Proactima Stavanger
Postboks 8034
4068 Stavanger
Norway

Proactima Oslo
Postboks 2369 Solli
0201 Oslo
Norway

Proactima Bergen
Kong Christian Fredriks plass 3
BI-bygget, 5006 Bergen
Norway

Proactima Trondheim
Abelsgate 5
7030 Trondheim
Norway

t: +47 40 00 19 33 – f: +47 51 87 57 41 – org. no. 915 641 938 – post@proactima.com – proactima.com

REPORT

Petroleum Safety Authority Norway (on behalf of the Norwegian Ministry of Foreign Affairs)

Overview of measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activities

Arctic Council, Task Force On Pollution Prevention (TFOPP)

Client:

Petroleum Safety Authority Norway

Contact persons:

Sigurd Robert Jacobsen & Øyvind Tuntland

Abstract:

The Task Force on Arctic Marine Oil Pollution Prevention (TFOPP), which was established by the Kiruna Ministerial Meeting in 2013 and delivered its recommendations to the Iqaluit Ministerial Meeting in 2015, identified an action to develop an overview of the existing and potential technical and operational safety measures specifically designed to prevent oil pollution in the Arctic marine environment due to offshore petroleum activities.

This report was prepared by Proactima for the Norwegian Petroleum Safety Authority acting on behalf of the Norwegian Ministry of Foreign Affairs. The development of the report has been financed by the Norwegian Ministry of Foreign Affairs. The final report will be delivered to the Ministry of Foreign Affairs for further processing with regard to the Arctic Council.

A comprehensive overview of measures has been established based on contributions from the industry and R&D institutions through a baseline survey in addition to reviewing open sources.

The report endeavours to provide a broad overview, covering the most important areas subject to the scope of work. However, due to the extent of the issues that have been investigated, the report may not have managed to capture all existing, ongoing or planned initiatives.

The report demonstrates that extensive research and development initiatives have been ongoing for several decades related to enhancing the safety of offshore petroleum activities in the Arctic and cold climate regions. The report, although being a documentation of facts, presents observations, recommendations and suggestions for further work.

Key words	Arctic, offshore, oil & gas, technology, research & development, oil spill prevention
Report no.	1071842-RE-01
Author(s)	Karianne Haver (Proactima), Ove Tobias Gudmestad (University of Stavanger), Lene Bjørnsen (Proactima), Espen Hoell (Proactima), Hermann S. Wiencke (Proactima), Trond Sagerup (Aker Solutions), Tor Johansen (Aker Solutions)
Confidentiality	Open
Revision no.	03
Date revised	16 December 2015
Pages	266

Rev. no.	Date	Reason for revision
00	22 October 2015	Final draft
01	15 November 2015	Final draft updated
02	24 November 2015	Final report
03	16 December 2015	Final report re-issued

Prepared by	**Verified by**	**For Proactima AS**
Karianne Haver	Hermann S. Wiencke	Richard Heyerdahl

Table of contents

1 Introduction

1.1 Background

The Task Force on Arctic Marine Oil Pollution Prevention (TFOPP), which was established by the Kiruna Ministerial Meeting in 2013 and delivered its recommendations to the Iqaluit Ministerial Meeting in 2015, identified an action to develop an overview of the existing and potential technical and operational safety measures specifically designed to prevent oil pollution in the Arctic marine environment due to offshore petroleum activities.

The main tasks of the TFOPP were to identify how best the Arctic Council can contribute to marine oil pollution prevention in the Arctic, to recommend a concrete plan of action, and, as appropriate, to develop cooperative arrangements to implement the action plan. The TFOPP held its inaugural meeting in Oslo, Norway in January 2014. It delivered its recommendations to the Arctic Council Ministerial Meeting in Iqaluit, Nunavut, Canada in April 2015. Norway and Russia were co-chairing the Task Force.

This report was prepared by Proactima for the Norwegian Petroleum Safety Authority (PSA) acting on behalf of the Norwegian Ministry of Foreign Affairs. The development of the report has been financed by the Norwegian Ministry of Foreign Affairs. The final report will be delivered to the Ministry of Foreign Affairs for further processing with regard to the Arctic Council.

1.2 Purpose

Regulators and the industry have regularly initiated research and development projects to explore operational and technical solutions that could contribute to safe Arctic oil and gas operations. There is, however, not produced an overview and status of the various initiatives. The purpose of this report is to establish a comprehensive overview of what is carried out and which activities are in progress, in order to demonstrate the present level of knowledge and to help avoid duplication.

1.3 Scope of work

The scope of work is 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. The scope includes, but is not limited to, exploration and development concepts, drilling and well technology, including capping and containment technology, production systems, riser and pipeline technology, loading and offloading systems, metocean and ice data, ice surveillance and ice management.

The topics, that have been mapped, include technology, research and development (R&D) activities, standards and guidelines, in addition to R&D centres, forums, portals, projects and programs. Established, ongoing and proposed new activities have been mapped. Relevant overviews already produced have been taken into account.

1.4 Limitations

Focus areas

The focus of the project has been on measures and issues that are specific for offshore petroleum activities in the Arctic and cold climate regions.

In this report risk reducing measures intended to reduce the probability of incidents leading to the release of hydrocarbons have had priority over consequence reducing measures.

- In this respect, capping and containment equipment is considered as a risk reducing measure with regard to the release of hydrocarbons to the marine environment
- Likewise, early detection equipment for leaks and spills is considered as a risk reducing measure with regard to further release of hydrocarbons to the marine environment

In this report, technical measures have been given priority over operational and organisational measures.

Scope of work limitations

The following issues have not been part of the scope of work:

- Issues, generic to petroleum activities, are not included in this report
- Oil spill response, including oil drift simulations, have not been part of the scope of work as it is covered by other TFOPP work measures
- Measures related to shuttle tankers and vessels operating on the open sea are not a part of the scope of work as it is covered by other TFOPP work measures

1.5 Terms and definitions

Neither TFOPP nor the Arctic Council has established a single geographic definition of the Arctic. For description of the Arctic areas included in this report the international standard ISO 19906:2010 on petroleum and gas industries Arctic offshore structures has formed the basis. However, relevant measures specifically designed to prevent oil pollution for other cold climate areas with similar challenges, are also included.

In this report the World Meteorological Organisation (WMO) sea ice nomenclature is strived to be used when describing sea ice and icebergs (WMO, 2014).

In this report the terms ‘Arctic and cold climate’ and ‘polar’ (notation used by the International Maritime Organization, IMO) are used interchangeably.

Abbreviations used throughout this report are given in Appendix 1.

1.6 Reference list

This report includes a literature study with reference to projects, experience, conventions, standards, guidelines, plans and other documents collected to form an overview of measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activities. The reference list is not complete, but includes a wide range of projects, standards, references and examples.

1.7 Follow-up of this work

This report will be handed to the Arctic Council by the Norwegian Ministry of Foreign Affairs. The report is a response to the TFOPP Petroleum Measure 1. The Arctic Council will decide how it wishes to use and follow up the report. The report will also be presented to the Arctic Offshore Regulators Forum (AORF) for use in discussion of focus issues for future work within the forum. The report is prepared so that it can be made openly available to the public, industry and research institutions. It is expected that the report will be published on the websites of the Arctic Council and the Norwegian Petroleum Safety Authority.

2 Executive summary

The Task Force on Arctic Marine Oil Pollution Prevention (TFOPP), which was established by the Kiruna Ministerial Meeting in 2013 and delivered its recommendations to the Iqaluit Ministerial Meeting in 2015, identified an action to develop an overview of the existing and potential technical and operational safety measures specifically designed to prevent oil pollution in the Arctic marine environment due to offshore petroleum activities.

This report was prepared by Proactima for the Norwegian Petroleum Safety Authority acting on behalf of the Norwegian Ministry of Foreign Affairs. The development of the report has been financed by the Norwegian Ministry of Foreign Affairs. The final report will be delivered to the Ministry of Foreign Affairs for further processing with regard to the Arctic Council.

To be able to focus the work towards the areas that have a high impact on the risk for acute oil pollution, a risk-based approach, focusing on measures that affect the undesirable events that have the highest impact on the risk for oil pollution in the Arctic marine environment, has been applied in this project. At a high level, the following undesirable events that may result in acute pollution have been considered relevant for Arctic offshore petroleum activity:

1. Process leak
2. Blowout
3. Riser / pipeline / subsea structure leak
4. Object on collision course
5. Damage to structure
6. Leak during loading / offloading

These undesirable events have formed the foundation for prioritising and structuring measures identified through this project. The measures have been structured according to the following themes:

- Metocean 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

A comprehensive overview of measures has been established based on contributions from the industry and R&D institutions through a baseline survey in addition to reviewing open sources. The report endeavours to provide a broad overview, covering the most important areas subject to the scope of work. This is achieved by the approach taken, however, due to the extent of the issues that have been investigated, the report may not have managed to capture all existing, ongoing or planned initiatives.

The report demonstrates that extensive research and development initiatives have been ongoing for several decades related to enhancing the safety of offshore petroleum activities in the Arctic and cold climate regions. Some observations, recommendations and suggestions for further work have been provided for each of the themes covered by the report.

3 Method description

To be able to focus the work towards the areas that have a high impact on the risk for acute oil pollution, a risk-based approach, focusing on measures that affect the undesirable events that have the highest impact on the risk for oil pollution in the Arctic marine environment, has been applied in this project. The following four step process was applied, see Figure 1.

Figure 1 Approach taken in this project

Prioritising issues to be included

The project covers a wide scope with the aim of presenting a comprehensive overview of ongoing and planned measures related to prevention of oil pollution in the Arctic marine environment due to offshore petroleum activities. At the same time as the scope is potentially large, the resources to complete the work are finite. Hence, it has been necessary to prioritise the issues that are to be included in the scope of work.

A workshop was performed with project owner (the PSA) and other key stakeholders from industry and R&D institutions, with the objective to:

1. Define the Arctic and cold climate regions to be prioritised.
2. Define the stages in offshore petroleum exploration and development, including relevant exploration and development concepts to be prioritised.
3. Define undesirable events for acute oil pollution relevant to Arctic offshore petroleum activities.

Wide screening information gathering

A wide screening of information covering all areas of the scope of work has been performed. This means technical and operational issues specific to the Arctic environment in all phases of an offshore development project.

The wide screening process has been carried out by identifying and screening relevant information from:

- Open sources such as journals, conferences, publications, student thesis, etc.
- A baseline survey of the industry and R&D institutions within the Arctic offshore petroleum industry

The baseline survey was conducted by distributing a cover letter and questionnaire to relevant industry and R&D contributors worldwide identified by project team. The cover letter and questionnaire are presented in Appendix 2 and Appendix 3, respectively.

In-depth information gathering

Following the wide screening process, an in-depth evaluation of prioritised relevant information from open sources has been performed, in addition to follow-up contact with key parties to obtain an in-depth understanding of relevant information. Areas considered to have only a small effect on the prevention of oil pollution were not prioritised in this step.

Information structuring and documentation

This report structures and documents the information gathered and forms a baseline overview to demonstrate the present level of knowledge and to help avoid duplication.

The report is structured as follows:

1. Prioritising issues to be considered
    - Defining Arctic and cold regions and identifying specific considerations for these regions
    - Defining stages in offshore petroleum exploration and development
    - Defining relevant exploration and development concepts for Arctic offshore petroleum activities
    - Defining undesirable events for the relevant Arctic offshore petroleum activities concepts
2. Wide screening information gathering
    - Overview of the main sources for relevant information
3. In-depth information gathering
    - Overview of technological and operational measures specifically designed to prevent or contain acute oil pollution related to Arctic offshore petroleum activities
    - Overview of standards and guidelines to enhance safety in Arctic offshore petroleum activities
    - Overview of R&D centres, forums, portals, projects and programs, contributing to sharing knowledge and enhancing safety in Arctic offshore petroleum activities

4 Arctic regions and specific conditions

This section presents different definitions for Arctic regions and which definition that has been applied in this report. Furthermore, specific conditions and challenges related to the Arctic and cold regions are described. This step is part of prioritising which issues are included in the project, see Figure 2.

Figure 2 Prioritising issues to be included

4.1 Arctic and cold climate regions

There are several definitions of the Arctic, amongst others the area north of the Arctic Circle at 66° 33'' north, the 10°C July isotherm and the tree line. The Arctic Monitoring and Assessment Programme (AMAP), which is a working group of the Arctic Council, has established a circumpolar region as a focus for its assessment activities that includes both High Arctic and sub-Arctic regions. In the marine environment, the 'AMAP area' includes northern seas that extend as far south as 51.1° North (James Bay, Canada). Furthermore, in the AMAP assessment of effects and potential effects of oil and gas activities in the Arctic, an oil and gas assessment area has been defined (AMAP, 2010). The oil and gas assessment area includes the Arctic production areas on the North Slope of Alaska, the Mackenzie Valley, the Norwegian offshore, and the West Siberian and Timan-Pechora basins of northern Russia, see Figure 3.

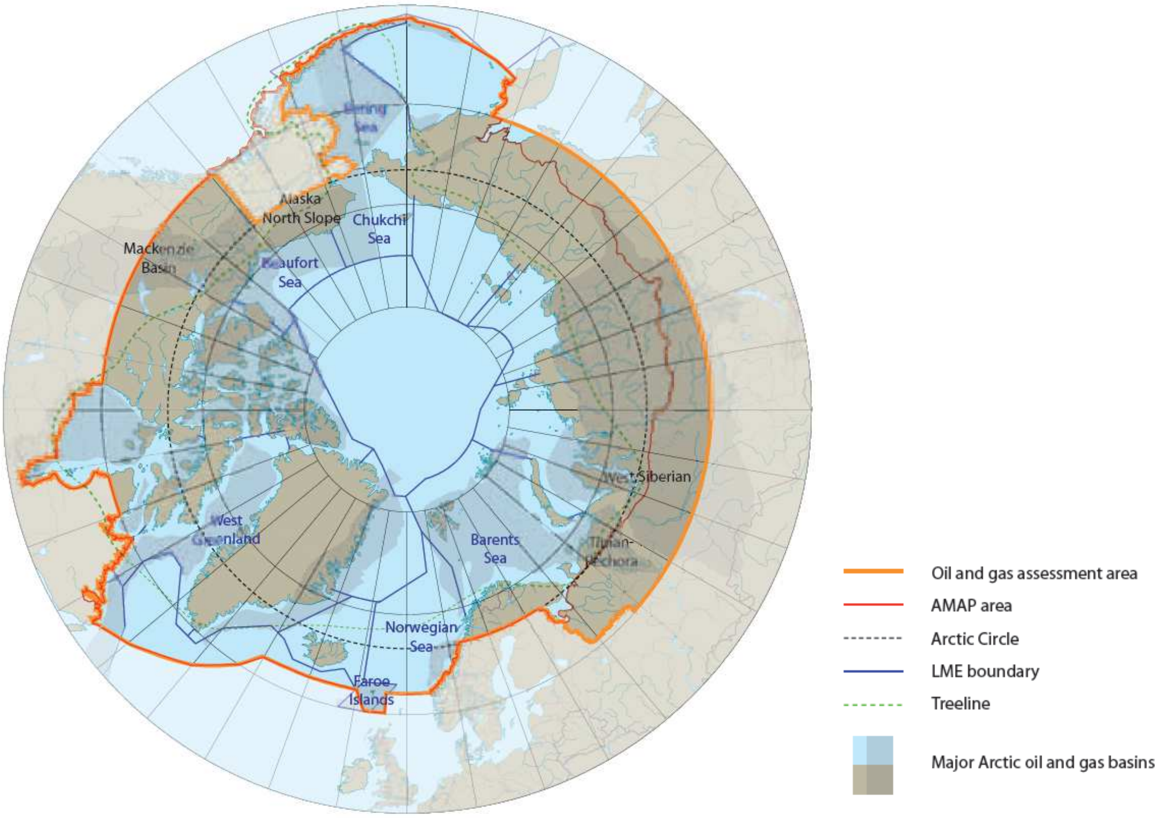


Figure 3 Defined areas within the Arctic (AMAP, 2010)

Regarding this report, the areas described in ISO 19906:2010 are considered to be the most relevant for offshore petroleum offshore activities in the Arctic. According to ISO 19906:2010 a total of 20 regions have been defined, see Figure 4. These regions include cold climate areas that traditionally are not included in the term “Arctic”. However, technology developed and R&D activities related to these areas may be of relevance for Arctic offshore petroleum activities and have therefore been included in this report.

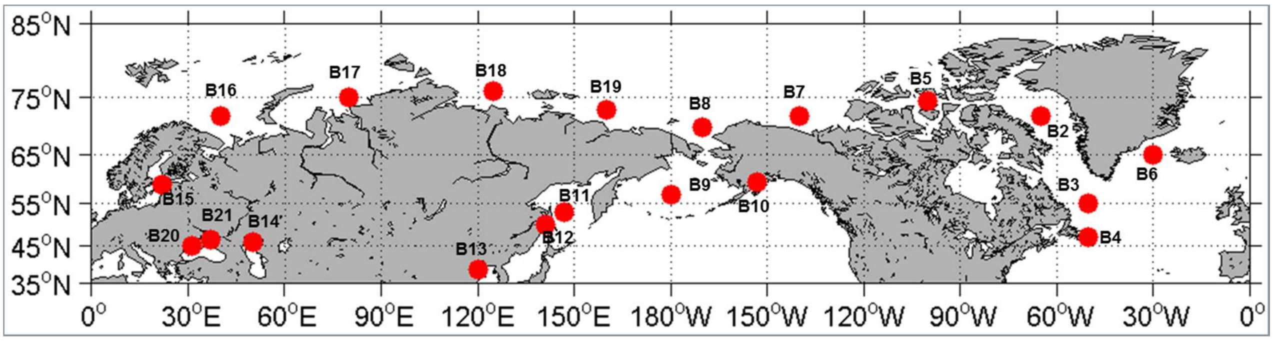


Figure 4 Arctic and cold regions defined in ISO 19906:2010

4.2 Specific conditions for the Arctic regions

Parameters used to define the overall situation in a specific area typically include (Gudmestad and Quale, 2011):

- Ice conditions throughout the season
- Temperature and wind chill; extreme lows
- Daylight hours by month

- Distance from shore
- Water depth

Other factors which have impact on design criteria are sea currents, storm and waves as well as permafrost and hydrate conditions. With such diverse conditions the technology requirements will therefore vary largely from area to area.

In the following sections, some specific conditions for the Arctic regions are described. For detailed regional descriptions of the physical environment for ice covered regions of the northern hemisphere, see Annex B in ISO 19906:2010.

A general challenge related to the climatic conditions of Arctic regions are the low number / lack of meteorological observations. Much of the data available are thus based on modelling of atmospheric conditions.

4.2.1 Daylight

Depending on the latitude, the number of daylight hours can vary from none in the winter period to 24 hours in the summer period. Platform and re-supply operations can be affected by the lack of daylight and sufficient lighting is a requirement for safe operation (ISO 19906:2010).

4.2.2 Visibility

Fog is of concern for parts of the year in some regions, severely limiting visibility. Fog appears particularly in the transition region between open water and ice covered seas (Gudmestad and Quale, 2011).

Fog is a widespread phenomenon in Arctic waters during summer. It occurs with moderate wind strengths, typical up to 5-7 m/s wind when warm, continental air flows out over the cold ocean.

Visibility is also affected by blowing snow and daylight hours.

4.2.3 Temperature

The air temperature is a critical parameter, both in the design of an offshore structure (for selection of material quality) in addition to its day-to-day operation (ISO 19906:2010). This relates to efficiency of both lubrication, fuel and seals. According to ISO 19906:2010 minimum temperatures of below minus 50°C may occur in certain Arctic and cold climate areas such as the Chukchi Sea, Laptev Sea and East Siberian Sea. Newfoundland and Labrador areas have minimum temperatures of about minus 20°C and minus 40°C, respectively. Furthermore, according to MET Norway (2012) minimum temperatures of minus 25°C may occur at 74°N in the Barents Sea.

The very low temperatures that can be experienced in the northern regions are hazardous both concerning their direct effects on human health and in their reduction of workers' efficiency and reaction time when they are exposed to cold. Furthermore, bulky protective clothing worn for warmth may interfere with tasks in ways that can cause increased risk for injury or accidents (Gudmestad and Quale, 2011), which may cause faulty operations to be carried out, potentially leading to release of hydrocarbons. In addition, the combination of low temperatures and wind causes the body's heat to be removed very quickly, obtaining a wind chill effect that may restrict work during combination of cold temperatures and wind.

The seawater temperature in the Arctic and cold regions is low during most of the year. This causes severe concerns during any evacuation and rescue operations as persons cannot survive long in cold-water. Improved survival suits have been fabricated during the last decade. In this respect, it should be noted that seawater freezes at minus 1.9°C. Low seawater temperatures also reduce the potential for oil on seawater to evaporate, putting more emphasis on oil spill prevention and equipment for oil spill collection.

4.2.4 Icing

Icing on a structure at sea requires a combination of water or moisture and surfaces above sea level with sub-freezing temperatures (ISO 19906:2010). There are two major types of icing; atmospheric (related to precipitation) and sea spray.

Sea spray is the most frequent and most important form of icing in the sea (ISO 19906, 2010). While the height of sea spray icing is usually limited to 15 m to 20 m above the sea surface, there have been reports of sea spray icing at up to 60 m above the sea surface. Sea spray can create possible hazardous events which may result in discharge to sea such as blocked valves, scupper plugs, winches and pipes, in addition to slippery decks, ladders and railings.

Icing of structures or structural members can result from fog, freezing rain, green water trapped on decks, wind and wave driven seawater spray, or tidal variation (Gudmestad and Quale, 2011). Icing modifies the aerodynamic and hydrodynamic properties, static stability and dynamic responses of the structure. Icing can also modify the buoyancy and stability of floating structures. Furthermore, icing can significantly raise the levels of wave and current actions on a structure due to changes in projected area, volume and surface roughness. Accumulation of ice on a structure can cause large increases of projected area and volume around and above the mean waterline. It can also make circular cylinders effectively rough.

4.2.5 Wind and wind chill

When a person is exposed to cooling, the effect on the person depends not only on the air temperature but also on the wind velocity. This concept of additional cooling is called wind chill and has been used for many years to identify potential hazards caused by the combination of wind and temperature (ISO 11079:2007). This can lead to reduced human performance and concentration which may lead to discharge to sea.

4.2.6 Precipitation and snow

Precipitation in the Arctic and cold regions falls both as rain and snow, although the amount of precipitation may be lower than in many other regions. Rain will freeze to a hard layer of atmospheric icing in case of low temperatures. Such a layer of icing can cause operations to be disturbed, for example navigation equipment can be set out of function, potentially leading to hazardous manoeuvring. Atmospheric icing can also be of concern for the stability of smaller vessels. Icing represents potential for slips and falls, and is of concern during operations.

Snowfall in the Arctic can be very intense; a polar low, for example, is often associated with troughs, snowfall and intense winds. Repeatedly snowing, melting and snowing can cause large accumulations of snow on structural members. In such cases, snow must be removed. Otherwise, snow can cause problems similar to atmospheric icing.

