants, In-Situ Burning, Mechanical Recovery, Shoreline Protection, Alternative Response Technologies.

Program name:	**DEMO 2000**
Start date – End date:	1999 – On going
Coordinator	The Research Council of Norway
Reports:	Not published
Objectives:	Basic priority of the program is to develop knowledge and technology to solve particular challenges in the currently opened areas of the Norwegian parts of the Barents Sea, including cold weather, shallow reservoirs, carbonates, long distances and logistics, and emissions to the external environment.

Program name:	**Barents Sea Exploration Collaboration (BaSEC)**
Start date – End date:	2015 -2018
Coordinator	Steering Committee of BaSEC
Reports:	https://www.norskoljeoggass.no/naringspolitikk/basec/
Objectives:	To find solutions that lead to robust exploration activity in the Barents Sea.

Program name:	**Petromaks 2**
Start date – End date:	2013 -2022
Coordinator	The Research Council of Norway
Reports:	Not published
Objectives:	To promote knowledge creation and industrial development to enhance value creation for society by ensuring the development and optimal management of Norwegian petroleum resources within an environmentally sustainable framework. The Arctic areas are among the thematic priority areas of the program.

Program name:	**Arctic Monitoring and Assessment Program (AMAP)**
Start date – End date:	1991 – On going
Coordinator	Arctic Council
Reports:	https://www.amap.no/documents/doc/assessment-2007-oil-and-gas-activities-in-the-arctic-effects-and-potential-effects.-volume-1/776 https://www.amap.no/documents/doc/assessment-2007-oil-and-gas-activities-in-the-arctic-effects-and-potential-effects.-volume-2/100
Objectives:	The Arctic Monitoring and Assessment Program (AMAP) is a program designed to deliver sound science-based information for use in policy- and decision-making. AMAP is a permanent working group of the Arctic Council.

Project name:	**Employing Chemical Herders to Improve Oil Spill Response Operations**
Start date – End date:	2008 - 2010
Coordinator	Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM –U.S.A.)
Report:	https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research//617aa.pdf
Objectives:	1. Research the use of herding agents in pack ice to enhance mechanical recovery of spilled oil with skimmers. 2. Conduct preliminary experiments to determine the feasibility of using herders to clear oil from marsh areas. 3. Carry out experiments to study if applying chemical herders around oil slicks on the open ocean could improve the operational effectiveness of subsequent dispersant application.

Project name:	**Effects of Dispersed Oil in Cold Environments**
Start date – End date:	2009 - 2011
Coordinators	University of Alaska Fairbanks (UAF), NewFields (NF)
Report:	http://neba.arcticresponsetechnology.org/media/1109/jip-ph-1-2-final-report-12-04-11.pdf
Objectives:	To evaluate biodegradation and toxicity of dispersed oil in cold water environments of the Beaufort and Chukchi seas.

Project name:	**ACCESS** **Arctic Climate Change, Economy and Society**
Start date – End date:	2011 - 2015
Coordinator:	Pierre and Marie Curie University (UPMC) - Paris 6
Reports:	http://www.access-eu.org/en/deliverables2/wp4.html
Objectives:	It is the main objective of WP4 of the project to provide a detailed assessment of the opportunities and multiple risks of hydrocarbon extraction in the Arctic Ocean.

Project name:	**GRACE** **Integrated oil spill response and environmental effects**
Start date – End date:	2016 - 2019
Coordinator:	Finnish Environment Institute (SYKE)
Reports:	https://cordis.europa.eu/project/rcn/200292_en.html
Objectives:	To develop, compare and evaluate the effectiveness and environmental effects of different oil spill response methods in a cold climate. In addition to this, to develop a system for the real-time observation of underwater oil spills and a strategic tool for choosing oil spill response methods.

Project name:	**BIOPADE** **Biological Impact of Oil Pollution in Arctic and Deep-sea Environment**
Start date – End date:	2017 - 2019
Coordinator:	Akvaplan Niva A.S.
Reports:	Not published
Objectives:	This project focuses on the potential biological impacts of anthropogenic activities in new oil exploration and production areas, mainly situated in Arctic and deep-sea marine environments.