4.2.7 Polar lows

Polar lows are small, rather intense low pressure systems in the Arctic (Gudmestad and Quale, 2011). They are formed at sea during cold air outbreaks during winter and are often characterised by their sudden and rapid development. Polar lows come with gale or storm force winds, seldom hurricane, and heavy snow showers, icing and changing wind direction. They typically cover an area of 100-500 km in diameter and can have a life span of 6 hours to 1-2 days, after which the weather conditions generally improve.

This phenomenon is known in the European sector of the sub-Arctic and Arctic. Polar lows are most frequent from October through March, during which period, on average, five to ten polar lows occur (ISO 19906:2010).

4.2.8 Water depths

The water depth in Arctic and cold region areas varies, however, it is not very deep. Water depths for current Arctic offshore oil and gas projects already in operation vary from 3 meters to 1 100 meters (Huaiyin, L. et al., 2015). It is important to beware of unchartered water, sediment transfer and presence of sand and mud banks.

4.2.9 Waves

Wave generation in ice covered seas is reduced relative to that in open water since the ice cover limits the available fetch (ISO 19906:2010). Wave propagation is reduced when waves travel into ice covered regions. In addition, waves are attenuated as they move through an ice covered region.

With retracting ice cover the waves may increase compared with today's situation. This is due to longer fetch creating larger waves.

4.2.10 Ocean currents

In regions with high current velocities, the current affects the speed with which ice interacts with a structure in addition to affecting the encounter frequency associated with various ice features.

Note that the tidal current changes direction at regular intervals (twice per 24 hours) and in areas where the tidal current is dominating, ice drift direction will change with current direction change.

4.2.11 Sea ice and icebergs

Sea ice is the single most important environmental factor affecting operations in the Arctic. Ice affects all aspects of oil and gas activities, from the design and construction of facilities which can withstand ice conditions to planning for transportation or possible rescue operations. There is no simple description or set of design criteria related to sea ice. The characteristics and their potential impact on oil and gas field developments are subject to specific studies on ice properties, ice drift and ice forces actually encountered in the prospective area.

The various Arctic and cold climate areas have different types of ice, i.e. first-year, second-year, multi-year, shelf or glacial. Furthermore, the occurrence and geometry of the ice features, such as icebergs, ice islands, level ice, rafted ice, rubble fields, leads or polynya, pressure and shear ridges, stamukhi, landfast ice, pack ice, shelf ice and glacial ice, varies (ISO 19906:2010).

4.2.12 Seabed conditions

Hydrates

Hydrates are methane frozen in the ground. This is a relevant condition at relatively shallow depths in cold climates as lower ground temperatures increase the probability of the presence of frozen gas hydrates. If the hydrates melt, this would cause release of gas and seabed failure.

Earthquake

Some Arctic and cold climate areas are subject to seismic activities that may result in earthquakes. It is essential that offshore structures in Arctic and cold regions are designed to withstand earthquakes that may occur. Examples of Arctic and cold regions that are known to be seismically active include Cook Inlet, Okhotsk Sea and Tatar Strait, Sea of Japan, Bohai Sea in addition to certain regions of offshore Canada (ISO 19906:2010).

Permafrost

Permafrost is a phenomenon where the ground remains at a temperature at or below 0°C for at least two consecutive years. Climate (past and present) has resulted in the occurrence of widespread permafrost even in deep water areas in some Arctic and cold regions (ISO 19906:2010).

Strudel scour

Strudel scour is a phenomenon peculiar to highly localised areas in the Arctic. In the Arctic spring, the rivers thaw first while the sea is still frozen. River water floods out over the sea ice, and from time to time encounters holes or a crack in the sea ice. The river water flows downward through the hole, and forms a strong rotating vortex, called a strudel (Palmer and Croasdale, 2012). Rivers that discharge into Arctic coastal waters can thaw well in advance of the bottomfast sea ice along the coast during the spring melt season (ISO 19906, 2010).

Seabed gouging

Seabed gouging occurs due to interaction of ridges, icebergs and stamukhi with the seabed (ISO 19906:2010). The river water flows onto the ice and spreads offshore, flooding substantial portions of the nearshore zone. Drainage occurs through discontinuities in the ice, which typically consist of tidal cracks, thermal cracks and seal breathing holes. In those circumstances where the drainage rate is high and the water depth relatively shallow (typically less than 7 m), substantial scouring of the sea bottom can occur.

4.2.13 Distance

Arctic offshore petroleum activities are characterised by long distances. For instance, the Terra Nova oil is produced from the Terra Nova FPSO which is located 320 km off the shores of Newfoundland. Furthermore, the gas condensate field Shtokman, which has been evaluated for development, is located 555 km from land. Long distances can give specific challenges related to logistics and emergency response and may impose stricter requirements to planning of the oil and gas activities.

5 Concepts for Arctic offshore petroleum activities

This section describes typical stages in an offshore exploration and development venture. Then the main concepts for Arctic exploration and development are described in addition to undesirable events that may result in acute pollution to sea from such development are described. This step is part of prioritising which issues are to be included in the project, see Figure 5.

Figure 5 Prioritising issues to be included

5.1 Stages in offshore petroleum exploration and development

Exploration and production ventures comprise stages of activities, starting with screening of potential exploration areas and ending with field abandonment. An example is presented in Figure 6.

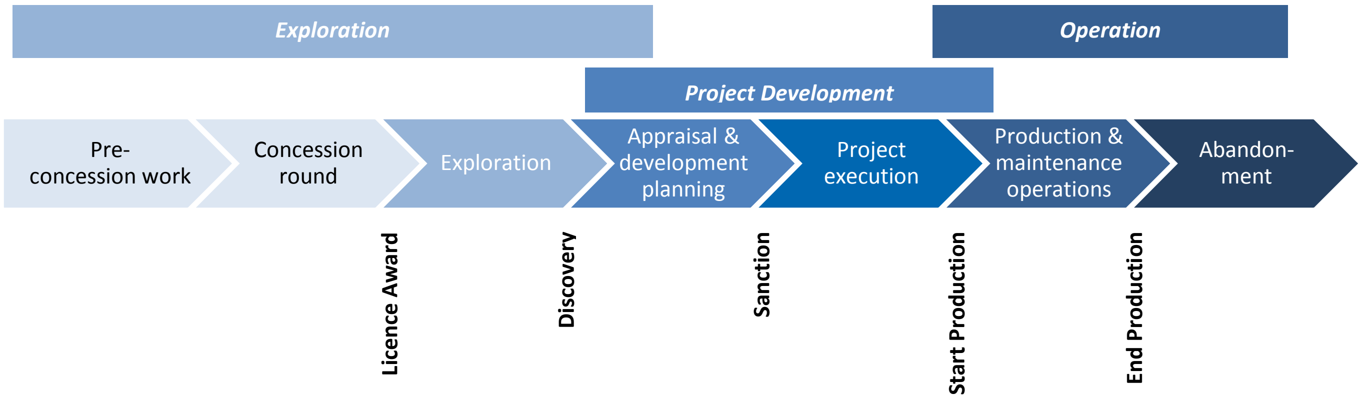


Figure 6 Stages of an exploration and development venture (redrafted from Gudmestad et al., 2010)

5.2 Relevant exploration and development concepts

There are different concepts relevant for petroleum activities that can give rise to undesirable events resulting in acute pollution to sea. The main groups of concepts, relevant for Arctic and cold climate offshore petroleum activities, are briefly described below.

Appendix 5 describes the technology implemented for existing and future planned installations in Arctic and cold regions.

5.2.1 Fixed structures

Fixed steel structures

A fixed steel structure platform consists of steel legs anchored directly onto the seabed, supporting a deck with space for drilling rig, production facilities and crew quarters. Such structures are relevant only for limited water depth and light ice conditions. This concept is applied in the Bohai Sea and Cook Inlet, Alaska.

Gravity base structures

A gravity base structure (GBS) sits on the seabed under its own weight. A GBS consist of caissons anchored directly onto the seabed and concrete legs, supporting deck with space for drilling rig, production facilities and crew quarters. Most of the designs have in common a base caisson (normally for storage of oil) and shafts penetrating the water surface to carry the topside. In the shafts normally utility systems for offloading, drilling, draw down and ballast are installed. In other designs the caisson is extended to above the surface. This concept is applied for example at offshore Sakhalin in the Okhotsk Sea, in Newfoundland (Hebron and Hibernia) and the Pechora Sea, and has previously been used as a drilling concept in the Beaufort Sea.

Man-made islands

A man-made island is an island that has been constructed by people rather than formed by natural means. Man-made islands are used in the Beaufort Sea.

Man-made islands are generally suited to shallow water Arctic and cold regions. There are several different island types (ISO 19906:2010):

- Sacrificial beach islands
- Slope-protected islands
- Sheetpile-retained islands
- Caisson-retained islands
- Hybrid islands

Furthermore, artificial ice islands have been used for exploration drilling and relief well purposes in Arctic and cold regions. There are three basic types of ice islands (ISO 19906:2010):

a) Grounded ice islands, created from flooding, spray ice and chipped ice
b) Floating or grounded ice islands, created by flooding to thicken the ice until sufficient area with sufficient bearing capacity is created
c) Rubble manipulation, with or without water flooding or spraying

Wave and/or ice coming up on the slopes is a large challenge for these designs.

5.2.2 Floating structures

Floating structures includes the hull, marine systems, offloading systems, mooring or station keeping system to hold the structure on location and risers connecting the unit to the well head (ISO 19906:2010). Floating structures may also be used to support other types of subsea operations.

Column stabilised (e.g. semi-submersible) and buoy type units

Semi-submersible marine structures are typically only movable by towing. They have the principal characteristics of remaining in a substantially stable position, presenting small movements when they experience environmental forces such as wind, waves and currents. Semi-submersible platforms have pontoons and columns, typically two parallel spaced apart pontoons with buoyant columns from those pontoons supporting a deck. Semi-submersible is the traditional drilling concept applied throughout the Arctic and cold climate regions during the summer season.

The Goliat FPSO is a buoy shaped structure that is installed for oil production at the Goliat field, Norway. The circular buoy shaped structure will not 'weather-vane' during the operation.

Ship shaped hull (e.g. FPSO / FSO) or barge units

Floating, Production, Storage and Offloading (FPSO) or Floating, Storage and Offloading (FSO) systems are typically barge / ship-shaped vessels and store crude oil in tanks located in the hull of the vessel. Their turret structures are designed to anchor the vessel, allow 'weather-vaning' of the units to accommodate environmental conditions minimizing the environmental action effects, permit the constant flow of oil and production fluids from the vessel to undersea field, all while being a structures capable of quick disconnect in the event of emergency.

If a floater is exposed to ice interaction this may give rise to potential undesirable events such as:

- Hull rupture due to ice interaction
- Mooring line failure due to ice interaction
- Riser and/or control line failure due to ice interaction

Production FPSOs are found in Newfoundland (Terra Nova and White Rose), and is being considered as a concept for the Shtokman FEED phase. Drilling ships can be used for drilling operations in ice covered waters.

5.2.3 Subsea structures

A subsea structure is a structure located at the seabed. The petroleum produced from subsea wells is extracted at the seabed, and is tied back to a production platform or an onshore facility. The wells are drilled by a moveable rig and the extracted oil or natural gas well stream is transported by pipeline under the sea before rising to the processing facility.

There are no full subsea production systems in Arctic or cold climate regions. However, technology developed for deep-water operations may also be relevant for Arctic and cold climate regions. Challenges related to subsea production systems are amongst others power supply, processing and injection of water, leak detection in addition to access for maintenance.

5.2.4 Extended reach wells from shore

Extended reach drilling (ERD), designed to drill wells at offshore targets from land-based locations or artificial islands, enables drilling in areas with level ice and/or icebergs without other precautions. Wells are drilled with a horizontal reach of more than 10,000 meters. Rosneft and ExxonMobil performed drilling operations from Sakhalin, with a horizontal reach of 12,033 meters and a measured depth of 13,500 meters (Rosneft, 2015).

This technology can be applied whenever close to shore, however, there are some challenges related to permafrost and erosion of the shoreline.

5.3 Undesirable events

At a high level, the following undesirable events that may result in acute pollution to the marine environment from Arctic offshore petroleum activities are considered relevant to the above-mentioned concepts:

1. Process leak
2. Blowout
3. Riser / pipeline / subsea structure leak
4. Object on collision course
5. Damage to structure
6. Leak during loading / offloading

Each of these events can be linked to one or more of the main groups of concepts relevant for exploration and development in Arctic and cold climate regions described in the previous section.

These undesirable events have formed the foundation for prioritising and structuring measures identified through this project. For each of these undesirable events, a mapping of barrier functions and corresponding risk reducing measures (i.e. barrier elements) has been performed, see Appendix 6. These undesirable events, barrier functions and barrier elements have been used to categorise and structure the measures identified through this project.

6 Overview of main sources for relevant information

In this section an overview of the main sources of relevant information for this project are presented. This step is part of the wide screening information gathering, see Figure 7.

Figure 7 Wide screening information gathering

The report endeavours to provide a broad overview, covering the most important areas subject to the scope of work. This is achieved by the approach taken, however, due to the extent of the issues that have been investigated, the report may not have managed to capture all existing, ongoing or planned initiatives.

6.1 Response from the baseline survey

A baseline survey has been conducted by distributing a cover letter and questionnaire to relevant industry contributors worldwide identified by project team. The questionnaire was sent to 136 industry and R&D institutions within the Arctic offshore petroleum industry, of which 85 responded to the request. The cover letter and questionnaire are presented in Appendix 2 and Appendix 3, respectively. In addition, information has been obtained through direct follow-up contact with several parties.

The main contributors to the baseline survey are listed in alphabetical order below. The full list of respondents, 85 in total, is presented in Appendix 4.

- ABS HETC
- Aker Solutions
- API
- Bureau Veritas
- Canatec Europe
- C-CORE
- Chevron Arctic Centre
- COSL Drilling Europe
- DEA Norway
- Det Norske
- DNV GL
- Dong Energy E&P Norway
- Dr.techn.Olav Olsen
- Edison Norway
- Eni Norway
- Faroe Petroleum
- FMC Technologies
- GustoMSC
- HSVA
- Inocean
- INTECSEA
- INTSOK

- ISPAS
- Keppel Offshore & Marine Technology Centre (KOMtech)
- Lundin Norway
- Kværner Concrete Solutions
- Lloyd's Register
- MARIN
- MARINTEK
- MET Norway
- Moss Maritime
- National Energy Authority (Iceland)
- National Energy Board (Canada)
- National Oilwell Varco
- National Research Council (Canada)
- North Energy
- NORUT
- NTNU (SAMCoT)
- Nuna Oil
- OMV Norway
- Peter Noble
- Preventor
- Shell International E&P
- SINTEF Petroleum Research
- SINTEF Safety Research
- Southwest Research Institute (SwRI)
- Statoil
- Stena Drilling
- Subsea 7
- Suncor Energy Norway
- Technip Norway
- The Research Council of Norway
- ThyssenKrupp Marine Systems
- Total E&P Norway
- Transocean Services
- Trendsetter Engineering
- Viking Ice Consultancy
- Wintershall Norway

6.2 Conference papers

A wide screening of information covering all areas of the scope of work was performed.

Papers from the two last conferences relevant to this project were reviewed:

- OTC's Arctic Technology Conference (ATC), held in Copenhagen, Denmark 23-25 March 2015
- The 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), held in Trondheim, Norway, 14-18 June 2015

In addition, papers from the following conferences and journals have been reviewed:

- ATC – OTC's Arctic Technology Conference (http://www.arctictechnologyconference.org/)

- ICETECH – International Conferences and Exhibitions on Performance of Ships and Structures in Ice
- ISOPE – the International Society of Offshore and Polar Engineers (http://www.isope.org/)
- Journal of Cold Regions Science and Technology (http://www.journals.elsevier.com/cold-regions-science-and-technology/)
- OMAE - ASME International Conference on Ocean, Offshore and Arctic Engineering (http://www.asmeconferences.org/conference-home/OMAE.cfm)
- POAC – International Conferences on Port and Ocean Engineering under Arctic Conditions (http://www.poac.com/
- The International Symposiums on Ice under the IAHR organisation (http://www.iahr.org/site/cms/contentviewarticle.asp?article=658)

6.3 National Petroleum Council (NPC) Arctic Potential Report

The National Petroleum Council (NPC) has conducted a comprehensive study considering the research and technology opportunities to enable prudent development of U.S. Arctic oil and gas resources. In March 2015, the report NPC Arctic Potential – Realizing the Promise of U.S. Arctic Oil and Gas Resources was published (NPC, 2015).

The report is a result of significant collaboration by Arctic experts from government, the industry, non-government organizations and Native Alaskans. The study plan was organised around two key themes:

1) Prudent development in the Arctic, and
2) Arctic research and technology

Part one provides context on Arctic development experience, resource potential, regulatory practices, and the ice and sea environment in general. Part two of provides an overview of emerging research opportunities, technology development, and collaborative approaches applicable to prudent development in the Arctic. The research and technology overview is grouped in six areas:

- Ice characterisation
- Oil and gas exploration and development
- Logistics and infrastructure
- Oil spill prevention, control and response
- The ecological environment
- The human environment

The report concludes that the technology exists today to safely and responsibly develop the U.S. Arctic and is supported by nearly a century of experience in the region. The Arctic environment poses some different challenges relative to other oil and natural gas production areas, but these are generally well understood.

However, the Council recommends additional research to both validate recently developed technology for use in the U.S. offshore, and to pursue technology extensions that could lead to improved safety, environmental or cost performance.

Key findings:

1. Arctic oil and gas resources are large and can contribute significantly to meeting future U.S. and global energy needs
2. The Arctic environment poses some different challenges relative to other oil and gas production areas, but is generally well understood
3. The oil and gas industry has a long history of successful operations in Arctic conditions enabled by continuing technology and operational advances

4. Most of the U.S. Arctic offshore conventional oil and gas potential can be developed using existing field-proven technology
5. The economic viability of U.S. Arctic development is challenged by operating conditions and the need for updated regulations that reflect Arctic conditions
6. Realizing the promise of Arctic oil and gas requires securing public confidence
7. There have been substantial recent technology and regulatory advancements to reduce the potential for and consequences of a spill

The report lists existing oil and gas projects that are in operation in Arctic environments, relevant standards for Arctic designs, and research and joint industry programs relating to Arctic technology.

The report has several study topic papers attached, which looks into the details of for example ice management and development drilling. These papers are working documents that were part of the analyses that led to development of the summary results presented in the report's executive summary and chapters. The papers represent the views and conclusions of the authors. NPC has not approved or endorsed the statements and conclusions contained in the documents, but has approved the publication of this material as part of the Arctic Potential report study process.

6.4 The Russian – Norwegian Oil & Gas industry cooperation in the High North

The RU-NO Barents Project is a Russian – Norwegian oil & gas industry cooperation project that has assessed the gap between the technology currently available and the technology needed for extracting oil and gas resources in the Barents, Pechora and Kara Seas in an environmentally sound and safe way. The RU-NO Barents Project was launched in 2012 and reports documenting the results of the work were published in December 2014 (RU-NO Barents Project, 2015). The RU-NO Barents Project was lead and chaired by INTSOK – the Norwegian Oil and Gas Partners organisation (http://www.intsok.com/).

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 endeavours in the High North. Focus was placed on the industry to execute the activity in a sustainable and responsible manner, with the petroleum industry taking the lead. The RU-NO Barents Project has mobilised the industry to:

- Assess common technology challenges Russia and Norway face in the development of the High North.
- Analyse existing technologies, methods and best practice Russian and Norwegian industry can offer for the High North today.
- Based on the above, visualise the need for innovation and technology development the industry in the two countries need to overcome.
- Promote stronger industrial links between the two countries.

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.

A separate report has been published for each major area. Each of these reports also contains a matrix that displays technology and solution providers within different services and product segments relevant to the major area.

Furthermore, as part of the environmental protection, monitoring systems and oil spill contingency, an overview of hydrocarbon exploration and production in the Arctic seas of Russia, showing technology trends in environmental and industrial safety, is presented. Note that this poster was originally made by Rosneft (RU-NO Barents Project, 2015).

6.5 Barents 2020

The Barents 2020 project was initially aimed at creating a dialog between relevant Norwegian and Russian stakeholders regarding safety of petroleum related activities in the Barents Sea. The aim was to arrive at common acceptable standards for safeguarding people, environment and asset values in the oil and gas industry in the Barents Sea, including transportation of oil and gas at sea. The project was funded by Russian and international companies with support from the Norwegian Government's Barents 2020 program. The project was conducted in four phases:

- **Phase 1 (October 2007-October 2008)** produced five 'position papers' and established the Norwegian – Russian partnership model for the project (Barents 2020, 2012).
- **Phase 2 (November 2008-March 2009)** prioritised and selected from a range of topics, seven key areas for further work in seven specialist working groups;
    1. Co-ordination of deliverables
    2. Design of floating structures in ice
    3. Risk management of major hazards
    4. Escape, evacuation and rescue of people
    5. Working environment
    6. Ice management – state of the art
    7. Operational discharges to air and water
- **Phase 3 (May 2009-March 2010)** identified 130 standards recommended for common use of which 64 can be applied "as is" and the remaining 66 can be applied provided special considerations are made for low temperatures and/or ice loading. The phase 3 final report was published in 2009 (Barents 2020, 2009).
- **Phase 4 (May 2010-May 2012)** brought forward from phase 3 those issues and topics in greatest need of completion, revision and detailed guidance. The recommendations provided by five of the seven working groups (2, 4, 5, 6 and 7) were submitted to the relevant standardisation body, primarily ISO technical committee (TC) 67's 19906 standard, and to the new TC 67 subcommittee (SC) 08 on Arctic operations. Working group 1 was tasked with recommending and guiding the process to format and channel the deliverables and results to the correct standardisation addresses, while working group 3 risk management, did not recommend any new standards, though was tasked with running seminars. The phase 4 final report was published in 2012 (Barents 2020, 2012).

6.6 Recommended literature

If interested in further literature on the subject for this report, the following text books are recommended:

- Arctic Offshore Engineering (Palmer and Croasdale, 2012)
- Actions from ice on Arctic offshore and coastal structures (Løset et al., 2006)
- Basics of offshore petroleum engineering and development of marine facilities (Gudmestad et al., 1999)

Conference and journal papers, as listed in section 6.2, will also provide insight and give updated information on current research activities.

7 Technological and operational measures to prevent oil pollution

This section describes the technological and operational measures initiated by R&D institutions and the industry identified through this project. These measures are specifically designed to prevent and contain the escape of fluids into the marine environment from offshore petroleum activities in Arctic and cold climate regions. Measures designed to withstand the special conditions in the Arctic and cold climate regions are important for preventing oil pollution. However, it is also important to ensure safe operation and allow for maintenance, both in terms of ensuring that it is possible to maintain the measure in addition to ensuring actual implementation of the maintenance according to plan.

This section assembles the in-depth information gathering, in addition to the information structuring and documentation steps, see Figure 8.

Figure 8 In-depth information gathering and information structuring and documentation

The measures are grouped according to the following themes:

- Metocean 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

Unless otherwise stated, the measures presented under each theme are listed alphabetically. Each measure is described only once, even though it may be relevant for several themes. A complete overview of all measures is provided in Appendix 7.

In addition, standards and guidelines relevant for Arctic offshore petroleum activities are presented in section 8. Furthermore, R&D centres, forums, portals, projects and programs are listed in section 9.

The following sources of information is found relevant for an overview of R&D needs to prevent oil pollution from Arctic offshore petroleum activities:

- **Arctic Development Roadmap:** At the initial stage of the Centre for Arctic Resource Development (CARD) program, an Arctic Development Roadmap was generated from data and information collected from numerous surveys with industry proponents (Taylor et al., 2012). The objective of the roadmap was to identify research and development needs for oil and gas development in Arctic and sub-Arctic regions. Environmental protection and environmental characterisation, together with ice management, ice loads / mechanics, station-keeping in ice, were considered to be the highest priority R&D issues.

- **Oil and gas in the 21 century (OG21),** the office for the Norwegian national petroleum technology strategy, is currently developing an overview of technology challenges for year-round oil and gas production at 74°North in the Norwegian part of the Barents Sea (DNV GL, 2015c).
- **Technology challenges and knowledge status:** The PSA has published a report discussing the technology challenges and knowledge status for reducing the risk for undesirable events resulting in acute pollution to sea with regard to offshore petroleum activities in the Norwegian part of the Barents Sea (PSA, UiS and IRIS, 2010). The report summarizes status as of 2010, and it is evident that several new research and development activities have been initiated since then.

7.1 Metocean and ice conditions

A significant challenge for the oil and gas industry in Arctic and cold climate areas is the metocean and ice conditions, and the challenges they create for the installations and operations. High quality metocean and ice data are vital for safe Arctic offshore petroleum activities. Metocean and ice data are valuable for all aspects of offshore activities, both in terms of:

- Design and design loads
- Operations, including seismic, drilling, installation and workover activities
- Health, safety and environment (HSE), e.g. related to working conditions

When performing operations in the Arctic and cold climate areas, it is important to also take into account that the weather may exacerbate quickly, making short term operations such as installation activities and workover operations a challenge.

Due to a low number of meteorological observation stations in the Arctic, meteorological forecast (available in real time) and hindcast (long data time series) generation has been associated with greater uncertainty than elsewhere. A lot of metocean data are being collected, and it has been claimed that the weather in the Arctic has worsened over the past decades. Orimolade et al. (2015) have looked into the correlation of data for the Barents Sea, and the conclusion was that the design wave conditions in the Barents Sea have not significantly worsened over the past 50 years.

Another issue for Arctic areas is that the polar ice cap is decreasing due to the ice melting. In the directions from the ice cap the fetch lengths increase in the late summer and early fall and this causes larger waves from the northern direction compared to waves previously being built up. The consequences are larger erosion of coastline and rougher weather conditions for structural design and for operations.

The following sources of information are found relevant for metocean and ice conditions:

- **ISO 35104 Arctic metocean, ice and seabed data:** A new ISO standard is under development, ISO 35104 Arctic metocean, ice and seabed data, which at the moment is close to committee draft. This standard has a separate section regarding physical environment data for Arctic operations and will require collection of ice and metocean data for operations and Arctic and cold climate areas. See also section 8.1.1.2.

Several JIPs regarding metocean and ice data are ongoing or have been conducted (grouped by geography):

<u>Arctic Ocean:</u>

- **GROW Fine Arctic (GFA) by Oceanweather:** This is a metocean study of the Arctic Sea where the standard continuous hindcast covers 29 years (1983-2011) of data.

- **International Arctic Buoy Program:** The Polar Science Center at the University of Washington has developed an International Arctic Buoy Program. The participants of the program work together to maintain a network of drifting buoys in the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes including supports to the World Climate Research Programme (WCRP) and the World Weather Watch programme. Data from the program have many used, i.e. research in Arctic climate and climate change, forecasting weather and ice conditions, validation of satellites, forcing, validation and assimilation into numerical climate models, tracing the source and fate of samples taken from the ice.
- **Pan Arctic Metocean Study (PAMOS):** PAMOS is a JIP that will gather data from previous experience with the Arctic, and will be completed in multiple phases including a large storm population hindcast with derivative statistics, continuous hindcast and ice edge sensitivity (IOGP, 2015).

Caspian Sea:

- **Caspian Sea Metocean Study (CASMOS):** The CASMOS JIP was initiated in 2001 with the objective to establish reliable normal and extreme wind, wave, surge and current climate data (IOGP, 2015). A hindcast study has been performed, which included 100 storms over a 52-year period 1948-2000 and covered a 10-year continuous period 1991-2000. CASMOS-2 extends the continuous hindcast to 50 years, adds 25 more storms, and includes new current and hydrodynamic model results, whereas a new phase of the JIP has focused on high-resolution wind modelling to account for katabatic winds.

Greenland

- **Northeast Greenland ice study:** The Bureau of Minerals and Petroleum (BMP) together with 12 oil companies have formed a northeast Greenland ice study group to conduct ice R&D work (Wright et al., 2014). The region northeast of Greenland has a limited open water season, heavy pack ice conditions, icebergs, low temperatures and poor visibility. Good data on the physical environmental conditions in this region are sparse. The objectives are to improve the state of knowledge of ice regimes that then inform ice management, logistics and other operational considerations through collaborator studies. Wright et al. (2014) highlight the northeast Greenland study group approach that has been developed, along with the northeast Greenland ice studies conducted by our group to date. They also highlight some of the results of the northeast Greenland ice study group projects carried out so far.

Kara and Barents Sea:

- **Barents Sea Metocean and Ice data Network (BaSMIN):** No observations exist for the central and eastern Barents Sea. Therefore the BasMIN JIP has recently been initiated with 15 cooperating oil companies. The JIP aims at increase data, competence and quality in weather forecasting / hindcasting for the central and eastern Barents Sea to increase safety related to weather limitations for operations and activities. The BaSMIN project plan in autumn 2015 to deploy:
    - 5 moorings with ice sensors and current profiler deployed during the 2015-2016 winter season with a potential and likely 1-year extension
    - 5 moored surface buoys for a minimum of 3 years
- **Goliat metocean data:** For the Goliat development project in the Norwegian part of the Barents Sea, Eni Norge has collected metocean data with buoys and will, during production, measure a number of metocean parameters from meteorological stations on the Goliat FPSO and with buoys, which will be reported to the MET Norway. Some of the metocean data will be available through MET Norway data series, while part of the data can be requested through the Goliat license.

- **Kara and Barents Sea Ice and Currents (KARBIAC):** To prepare for oil and gas exploration in the Kara and Barents Seas, KARBIAC JIP was initiated (IOGP, 2015). The overall objective was to produce sufficiently accurate information about long-term cycles and trends, in particular with regard to currents and sea ice. The results from an intermediate hindcast project, referred to as KARBIAC Phase 2b, was published in 2011.
- **Mapping of ice occurrence:** The PSA has initiated a pre-study regarding mapping of ice occurrence in the Norwegian part of the Barents Sea. Through this project information will be gathered regarding icebergs, growlers, bergy bits and snowfall that can impact petroleum activities on the Norwegian continental shelf north of 73°. There is limited knowledge of this today. Ice occurrence in this area that is difficult to detect may represent a risk for drilling operations and may give acute pollution to sea in the case of an undesirable event. Obtaining this knowledge is regarded a prerequisite for developing safe petroleum activities in the Norwegian High North. Obtaining this knowledge will be seen in light of research, education and knowledge about the Norwegian High North, in addition to climate changes, environment and natural resources in the area. The pre-study has been initiated in 2015, while the main project is planned initiated in 2016.

Newfoundland & Labrador

- **Metocean and ice characterization for the Newfoundland and Labrador regions:** In Canada, C-CORE has recently completed a study for Nalcor Energy on metocean and ice characterization for the Newfoundland and Labrador regions (King et al., 2015). The metocean study looks into metocean conditions, including winds, waves, currents, fog, vessel icing, pack ice, icebergs and ice islands and the influence of environmental changes on such conditions. The study illustrates what is known about the existing metocean conditions for offshore Newfoundland and Labrador, and how the region ranks compared to other ice-prone regions (the North Sea, Barents Sea, Kara Sea, Caspian Sea, offshore Sakhalin Island, Chukchi Sea, Beaufort Sea and East and West Greenland). To facilitate the use of this vast data set, Nalcor has used the Nalcor Exploration Strategy System (NESS), an interactive map-based system. In addition to the metocean data, NESS also includes other geographic and geophysical data for Newfoundland and Labrador's offshore, including sedimentary basins, offshore boundaries, well data as well as licenses.

Other research activities for gaining information on metocean and ice conditions are:

- **High frequency (HF) radar deployment in Alaska by AOOS:** HF radar deployments in Alaska. From 2011, HF radar stations have been located in the Chukchi Sea, Alaska. Project data is available in near real time through the AOOS data portal, and through the University of Alaska Fairbanks.
- **High frequency (HF) radar deployment in the Barents Sea by MET Norway:** HF radar deployments at the coast of Northern Norway. These will measure radial components of the surface currents. The project will improve the current forecasts and increase the oil spill modelling capability in the Barents Sea. Data (both raw and model) will be made available to the public via the THREDDS server hosted by MET Norway.
- **Norwegian Young sea ICE cruise (N-ICE2015**, http://www.npolar.no/en/projects/n-ice2015.html**):** The main objectives of the project were to understand the effects of the new thin, first year, sea ice regime in the Arctic on energy flux, ice dynamics and the ice associated ecosystem, and local and global climate. As part of the project, the vessel RV Lance was frozen into the ice during the winter 2015. The vessel froze into the ice at approximately 83° North on 15 January 2015. Then, Lance drifted passively in the ice with researchers located onboard, until it was released by the ice in the beginning of May 2015.

Relevant portals for metocean and ice data:

- **Arctic Portal** (http://www.aoos.org/aoos-data-resources/) focuses on the northern Bering, Chukchi and Beaufort Seas. It integrates several hundred layers ranging from habitat type, climatic regimes, tagged animal locations, current weather conditions, political and ecological boundaries, and research instruments. A data layer catalogue enables users to browse data and metadata by category or keyword.
- **Cook Inlet Response Tool** (http://www.aoos.org/aoos-data-resources/) is a data visualization tool that incorporates multiple types of data (real-time sensors, model output, GIS layers, etc.) on a single screen for the Cook Inlet. Unique to this tool is the ability to view video imagery and still photos for the entire coastline, drawing from the ShoreZone project. This allows users to virtually "fly the coast", and integrate that information visually and spatially with other types of data.
- **eKlima:** For the Norwegian Arctic, including Svalbard, Bjørnøya, Hopen and Jan Mayen, MET Norway has developed eKlima (http://met.no/Klimadata+fra+eKlima.9UFRvY1M.ips which is a web portal that gives free access, available to everyone, to weather and climate data from MET Norway. The climate database contains data from all present and past weather stations of MET Norway, as well as data from other institutions (owners) that are allowed to be distributed. This includes data from a number of weather stations in the Norwegian Arctic, including Svalbard, Bjørnøya, Hopen and Jan Mayen.
- **OSI SAF High Latitude Center:** In 1992, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) created Satellite Application Facilities (SAFs) based on co-operation between several institutes and hosted by a National Meteorological Service. One of the objectives of the Ocean and Sea Ice (OSI) SAF is to produce, control and distribute operationally in near real-time OSI SAF products using available satellite data with the necessary users support activities. As part of this, the OSI SAF High Latitude Center website gives information and products from the high latitude part of the EUMETSAT OSI SAF. The High Latitude Center has responsibility for the production and distribution of the OSI SAF Sea Ice products. They also produce the high latitude part of the OSI SAF sea surface temperature and radiative flux products. The webpage is hosted by MET Norway at http://osisaf.met.no/.
- **BarentsWatch** (https://www.barentswatch.no/) is a comprehensive monitoring and information system for large parts of the world's northern seas. By coordinating information and developing new services based on the combination of data, BarentsWatch will disseminate a better factual basis and more comprehensive picture of the activities in, and condition of, our seas and coastal areas. The system will make relevant information and services more easily accessible for authorities, decision-makers and general users. This will simplify access to and ensure the exchange of public information. An open part of BarentsWatch shall be an information portal available to everyone. This was launched in 2012, and is being developed incrementally. The portal has information about topics such as the climate and environment, marine resources, oil and gas, maritime transport and maritime law, among other things. There are also map services, an overview of ports, and news from about 25 partners.
- **ArcticWeb:** In Norway, seven operators on the Norwegian continental shelf initiated a JIP to develop the ArcticWeb (http://www.arcticweb.com/) to simplify access to public data sources in the Arctic region. The information is used by oil and service companies for the purpose of exploration, early field development, environmental risk analysis, emergency preparedness, safety assessments and more. Information is presented to the users via search and map interfaces, for exploration and analysis. Information can also be exported to Excel and Shapefile format for use in corporate data systems. ArcticWeb covers the entire Norwegian continental shelf with data from a wide-range of Norwegian key data owners. These are amongst others Institute of Marine Research, Geological Survey of Norway, MET Norway, Norwegian Directorate of Fisheries, Norwegian Coastal Administration and Norwegian Petroleum Directorate.

- **Shell Ice and Weather Advisory Center (SIWAC):** In Alaska, publically available data sources for weather services are scarce and insufficient for advising field operations. In 2007, Shell established the Shell Ice and Weather Advisory Center (SIWAC) to close the gap by building observational capacity, purchasing satellite SAR imagery and establishing an internal ice and weather forecasting program. The SIWAC forecasters develop numerous daily products including site-specific, wide-area, vessel routing, and weather window forecasts that are delivered to end users through websites and live briefings. To aid in improving forecasting performance and research across the board, Shell entered into a Memorandum of Agreement with the National Oceanic and Atmospheric Administration (NOAA) in 2012. This collaborative agreement makes Shell's Arctic metocean data and ice charts publically available through NOAA and fosters dialog between the SIWAC and NOAA forecasters (Raye, 2015).
- **Nalcor Exploration Strategy System (NESS)** is an interactive map-based system. NESS includes metocean data as well as other geographic and geophysical data for Newfoundland and Labrador's offshore, including sedimentary basins, offshore boundaries, well data as well as licenses.

7.1.1 Weather forecasting

Forecasting of winds, polar lows, currents, etc. is vital to ensure safe offshore petroleum activities in the Arctic. It is essential to know what is on the horizon to anticipate hazards and identify compensating measures. Below follows a description of the forecasting methods identified during this project. Forecasting of ice and icebergs is covered in section 7.2.1.

- **Forecasting methods for polar lows:** MET Norway has developed new forecasting methods for polar lows, including probability for occurrence and wind strength for the Barents Sea (BarentsWatch, 2015). The forecasting method is based on an ensemble prediction system, which is the forecast model is run several times for the same weather situation using slightly different starting conditions to produce a similar number of forecasts conditions. MET Norway is working to develop new models for prediction of polar low trajectories. A reliable prediction would, however, require a higher resolution model of the area of concern.
- **Forecasting polar lows in Barents and Kara Seas:** Nikitin and Chumakov (2015) have conducted a case study of polar lows in Barents and Kara Seas during 2014 on the basis of forecasts produced by the atmospheric model COSMO-Ru. Satellite data and observational data from coastal hydrometeorological stations were used for verification of the forecast. Nikitin and Chumakov show that the model reproduces wind gusts speed rather accurately. Comparing the results with calculations based on the methods recommended by ISO 19901 standard shows some discrepancies due to neglecting unstable air stratification in the latter case.
- **Forecasting weather, emissions and sea and ice conditions in Arctic waters:** The Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA) works with developing knowledge and technology for monitoring of the maritime conditions and forecasting of weather, emissions and sea and ice conditions in Arctic waters. These factors are essential for the petroleum, shipping and fishing industries to be able to conduct safe and sustainable operations in the northern waters.
- **Ocean current modelling:** Simula Research Laboratory / KALKULO conducts a project that looks into the scientific basis and state-of-the-art for ocean current modelling with the intention of contributing to improved ice modelling.
- **Reference information on the state of the physical oceans and regional seas:** The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic reference information on the state of the physical oceans and regional seas. The observations and forecasts produced by the service support all marine applications. The provision of data on currents, winds and sea ice help to improve ship routing services, offshore operations or search and rescue operations, thus contributing to marine safety. CMEMS is part of the European Earth observation

programme, Copernicus (formerly named GMES, for Global Monitoring for Environment and Security).

7.1.2 Technology for metocean data collection

Research and development activities related to metocean data collection:

- **Arctic center for unmanned aircraft (ASUF**, http://www.asuf.no/english) is a national and international focal point in the use of unmanned aircraft for emergency preparedness, environmental monitoring and technology development in the Arctic. The centre also contributes to increased safety in connection with commercial flights and ambulance, rescue and police operations. ASUF develops communication systems, sensors and instruments, algorithmic and analytical tools and navigation and control systems, as well as testing new materials and adapting these for use in cold and extreme climates.
- **Autonomous aerial systems for marine monitoring and data collection:** The centre for Autonomous Marine Operations and Systems (AMOS, https://www.ntnu.edu/amos/) conducts a project on autonomous aerial systems for marine monitoring and data collection. The research focuses on operations with unmanned aerial vehicles (UAVs) that have the capability to handle a number of operational events without operator input, including intelligent command execution with path re-planning, energy management, fault-tolerant control, automatic launch and recovery from ships, operational safety and collision avoidance, management of communication quality of service, and online pursuit of mission objectives based on real-time payload sensor data information processing such as object tracking and obstacle avoidance, as well as optimal trajectory planning for updating estimates of distributed parameter phenomena being observed.
- **Autonomous surface vessel:** The Memorial University of Newfoundland (MUN) – Autonomous Oceans Systems Laboratory (AOSL, http://www.engr.mun.ca/aosl/projects.html) is developing an autonomous surface vessel to provide the AOSL with an unmanned vessel to:
    - Support research on autonomous underwater vehicles (AUVs)
    - Serve as a research and development platform for vehicle control algorithms, autonomous sampling algorithms and multi-vehicle networks
    - Support undergraduate and graduate learning in the fields of system design, dynamics and control.

  A catamaran has been designed and the hulls have been completed in October 2010. The vessel's control and communication software is currently under development.
- **Autonomous underwater vehicle based research:** MUN is conducting interdisciplinary autonomous underwater vehicle (AUV) based research. A part of this is the MUN Explorer AUV which is a 4.5 meters ocean-going AUV with a 3,000 meters depth capability built by International Submarine Engineering Ltd. In the lab and while fully ocean capable it is being operated initially in coastal areas of Newfoundland for environmental monitoring, seabed imaging and vehicle dynamics testing. Work is on-going to develop the payload of the vehicle to include conductivity-temperature-depth, sonar and camera devices giving it more versatility and capabilities.

7.2 Ice management

Ice management involves various technical and operational procedures that can be used to mitigate ice actions on fixed, floating and subsea structures. Such operational ice management procedures include ice detection, tracking, forecasting, ice protection barriers, threat evaluation, icebreaking, ice clearing, iceberg towing and ice alert procedures. Operational reactions include shut-in / shut-down production / operation, disconnection and removal, clearing of snow and ice accumulations, in addition to seasonal operation. **An ice management strategy** may typically include the following stages (PRNL, 2014):

1. Detection

2. Monitoring / threat analysis
3. Towing and icebreaking
4. Station-keeping / disconnection

A lot of work has been executed regarding ice management, both as research projects, joint industry projects and technology development. The following sources of information are found relevant for ice management:

- **Arctic operations handbook JIP (2012-2013)** focused on the operational activities for transport and installation of fixed, floating and subsea units, as well as for dredging, trenching, pipe laying and floating oil and gas production in Arctic and cold weather conditions. The prime purpose of the JIP was to identify gaps in the existing standards and guidelines. Specific recommendations were subsequently proposed with the intention to contribute to the development of internationally accepted standards and guidelines (Wiersema et al., 2014). In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPs. However, only the SALTO JIP was initiated for various reasons. See also section 8.1.
- **Challenges related to ice management in Arctic offshore operations and field developments:** Eik (2010, in his PhD thesis at NTNU, Trondheim, Norway) identified challenges and solutions for ice management in Arctic offshore operations and field developments.
- **Ice management – NPC topical paper # 6-8 (NPC, 2015):** The paper refers to examples of ice management systems that have been developed over time to allow safe operations in ice regimes.
- **Ice management videos by AKAC Inc.:** AKAC Inc. has issued two videos on ice management for educational purposes; http://www.akacinc.com/category/video/
- **ISO 35104 Ice management:** A new ISO standard, ISO 35104 Ice management, is under development which at the moment is close to committee draft. The overall objective of the standard is to ensure that ice management is planned, engineered and implemented within defined and recognized safety / confidence levels, wherever they are performed. See also section 8.1.1.2.
- **PRNL's Ice management program:** The Petroleum Research of Newfoundland and Labrador (PRNL) has initiated a multi-year ice management program aimed at the development of improved ice management capabilities for operations in Arctic and harsh environments (PRNL, 2014). The goal is to develop enhanced ice management technologies and tools for use at various stages of the overall process. The vision, strategy and overall scope of the program was developed with input from industry and a gap analysis conducted by C-CORE in 2010-2011. As part of the Ice Management Program several JIPs have been formed. These are discussed under the relevant topics. Focus areas are:
    - Ice and iceberg detection
    - Enhance iceberg and sea ice drift forecasting
    - Towing of large icebergs
    - Operations in sea ice
    - Station keeping in sea ice
    - Technology integration and training

In the next paragraphs the ice management measures revealed in this project are described.

7.2.1 Ice forecasting, detection and monitoring

Offshore operations in ice environments require detailed knowledge of ice conditions. Reliable forecasts of ice drift behaviour for first year sea ice and extreme ice features such as thick multi-year ice and icebergs are essential in supporting ice management activities and in supporting effective operational decision making.

Drift forecasting involves predicting the future trajectories and sizes of sea ice and/or icebergs using experience, past drift and drift models. Drift forecasts are important to consider for design of new platforms, as well as operations in iceberg and sea ice physical management and for station-keeping. Forecasting of icebergs and sea ice share many similarities, but forecasting of sea ice is more complex due to interactions of stresses between floes, the possibility of ridging and ice growth as well as new ice formation.

Operators need long term forecasts of when sea ice will arrive at a location, the severity of conditions and when conditions will become too severe, requiring demobilisation. Short term forecasts are needed to determine which ice features present the highest risk and should be managed, at what point operations should be shut down, and when should equipment and personnel be moved off site.