Project name:	**Force 7**
Start date – End date:	2013 - 2015
Coordinator:	Rina Consulting S.P.A.
Reports:	https://cordis.europa.eu/project/rcn/106833_en.html
Objectives:	To develop a high performance oil spill recovery system suitable to effectively operate in rough sea waters based on improved oleophilic / hydrophobic materials.

Project name:	**SMACC** **Studies of materials behavior for future cold climate applications**
Start date – End date:	2013 - 2018
Coordinator:	SINTEF
Reports:	https://app.dimensions.ai/details/grant/grant.4647066
Objectives:	To develop robust and cost effective materials and solutions for use in Arctic areas.

Project name:	**OFFSHORELAW** **The International Law of Offshore Construction: Cutting Through Fragmented Legal Regimes Towards Better Governance**
Start date – End date:	2012 - 2014
Coordinator:	Utrecht University
Reports:	https://cordis.europa.eu/project/rcn/102831_en.html
Objectives:	To clarify the international legal framework that regulates the life of offshore constructions in order to provide useful legal tools to both private investors and policy makers.

Project name:	**MORICE** **Mechanical Oil Recovery in Ice-Infested Waters**
Start date – End date	1995 -2002
Coordinator:	SINTEF
Reports:	https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research//310ae.pdf https://www.sciencedirect.com/science/article/pii/S0025326X03002066
Objectives:	To develop technologies for more effective recovery of oil spills in ice.

Project name:	**Wendy Schmidt Oil Cleanup XCHALLENGE**
Start date – End date:	2010 - 2011
Coordinator:	X PRIZE Foundation
Reports:	https://www.xprize.org/prizes/oil-cleanup
Objectives:	To inspire a new generation of innovative solutions that will speed the pace of cleaning up seawater surface oil resulting from spillage from ocean platforms, tankers, and other sources.

Project name:	**e-URready4OS** **Expanded Underwater Robotics Ready for Oil Spills**
Start date – End date:	On - going
Coordinator:	European Commission
Reports:	http://www.upct.es/urready4os/?lang=en
Objectives:	Expanded Underwater robotics ready for oil spills (e-URready4OS) is an EU DG-ECHO co-funded project aimed to join forces to make available to European Civil Protection a fleet of autonomous underwater vehicles (AUVs), unmanned aerial vehicles (UAVs) and unmanned surface vehicles (USVs) with operational capability to intervene against oil spills in European Seas using new cooperative multivehicle robotic technologies.

Project name:	A UAV SAR System for Oil Spill Detection in the Arctic
Start date – End date:	2014 - 2015
Coordinator:	NTNU
Reports:	http://www.mechatronics.hials.org/project/a-uav-sar-system-for-oil-spill-detection-in-the-arctic/
Objectives:	1. To explore and verify multi-frequency and full-polarimtric SAR for oil-in-ice technology. 2. To analyze and design a UAV SAR system. 3. To establish a solid research group on underwater robotics.

Project name:	Copernicus
Start date – End date:	On - going
Coordinator:	European Commission
Reports:	https://www.copernicus.eu/en/news/news/copernicus-services-information-and-sentinel-products-arctic-region
Objectives:	Copernicus is the European Union's Earth Observation Programme which provides information products via the Sentinel series of satellites. Among other tasks, monitoring and forecasting of the Arctic Ocean waters conditions is performed.

Project name:	ARCSAR
Start date – End date:	2018 - 2023
Coordinator:	Joint Rescue and Coordination Centre – North Norway
Reports:	http://arcsar.eu/
Objectives:	To establish and support a new Arctic and North Atlantic Security and Emergency Preparedness Network (ARCSAR) for practitioners involved in front-line security and emergency response, directly involving practitioners, existing networks, stakeholders in universities, research centers, and industry, and those involved in governance, and policy-making.

Project name:	MOSAiC Multidisciplinary drifting Observatory for the Study of Arctic Climate
Start date – End date:	2019 - 2020
Coordinator:	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)
Reports:	https://www.mosaic-expedition.org/
Objectives:	In September 2019 the German research icebreaker Polarstern will depart from Tromsø, Norway and, once it has reached its destination, will spend the next year drifting through the Arctic Ocean, trapped in the ice. MOSAiC will contribute to a quantum leap in our understanding of the coupled Arctic climate system and its representation in global climate models. The focus of MOSAiC lies on direct in-situ observations of the climate processes that couple the atmosphere, ocean, sea ice, bio-geochemistry and ecosystem.