Portals and projects for satellite-based detection and monitoring ice and iceberg conditions:

- **IcebergFinder.com:** The website http://icebergfinder.com/ is a website that reports the locations of icebergs along Newfoundland & Labrador's east coast. During the iceberg season, satellite surveillance is used to locate the icebergs, which are then mapped using Google Maps.
- **Ice charting guideline:** This project involves development of guidelines for the use of satellite-based ice information in the oil and gas sector (C-CORE, 2014). The industry has spent significant effort developing standards for operations in the Arctic, however, no industry-wide standard exists for ice charting. The guideline will cover offshore oil and gas industry, from the polar regions to the mid-latitudes, and for current and future developments. The guideline will be limited to sea ice and icebergs, and will not cover other metocean conditions. The project is conducted by C-CORE, Polar Imaging Ltd. and Bear Ice Technology / Shell, and is supported by IOGP and ESA.
    - Phase 1: Requirements and current practices (completed)
        - Description of the oil and gas lifecycle and corresponding ice assessment and monitoring needs
        - Ice assessment, monitoring product / service requirements and current remote sensing practices by region; Beaufort Sea, Chukchi Sea, Sea of Okhotsk, Canada East Coast, Greenland, Barents Sea (Shtokman field), North Caspian Sea, Bohai Sea, Southern Atlantic (Falklands) and Kara Sea
        - Preliminary identification of constraints and opportunities, and corresponding conclusions and recommendations
    - Phase 2: Development of guideline document (in progress)
- **Monitoring Arctic land and sea ice using Russian and European satellites (MAIRES, 2011-2014):** The objective of the MAIRES project (http://maires.nersc.no/) was to develop methodologies for satellite monitoring of Arctic glaciers, sea ice and icebergs. Methodologies to retrieve quantitative information from the European Space Agency (ESA) and Russian Space Agency data will be developed, and examples of satellite derived products for each of the three thematic areas will be presented. The main satellite data will be Synthetic Aperture Radar (SAR), optical and infrared images, radar altimeter data, passive microwave data and geoid data from GOCE (Gravity field and Ocean Circulation Explorer). The MAIRES project is focussed on the Barents and Kara Sea region.
- **Monitoring hazardous sea ice features using satellite imagery:** The Canadian Arctic is a highly dynamic environment that has the oldest and thickest sea ice in the world. The ice includes various features hazardous for shipping and offshore operations. Zakharov et al. (2015) describe a technology addressing the problem satellite based monitoring of hazardous ice features, which include ice ridges, hummocks and rubble fields. Additional attention was paid to identifying glacier ice (ice islands and icebergs). Zakharov et al. (2015) have demonstrated the technology using images collected over the Canadian Arctic in 2013-2014 and verified the ice features by analysing high resolution satellite optical images that overlap spatially and temporally with the synthetic aperture radar (SAR) data. Various satellite images and data fusion techniques were explored by

Zakharov et al. (2015) for identifying ice features and retrieving their characteristics. Ice parameters being studied include height, size and frequency of ice features. The work by Zakharov et al. (2015) addresses the problem of quantitative retrieval of hazardous ice features from a variety of SAR and optical images:
    - Data fusion and SAR polarimetry provide valuable information for detecting glacier ice and hummocks, especially when these features are embedded in pack ice.
    - Detecting small features in low resolution data can be challenging, but medium resolution optical and SAR fusion has been successful at distinguishing first-year and multi-year deformed ice features. Using dual polarized SAR data alone, it is possible to highlight glacier ice, but manual interpretation is required to verify results.
    - Future work for this area will be to assess the utility of SAR and optical fusion products for automatic feature detection.
- **Satellite-based information and data services in the polar regions and the cryosphere by Polar View:** Polar View (http://www.polarview.org/) is a global organization providing satellite-based information and data services in the polar regions and the cryosphere. Their services include enhanced sea ice information (charts and forecasts) as well as ice-edge and iceberg monitoring data. They also provide monitoring services for lake and river ice, snow cover maps and glacier monitoring and assessment.

General detection and monitoring of ice conditions has traditionally been conducted by unmanned aerial vehicles and flight surveillance. A lot of effort is put into research and development of new technology regarding detection and monitoring of ice conditions. The technology development and research activities regarding ice detection and monitoring identified are presented below.

One part of the **PRNL Ice Management Program** (PRNL, 2014) focuses on ice and iceberg detection / discrimination. One of the objectives of the program is to be able to detect ice / icebergs in remote locations, to discriminate between icebergs and other targets, to detect icebergs in high seas and in sea ice, and to provide sea ice characterization (e.g. ice thickness). As part of this program, several research programs are initiated that may improve the effectiveness of ice and iceberg detection. This includes:

- **Advanced satellite radar JIP (2012-2013):** C-CORE led a project to extend the capabilities of satellite radar to distinguish between multi-year ice and other ice variations. The project involves advanced satellite radar-based iceberg detection and sea ice monitoring. Furthermore, the project includes software enhancements and ice island hindcasting.
- **Dual polarized radar JIP (2012):** Rutter Inc. has received funding to build and test an advanced radar system that is capable of providing enhanced ice navigation and detection. The dual polarized radar is expected to help operators distinguish between the much harder multi-year ice and first-year ice. The project involves enhancement of Rutter Inc.'s dual-polarized Sigma 6 marine radar platform for better detection and discrimination of multi-year ice.
- **Ice thickness radar JIP (2013-2015):** JIP led by C-CORE to develop a radar system for characterizing ice thickness for tactical ice management purposes. Field trials of this are being considered.

Another part of the **PRNL Ice Management Program** (PRNL, 2014) focuses on enhanced iceberg and sea ice drift forecasting with the following project:

- **Enhanced iceberg and sea ice drift models and forecasts:** The objective of the JIP is to develop technologies for improving ice and iceberg drift forecasting. The JIP is a part of the PRNL Ice Management Program.

Since the 1990s upward-looking sonar (ULS) has been used to monitor ice thickness in Arctic and cold regions. The following initiatives are mentioned:

- **Advanced acoustic instrumentation for deep sea imaging and sensing project (2013-2015):** PRNL funded research project undertaken by Kraken Sonar Systems Inc. to develop and demonstrate a high resolution acoustic sensor for 3D seabed survey and underside ice profiling with increased area coverage rate compared to currently available technologies. A high coverage rate will minimize the time required to survey a given area, thereby reducing the cost of the survey and the risk for personnel exposed to harsh environmental conditions. High resolutions imagery and topography are useful for seabed exploration, infrastructure survey, characterization of ice thickness and composition and potentially for detection oil spills either on the seabed or at the ice / seawater interface.
- **ASL Environmental Services' ice profiler** (http://www.aslenv.com/ips.html): This is an upward-looking sonar device mounted on the sea floor to accurately measure ice draft. In order to estimate ice forces, production rates and mass balances, accurate measurements of ice thickness are essential.
- **Field data for sea ice and iceberg drift offshore Newfoundland and Labrador:** Three ice drift beacons have recently been deployed offshore Newfoundland and Labrador. Taylor et al. (2015) present a description of the beacons used, deployment activities, as well as results from these beacons are reported, along with initial analysis of the data. These new data provide interesting and sometimes unexpected drift behaviour. Results from these beacons are analysed in light of ocean current and wind data and conclusions regarding the correlations between these environmental conditions and observed drift behaviour are discussed for each case.
- **National Snow and Ice Data Center** (http://nsidc.org/) has gathered a data set that consists of upward looking sonar draft data collected by submarines in the Arctic Ocean. Data is provided as ice draft profiles and statistics derived from the profile data. The statistics include ice draft characteristics, keels, level ice, leads, un-deformed and deformed ice (NSIDC, 2006).
- **Nortek's AWAC Ice profiler** (http://www.nortekusa.com/): Nortek's AWAC (acoustic wave and current) ice profiler is a combined current profiler, wave directional system, and ice profiler. For ice measurements, the AWAC can be used to detect the interface between water and ice as an ice profiler. The surface is a strong acoustic reflector, and this is true also when the water surface is covered with ice. When compared with a reference measurements the AWAC can be used to estimate the surface ice thickness. This method was used during the winter 2008/2009 in the Arctic with very good results (Magnell et al., 2010).

Technology for ice and iceberg detection:

- **C-CORE's altimeter ice detection (AID):** C-CORE has been working with its LOOKNorth R&D team to develop the Altimeter Ice Detection (AID) tool (https://www.c-core.ca/AID). AID uses freely available satellite altimeter data. The AID offers the ability to surveil large areas quickly, identifying target areas that can be further investigated using Synthetic Aperture Radar (SAR). Work is ongoing to improve ship / iceberg discrimination in AID and to compare AID detections against C-CORE's extensive in-house historical SAR datasets. The aim is to reliably extrapolate iceberg population within an area of interest from an AID point detection.
- **C-CORE's ship and iceberg detection tool:** C-CORE has developed a semi-automated satellite surveillance tool that will increase the capability for ship and iceberg detection with up to 95% accuracy. Performance analysis of available sensors and a framework for integrating all available data will provide an up-to-date and accurate wide-area picture (https://www.c-core.ca/IceManagement).

Technology and R&D activities for navigation and operation:

- **Canatec's ice advisor program** (http://www.canatec.ca/): Canatec has developed a software and hardware for measuring, communicating and forecasting ice movement. The software package contains all public available imagery for the total Arctic.
- **Rutter Inc.'s Ice Navigator:** The Sigma S6 Ice Navigator (http://www.rutter.ca/ice-navigator) is an ice navigation solution for ice defence, ice breaking and port access. It is an ice detection and navigation system that enables ships operating in ice to differentiate between open water, ice pans, leads in ice fields, and thicker ice ridges that impact operations in ice zones. The Ice Navigator is developed to detect both large icebergs as well as bergy bits and growlers that can significantly damage a vessel or platform. The situational awareness provided by the Ice Navigator occur across a wide range of sea states, weather, and daylight conditions, providing tactical information essential for real time route planning and decision making.
- **PractICE JIP:** In the follow-up from the Arctic operations handbook, the PractICE JIP together with several other JIPs were suggested. However, the PractICE JIP has not been initiated. The aim of the PractICE JIP would be to provide a real-time simulation platform enabling practical simulations of offshore operations in ice. It would build on previous conceptual studies, initial model work and would comply with training objectives and requirements set by the industry.
- **Safe Arctic logistics, transport and operations (SALTO, 2014-2017):** The SALTO JIP will provide a PC simulation tool for risk-based, probabilistic design to help the industry prepare for the environmental conditions (wind, fog, ice, icing) of the Arctic and, henceforth, to optimise operations of ships and offshore constructions. Pre-knowledge of workability, risk and limiting conditions will lead to enhanced safety and reduced environmental impact. This JIP was initiated following the Arctic operations handbook JIP http://www.marin.nl/web/JIPs-Networks/Public/SALTO.htm
- **Viking Ice Consultancy's common operational picture display** (http://www.viking-ice.com/whatwedo): The system includes real time tracking of ice objects and vessels, communication and reporting and display of all relevant metocean and ice data. This system will provide for a better basis for decision making. The system was first time used in the Kara Sea in 2014.

7.2.2 Station-keeping in ice

To extend the operating season of drill ships and floating platforms, systems must be in place to enable the vessels to maintain station in the presence of ice. There are two station keeping systems that have been used successfully in ice conditions: mooring systems and dynamic positioning (DP) systems (PRNL, 2014).

Mooring systems are station keeping systems that use mooring lines and anchors to hold an installation at the desired location. The mooring system arrangement is dependent on the anticipated loading and hence is individually selected for each project. In general, redundancy is built into the mooring system design to prevent disconnection in the event of a mooring line failure (PRNL, 2014).

Automated dynamic positioning (DP) generally relies on the use of a combination of sensors, computer programs, propellers and thrusters to hold an offshore structure on location. The information gathered by the sensors is sent to the computer program which calculates the required thrust magnitude and direction required to maintain position. The calculations conducted by the DP program are fed to the propulsion system (propellers and thrusters) to direct thrust output. DP operations can also be performed manually but are generally limited to short durations (PRNL, 2014).

Experience from station-keeping in ice, listed chronologically:

- **ACEX, the Arctic Coring Expedition (2004),** was a venture by the International Ocean Development Program (IODP) to extract core samples from the Lomonosov Ridge, at a point only 250 km from the North Pole. The offshore operations took place in the late summer of 2004. ACEX was a logistical challenge because the drillship had to hold its position while surrounded by the moving sea ice of the Arctic Ocean. This required two icebreakers, the Oden (Swedish) and Sovetskiy Soyuz (Russian) to crush large ice floes into small pieces which allowed a third icebreaker, the Vidar Viking (Swedish), specially converted for the task, to maintain position and undertake the coring. This operation demonstrated that station-keeping in thick moving ice could be successfully performed provided that it was possible to go off location during the highest ice load situations.
- **DP operations in ice offshore Sakhalin:** Keinonen et al. (2000) describes the DP operations in ice offshore Sakhalin that took place in 1999 when the CSO Constructor installed the subsea infrastructure and pipeline from the Molikpaq facility to the offshore loading buoy system (SALM) position. The operation lasted six weeks in the presence of widely varying ice conditions, including, in several occasions ten tenths of ice cover and ice pressure. The operation was supported by two icebreakers, Smit Sakhalin and Magadan. Furthermore, the ice operation was managed by an ice management team, which for this operation developed specific ice management techniques based on offshore ice operational experience in the Canadian Beaufort Sea. This DP operation was the first of its kind in the world to take place in the presence of a significant amount of moving ice. Imminent presence of severe ice at the CSO Constructor, required stopping of DP operations and allowing the vessel to drift with the ice. This occurred on several occasions in May 1999, leading to a need to drift with the ice. The total ice induced downtime over the whole operation was approximately 22%. The operation was considered successful as it was performed safely, on schedule (Keinonen et al., 2000).

  The above information has been confirmed by Reed (2014), summarising experience from Sakhalin operations.

Station-keeping systems must take into consideration local ice conditions, water depth and ice management support. Many Arctic regions consist of shallow water depths, which necessitate small vessel offsets, favouring designs that use moorings to maintain location. For developments in deeper water, larger offsets are permissible and dynamic positioning (DP) solutions may be a viable alternative (CARD, 2015). The following research initiatives have been identified:

- **Centre for Arctic Resource Development (CARD**, https://www.card-arctic.ca/**)** conducts a research program on station-keeping in ice. Detailed understanding of ice conditions, ice mechanics and loading, ice management and the response of floating systems are necessary inputs in the development of station-keeping solutions for ice environments. Key research topics identified for CARD's station-keeping program includes:
  - Scale-model testing of ice induced loads on mooring systems and DP floating systems
  - Modelling of loads on moored floating platforms
  - Modelling of loads on DP platforms
  - Concept evaluation and downtime reduction tools
- **Challenges related to station-keeping in ice:** Bonnemaire et al. (2007) describe challenges related to station-keeping in ice. The paper describes structural considerations and presents examples from research projects involving NTNU, Statoil and Barlindhaug Consult. Bonnemaire et al. propose implementing a disconnection possibility of the moored structure in combination with an efficient ice management system to make it possible to design cost-effective solutions with high regularity and uptime for drilling, production and offloading in severe ice conditions.

- **National Research Council of Canada (NRC, http://www.nrc-cnrc.gc.ca/eng/)** has for many years focused on improving station keeping capabilities for both moored and DP Arctic vessels. Amongst others, the following research activity is mentioned:
    - **Station keeping of drillships under changing direction of ice movement:** The ability of a drillship to maintain its heading to face oncoming pack ice is crucial under situations involving pack ice drift direction changes. Sayed et al. (2015) have examined the performance of a vessel employing a Thruster-Assisted Mooring (TAM) system under such conditions. Numerical simulations were used to determine the stresses and deformations within the moving pack ice cover, as well as the response of the drillship. The results provide insights in the manner in which drillships can correct their heading given pack ice drift direction changes.
- **Russian research on station-keeping in ice:** Onishchenko et al. (2015) have performed analytical estimations of the manoeuvrability of a moored floating production unit (FPU) with an internal turret in close ice. The process of the FPU rotating has been analysed within relatively simple engineering models based on consideration of mass, momentum and energy balances. An assessment has been performed of the mechanical work that is required for ice breaking and further ice piling up near the moving FPU hull. Conservative estimates demonstrate that the active turn of an FPU by 90° at reasonable angular velocity in medium first-year level ice would require the total power being well above values now available. Another model considers an FPU turning on the spot in broken compact ice. Comparison of the two cases demonstrates that the overall design of the FPU mooring system can be inadequate when the design ice loads are addressed only for the case of FPU heading against ice drift direction.
- **Statoil and HSVA** have recently reported from tests of dynamic positioning in ice (Metrikin et al., 2015). The work is continuing.

In the Arctic, station keeping is challenging because of the extreme unpredictability and rapid variations of the ice load forces affecting ships and platforms. A lot of research has been executed that deals with station keeping in Arctic and cold climate areas. Some JIPs which deal with station keeping in ice are described below.

One part of the **PRNL Ice Management Program** (PRNL, 2014) focuses on station keeping in sea ice. The objectives of this part of the program is to advance the understanding of the magnitude and nature of pack ice loads on vessels, including mooring and/or station-keeping forces, to determine response actions necessary for station keeping and to develop technologies for station keeping. PRNL has two JIPs underway to advance the industry's knowledge of global ice loads on both moored and DP floating vessels (and vessel responses) in ice:

- **Enhanced DP operations in ice environments (initiated 2014):** The objective is to enhance DP control algorithms to respond to ice loads. The scope includes an extensive series of model tests in ice in support of algorithm development, and deployment of the software into a simulation environment to assist in training, operational assessment, risk analyses and equipment design. This is a multi-year project executed by Centre for Marine Simulation (Fisheries and Marine Institute of MUN), NRC and Kongsberg Maritime.
- **Ice loads on floating structures (initiated 2013):** Phase 1 "State-of-the-art review, gap analysis and recommendations" was completed by a consortium led by ABS' Harsh Environment Technology Centre (HETC) in 2014. Phase 2 plans are being reviewed. Potential work includes full scale field data collection of ice loads on, and responses of, moored floating structures in managed and unmanaged pack ice conditions, and related assessment of numerical and physical model tests and load predictions. Kwan et al. (2014) describe phase 1 of the JIP.

Other research activities related to station keeping in ice are listed below.

- **AKAC Inc. DP operations in ice:** AKAC Inc. is conducting research related to DP operations in ice (http://www.akacinc.com/project_type/sred/). Their R&D is directly linked to their experience and held key positions in two full scale operations in ice: the ACEX and the CSO Constructor. Their focus is on development of model testing procedures for DP vessels, the design of vessels specifically adapted for DP operations, and operational procedures that permit optimal, safe use of these new capabilities.
- **Arctic mooring systems JIP (2013-2016):** Development of design standards and operation practices for Arctic and other cold regions mooring systems. The aim is to create a guidance document which can be used as a foundation document for industry standards or company specific design and operations guidelines worldwide (Kwan et al., 2014).
- **Dynamic positioning in ice (DYPIC, 2010-2012):** Development of a tool box which allows the prediction of station keeping capability of different vessel types and offshore structures under various ice conditions. Kerkeni et al. (2014) summarize the work performed within the project and spotlights the technical and scientific findings emerged from it. Special attention is paid to two facets of the project: the design of experimental devices, systems and set-ups for ice tank testing including the development of a DP system for model basin facility, and the development of an ice basin numerical simulator. Finally, Kerkeni et al. (2014) discuss the opened perspectives with a special focus on the operational matters.

7.2.3 Physical ice management

Issues related to performance of physical ice management operations are far reaching, of high importance and scope. For the purpose of this report, physical ice management has been grouped into towing of icebergs and icebreaking.

Towing of icebergs

Towing of icebergs is a known method for physical ice management in the open waters on the Grand Banks, offshore Newfoundland. See Figure 9 for an illustration.

Figure 9 Towing of iceberg (Courtesy of C-CORE)

One part of the **PRNL Ice Management Program** (PRNL, 2014) focuses on towing icebergs in sea ice. The objectives for towing icebergs in sea ice are to develop and test methods for towing icebergs in pack ice and to develop training material and/or simulation tools for towing large icebergs.

- **Towing iceberg in sea ice JIP (initiated 2013):** A JIP to investigate the practical and technical feasibility for towing icebergs in various levels and types of sea ice coverage was initiated in 2013. Initial work was being executed by Canatec and other partners. The scope for this project consists of defining performance scenarios to assess the practical and technical feasibility of towing icebergs and other objects such as work barges in various levels and types of sea ice coverage. The scenarios will consider both first year and multi-year ice coverage from 1/10 to 10/10 with and without icebreaker support. A major objective is to identify the marine spread - the number and types of vessels required, as well as the costs associated with such an operation and estimate tow loads for selected scenarios. Follow-on work may include field work to collect data for validation of towing feasibility.

Other technology development and research activities regarding towing of icebergs:

- **C-CORE's / Fugro's / Pro-Dive's iceberg profiling project (2012):** C-CORE was responsible for software development, data collection and production of the above-water portion (sail) of the iceberg profile. The iceberg sail model was developed using photogrammetric software through which iceberg photographs taken by a common-trigger three-network camera system were used to render 3D point cloud in Universal Transverse Mercator (UTM) coordinates and Coordinated Universal Time (UTC). The model data quality produced from this expedition is believed to rival any iceberg profile data set collected to date (https://www.c-core.ca/IcebergProfiling).

- **C-CORE's iceberg towing net:** C-CORE has developed an iceberg towing net to reduce risk of iceberg roll during towing operations (https://www.c-core.ca/ice).
- **C-CORE's towing decision support tool** is a computer package to aid towing decisions (https://www.c-core.ca/IceManagement).
- **Stability and drift of icebergs under tow:** C-CORE received funding from Petroleum Research Atlantic Canada (PRAC) to research the relationship between iceberg stability and towing parameters such as tow force, point of application, acceleration and tow speed. The project also focused on whether tow strategy can be optimized using a model that integrates the forces from the sail and the keel of the iceberg. The end result is a set of practical guidelines to improve the effectiveness of iceberg towing operations, which may pave the way for the use of physically-based models in iceberg management (C-CORE, 2005).

Icebreaking

An icebreaker is any vessel whose operational profile may include escort or ice management functions, whose powering and dimensions allow it to undertake aggressive operations in ice-covered waters (OCIMF, 2014). The following initiatives have been identified:

- **Ice management with icebreakers:** The operational experience with stationary vessels in moving ice, and the use of ice management with icebreakers to enhance the operability in ice, is described by Keinonen et al. (2007).
- **Icebreaker technology using azimuth** radically changed the ice management operations during the last year of oil production in Sakhalin Energy Investment Company offshore project (Keinonen et al., 2007).
- **AKAC's azimuth icebreaker technology:** AKAC directly applies azimuth icebreaker technology in both ice trials and ice management operations. Based on this AKAC is developing numerical tools and icebreaker designs that will maximize the efficiency of azimuth technology.
- **AKAC's physical ice management services:** AKAC Inc. is conducting project and R&D activities related to physical ice management.
- **Aker Arctic's double acting tanker (DAT):** Aker Arctic has developed a double acting tanker (DAT) for transport in ice covered seas (Juurmaa et al., 2002). The vessel is designed to follow the double acting principal and the hull form is designed accordingly. The vessel is fitted with bulbous bow, designed to be capable of operating in light ice conditions, whereas the stern shape is of icebreaking type, in order to operate independently in severe ice conditions. This design allows for the vessel to run efficiently in both ice conditions and open water.
- **Arctic drillship in ice with and without ice management:** Keinonen et al. (2007) evaluate an Arctic drillship developed by Statoil in terms of its achievable operability in moving ice, specifically when ice management by icebreakers is used to support it.

7.2.4 Disconnection

Disconnection involves the planned separation of the risers (and mooring, if applicable) from a floating structure (ISO 19906:2010). Moored vessels operating in ice will need to be able to disconnect under high ice loads. Disconnecting / re-connecting may be a regular activity and the turret systems will need to be robustly designed to allow for reliable, routine operational use under heavy ice loads, not only for use in an emergency disconnect (Taylor et al., 2012).

The following sources of information are found relevant for disconnection:

- **Arctic operations handbook** recommends guidelines for the reliability of the disconnection operations to ensure the integrity of the station-keeping and offloading capability after later re-connection (Wiersema et al., 2014).

- **Challenges of deep-water Arctic development:** Hamilton (2011) reviews the key technical challenges facing deep-water high-Arctic development along with the current industry efforts aimed at meeting the challenges. Furthermore, Hamilton (2011) describes the necessity of disconnection and reconnection capability because some multi-year ice features cannot be managed by the largest conceivable icebreaker.
- **Design considerations for disconnection** and subsequently reconnection, in addition to corresponding requirements, are described in ISO 19906:2010 and API RP 2N:2015.

Operating experiences with disconnection:

- **Navion Munin FPSO at the Lufeng field in the South China Sea:** In this area, typhoons are frequent and the area is affected by solitons (subsurface waves generated by tidal variations). The FPSO has been designed to disconnect and temporarily abandon the Lufeng field when typhoons approach the field (Tangvald et al., 2009). Wellstream fluid arrives on the FPSO via two flexible production risers. Station-keeping of Navion Munin is provided by a submerged turret production (STP) concept. The FPSO is moored with a conventional catenary mooring system consisting of six symmetrically spread mooring lines all connected together in the upper end to the disconnectable STP buoy. The mooring lines are designed for two operational modes: 1) Disconnected – with the STP buoy submerged to a depth of approximately 45 meters below the water surface and 2) Connected – with the STP buoy and turret connected to the ship 52 meters from the bow. The extreme condition for FPSO disconnection from the STP buoy is the 25 year return wave which has a significant wave height (Hs) of 7.0 meters. When the FPSO is disconnected, the remaining STP buoy and mooring lines are designed to withstand conditions of 100 year return typhoon, which has a significant wave height (Hs) of 13.7 meters. Preparation for disconnection is initiated when forecasted conditions exceed 7 meter significant wave height. During the two first years of operation, Navion Munin has disconnected 4 times due to extreme weather conditions. The average production downtime associated with temporary field abandonment has been 96 hours. From offloading is stopped, the Navion Munin can disconnect within approximately 17 hours. However, it is noted that the operating disconnection and subsequently reconnection experience with Navion Munin is limited to two risers.

R&D initiatives include:

- **Arctic mooring systems - disconnect and reconnect devices:** Kwan et al. (2014) describe disconnect and reconnect devices for Arctic petroleum activities in terms of ice management (move-off capability), internal disconnectable turret mooring, interocean rig anchor release, subsea ballgrab and a new device specifically designed for Arctic operations called QDR (Quick Disconnect Reconnect).
- **Disconnection requirements for a moored floater in hard ice conditions:** Gudmestad et al. (2009) discuss the design requirements for the mooring of floating offshore production systems for Arctic conditions with drift ice. Scenarios for determining relevant design action effects are discussed and the paper emphasises the inclusion of dynamic effects. Then, the effect of methods to mitigate the actions through ice management (vessel vaning and use of propellers to open up leads) is evaluated. Furthermore, the need for disconnecting the floater in extreme conditions is reviewed. The operational procedures and potential downtime in case of disconnection are finally discussed.
- **Disconnectable mooring systems for Arctic conditions:** SBM Offshore is developing a new disconnection and reconnection system for a ship-shaped floating production unit (FPU) in Arctic conditions (Bauduin et al., 2015). Bauduin et al. (2015) review the requirements to and challenges of disconnection and reconnection systems. Furthermore, the development of SBM Offshore's new disconnection and reconnection system is presented.

7.3 Drilling technology, well integrity and well control

The following sources of information are found relevant for drilling technology, well integrity and well control:

- **API RP 96 Deepwater well design and construction** provides engineers a reference for deep-water well design as well as drilling and completion operations. This recommended practice can also be useful to support internal reviews, internal approvals, contractor engagements, and regulatory approvals.
- **API Specification 4F:2013 Specification for drilling and well servicing structures:** This specification states requirements and gives recommendations for suitable steel structures for drilling and well servicing operations in the petroleum industry, provides a uniform method of rating the structures, and provides two Product Specification Levels. This specification that addresses the fabrication of such structures used in cold climate.
- **Arctic well integrity and spill prevention methods and technology – NPC topical paper # 8-10 (NPC, 2015):** The paper describes the state-of-the-art for well integrity and spill prevention. It refers to general methods of prevention of hydrocarbon spill and prudent well designs, not methods specifically developed for the Arctic. However, it describes the experiences with Arctic wells from the Norman wells in Canadian Northwest Territories in 1920 until wells today.
- **Drilling and well challenges in the Arctic:** Torsæter and Vrålstad (2014) discuss the subsurface challenges related to drilling, well construction and petroleum production in the High North and the importance of these challenges being thoroughly explored in order to ensure safe and cost-efficient Arctic wells.
- **Initiatives and efforts under the auspices of IOGP:** Winkler et al. (2015) describes advancement initiatives and efforts under the auspices of IOGP regarding prevention and mitigation of a loss of well control incident and places them into the Arctic context. These initiatives include development of new technology, equipment, guidelines, standards as well as knowledge sharing. The initiatives are aimed at both improving incident prevention and the robustness of response measures.
- **Joint industry task forces in response to the Gulf of Mexico Macondo incident:** In response to the Gulf of Mexico Macondo incident, the offshore oil and gas industry assembled four Joint Industry Task Forces (JITFs) on 1) Offshore Operating Procedures, 2) Offshore Equipment, 3) Subsea Well Control and Containment and 4) Oil Spill Preparedness and Response. The JITFs were not involved in the review of the Macondo incident; rather, they brought together industry experts to identify best practices in offshore drilling operations and oil spill response; with the definitive aim of enhancing safety and environmental protection. The ultimate goal for these JITFs is to improve well containment and intervention capability, spill response capability, and Industry drilling standards to form comprehensive safe drilling operations. A common executive summary report for all four JITFs was delivered in March 2012. The recommendations from the JITFs may also be applicable for operations in the Arctic.
- **NORSOK D-010 Well integrity in drilling and well operations standard (2013)** defines the minimum functional and performance oriented requirements and guidelines for well design, planning and execution of safe well operations. The focus of the standard is well integrity.

7.3.1 Drilling technology and well integrity

SINTEF is a broadly based, multidisciplinary research institute with international expertise in technology, medicine and the social sciences. SINTEF conducts contract R&D as a partner for the private and public sectors, and is among the four largest contract research institutions in Europe (http://www.sintef.no/en). SINTEF conducts research and studies on the following Arctic topics:

- **Arctic plugging and abandonment:** SINTEF has research targeting permanent well plugging and abandonment, which aims to ensure that the wells can be safely sealed after production has ended.
- **Arctic well integrity:** Study of leakages occurring as a result of downhole temperature variations in Arctic wells (injection of cold fluids or production of hot fluids through a cold well).
- **Automated drilling:** In the Arctic it might be necessary to automize drilling, especially in harsh and varying weather conditions with relatively short time windows. SINTEF has an ongoing knowledge-building project for the industry with Huisman where they do research on automated drilling to ensure consistency and improve efficiency of drilling operations.
- **Decision support during drilling:** SINTEF studies monitoring and decision support based on advanced mathematical models to ensure consistency and reduce the number of unwanted events. The work is developed with eDrillingSolutions, ConocoPhillips Norway and China National Offshore Oil Corporation.
- **Degassing of fluids:** Measurements of the dynamics / kinetics of gas loading is ongoing, and may easily be extended to degassing. This issue is especially important when the mud is at low temperature with high liquid viscosity.
- **Drilling through gas hydrate bearing sediments:** Study of how to ensure borehole stability when drilling through gas hydrate bearing sediments.
- **Mechanical testing of Arctic core samples:** Arctic rocks / sediments have been exposed to different pressure and temperature histories compared to more southern ones. SINTEF has mechanically tested various Arctic shales from Havis and Bay du Nord. Knowing the behaviour of Arctic rocks is important to ensure efficient and safe drilling.
- **Mud-weight control during Arctic drilling operations:** In the Arctic, permafrost and gas hydrate bearing sediments below the seabed present a technical problem for drilling operations. If pressurised gas is encountered in or below such formations, the most important challenge is to be able to control the well. If these sediments begin thawing during drilling, the second problem is stability of the borehole. Both these issues are strongly dependent on the choice of mud and mud weight. SINTEF Petroleum Research has looked into this area, and has developed a methodology that can aid mud and mud-weight choices during Arctic drilling. The method involves using a numerical borehole stability code, which calculates the safe mud-weight window (Torsæter et al., 2015).
- **Testing of drilling fluids:** SINTEF takes detailed measurements of fluid properties over a large range of temperatures, from very low to high. Functionality of fluids and materials are required down to lower than -20 degree Celsius. In the DrillWell project they typically characterize rheology, density and stability of drilling fluids.
- **Training simulator for Arctic drilling:** SINTEF has developed an advanced training simulator for drilling with very realistic responses to normal drilling and unwanted events with the actual upcoming well as a case. This gives the drilling team good preparation for handling possible challenges. The simulator can be extended also to include typical Arctic drilling problems (short time windows / seasons - faster drilling operations necessary, drilling through gas hydrate bearing sediments, large temperature variations between bottom and top of well, sensitive environment).
- **Well materials for the Arctic:** SINTEF is studying several types of annular sealants for wells, and several types of plugging materials. These have the potential to ensure more robust wells, which will be a requirement in the sensitive Arctic.
- **Wellbore positioning:** Research on how to avoid collisions as a result of poor wellbore positioning accuracy (azimuth) in the Arctic.

Additional measures relevant for Arctic drilling operations are:

- **Cement formulations for permafrost:** Special cement formulations may be necessary for drilling operations in areas with permafrost (Winkler et al., 2015).
- **Drill cutting and waste injection assurance in the Barents Sea:** Pour et al. (2015) discusses the various factors that need to be considered for a reliable drill cutting and waste injection operation, including the surface and subsurface risks.
- **Global and local geomagnetic reference model for improving wellbore surveying accuracy:** A four year JIP where the aim is to improve drilling accuracy by modelling all sources of the geomagnetic field that affect the wellbore surveying (ConocoPhillips and Lundin, 2013). Aeromagnetic surveys will be integrated with data from ground observatories and satellites, including observation of auroras.
- **Mudline cellar / glory hole / well cellar /:** A glory hole is an excavation into the seafloor that may house the wellhead equipment and the BOP. The purpose of the glory hole is to protect the equipment against exposure to deep keeled ice features (Winkler et al., 2015).

Based on the feedback from the baseline survey, the following technology is mentioned regarding drilling equipment to enhance safety of drilling operations in Arctic marine environment:

- **Chevron** has through the baseline questionnaire described their continuous improvement in well integrity through proprietary technology research and development. Participation in specific well secure initiatives, through JIPs, either specifically with Arctic application or with transferability of findings to Arctic operations.
- **DrillWell**, The Drilling and Well Centre for Improved Recovery, is a Norwegian research cooperation with the vision to unlock petroleum resources through better drilling and well technology. They perform targeted research and development, focusing on safe and efficient drilling process, drilling solutions for improved recovery and well solutions for improved recovery. Some research and development activities are Arctic specific.
- **National Oilwell Varco** has developed and quoted several concepts / layouts for drilling packages and cranes suitable for Arctic operations. National Oilwell Varco applies a contained system approach, thus, minimising the consequences of a leak, in addition to using electrical drive systems over electro-electrical systems which reduce the probability of leaks.
- **Weak link bail systems:** For semi-submersible drilling rigs weak link bail systems function as a riser safeguard and weak link system during e.g. completion, well testing, well intervention and workover riser operations.
    - **Weak Link Bails by Scan Tech** is a device that prevents damage to the well barriers in case of accidental loads in the riser system. At the set load the Weak Link Bail will shear, allowing the stroke of the Weak Link Bail to increase, offering overload protection to all components in the riser, wellhead and derrick. The equipment serves as its weakest link, and is controlled fracture when conditions warrant before fixed gear gives way.
    - **WellSafe Explorer by Well Partner** is a bail system currently under development. The system is developed for semisubmersible drilling rigs and shall function as a riser safeguard and weak link system during subsea well testing, subsea completions, well clean-up and riser based intervention operations. The system will be a significant contribution to safety in "locked to bottom" type operations from floating rigs.

7.3.2 Well control

Relief well

A relief well is a contingency measure used to respond to an out-of-control well. A relief well is a directional well drilled to communicate with a nearby uncontrolled (blowout) wellbore and control or stop the flow of reservoir fluids (NPC, 2015). If it is assumed that the original rig is disabled, a second rig would need to be mobilised and brought into proximity of the flowing well. The second rig will need to be equipped with casing, cement, drilling fluids and wellhead equipment to construct the relief well. The distance between the blowout well and the relief well typically ranges between 500 feet and 3,500 feet.

The following measures related to relief well drilling have been identified:

- **Same Season Relief Well (SSRW) Policy:** In the Canadian Arctic offshore, the National Energy Board (NEB) has a policy that says the applicant must demonstrate, in its contingency plan, the capability to drill a relief well to kill an out-of-control well during the same drilling season (NEB, 2014). This is the Same Season Relief Well (SSRW) Policy. An applicant wishing to depart from the SSRW Policy would have to demonstrate how they would meet or exceed the intended outcome of the Policy. Assuming that the relief well is drilled by a second rig, this means that the relief well must be completed, and both wells secured, in the same operating season before ice conditions exceed the safe operating capability of the selected drilling system, marine support and emergency response equipment (Scott and Denstedt, 2015).
- **Trendsetter Engineering's service line for source control:** The solution is a comprehensive package ranging from strategic to tactical response services. This strategic response group provides services such as source control training, emergency response and logistics planning, as well as subject matter experts for drill, exercise and actual response support. The tactical response group provides the "boots on the ground" team to conduct field engineering, equipment build, test, installation and operation, as well as ancillary engineering work on location, such as sea fastening planning and operational procedure modifications.
- **Trendsetter Engineering's well kill manifold concept** can be used for wells when determined adequate kill rates cannot be achieved from a single vessel. The well kill manifold allows for sufficient pump rates to be achieved through a single relief well by manifolding multiple kill vessels into the well near the wellhead and providing a flow path through the annulus. Well kill can be achieved by injecting through the well kill manifold, down the relief well, through the formation into the flowing well at a high flow rate that forms a homogeneous slug with enough fluid head to stop flow.

Additional well control devices and techniques are now available that are independent of the controls on the drilling rig. Examples of these devices are capping stacks that can be quickly deployed after an incident and subsea shut-in devices that are installed on the well during the drilling process (NPC, 2015). Scott and Denstedt (2015) discuss the regulatory flexibility required to utilise the potential value offered by the adoption of emerging technologies. Three cases are discussed; 1) using a relief well (current situation), 2) using well capping and relief well, and 3) using well capping only.

Shut-in devices

Subsea shut-in devices are pre-installed on the high-pressure wellhead housing below the rig's BOP stack. The advantage of this 'drill-through' arrangement is that the pre-installed shut-in device reduces the response time to seal the wellbore. This quick response characteristic could be advantageous in remote locations to ensure the well is secure if the rig needs to leave or is forced off location without the proper time available to secure the wellbore by more traditional methods. The operators have proposed a subsea shut-in device as an equivalent alternative to a single season relief well for the Arctic region (NPC, 2015).

Examples of Arctic subsea shut-in devices are:

- **Cameron's single BOP Environmental Safe Guard System (ESG):** The system implies a single BOP on the wellhead that can shear and seal the well if required, allowing the rig to disconnect and move away.

- **Chevron's Alternative Well Kill System (AWKS):** Chevron, in a technology agreement with Cameron, is developing an enhanced BOP system, ref. Figure 11, involving:
    - Shear and seal simultaneously in a single step using a single ram
    - Cut and seal on the range of grade and weight of drilling and production tubular bodies (including casing) planned for well program
    - The AWKS safety package for existing drill systems includes a twin AWKS system with completely independent back-up system.
- **ConocoPhillips' Auxiliary Safety Isolation Device (ASID):** The ASID is designed to have a minimum of two blind shear rams that could be controlled from either the drilling unit or remotely from a location off the drilling unit. If loss of well control occurs, the ASID can be activated immediately and is intended to regain well control in minutes. The ASID can be deployed with all types of drilling units. Although it is considered a type of BOP, it does not replace the drilling unit's BOPs.
- **Trendsetter Engineering's Mudline Closure Device (MCD):** The MCD is a type of capping stack that provides direct capping and containment capability in a drill through package. It is installed between the BOP and subsea wellhead and can be used to shear and isolate the well should a loss of well control occur. The MCD provides a clean re-entry capability and is capable of monitoring, logging and transmitting pressure and temperature readings up to 9 months should the rig need to abandon the well due to an unforeseen event. Ref. Figure 10.
- **Trendsetter Engineering's Secondary BOP controls and intervention:** Trendsetter Engineering has developed independent back-up controls / subsea accumulator modules (SAMs) with acoustic and ROV control for mudline cellar applications.

Figure 10 Trendsetter Arctic Class 18 ¾" 15,000 psi drill through Mudline Closure System (Courtesy of Trendsetter Engineering)

Figure 11 Chevron's dual ram Alternative Well Kill System, AWKS (Courtesy of Chevron)

Capping

As a result of the Macondo blowout and oil spill incident in 2010 and the cessation of subsea drilling, capping stack technology was developed. While a BOP is a safety device meant to prevent a blowout from occurring, that is always present when drilling, a capping stack is the centrepiece of a containment system kept in readiness at an onshore or near offshore location (Madrid and Matson, 2014). It is only deployed after the BOP has failed to serve its purpose and a blowout has occurred. The 'capping stack' is a piece of equipment that is placed over the blown-out well as a 'cap'. Its purpose is to stop or redirect flow of hydrocarbons before the well is permanently sealed. Once fully operational, the capping stack provides a dual barrier for containment, a BOP ram plus a containment cap. The basic operational need of the stack is to attach and seal on a subsea well during an active blowout, then shut in safely.

The following initiatives have been identified:

- **API RP 17W:2014 Subsea capping stacks** provides recommended practices for design, manufacture and use of subsea capping stacks. The document applies to the construction of new subsea capping stacks and can be used to improve existing subsea capping stacks. The standard does not include recommendations or procedures nor equipment for containment systems that may be connected to a subsea capping stack.
- **Portfolio of capping stacks:** Today, specialized service companies have built a portfolio of capping stacks for every offshore scenario, including systems uniquely designed for shallow water Arctic drilling operations, for which glory holes (well cellars / mudline cellars) are excavated below the seafloor to protect well equipment such as BOPs for ice ridge scouring (Madrid and Matson, 2014).

Capping stacks specifically developed for the Arctic:

- **Trendsetter Engineering's / Shell's Arctic Capping Stack:** Trendsetter Engineering developed an Arctic Capping Stack for Shell in 2012. It is built in such a way that it can be used as an emergency pressure containing device that acts as a barrier in case of BOP failure (Trendsetter Engineering, 2012). The capping stack is designed to be operated in shallow water depths (200 fsw). Furthermore, built with ROV interfaces, the Arctic capping stack is ROV operable and capable of capturing / processing 100,000 barrels of fluid per day, with onboard accumulation for rapid well control. In June 2015 BSEE personnel witnessed the deployment and manoeuvring of the capping stack off the rear deck of the M/V Fennica to 150 feet of water, which is deeper than Shell's current well sites in the Chukchi Sea. The capping stack functioned properly under pressures exceeding the maximum expected pressures Shell may encounter in the Arctic.

Containment

A containment dome is a component of a system designed to collect the hydrocarbons flowing from the wellhead in the event that a capping stack could not completely stop an uncontrolled subsea flow event. The hydrocarbons collected are pumped back to a barge for further processing.

Containment systems for the Arctic:

- **Shell's Arctic containment system:** Shell has developed an Arctic containment system which includes a capping stack, a containment dome and a production processing system on board the Arctic Challenger (BSEE, 2015b). The Arctic Challenger is a ship-shaped barge that houses the containment dome and the offshore support vessel facilities that are necessary in order for the containment system to be deployed effectively. The 20-feet-tall steel containment dome would be used in the event that a capping stack could not completely stop an uncontrolled subsea flow event. Rather than attaching to the top of the blowout preventer as the capping stack did at the Macondo well in Gulf of Mexico, the containment dome is lowered to the seafloor over the well site by use of buoyancy tanks. The hydrocarbons flowing from the wellhead are collected at the top of the dome and pumped back to the Arctic Challenger for processing. The capabilities of the capping stack and containment dome must meet the requirements that are specific to the characteristics of the proposed well.
- **Trendsetter Engineering's Divert / Flow Control (DFC) system:** The DFC system is a pre-installed flow diversion system in the event well shut-in cannot be achieved. This can be related to breach of well bore integrity of release of gas on the drilling rig. The DFC system can enable subsea flow diversion, surface flaring or surface containment. The DFC provides divert / flow capability which can enable re-boarding the rig, re-entering the well to perform a well kill operation and preparing for centralised oil collection for oil spill response operations.

7.4 Pipelines and subsea structures

Offshore pipelines may be used in conjunction with Arctic offshore production platforms to export the produced hydrocarbons to shore. Additionally, subsea pipelines may be used for in-field transfer from subsea wellheads to a production platform or from a production platform to a nearby buoy or similar for offloading to export tanker. Furthermore, offshore pipelines may be used to export production from subsea wellheads directly to shore.

The following sources of information are found relevant for pipelines and subsea structures:

- **Arctic subsea pipelines and subsea production facilities – NPC topical paper # 6-6 (NPC, 2015):** The paper refers to offshore pipelines that are already installed in the USA, Canada and Russia. It describes that pipelines must be designed to prevent damage due to interaction with deep ice keels, and that burial is the most common method for pipeline protection.
- **Design and installation challenges for Arctic offshore pipelines:** Paulin et al. (2014b) discuss the design and installation challenges for Arctic offshore pipelines. The major design loads that are considered for Arctic projects include ice gouging, strudel scour, upheaval buckling as well as thaw

settlement. When considering routing a pipeline, several criteria must also be considered. Pushing the limits to developments further offshore in deeper water will require that additional consideration be given to aspects related to pipeline design, in particular with respect to burial for protection against ice gouging.

- **Design of Arctic offshore pipelines** is discussed in ISO 19906:2010, API RP 2N:2015 and DNV-OS-F101:2013.
- **Ice features action on seabed:** Vershinin et al. (2007) have prepared a comprehensive summary of the effects of ice ridges on pipelines and subsea structures. The work is to a large degree based on work carried out by Liferov (2005, in his PhD thesis at NTNU).
- **Integrity monitoring of Arctic pipelines:** Thodi et al. (2015) describe the operating principles and technology status of leak monitoring systems for Arctic pipelines.
- **State of the art review:** A state of the art review, including methods used for offshore Arctic pipeline design have been documented by DNV (2008).