Project name:	Blue-Action
Start date – End date:	2016 - 2021
Coordinator:	Danish Meteorological Institute
Reports:	http://www.blue-action.eu/index.php?id=4661
Objectives:	1. To improve our understanding of the impact of a changing Arctic on Northern Hemisphere weather and climate. 2. To improve the safety & wellbeing of people in the Arctic and across the Northern Hemisphere. 3. To reduce the risks associated with Arctic operations and resource exploitation. 4. To support evidence-based decision-making by policymakers worldwide.

Project name:	Science Based Regulation of Arctic Energy Installations
Start date – End date:	2017 - 2018
Coordinator:	Nottingham Trent University
Reports:	https://gtr.ukri.org/projects?ref=AH%2FR003203%2F1
Objectives:	This grant will facilitate development of a transdisciplinary network of academics and stakeholders designed to provide a 360 degree review of the governance and regulation of threats and impacts to the environment, industry, local communities and other stakeholders associated with offshore energy installations in the Arctic.

Project name:	RU-NO Barents Project Russian – Norwegian Oil & Gas industry cooperation in the High North
Start date – End date:	2012 - 2015
Coordinator:	Norwegian Oil and Gas Partners (INTSOK)
Reports:	https://www.norwep.com/Market-info/Markets/Russia/RU-NO-Project/Project-Reports
Objectives:	The main objective of the RU-NO Barents Project was, through industry cooperation and knowledge of Arctic technology needs, to contribute to the growth of the Russian and Norwegian industry participation in future petroleum endeavors in the High North. The RU-NO Barents Project focused on the following five major areas: 1. Logistics and transport. 2. Drilling, well operations and equipment. 3. Environmental protection, monitoring systems and oil spill contingency. 4. Pipelines and subsea installations. 5. Floating and fixed installations.

Project name:	**Barents 2020**
Start date – End date:	2007 - 2012
Coordinator:	DNV GL
Reports:	https://www.dnvgl.com/oilgas/arctic/barents-2020-reports.html
Objectives:	The objective of the Russian-Norwegian Barents 2020 project was to recommend standards for oil and gas activities in the Barents Sea which would ensure that the safety level would be at least as good as in the North Sea.

Program name:	**NOAA's Arctic Program**
Start date – End date:	On going
Coordinator:	National Oceanic and Atmospheric Administration U.S. Department of Commerce
Reports:	https://www.arctic.noaa.gov/
Objectives:	NOAA's Arctic Research Program provides environmental intelligence that forms the foundation for understanding the complex Arctic system to support effective stewardship, resilient communities and economies.

Program name:	**IABP** **International Arctic Buoy Programme**
Start date – End date:	1991 – On going
Coordinator:	U.S. Interagency Buoy Program (USIABP)
Reports:	http://iabp.apl.washington.edu/overview_history.html
Objectives:	The objective of the International Arctic Buoy Program (IABP) is to establish and maintain a network of data buoys in the entire Arctic Ocean to provide meteorological, sea ice and oceanographic data for real-time operational requirements and research purposes, including support to the World Climate Research Program (WCRP) and the World Meteorological Organization (WMO) World Weather Watch (WWW) Program. The Program will build upon cooperation among agencies and institutions with arctic interests.

Program name:	**Arctic Research Programme**
Start date – End date:	2010 - 2016
Coordinator:	Natural Environment Research Council (UK)
Reports:	http://arp.arctic.ac.uk/news/published-papers/
Objectives:	To improve capability to predict changes in the Arctic, particularly over timescales of months to decades, including regional impacts and potential for feedbacks on the global Earth System.

Project name:	**BaSMIN** **Barents Sea Metocean and Ice data Network**
Start date – End date:	2016 -2018
Coordinator:	Equinor (Statoil)
Reports:	Not Available
Objectives:	The BaSMIN project's purpose is to understand the effects of environmental forces on future offshore fixed and floating installations. Early acquisition of ice and metocean data will help oil and gas operators to reduce risks when exploring in frontier regions.