7.4.1 Pipeline and subsea structure integrity

Unique pipeline design aspects for Arctic conditions include analysis of the potential effects of Arctic specific environmental loadings (e.g. ice scour, strudel current scour, permafrost) and the effective use of limit stage design for extreme loading conditions. See Figure 12.

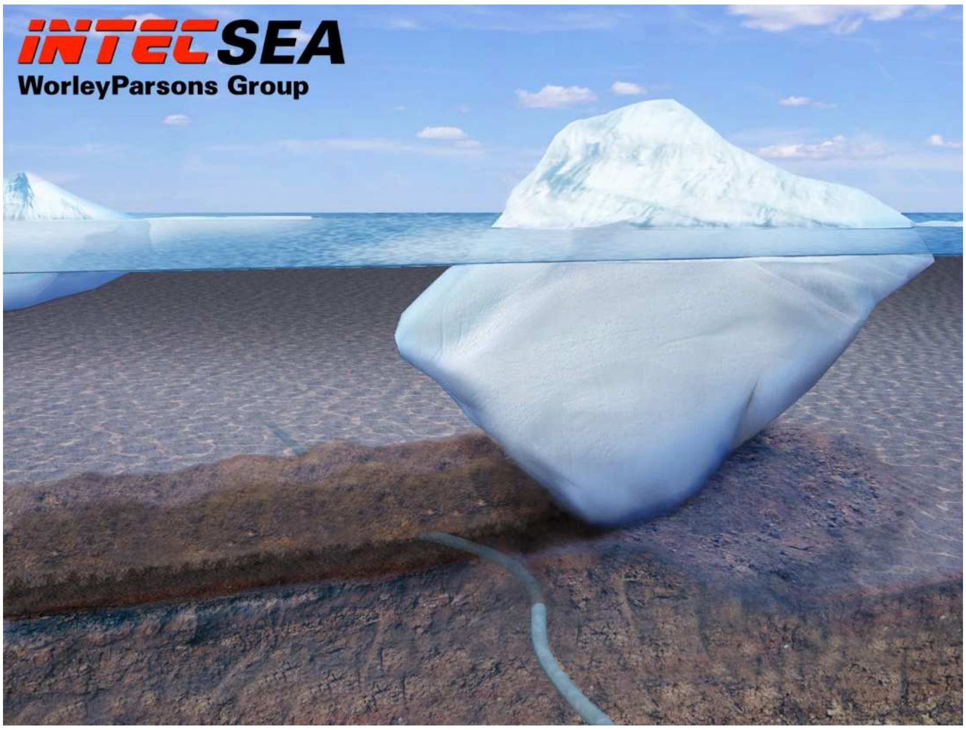


Figure 12 Iceberg scour (Courtesy of INTECSEA)

An important design concern for offshore Arctic pipelines and subsea infrastructure facilities is protection from interaction with ice. The pipeline and subsea infrastructure facilities may be damaged due to impact with icebergs or gouging ice. There may also arise flow assurance issues, like gas hydrate formation or solidification of waxes in crude oil, due to low surrounding temperature. Also, the pipeline has the potential to experience upheaval buckling due to high thermal expansion when the pipeline is heated by production fluid in cold seabed environment. Discontinuous subsea permafrost may lead to high differential settlements of the pipe which can induce significant strains in the pipeline (NPC, 2015).

Known measures to protect Arctic offshore pipelines are:

- Pipeline trenching / burial below depth of gouging ice
- Engineered protection structure (e.g. embedded steel or concrete caisson or steel protection structures that extend above the sea floor)
- Insulation of pipeline to avoid thawing of underlying permafrost
- Pipe-in-pipe design
- Pipeline geometry
- Isolation valves

Regarding pipeline and subsea structure integrity, **C-CORE**, whose geotechnical engineering group undertakes physical and numerical modelling studies for diverse clients and have extensive expertise in the oil and gas pipeline sectors in Arctic regions, has led several joint industry projects (JIPs). Amongst these are, presented in chronological order:

- **PIRAM (Pipeline ice risk assessment and mitigation, 2007-2009):** PIRAM developed methodologies to determine contact frequency and loads from gouging ice keels and established pipeline behaviour in response to ice keel load events. The JIP developed engineering models and procedures that could be implemented into industry best practices for mitigation of risk and protection of pipeline infrastructure (https://www.c-core.ca/piram). Key learnings from the PIRAM project was that the initial properties of the ice (particularly the degree of consolidation and bonding) and the confining pressure as the keel begin to dig into the seabed are important factors limiting the gouge depths.
- **SIRAM (Subsea ice risk assessment and mitigation, 2007-2009):** SIRAM was a C-CORE led JIP that aimed at quantifying site specific risks and developing broadly applicable solutions, including mitigating techniques and structures for protecting subsea infrastructure from interaction with ice and iceberg keels (https://www.c-core.ca/siram).
- **DIRKS (Development of ice ridge keel strength, 2011-2015):** C-CORE's Centre for Arctic Resource Development (CARD) built the DIRKS project based on knowledge from the PIRAM project. The DIRKS project investigated the failure mechanisms associated with gouging ice ridge keels and the conditions under which these keels will continue to gouge without breaking up. This is important for the design of subsea structures in shallow waters where ice keels have been observed to scour the seafloor posing a threat to pipelines and subsea infrastructure. The project is designed to help understand the effects the temperature, confining pressure, consolidation time, and drift speed have on the strength and failure characteristics of a first year ice-keel (https://www.card-arctic.ca/DIRKSProject).
- **MIR (Mechanics of ice rubble project, 2014-2016):** Based on the knowledge from the DIRKS project, CARD has recently initiated the MIR project. The main focus of the MIR project is to gain a greater understanding of the fundamental mechanics and key physical parameters that contribute to the strength of the ice keel as it interacts with structures. CARD researchers will conduct a series of tests and numerical simulations to study the thermomechanical behaviour of the ice rubble and its behaviour when it interacts with a structure or with the sea floor (https://www.card-arctic.ca/MIR).

Other industry initiatives regarding pipeline integrity are:

- **Full scale gouging JIP (2012 – Phase 1):**The overall objective is to reduce the technical uncertainty associated with design of buried pipelines for ice-prone regions, including assessment of the feasibility of establishing a full scale gouging test facility. Phase 1 is administered by MMI Engineering in partnership with Golder Associates and INTECSEA, and is funded by PRNL. INTECSEA is involved in studying the magnitude and parameters that affect subgouge displacements for the design of buried submarine pipelines in cold regions. The objective is to advance the design of buried submarine pipelines in cold regions subject to ice gouge conditions through the development of a large scale 1g physical test facility and to use the data collected through the test program for calibration and verification of numerical models.

- **IceGouge JIP (2013-2016):** This JIP will validate engineering models and develop best guidelines for the design of offshore pipelines in ice gouge environments. The JIP has been initiated by Wood Group in cooperation with Memorial University of Newfoundland (MUN).
- **ICE PIPE JIP (2008-2009)**: The objective of this JIP was to establish a DNV Recommended Practice for Arctic offshore pipelines that will present a common and documented approach to achieve an acceptable safety level for offshore pipeline projects in cold climate regions (DNV, 2008).
- **Trenching JIP (2011 – Phase 1):** The objective of the JIP is to develop proven trenching system for protection of subsea systems against ice scouring of seafloor so future field developments can be planned based upon reliable, predictable execution of trenching effort. The JIP is planned to be a research and technology development project with four phases. INTECSEA has been awarded a contract by PRNL for phase 1 of the JIP. The overall objective is to prove a trenching system that is capable of meeting the below requirements (Paulin et al., 2014a):
    - Trenching to depths greater than current industry norms (burial depths greater than 3 meters with potential trench depths as much as 7 meters)
    - Trenching in highly variable soil conditions that may include sand, gravel, clay, glacial till and bedrock, including the possible presence of boulders
    - Trenching in water depths beyond the majority of trenching requirements (water depths from 5 meters up to 300 meters)
    - Operating in harsh marine conditions (e.g. the Western North Atlantic

The following research and technology development initiatives have been identified:

- **Analysis methods for pipelines in ice gouge environments:** INTECSEA is developing advanced analysis methods for pipelines in ice gouge environments. Conventional methods to evaluate the ice gouge loading on a buried pipeline rely on decoupled analysis of the ice-soil and soil-pipe responses, which is believed to be a conservative approach and not adequately representative. El-Gebaly et al. (2012) investigate ice gouging using advanced numerical modelling techniques to reduce the conventional conservatism and better quantify the loads experienced by the pipeline due to ice gouges.
- **Bundle technology:** Burial under the seabed is the common practice of protecting offshore pipelines and these pipelines are often installed as bundles for many reasons, including economic considerations, short installation windows, and technical issues (Georghiou et al., 2015). Bundles have been used in all of the developments utilising subsea pipelines offshore the North Slope of Alaska. INTECSEA extend the state of practice of analysing buried pipelines using pipe-soil-interaction elements on individual pipelines to account for the effects of the different pipelines in the bundle (Georghiou et al., 2015). The behaviour of a bundle cannot be accurately modelled as a sum of individual parts or as an equivalent bundle. Georghiou et al. (2015) present an example for permafrost thaw settlement of a bundle, where the individual models would result in over conservatism in determining the maximum axial strains. According to Georghiou et al. (2015) a more complete model of the given scenario should be sought in future designs to reduce unnecessary conservatism.
- **Labrador iceberg scour risk:** C-CORE has conducted seabed surveys to define the Labrador iceberg scour regime have captured over 7,300 km2 of high-resolution multibeam on or near the Makkovik Bank on the Labrador Shelf and a data set of over 27,000 scour features. Scour data have been extracted from less than half of the area shown on the mosaic. Repetitive mapping of the seabed to estimate iceberg scour formation rates has been performed by comparing modern multibeam against sidescan mosaics collected in the 1970s and 80s, as well as comparing two multibeam surveys collected in 2003 and 2008. Additional repetitive surveys covering larger areas are planned

for the future. Data collected to date (along with additional modelling to evaluate variations in scour formation rates) show another order of magnitude reduction in pipeline contact risk is possible, and that with foreseeable advances in pipeline trenching technology a 1000-year reliability target is reasonable.

- **Subsea processing and ultralong multiphase transport:** SINTEF is participating in R&D activities related to subsea processing and ultralong multiphase transport. Current challenges in long-distance multiphase transport are related to effects of water such as water accumulation, corrosion and generally incomplete understanding of three phase flow. In the Arctic there may be long distances and long (cold) multiphase pipelines will be necessary for optimal field exploration.
- **Trenching technology for pipelines:** INTECSEA is conducting R&D activities related to trenching technology. Paulin et al. (2014a) discuss trenching considerations for Arctic pipelines. Offshore pipelines installed in the Arctic and other cold regions are often buried to reduce the risk of damage from ice gouging, upheaval buckling, and other loading challenges specific to the region. Pipeline burial is normally achieved through trench excavation and backfill. As developments are proposed for areas that experience relatively deep ice gouging (up to 5 meters), burial depth requirements will exceed the capabilities of current technologies. New technologies capable of working in deeper water, achieving greater burial depths, achieving reasonable trenching advance rates, operating in harsh environments, and trenching through variable and difficult seabed soils will be required.

7.4.2 Pipeline integrity monitoring and leak detection

Pipelines may be damaged following excessive strains due to the effects of ice gouging, strudel scour, upheaval buckling, frost heave and permafrost thaw settlement along with other loading and failure mechanisms (corrosion, third party damage etc.). Additional challenges are seasonal ice cover and remote location. The following initiatives regarding pipeline integrity monitoring and leak detection have been identified:

- **Arctic pipeline leak detection JIP (2014-2016):** Testing of fibre optic cable distributed sensing leak detection systems for Arctic and cold region applications. The overall aim of the JIP is to test detectability, determine minimum thresholds of detection (i.e. minimum leak rate and response time), enhance technology readiness level, simulate cold-region, deep-water environmental testing, and identify false alarm rate.
    - Phase 1: Designing, costing, scheduling and execution planning to establish the basis and boundary of the testing program – completed 2014.
    - Phase 2: Large scale field testing in a simulated environment in St. John's, Newfoundland & Labrador, Canada – 2015-2016 proposed.
- **Bundle technology for Arctic pipelines:** Subsea 7 is developing bundle technology for Arctic pipelines. The technology includes, but is not limited to, fibre optics for real time detection of pressure, temperature, strain and leaks.
- **Detection of leaks in offshore pipelines JIP (2013-2015):** The JIP led by Southwest Research Institute (SwRI) focuses on distributed sensors for offshore pipeline leak detection. The overall scope was to study the leak behaviour (thermal, acoustic) for various leaks and perform testing of fibre-based systems. The overall objective was to determine, in a controlled environment, if the two candidate technologies, distributed temperature sensing (DTS) and distributed acoustic sensing (DAS), can detect small (<0.25") leaks. Siebenaler et al. (2015) describe the JIP and describes the physical characteristics of potential underwater leaks using lab-scale experimental analysis. Large-scale testing results are planned for publishing in 2015.
- **Real-time integrity monitoring system using fibre optics:** INTECSEA is developing a real-time integrity monitoring system which is a sensor-based monitoring system aiming at enhancing the productivity of Arctic pipelines (Thodi et al., 2015). The intent is to assess operating conditions and

performance, improve performance and pipeline throughput, extend life, inform the operator if pipeline integrity is compromised, and provide the necessary information to perform optimal inspection and maintenance activities. Thodi et al. (2015) present the detectability and operating principles of fibre optic cable systems in the Arctic including the experience gained from using them in past projects. The paper focuses on detecting integrity threats arising from the unique Arctic design and operational challenges. Furthermore, the paper covers the operating principles and technology status of leak monitoring systems for Arctic pipelines. The paper concludes that fibre optic cable distributed sensing systems, such as distributed temperature sensing and distributed acoustic sensing, have a high potential to be used for Arctic pipelines to detect and locate leakages.

7.5 Facility design

The following sources of information are found relevant for facility design:

- **API RP 2N:2015 Arctic offshore structures:** The recommended practice, which is a modified adoption of the ISO 19906:2010 Arctic offshore structures standard specifies practices for planning, designing and constructing structures and pipelines for Arctic conditions.
- **ISO 19906:2010 Arctic offshore structures:** The standard ISO 19906:2010 Arctic offshore structures specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. The standard is currently under revision and Draft International Standard (DIS) version is planned for mid-2016.
- **Challenges of deep-water Arctic development:** The oil and gas industry has demonstrated the ability to drill and develop offshore oil and gas resources in first-year sub-Arctic ice and in shallow-water high-Arctic environments. However, development in deep water (water depths exceeding 100 meters) remains a formidable challenge due to small, unpredictable open-water windows and large environmental loads from multi-year ice features. Hamilton (2011) reviews the key technical challenges facing deep-water high-Arctic development along with the current industry efforts aimed at meeting the challenges.
- **Maintenance and inspection activities:** Oil and gas facilities require regular inspection and maintenance to function safely and without need for emergency interruptions. In cold climate, the challenges related to frozen equipment, ice and snow as well as freezing temperatures represent a challenge. Experience from running land-based operations under similar conditions exist and are taken into account. Furthermore, the experience of the maritime and fishing industries is of great value to ensure safe operations. For an overview, see Markeset et al. (2015).
- **NORSOK N-003 Actions and action effects:** The standard specifies general principles and guidelines for determination of characteristic actions and action effects for the structural design and assessment and for the design verification of structures. The standard is applicable to the design and assessment of complete structures including substructures, topside structures, vessel hulls, foundations, mooring systems, risers and subsea installations for all types of offshore structures used in the petroleum activities, including bottom-founded structures as well as floating structures. The standard is primarily written for facilities on the Norwegian continental shelf (including the continental shelf of Svalbard) as defined by the Norwegian Petroleum Directorate 16 June 2014, but the principles may also be applicable for other areas. Edition 3 of the NORSOK standard N-003 Actions and action effects is under development, planned to be published in 2015.

The following industry initiatives are found relevant for facility design:

- **IceStruct (2009-2012):** The aim of this project was to provide design guidelines in compliance with ISO 19906:2010, Arctic offshore structures. Deliverables:
    - o The IceStruct JIP commentary on ISO 19906, which is a document identifying gaps in the ISO 19906 standard and commenting on possible solutions aimed at filling these gaps

- The IceStruct JIP guideline, which is a step-by-step 'recipe' guidance document, targeted at the offshore designer, for obtaining appropriate characteristic ice loads and ice load effects, which are required for design checks according to standard offshore design practice. This guideline is currently under development into a DNV Recommended Practice; DNV-RP-C209.
    - The IceStruct JIP background report, documenting the basis for the work done towards producing the first two deliverables
- **Durable advanced concrete solutions (DACS, 2015-2019):** Kværner Concrete has initiated a JIP to develop knowledge, methods and tools to create concrete constructions that will withstand environmental effects in an Arctic environment. The project is divided into the following work packages (SINTEF, 2015a):
    - Early age cracking and crack calculation in design
    - Production and documentation of frost durable concrete
    - Concrete ice abrasion
    - Ductile lightweight aggregate concrete (LWAC)

The following industry R&D initiatives are found relevant to facility design:

- **Arctic jack-up design:** Keppel Offshore and Marine Technology Centre is conducting R&D activities on mobile offshore self-elevating drilling units (MODU) for open water exploration drilling and for extended season development drilling over a wellhead.
    - Wang et al. (2012) review studies carried out to determine the feasibility of using a modern high capacity jack-up MODU for exploratory drilling in areas with water depths less than 50 meters and where sea ice can move in with high concentrations. The studies, including structural analysis, ice management approaches and well control considerations are reviewed, in addition to the further potential of jack-ups in the Arctic (Wang et al., 2012).
    - Shafer et al. (2013) describe the basis of design and specifications for a self-elevating Arctic MODU for use in water depths from 10 to 50 meters, capable of drilling a wide range of wells.
- **Challenges with bringing collision risk models used in the North Sea and Norwegian Sea to the Barents Sea:** Hassel et al. (2015) discuss the challenges with bringing the industry standard risk model for ship-installation impacts (COLLIDE) used in the North Sea and Norwegian Sea to the Barents Sea. The COLLIDE collision risk model relies heavily on operational elements and risk reducing measures commonly found throughout the North Sea and Norwegian Sea. These are presently not available in the Barents Sea. The main operational barriers and risk reducing measures against ship-installation impacts in Southern Norway are two control centres that operate an integrated network of radars, VHF stations and AIS base stations. The same level of emergency resources, surveillance and communication coverage is not available in the Barents Sea. The lack of infrastructure and available resources affect core assumptions in collision risk assessment models and may cause otherwise minor incidents to have a more serious outcome in a remote area. Hassel et al. (2015) discuss these challenges and propose alternatives to overcome these issues.

7.5.1 Ice loads

Ice loads on structures are determined by the actions of ice and ice ridges. The loads from ice ridges can become very high from consolidated ridges (Høyland, 2002). Furthermore, for stationary facilities, the rubble generation around the facilities is of concern (Barker and Timco, 2005).

Reliable designs of Arctic offshore and coastal structures requires a proper quantification of the physical environment as well as good prediction models from the response of structures in the interaction with ice features. Defining ice loads in terms of how the load builds during interaction with a structure is an area involving much uncertainty.

Research on observed incidents, presented in chronological order:

- **Nordvik, Kara Sea, the Matisen Strait 2013:** In September 2013, the tanker Nordvik was holed by an ice floe and suffered ingress of water in the Matisen Strait in the Kara Sea (Marchenko, 2014). New regulations have been inacted in the Russian Arctic since 2013. All vessels need to have permission issued by the Northern Sea Route Administration (NSRA), to navigate in the waters controlled by the administration. The tanker Nordvik had been given permission by the NSRA to sail in the Kara and Laptev Seas under light ice conditions and only escorted by an icebreaker. The Federal Agency for Sea and River Transport stated that the tanker acted in violation of the permit by entering waters with medium ice conditions without an icebreaker escort. Experienced captains submitted that it was quite possible that the ice conditions had changed rapidly and that the tanker had unintentionally ended up in an area with heavy ice conditions. The Commission has not yet decided the case proceedings. Nevertheless, on September 4 the tanker was struck and holed by ice. The tanker quickly began taking in water through one of the ballast tank. The hole, which measured 100 cm x 10 cm, was plugged with a cement box to stem the water ingress on September 10. There were not any oil leakage. The accident showed that ice conditions in the Arctic remain harsh and unpredictable.
- **Marine icing on KV Nordkapp in the Barents Sea 1987:** On a voyage from Tromsø to the waters east of Bjørnøya in late February 1987, the Norwegian Coast Guard vessel KV Nordkapp experienced heavy icing due to a polar low that raged over these waters during the voyage (Samuelsen et al., 2015). This polar low developed in an unstable air mass due to a cold-air outbreak over relatively warm waters. KV Nordkapp experienced air temperatures in the range of minus 10°C to minus 20°C, and was moving against 20-30 m/s winds producing waves up to 7.5 meters high. During the icing event KV Nordkapp accumulated 110 tons of ice. The icing was encountered all the way from the hull just above the water level to the top of the wheelhouse. Samuelsen et al. (2015) have analysed the icing event and made calculations for comparison between observations and modelling results.
- **Ice interactions with Molikpaq in the Beaufort Sea 1985-86:** The ice interactions with the Molikpaq Amauligak I-65 in the Beaufort Sea over the 1985-86 winter season represent the only data set on direct measurements of multi-year ice loading on an offshore structure (Jordaan et al., 2011). Several JIPs were initiated on dynamic ice structure interaction of the Molikpaq that produced confidential reports in 1987, 1989 and 1991. Through limited access to the reports and data, a number of papers were published. The estimated loads differed, which left an uncertainty on multi-year ice loads. On April 12, 1986 Molikpaq experienced a series of loading events when second-year and multi-year ice moved against the structure. The highest loads that the Molikpaq experienced during the 1985-86 season were during this day. Extensive ice thickness measurement had been taken in the ice around the Molikpaq prior to April 12th. Thickness of up to 6 m were measured and 8 to 12 m estimated for a multi-year hummock. In 2006, the Canadian Hydraulics Centre at the National Research Centre of Canada (NRC) analysed the maximum ice force on the Molikpaq during the April 12, 1986 event, during which day the Molikpaq experienced the highest loads during the 1985-86 season (Frederking and Sudom, 2006). This estimated maximum load is in contrast to higher and lower values quoted in the literature for the April 12 event. In 2007, a new JIP was initiated, re-evaluating the Molikpaq multi-year ice loads (Jordaan et al., 2011). The conclusion from this JIP is that the 'best estimate case' loads determined through the JIP, which are about half the previous estimates, are an improved representation of multi-year ice loads on the Molikpaq over the 1985-86 season.

The following research initiatives have been identified:

- **C-CORE's ice engineering services (https://www.c-core.ca/ice):** Since 1975, C-CORE has provided research-based advisory services to help clients mitigate operational risk in harsh environments. C-CORE conducts applied engineering research and development focusing on ice loads and risk evaluation, finite element and numerical analyses, as well as field studies in support of client research and development activities.
- **National Research Council of Canada (NRC, http://www.nrc-cnrc.gc.ca/eng/)** has for many years focused on investigating ice loads on offshore structure.
- **SAMCoT** (https://www.ntnu.edu/samcot) is a centre for research based innovation with long-term funding by the Research Council of Norway and the Energy Industry. The vision of SAMCoT is to be a leading national and international centre for the development of robust technology needed by the industry operating in the Arctic region. SAMCoT started in 2011, and is tasked to meet the engineering challenges due to ice, permafrost and changing climate for the benefit of the energy sector and society. Research is divided in six different work packages; 1) Data collection and process modelling, 2) Material modelling, 3) Fixed structures in ice, 4) Floating structures in ice, 5) Ice management and design philosophy and 6) Coastal technology.
    - Kuiper et al. (2015) describes how SAMCoT is preparing and contributing to the sustainable industry development in the Arctic region. Research and development of new Arctic technology, the implementation of innovative methods in the oil and gas industry, collaborative way of working, and education of the next generation engineers are highlighted in the paper.
- **STePS2 (Sustainable Technology for Polar Ships and Structures)** was a research project at Memorial University of Newfoundland (MUN) from 2009 to 2014. The aim of the project was to increase the understanding of impact forces between ice and steel structures and to improve the tools that are used to design ships and structures for year-round Arctic operations.

Research activities specific to ice loads:

- **Concrete ice abrasion:** Concrete structures in marine environments subject to sea ice interaction are at risk of erosion and damage. Industry is interested in characterising the ice abrasion phenomenon so that abrasion risk can be managed. Tijsen et al. (2015) present results of experiments which have an exploratory character in order to identify the abrasion phenomenon and qualitatively observe the corresponding processes. Concrete of varying mixtures has been examined and the effects on the concrete surfaces from repeated static ice-bonding and bond-breakage is analysed by Tijsen et al. (2015).
- **Failing ice sheet - preliminary results of 3D simulations:** Heinicke et al. (2015) have studied the failure of an initially intact ice sheet against an inclined structure, where the most prevailing forces on the ice sheet are vertical. When an initially intact ice cover moves against an inclined structure, it fails by fragmenting into discrete ice blocks which then accumulate in front of the structure and form an increasingly large rubble pile. Understanding this fragmentation process and predicting the subsequent ice load on the structure are important for the design and operation of marine structures in ice-covered waters. Heinicke et al. (2015) describe the theory and results of the simulations performed. The simulated fracture process is then validated with analytical models and field experiments described in the literature. Focus is laid on cantilever beam tests and vertical breakthrough tests. The conclusion is that simulations agree with the literature data (Heinicke et al., 2015).
- **Ice failure processes (2005-2010):** The project involved technical and practical considerations of petroleum exploration, examining how to minimize the risk of damage caused by icebergs. By studying the composition of ice, structural design and creating models of iceberg impacts, it was noted that engineers are able to build ice-resistant structures to withstand certain loads. Another

valuable aspect of the research was the incorporation of risk analysis and probability into the larger challenge of operating offshore structures in iceberg-busy waters. Research to date has helped provide a necessary first step towards defining the fundamental role played by such mechanical processes as ice crushing, spalling, fracture and damage on global load reduction, which is crucial to achieving the ultimate goal of a reduction in the amount of conservatism used in the design of offshore structures and vessels. The next phase of research involves a series of medium scale ice tank tests to further knowledge of how ice loads are transferred to structures and any scale-effect biases contained in the experimental data. In particular, the goal of understanding the scale effect is crucial to making improvements in the economical design of offshore structures. The project was undertaken by Memorial University of Newfoundland (MUN), in collaboration with National Research Council of Canada (NRC) and industry partners (http://pr-ac.ca/index.php?id=93)

- **Ice ridges - consolidation of first-year sea ice ridges:** Sea ice ridges are formed by compression or shear in the ice cover. The ice cover is broken and a pile of broken ice, water, snow and air is created. Ridges are important ice features from an engineering as well as from a geophysical point of view (Høyland, 2002). The ridging process changes the drag from winds and currents which makes ridging and ridges important to large-scale constitutive models for sea ice. Furthermore, ridges are zones of material inhomogeneity in the ice cover, and they represent zones of strength or weakness in the ice cover depending on their degree of consolidation. Thus, in many Arctic and sub-Arctic areas, ridges may represent the design load for offshore structures. However, it is not clear what load a first-year ridge can exert on a given structure or how the ridge deforms. It depends on the age and composition of the ridge as well as the structure. Høyland (2002) describes the measurements that have been performed of temperature development, geometry morphology and physical properties in three first-year sea ice ridges at Spitsbergen and in the Gulf of Bothnia. The corresponding thickness and the physical properties of the surrounding level ice were also measured. The thickness of the consolidated layer was examined through drilling and temperature measurements. The results showed some differences, for which three possible explanations are discussed by Høyland (2002); surrounding currents, different keel shapes and difference in salinity. The results were that (Høyland, 2002):
    - The thickness of the consolidated layer depended on the method of investigation.
    - The measured growth of the consolidated layer did not depend on the method of investigation.
    - The scatter of the physical properties in the consolidated layer was higher than that of the level ice.
    - The consistency of the unconsolidated rubble differed markedly at the two sites.
- **Ice rubble generation for offshore production structures:** Barker and Timco (2005) research the state-of-the art use of ice rubble generators and ice protection structures. Analysis of ice load data have shown that rubble fields can be very beneficial for attenuating ice loads. The ice rubble, which is large accumulations of broken ice pieces that ground around offshore structures, reduce the ice load by transmitting some of the ice load to the seabed and preventing ice crushing on the face of the structure. A hybrid design of an ice rubble generator and an ice protection structure, has the potential to reduce ice loads by stabilising the ice rubble surrounding offshore structures during the winter, and by providing a depth-limiting mechanism for summer ice floes (Timco and Barker, 2005). Furthermore, the use of year-round passive load-reduction technology would significantly reduce the ice loads, which would result in lower-cost structure and increased environmental integrity (Timco and Barker, 2005). Their research assembles available information on protective structures that have generated rubble. The majority of structures investigated were designed for use in shallow (approximately 4 meters) of water. However, a number of concepts show the potential to be adapted for deeper water use. Structures specifically designed to generate rubble have focused on rubblemound berm or barge-based structures, which, although costly for deep water, appear to hold the most promise for a number of locations in the Canadian Beaufort Sea (Barker and Timco, 2005). Additionally, an arrangement of piles designed to hold back rubble or to

encourage the formation of a stable ice sheet, comprised of highly loaded torsion piles, could be suitable for the Canadian Arctic.

- **Toward a holistic load model for structures in broken ice:** Kim et al. (2015) present several semi-analytical solutions that are useful to model interaction between floe ice and structures. The ambition is to support the development of multi-body numerical simulators that incorporate rigid-body dynamics, hydrodynamics and ice mechanics in a 3D space. Furthermore, the Kim et al. delineate a new map of competing failure modes of ice floes that includes ice crushing depth distribution for the dominant ice failure modes.

The **phenomenon of dynamic interaction between an ice floe and a vertical offshore structure** is a complex problem (Kuiper et al., 2015). Such ice induced vibrations may lead to fatigue which again may lead to leakages:

- **Kuiper et al. (2015)** discuss the phenomenon of ice-induced vibrations, the topics related to the phenomenon that are not yet solved, and SAMCoT's contribution to research on this phenomenon.
- **Kärnä et al. (2010)** have addressed the condition where a vertical offshore structure is subjected to actions of level ice. The simulations show that the dynamic response to ice action is a complicated phenomenon in cases where the structure has several eigenmodes in the frequency range below 10 Hz. The results show that:
    - The real action speed of an ice floe can be significantly lower than the free-field ice speed, which is not affected by the presence of offshore structure(s)
    - Ice crushing on a vertical structure may create multimodal response where frequency lock-in at an eigenmode is associated with nearly harmonic vibrations at one or several other modes

Technology for simulation of ice loads on structures:

- **C-CORE's Sea Ice Loads Software (SILS):** The Sea Ice Loads Software (SILS) tool was developed as a JIP to estimate extreme first-year and multi-year sea ice loads on offshore structures, both in probabilistic and deterministic modes. It assists users in the selection of design loads for concept evaluation and for feasibility and scoping studies. Compliant with ISO 19906 standards, it is a flexible tool, accepting inputs of differing structure types and designs, ice and environmental conditions, seasonality and interaction models.
- **GPU based event mechanics (GEM) simulation technology:** This technology aims at assessing the effectiveness of physical ice management and ice loads on structures. Daley et al. (2014) describe a GEM model of the action of managed pack ice on a floating offshore structure. The work represents a further exploration of the possibilities of GEM technology, which was previously used to explore both resistance and local structural loads for ships transiting pack ice. The work is part of the STePS2 (Sustainable Technology for Polar Ships and Structures) research project at Memorial University of Newfoundland (MUN) from 2009 to 2014.
- **Ice simulation tool for Arctic platform design:** A new type of ice simulation tool for offshore platform design is being developed by Cervval and Bureau Veritas on behalf of Technip (Dudal et al., 2015). The aim for the simulator is to predict the flow of ice around both fixed and floating offshore structures of different shapes using a multi-model approach. The simulator is not envisaged to replace the verification stage of testing in an ice basin, but to enable an optimization of the design on a standard PC which is then confirmed in an ice tank. The simulator program based on a multi-model approach has been developed to predict ice behaviour and loads exerted on offshore engineering structures accounting for water currents and the mutual reciprocal actions between an offshore structure, ice sheet / ice floes, ice blocks due to ice sheet or ice floes failure, water, current and the seabed. Dudal et al. (2015) illustrate the complexity of the simulator and how it treats each ice fragment individually, and the effect of current and the seabed. The validation of the simulator builds on results of ice model tests and shows a good agreement with

ice basin tests. Even though the simulator is not yet considering the local ice edge crushing and snow effects, the software is already able to simulate ice interaction with any type of structure shape considering ice failure due to bending, crushing or a combination of both and may be used for structures optimization, minimizing the ice loading and ice rubble build-up, prior to final verification in a test basin (Dudal et al., 2015).

The following industry initiatives have been ongoing regarding ice loads on structures:

- **IceStream JIP:** In the follow-up from the Arctic operations handbook, the IceStream JIP together with several other JIPs were suggested. However, the IceStream has not been initiated. The IceStream JIP would be a follow-up of the pilot IceStream project. A floating structure would be modelled, along with a generated set of ice particles. Additionally, model tests would be carried out in the NRC ice tank, as well as with artificial ice at MARIN.
- **MARICE (2009-2013):** A JIP led by DNV which studied the process of sea spray icing (marine icing). When wind and waves whip sea spray onto a ship or rig, the resulting accumulation of ice can pose a risk to the safety of the vessel and its crew and jeopardize their ability to operate effectively. The purpose of the project was to study ice accretion in Arctic weather conditions by scientific experiments, to model this process using physically realistic understanding of marine icing and translating that knowledge into guidelines and recommendations for vessel design and operation, including emergency response (DNV, 2014).
- **Rig spray (2014-ongoing):** DNV GL has initiated a JIP which aims at developing a simulation tool that bridges functional winterisation requirements and real physical conditions for drilling rigs, production platforms and vessels to ensure that the design of icing-mitigation measures delivers both safety and cost benefits.
- **SAFEARC – Safe Arctic Marine Operation (2011-2014):** The objectives of this DNV GL led JIP were to learn and investigate operations aspects, demands and challenges of ice-going ships, and to study the forces of ice on podded propulsion through full-scale measurements. The main purpose was to calibrate the DNV GL class rules and assess the IMO Polar Code requirements for ship hull and machinery design, and to investigate efficient operational patterns and efficient propulsions system design (DNV GL, 2015b).
- **Drilling units for cold climate regions:** The PSA has initiated a pre-study for evaluating drilling units for the Norwegian part of the Barents Sea. In this project the risk of using semi-submersible drilling units will be compared with using drillships in areas where growlers and bergy bits can affect the integrity of drilling and well control equipment at sea level. The project will map protection methods and evaluate the need for other types of drilling units than what is currently used in the Norwegian part of the Barents Sea. Knowledge will be gathered, in particular how this is handled at other countries' continental shelves where attention is towards simplified relocation of units between the shelves. The pre-study has been initiated in 2015, while the main project is planned initiated in 2016.
- **Structural integrity in cold climate regions:** The PSA has initiated a pre-study for evaluating challenges for structural integrity such as movement of semi-submersible units and ships in ice-covered waters, including anchor loads, loads on structural members due to lumps of ice (growlers) in waves. Furthermore, the development of models for icing (atmospheric and sea spray) will be evaluating and knowledge regarding cracking and material fracture in temperatures below -20°C will be gathered. The work will be seen in light of research, education and knowledge about the Norwegian High North. The pre-study has been initiated in 2015, while the main project is planned initiated in 2016.

7.5.2 Ice model testing

An ice tank is a model basin whose purpose is to provide a physical modelling environment for the interaction of ship, structures or sea floor with both ice and water. Some examples of the role of ice model testing are:

- **Ice model tests for development of ships:** Wilkman (2015) discusses the role of ice model tests in development of ships, different aspects of icebreaking and steps taken to develop vessels using ice model tests.
- **Ice model test of an Arctic SPAR:** Bruun et al. (2009) presents results from an ice model test of a SPAR platform in level ice and ice ridges. The ice model tests were performed at HSVA on behalf of Aker Solutions as a part of a study performed in 2008. The platform was tested in fixed configuration with a low and high ice drift velocity in 100 year return conditions with level ice and ice ridges. The ice model test shows that the concept is feasible to operate in the tested ice conditions.
- **Ice model testing of structures with a downward breaking cone at the waterline:** Two large ice model test campaigns were performed in the period 2007-2010 as a part of a JIP. The objectives of the project were to investigate different floater geometries and ice model test set-ups (model fixed to a carriage and pushed through the ice vs. ice pushed towards a floating model moored to the basin bottom) and their influence on the ice failure mode and structure responses in the various tested ice conditions. Bruun et al. (2011) present the objectives and motivations for the project, the models tested, the target test set-up for the various tested configurations and the test matrix. Initial results from a fixed model tested in three first-year ice ridges with similar target ice properties are also presented and compared.

The major ice testing tanks are located at:

- Aker Arctic in Helsinki, Finland
- HSVA in Hamburg, Germany
- Krylov Shipbuilding Research Institute in St. Petersburg, Russia
- National Research Council's Ocean, Coastal and River Engineering (in association with MUN) in St. John's, Canada

Other ice tanks are located as follows:

- Aalto University (Helsinki, Finland),
- Arctic and Antarctic Research Institute (St Petersburg, Russia)
- Cold Regions Research and Engineering Laboratory (Hanover, New Hampshire, USA)
- Iowa Institute of Hydraulic Research (Iowa, USA)
- Japan Marine United Corporation (Japan)
- Maritime & Ocean Engineering Research Institute (Korea)
- National Marine Research Institute (Tokyo, Japan).
- National Research Council (Ottawa, Canada)

7.5.3 Material selection

The properties of materials change when the temperature changes. For example, in low temperatures metallic materials get brittle and they contract, creating stresses and an increased risk of fracture failure. This is also the case for polymers. Equipment exposed to large temperature variations must therefore be designed to withstand the variations. In summary, knowledge is required as to material's behaviour (fatigue, corrosion, brittle fracture etc.) when used for extensive periods in cold temperatures.

Ongoing initiatives include:

- **Anti-icing coatings using nanotechnology:** The project involves development of anti-icing coatings using nanotechnology for use on vessels and offshore structures. The project is part of ConocoPhillips' and Lundin's Northern area program and SINTEF is host institution (ConocoPhillips and Lundin, 2013). The project will focus on the modification of commercial coating systems to obtain durable icephobicity. Through the use of micro and nanotechnology, ice-repellent surface coatings will be developed and characterized. The ice adhesion properties will be evaluated and compared to existing commercial coatings through laboratory testing and field tests.
- **Arctic materials (phase I: 2008-2012, phase II: 2013-2018, https://www.sintef.no/projectweb/arctic-materials/):** The overall objective of the project is to establish criteria and solutions for safe and cost-effective application of materials for hydrocarbon exploration and production in Arctic regions. The main research tasks are aimed at developing understanding and models to describe the performance of materials under conditions of specific interest for Arctic applications; low temperatures, large temperature variations and large imposed deformations. An overall research task is to develop guidelines for qualification of materials for use under Arctic conditions. The project will address steel materials and weldments, polymer materials, and composite and hybrid solutions.
- **MARICE (2009-2013):** A JIP led by DNV which studied the process of sea spray icing (marine icing). When wind and waves whip sea spray onto a ship or rig, the resulting accumulation of ice can pose a risk to the safety of the vessel and its crew and jeopardize their ability to operate effectively. The purpose of the project was to study ice accretion in Arctic weather conditions by scientific experiments, to model this process using physically realistic understanding of marine icing and translating that knowledge into guidelines and recommendations for vessel design and operation, including emergency response (DNV, 2014).
- **Performance characteristics of surface protection coating systems for offshore structures under Arctic conditions:** Eight organic coating systems have been investigated according to their performance under Arctic offshore conditions (Irmer et al., 2013). Three performance groups were considered; corrosion protection performance, performance under mechanical loads, and de-icing performance. The investigations involved the following tests; accelerated corrosion protection / ageing testing, anti-icing tests, tests for coating and ice adhesion, impact resistance tests, hardness measurements, and wettability tests. The test conditions were adapted to Arctic offshore conditions, which mainly covered low temperatures down to -60°C, dry-wet cycles, and UV radiation. Testing facilities for icing / de-icing performance tests have been developed. Standard offshore tests for corrosion protection assessment were partly modified. The coating systems investigated were organic coating systems which differed in generic coating material, number of layers, dry film thickness and application method. Irmer et al. (2013) present the experimental design, the test methodologies, and test facilities used, in addition to discussing the results of the investigations. Based on an assessment scheme, a ranking of coating systems is recommended regarding their protection performance under Arctic offshore conditions (Irmer et al., 2013).
- **Studies of materials behaviour for future cold climate applications (SMACC, 2013-2018):** The overall objective of the SMACC-project (studies of materials behaviour for future cold climate applications) is to develop robust and cost effective materials and solutions for use in Arctic areas. The project comprises:
    - Development of a material database for material properties at low temperatures with an integrated toolbox for post-processing of data and modelling
    - Characterization of materials at low temperatures and actual loads, including structural steels / pipelines, polymers / polymer coatings and light weight solutions (e.g. aluminium)
    - Develop relevant models for materials behaviour and degradation under relevant conditions

- **Thermo responsive elastomer composites (TREC, 2014-2017):** TREC by material formulations including negative thermal expansion filter (FMC Technologies, 2015):
    - o Cater for seal contraction and may provide additional energizing effect at low temperatures
    - o Especially useful for low pressure sealing situations and in particular with gas

7.5.4 Winterization

Winterization includes all design, layout and operational measures made with respect to safe operability and maintainability in a cold climate (Bourmistrov et al., 2015). Winterization measures represent the most common safety barrier in the Arctic. Winterization is primarily focused on the adverse effects and control of freezing, icing, wind chill and material properties in cold temperature. It is important to dimension the design including safety instrumented systems, gas detectors and drain system to ensure that the systems work in the given conditions such as low temperature, icing, etc.

There are a variety of techniques for winterization and these include, but are not limited to, self-draining pipes, maintaining flow in lines, insulation, protective heating, use of an enclosure, use of chemical or mechanical seals on instrumentation, use of wind walls to reduce rate of heat loss, reducing freezing point of materials by adding chemicals as well as protection of equipment from ice falling from higher equipment, flare towers and communication towers (ISO 19906:2010).

One drawback of winterization may be that access for maintenance is reduced due to the winterization measures. Another challenge relates to the power required for ventilation in order to ensure that gas accumulations do not reach a critical level where gas explosions may occur in closed rooms.

The following activities have been identified related to winterization:

- **Aker internal best practice for winterization:** Aker has developed internal best practices to be consulted regarding possible winterization solutions for different areas.
- **DNVGL-OS-A201 Winterization for cold climate operations (2015):** The objective of the standard is to provide general principles for preparation of mobile units and offshore installations for intended operations in cold climate conditions (DNV GL, 2015a).
- **Drilling rig Polar Pioneer** was the first semi-submersible drilling rig built and winterized for cold climate conditions. The rig has been operating successfully in cold climate areas since 1985.
- **Explosion safety drivers for Arctic platform design:** Lloyd's Register is conducting research on explosion safety drivers for Arctic platform design, specifically for enclose mechanically ventilated modules (Dalheim et al., 2012).
- **GMC Electro heating panels:** The electric power needed for winterization of a rig or other facilities may become very large. The Norwegian company GMC Electro is developing lightweight heating panels designed for maximum effect with minimum of energy use.
- **Risk-based winterization for vessels:** Yang et al. (2013) proposes a risk-based approach for the selection of winterization technologies and determination of winterization levels or requirements on a case-by-case basis. Temperature data are collected from climatology stations located in the Arctic regions. Loading scenarios are defined by statistical analysis of the temperature data to obtain probabilistic distributions for the loadings. Risk values are calculated under different loading scenarios. Based on the risk values, appropriate winterization strategies can be determined. A case study is used to demonstrate how the proposed approach can be applied to the identification of heating requirements for gangways.
- **Stamas Engineering Arctic Blankets:** Insulated Arctic blankets can be used to cover flanges, valves, expansion joints, heat exchangers, pumps, turbines, tanks, and other irregular surfaces. The blankets are flexible and vibration resistant and can be used with equipment that is horizontally or vertically mounted or that is difficult to access. Any high temperature piping or equipment should

be insulated to reduce heat loss, emissions and improve safety. The insulated blankets can be easily removed for periodic inspections or maintenance, and replaced as required.

- **Stamas Engineering Arctic Pads:** Arctic pads are heated rubber mats providing a durable, non-slip surface for Arctic and harsh environments that can be used on stairways, platforms, landings, escape ways, muster stations, marine and topside decks, rig floors etc. Embedded within the core is a self-regulating heat trace, which is commonly used throughout many industry sectors for freeze protection.
- **Thermon Solutions Arctic offshore and maritime heating solutions:** Thermon Solutions has developed anti-icing and de-icing solutions for offshore facilities and vessels. They have developed a trace heating system designed for pipes, vessels, instruments and equipment to ensure that they are adequate for operation in low temperatures with cold seawater and high wind.

7.6 Loading and offloading

Low temperatures, high seas and movements of sea ice, in particular when changing drift direction, may increase the possibility for incidents during diesel bunkering of a drilling rig or when transferring oil from e.g. a barge or a vessel to a shuttle tanker. Current experience related to offloading operations in Arctic and cold climate regions shows that additional safety barriers related to the bow loading system are required. This may impose operational limitations for loading and offloading activities and will necessitate disconnection of the operation.

The following sources of information are found relevant for loading and offloading in Arctic and cold climate regions.