Project name:	**Oil Spill Preparedness in Small Communities**
Start date – End date:	2015 – 2017
Coordinator:	Institute of the North
Reports:	https://ppr.arcticinfrastructure.org/
Objectives:	The project "Oil Spill Preparedness in Small Communities" was approved by the Emergency Prevention, Preparedness and Response (EPPR) Working Group of the Arctic Council in June 2015. The project co-leads Norway, U.S., Canada and Aleut International Association developed a community self-assessment tool that will help EPPR better understand community preparedness and risk exposure.

Project name:	**MOSIDEO** **Microscale interaction of oil with sea ice for detection and environmental risk management in sustainable operations**
Start date – End date:	2015 – 2018
Coordinator:	Norut Northern Research Institute
Reports:	https://norut.no/en/prosjekter/microscale-interaction-oil-sea-ice-detection-and-environmental-risk-management
Objectives:	The primary objective of the research project MOSIDEO is to advance our knowledge of the interactions between oil and sea ice pore structure and develop parametrised description of oil behaviour and its influence on radar signals. This is a prerequisite for risk assessment and contingency planning of oil spills in sea ice-covered waters.

Project name:	**Technology for mapping and monitoring of the oceans**
Start date – End date:	On going
Coordinator:	NTNU AMOS
Reports:	https://www.ntnu.edu/amos/amos-project-1
Objectives:	This project considers modelling, mapping and monitoring of the oceans and seabed, and coordinated networked operations; real time processing of payload data, intelligent payload systems and sensor fusion; big data analytics, machine learning, artificial intelligence. Light climate as que of life.

Project name:	**Marine robotics platforms**
Start date – End date:	On going
Coordinator:	NTNU AMOS
Reports:	https://www.ntnu.edu/amos/amos-project-2
Objectives:	This project concerns the development of robotic platforms for autonomous marine operations and systems.

Project name:	**Risk management and maximized operability of ship and ocean structures**
Start date – End date:	On going
Coordinator:	NTNU AMOS
Reports:	https://www.ntnu.edu/amos/amos-project-3
Objectives:	The focus will be on the development of methods that maximize operability with improved risk management. This will be achieved by combining advanced numerical hydrodynamic and structural mechanical models for analysis, monitoring and control. Application areas include offshore wind turbines, aquaculture installations, oil and gas installations, coastal infrastructures, coupled multibody, marine structures, marine operations, autonomous ships, inspections and installations.

Program name:	**Ice Management Program**
Start date – End date:	2010 – On going
Coordinator:	Petroleum Research of Newfoundland and Labrador (PRNL)
Reports:	http://petroleumresearch.ca/index.php?id=166
Objectives:	Petroleum Research has established a multi-year Ice Management Program (IMP) aimed at the development of improved ice management capabilities for operations in arctic and harsh environments.

Project name:	**MAIRES** **Monitoring Arctic Land and Sea Ice using Russian and European Satellites**
Start date – End date:	2011 - 2014
Coordinator:	Nansen Environmental and Remote Sensing Center
Reports:	https://maires.nersc.no/
Objectives:	The overall objective of the MAIRES proposal is to develop methodologies for satellite monitoring of Arctic glaciers, sea ice and icebergs. The proposal will demonstrate the benefits of combining Earth Observation data from European and Russian satellites for operational mapping, interpretation and forecast of land and sea ice variations in the Eurasian Arctic with subsequent applications in the socioeconomic sector. The results of the proposal will contribute to improved understanding of changes in land and sea ice in response to climate change in the Arctic. The MAIRES project is focused on the Barents and Kara Sea region.

Project name:	**SALTO** **Safe Arctic logistics, transport and operations**
Start date – End date:	2014 - 2017
Coordinator:	Maritime Research Institute Netherlands (MARIN)
Reports:	http://www.marin.nl/web/JIPs-Networks/JIPs-public/SALTO.htm
Objectives:	To provide a risk based design tool to help industry to prepare for the Arctic environmental conditions (wind, fog, ice, icing) and hence to optimize operations of ships and offshore constructions.

Project name:	**The Arctic DP Research Project: Effective Station keeping in Ice**
Start date – End date:	2010 - 2014
Coordinator:	NTNU
Reports:	http://www.mic-journal.no/pdf/2014/MIC-2014-4-1.pdf
Objectives:	To strengthen the competences of the Norwegian maritime industry in Arctic offshore operations with special focus on dynamic positioning (DP).

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