- **Experience and challenges related to loading / offloading in ice:**
    - Jensen (2002, in his PhD thesis at NTNU, Trondheim, Norway) studied concepts for loading of hydrocarbons in ice-infested waters.
    - Bonnemaire (2005, in his PhD thesis at NTNU, Trondheim, Norway) continued Jensen's studies by studying different loading concepts and documented that offshore loading in ice should be feasible in principle.
    - Offshore loading in ice has been implemented at offshore Sakhalin using a buoy which was submerged during the heavy ice seasons.
    - Lukoil has installed a tower offshore Varandey from which offshore loading is taking place, see Figure 13.
    - Subbotin (2015, in his MSc thesis at the Gubkin University of Oil and Gas in Moscow, Russia, and UiS, Norway) has reviewed oil-offloading solutions for the Pechora Sea exemplified by the Prirazlomnoye field. Challenges related to ice movements limit the weather windows for the offloading operations.
- **IceTower JIP:** In the follow-up from the Arctic operations Handbook, the IceTower JIP together with several other JIPs were suggested. However, the IceTower JIP has not been initiated. The IceTower JIP initiative would have involved the instrumentation of an offloading tower encountering severe ice floes. During three winter seasons, the loads on the tower and the ice conditions would be monitored.
- **Offtake and tankering – NPC Topical paper # 6-7 (NPC, 2015):** The paper describes some of the recent experience with tanker offtake and transport in Arctic and Sub-Arctic waters, which illustrates the advanced state of the art of design, construction and operation of the physical plant required.
- **Winterization of loading systems:** Nikolaisen et al. (2015) have looked into the critical winterization aspects related to bow loading systems on shuttle tankers, and how to control such risks. The study showed (as expected) that the most effective safety barrier is to carry out work only during suitable weather windows in order to control the risks. This calls for further studies regarding proper weather limitations related to Arctic offloading operations. Selection of design

temperatures for all materials is also of immediate concern when deciding on the winterization design.

Figure 13 Offshore offloading in ice at Varandey, Pechora Sea, Russia (Courtesy of Aker Solutions)

7.7 Communication solutions

Communication services are essential for all offshore petroleum activities. Communication services are amongst others required for receiving status on environmental conditions and for navigation. It is important with operative communication services of high quality and coverage. However, the satellite coverage in the Arctic is poorer than in other more developed areas. Furthermore, navigation and communication systems are exposed to special performance degrading factors in the High North. For navigation systems the ionospheric disturbances, icing on antennas and relatively limited access to differential corrections and integrity information on global navigation satellite systems (GNSS) are the most important factors (Statoil, 2014).

The following sources of information are found relevant for communication solutions:

- **Arctic communication challenges:** Bekkadal (2014) outlines the Arctic communication challenges and the current situation, in addition to identifying future systems capable of mitigating the lack of adequate electronic communications infrastructure in the High North.
- **Communication solutions – NPC topical paper # 7-10 (NPC, 2015):** The paper describes the telecommunications transport methods being utilized in northern Alaska; satellite, point to point radio (microwave) and fibre optic connectivity. The paper points out that the current communications infrastructure does not integrate well into the modern broadband world, as the infrastructure to support them is limited, and the opportunities for further development of telecommunication facilities (fibre optic connectivity, long hall microwave networks) are economically challenging and require significant infrastructure to support. Furthermore, the paper points out that enhanced telecommunications capabilities in northern Alaska would benefit from

the availability of broadband services, as the development of this will link communities and bring necessary broadband bandwidth to enable them to participate in capabilities similar to the rest of the USA. The development of a suitable telecommunications infrastructure will require a coordinated (industry, federal, state and local) investment decision.

Currently available communications solutions include:

- **Geostationary (GEO) satellites:** The most common technology used for maritime communications are satellite systems. Most of these are based on geostationary (GEO) satellites that orbit the earth above the equatorial line. They have little or no cover in the northernmost part of the Arctic. Their low angles of elevation make them more vulnerable to external influences. The theoretical limit for GEO systems is 81.3° North, but instability and signal dropout can occur at latitudes as low as 70° North under certain conditions (SINTEF, 2015b).
- **GLObal NAvigation Satellite System (GLONASS, https://www.glonass-iac.ru/en/)** is the Russian navigation system, presently with 24 operative satellites in three orbits with 64.8° inclination to equator. The system is well suited for positioning at high latitudes (Statoil, 2014).
- **Global Positioning System (GPS, http://www.gps.gov/)**, the USA navigation system, provides location and time information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites. GPS satellites cross the equatorial plane with 55° angle, 24-32 satellites are in operation (Statoil, 2014).
- **Iridium satellite constellation** (https://www.iridium.com/) provides radio band communication at high latitudes with limited band width. 66 satellites are presently in operation in 6 orbital planes with 86.4° inclination. It is the only satellite system that currently provides full coverage in the Arctic, however, problems have been reported, the system occasionally shuts down and it can take several minutes to reconnect (SINTEF, 2015b).

Statoil's operational experience from rig positioning in the High North, is that several measures must be implemented to secure positioning in the High North, i.e. use of both GPS and GLONASS navigation system onboard a rig with high quality cables and short length to reduce loss of signals, special antennas designed for satellites with low elevation, optimal placement of antennas to secure free sight to satellites as well as Precise Point Positioning and Iridium satellites to receive clock and orbital corrections. Incorrect positioning of the rig may result in health, safety and environmental consequences, e.g. danger of encountering shallow gas and damage to marine infrastructure (Statoil, 2014).

There is ongoing research and development activities of both satellite coverage, communication equipment and software modelling. The activities identified are listed below:

- **Advanced Research in Telecommunications Systems (ARTES, https://artes.esa.int/):** The ARTES programme is a long-running, large-scale programme that enables European and Canadian industry to explore, through R&D activities, innovative concepts to produce leading-edge satcom products and services.
- **Arctic Fibre's fibre optic telecommunications project (http://arcticfibre.com/):** The project involves developing one of the largest subsea cable networks in the world. Arctic Fibre will connect Asia to Western Europe via the southern portion of the North West passage through Canadian and Alaskan Arctic. In addition Arctic Fibre will be bringing affordable high speed Internet access to the Arctic.
- **Arctic satellite communication (ASK, 2013-2015):** A project has been conducted to evaluate the feasibility of a Norwegian satellite project that could provide broadband coverage in the Arctic. Phase 1 involved identifying future needs for data communication in the Arctic, in addition to possible technical solutions. In phase 2, the output and conclusions from phase 1 were followed up in more detail. Based on this a conclusion will be made regarding investing in a HEO satellite system for the Arctic (Telenor Satellite Broadcasting, 2014).

- **Communications in the High North and other remote areas (COINOR, 2012-2016):** The primary objective of the COINOR project is to minimize the knowledge gap on telecommunications in the High North, in order to provide sound recommendations on how to alleviate the current lack of infrastructure and technological solutions (Bekkedal and Fjørtoft, 2014). This applies both to the Arctic user community, the oil and gas sector, and the associated suppliers of communication products and services as well as the public authorities.
- **Galileo (**http://www.gsa.europa.eu/galileo/why-galileo**)**, the European navigation system, is under development, planned to be in service from 2016. The complete Galileo constellation will comprise satellites spread evenly around three orbital planes inclined at an angle of 56° to the equator. From most locations, six to eight satellites will always be visible, allowing positions and timing to be determined very accurately to within a few centimetres. Interoperability with the USA system of GPS satellites will increase the reliability of Galileo services.
- **Highly Elliptical Orbit (HEO) satellites** are under feasibility evaluation. Such satellites are expected to provide good communication also in polar regions.
- **Iridium NEXT** (https://www.iridium.com/), the second generation Iridium satellite constellation, is under deployment. Iridium NEXT which will provide L-band data speeds of up to 1.5 Mbps and high-speed Ka-Band service of up to 8 Mbps. Iridium NEXT is scheduled to begin launching in 2015, and planned to be fully deployed within 2017.
- **MARINTEK** has since 2007 run several projects investigating the status of communication at sea in the Arctic. From interviews, theoretical analyses and practical field tests they have learned that the current communication infrastructure is inadequate for the operational requirements of expected future maritime activities in the Arctic.
- **Maritime radio system performance in the High North (MARENOR, 2012-2015):** The MARENOR project aims to quantify the performance of the most common navigation and communication systems being used in the High North, through data acquisition and data analysis. The MARENOR result will be a tool for prediction of navigation and communication system performance in the High North. http://sintef.no/en/marintek/
- **Polaris (2015-2016,** http://due.esrin.esa.int/stse/projects/stse_project.php?id=193**):** The project shall study the user needs and high-level requirements for the next generation of observing systems for the polar regions. In the long-term the project aims at stimulating the development of novel space mission concepts for the polar regions that may exploit new and existing European operational capacity in order to address, in a cost-effective manner, new scientific and operational information needs. The main tasks are:
    - Identify information requirements of polar researchers through close dialogue with key user representative bodies across the breadth of user categories
    - Identify information gaps, considering existing and planned earth observation and other space and non-space based systems (such as GNSS, AIS, telecommunications and in-situ measurements)
    - Prioritise the gaps in consultation with polar research stakeholders
    - Identify potential new integrated information services made possible by the synergetic use of space and other assets to meet the polar information gaps, and perform a preliminary assessment of the high-level mission requirements for supplying these integrated services

7.8 Human resources and competence

The **health aspects of work in extreme climates** are discussed in the IPIECA & OGP report (2009).

Hansen (2014) presents **human factors and special reactions to be aware of** in incidents in cold, dark and remote areas.

Furthermore, the PSA has recently initiated a pre-study for **evaluating the human performance when working in cold climate**. Through this project knowledge will be gathered regarding working environment risk for employees working on units in the Norwegian High North.

Due to the harsh physical conditions in the Arctic some months of the year, there is a need for special training of personnel to ensure that work in the extreme conditions can be conducted safely:

- The humans involved will have to gain competence related to handling ice and icy conditions and evacuation in cold and darkness. Experience from fisheries in these areas is of relevance.
- It is suggested that all personnel involved in working during cold periods should pursue training using the special survival suites developed particularly for cold climate conditions. Personal protection equipment should be tailored for each individual to a much larger degree than for personnel working under normal conditions.
- As long periods of waiting on weather may apply, psychological tests may reveal who has sufficient patience to be involved.
- Awareness about potential psychological and physical effects of Arctic light conditions.
- Competence on Arctic challenges in general, and local challenges in particular, are essential for all aspects of HSE.
- Individual knowledge, skills, attitude and experience are important both to understand (subjective versus objective) and handle new dangers and challenges, and the effects from possible combinations of several challenging factors / dangers.
- Special skills are also needed for certain operations. The new ISO standards on Ice Management (ISO 35104, in preparation) calls, for example, on considerable training, including simulator training in extreme situations.

7.9 Management

For a company involved in operations in the cold climate region, challenges are also faced by the company management, whether it be the operating company or contractors. The management must understand the specific conditions in order to operate safely in the Arctic:

- This do include patience to wait for operational weather and trusting that the staff at the location manage the conditions. The assistance from meteorologists is recommended.
- Undue pressure to work in extreme conditions must be avoided as the ability to limit an unwanted incident to escalate with the possibility for release of hydrocarbons is reduced under such severe conditions.
- It is suggested that staff in management positions conduct training at the location to understand the extreme conditions.
- The planning and contracting must take possible delays into account. Special awareness must be taken in case of dense fog where transport possibilities for personnel may be reduced, possibly causing costly delays.

7.10 Oil spill detection

The scope of this project is measures designed to prevent and contain the escape of fluids into the marine environment from offshore petroleum activities in Arctic and cold climate regions. However, detecting a potential leak is essential in order to limit the potential spill and to prevent the incident to develop further. Furthermore, it is important to detect the leak at the source. Thus, measures related to oil spill detection have been included in this report. Measures related to oil spill response, including monitoring and oil drift simulations, have not been covered by this report.

It is a challenge to detect oil spills, especially in ice covered waters. Traditionally, oil spills have been detected by imaging systems that can be used from helicopters, fixed wing aircraft, vessels and drilling platforms. Visual interpretation from still and video cameras still remain an important element of operational surveillance. A lot of work is done in the field of oil spill detection to develop remote sensing technologies to monitor oil under varying conditions of ice and visibility.

This report has identified the following major international industry initiatives targeting oil spill detection in the Arctic:

- **Arctic Response Technology JIP (ART JIP, http://www.arcticresponsetechnology.org/) on Oil Spill Detection and Mapping in Low Visibility and Ice (2012-2016):** A phase one assessment and evaluation of existing and emerging technologies has been performed that includes an evaluation of further research and development needs, logistical support requirements, and operational considerations including testing opportunities. The project has published two reports on *Oil spill detection and mapping in low visibility and ice: Surface remote sensing* (Puestow et al., 2013) and *The capabilities for detection of oil spills under sea ice from autonomous underwater vehicles* (Wilkinson et al., 2013). Based on this assessment, a test program was developed to identify and qualify the most promising sensors and platforms capable of determining the presence of oil on, in, and under ice and mapping its extent. Phase two experiments were initiated in November 2014.
- **Oil spill response JIP (OSR JIP, 2011-2014, http://oilspillresponseproject.org/):** In response to the Macondo oil spill incident, a JIP on oil spill response was initiated in 2011, managed by IPIECA (The global oil and gas industry association for environmental and social issues on behalf of IOGP). The project is taking proactive steps to develop modern tools and technology to ensure effective solutions are available to handle a potential spill. As part of the JIP, there are four JIPs related to surveillance, monitoring and tracking. Several reports have been published regarding detection of oil spill:
    - Capabilities and Uses of Sensor-Equipped Ocean Vehicles for Subsea and Surface Detection & Tracking of Oil Spills (Battelle, 2014)
    - Capabilities and Uses of Sensor and Video-Equipped Waterborne Surveillance-ROVs for Subsea Detection and Tracking of Oil Spills (Oceaneering, 2014)
    - An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Satellite Remote Sensing (Polar Imaging Ltd., 2014)
    - An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Airborne Remote Sensing (Polar Imaging Ltd., 2015a)
    - Surface Surveillance Capabilities for Oil Spill Response using Remote Sensing (Polar Imaging Ltd., 2015b)

In addition, there are several other industry projects:

- **Advanced acoustic instrumentation for deep sea imaging and sensing in Arctic and harsh environments (2013-2015):** This PRNL funded project is to develop and demonstrate a high resolution acoustic sensor for 3D seabed survey and underside ice profiling with area coverage rate that greatly exceeds currently available technologies such as sidescan and multi-beam sonar. The rationale for this development is that a high coverage rate will minimize the time required to survey a given area, thereby reducing the cost of the survey and the risk for personnel exposed to harsh environmental conditions. High resolution imagery and topography are useful for seabed exploration, infrastructure survey, characterization of ice thickness and composition, and potentially for detecting oil spills either on the seabed or at the ice / seawater interface.

- **Detection of leaks in offshore pipelines JIP (2013-2015):** The JIP led by Southwest Research Institute (SwRI) focuses on distributed sensors for offshore pipeline leak detection. The overall scope was to study the leak behaviour (thermal, acoustic) for various leaks and perform testing of fibre-based systems. The overall objective was to determine, in a controlled environment, if the two candidate technologies, distributed temperature sensing (DTS) and distributed acoustic sensing (DAS), can detect small (<0.25") leaks. Siebenaler et al. (2015) describe the JIP and the physical characteristics of potential underwater leaks using lab-scale experimental analysis. Large-scale test results are planned for publishing in 2015.
- **DNV-RP-F302:2010 Selection and use of subsea leak detection systems (2010):** The objective of this recommended practice is to summarize industry experiences and knowledge with relevance to selection and use of detectors for a subsea leak detection system (DNV, 2010b). The document is a result of a JIP on leak detection ongoing from 2005 to 2010.
- **Leak detection project:** The overall objective of this project is to adapt environmental sampling processor (ESP) modules to the autonomous detection of oil-degrading microbial targets as a means to detect subsurface oil leaks from oil and gas installations (ConocoPhillips and Lundin, 2013). The long-term vision is to accommodate the ESP onto an autonomous underwater vehicle. The project is part of ConocoPhillips' and Lundin's Northern area programme and the host institution is IRIS.
- **Microscale interaction of oil with sea ice for detection and environmental risk management in sustainable operations (MOSIDEO):** The primary objective of the research project MOSIDEO is to advance the 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 ice-covered seas.
- **Offshore leak detection JIP (2014-2015):** DNV GL has taken the initiative to establish a JIP for developing a Recommended Practice for offshore leak detection. The JIP aims at shaping the future of offshore leak detection and gaining state of the art knowledge in this emerging field. The project will define relevant functional requirements and general specifications for a leak detection system as well as developing a methodology for designing an integrated system, including surface and subsea technologies.
- **Oil spill detection and management JIP (initiated 2014):** The objective of the JIP is to improve oil spill management via communication infrastructure and management systems. Firstly, Aptomar will develop the functionality to provide remote control of the SECurus system – a technology that is used to detect and combat oil spills. Secondly, the JIP will develop a system that facilitates integration of all types of existing camera sources – from ROVs and PSVs to platforms and fishing vessels – including geographical information, into Aptomar’s tactical collaboration and management system.

Industry technology and R&D initiatives include:

- **Biota Guard’s Subsea leak detection (http://biotaguard.no/services/subsea-leak-detection/):** Biota Guard’s leak detection service is a highly sensitive early warning system comprising hardware, data management tools, analytical framework and visualization tools. The service uses three complementary detection principles – biosensor, acoustic and optical to provide leak detection service.
- **C-CORE’s Remote sensing technology (https://www.c-core.ca/):** C-CORE's capability in remote sensing centres on expertise in satellite based Earth Observation (EO) and terrestrial radar systems for amongst others monitoring of oil slicks and water quality.
    - **Oil spill detection and modelling in Hudson and Davis Straits (2014):** LOOKNorth completed a study in July 2014 to assess the current state of oil spill monitoring and

response capability in the Hudson Strait and Davis Strait areas, and to recommend improvements; it provides a snapshot of the state of the art in oil spill detection and impact prediction, reviewing existing research on the use of remote sensing technologies for oil spill monitoring in Arctic waters, the modelling of oil fate and trajectories in the presence of ice, and experience to date in Arctic transportation operations. It also includes an assessment of local capabilities in Nunavut (and gaps therein) to respond to oil spills, as well as recommendations to increase local capacity of effective oil spill response (LOOKNorth, 2014).
    - **Participation in the ART JIP** and involved in preparing one of the two reports from phase 1 on *Oil spill detection and mapping in low visibility and ice: Surface remote sensing* (Puestow et al., 2013)
- **INTECSEA's Real-time integrity monitoring system using fibre optics:** INTECSEA is developing a real-time integrity monitoring system which is a sensor-based monitoring system aiming at enhancing the productivity of Arctic pipelines (Thodi et al., 2015). The intent is to assess operating conditions and performance, improve performance and pipeline throughput, extend life, inform the operator if pipeline integrity is compromised, and provide the necessary information to perform optimal inspection and maintenance activities. Thodi et al. (2015) present the detectability and operating principles of fibre optic cable systems in the Arctic including the experience gained from using them in past projects. The paper focuses on detecting integrity threats arising from the unique Arctic design and operational challenges. Furthermore, the paper covers the operating principles and technology status of leak monitoring systems for Arctic pipelines. The paper concludes that fibre optic cable distributed sensing systems, such as distributed temperature sensing and distributed acoustic sensing, have a high potential to be used for Arctic pipelines to detect and locate leakages.
- **ISPAS' Oil spill detection radar** (http://www.ispas.no/): In 2012 ISPAS signed a contract with Statoil for the research and development of a new oil spill detection radar for detecting oil spills at sea. The objective of the project was to develop a high frequency radar for the detection and quantification of oil spills on the sea under all weather conditions. This will significantly improve the oil spill detection capabilities and reduce the number of false alarms and allowing for targeted and efficient oil spill environmental monitoring and management. The radar shall be able to detect oil spills on both calm sea and with waves. The radar will be tested at the Edvard Grieg field at the Norwegian Continental Shelf during 2015. ISPAS has recently signed a contract with Statoil for the delivery of a new advanced Oil Spill Detection radar system for the Johan Sverdrup oil field at the Norwegian Continental Shelf.
- **KSAT, Kongsberg Satellite Services** (http://www.ksat.no/) provides maritime monitoring and surveillance services using data from several radar and optical sources. KSAT is offering near-real-time services providing accurate information to oil and gas and government customers based on satellite imagery within less than 20 minutes.
- **NORUT**, the Northern Research Institute, located in Narvik, Norway has ongoing research related to Arctic Earth Observation and Surveillance Technologies (2009-2017) http://norut.no/nb/prosjekter/arctic-earth-observation-and-surveillance-technologies.
- **Rutter Inc.'s Sigma S6 oil spill detection radar (**http://www.rutter.ca/oil-spill-detection**):** The Sigma S6 Oil Spill Detection (OSD) and monitoring system combines proven strength in early detection with tools that generate essential information about oil spill volume, thickness, deformation and drift. Rutter's systems have been extensively tested and proven effective in independent trials conducted by the Norwegian Clean Seas Association for Operating Companies (NOFO). The systems have been integrated with Sigma S6 Ice Navigator to provide simultaneous oil and ice detection and tracking capabilities on one display.
- **SINTEF's Research on subsea leak detection (**http://www.sintef.no/en**):** SINTEF conducts R&D activities regarding subsea leak detection.

7.11 Development of new concepts for exploration and production activities

Offshore petroleum exploration and production activities in the Arctic impose some unique challenges. This drives the development of new concepts. The following sections present R&D initiatives regarding new concepts for offshore petroleum exploration and production activities in the Arctic in terms of both fixed, floating and subsea structures, that may contribute to preventing oil pollution to sea.

7.11.1 Mobile offshore drilling units (MODUs)

Aker Solutions and Aker Arctic have developed an **Arctic drillship concept design** for a MODU with capabilities to perform extended season drilling in waters with sea ice (Bruun et al., 2015). The objective of the drillship design is to propose a concept that may extend the drilling season in areas with limited open water season by having capability to perform drilling operations during interaction with sea ice. Focus has been on the elements that enables these operations such as design of the drilling topside for low air temperature, capability of performing drilling operations through a forward located turret moonpool, performing internal handling when having a forward located turret moonpool position and design optimisation of hull lines and turret position for sea ice interaction. See Figure 14.

Figure 14 Aker Solutions Arctic Drillship (Courtesy of Aker Solutions)

ConocoPhillips and Keppel Offshore and Marine Technology Centre, have jointly developed a basis of design and specifications for a self-elevating **Arctic MODU** for use in water depths from 10 to 50 meters for drilling a wide range of wells (Shafer et al., 2013). The intention is to achieve year-round operation, development and exploration. Shafer et al. (2013) detail major items that impact the size, weight and configuration of an Arctic MODU. This will result in a conceptual unit design that will be used to determine ice loads, layout and structural design of the Arctic MODU. The MODU will not be designed for the highest possible ice load. In the event an ice feature is forecasted to result in loads that exceed the MODU's capabilities, the MODU will be moved. Furthermore, an ice management system will be in place for all Arctic MODU operations.

GustoMSC has developed a portfolio of solutions for Arctic offshore drilling comprising both jack-up type and drillship type solutions (Wassink and List, 2013). The designs are developed to address the specific challenges of exploratory and development drilling in the Arctic, and are developed to cover the full extent of the Arctic, from very shallow to deep water.

- **The SEA ICE series** of jack-ups has been developed with four circular legs and hydraulic jacking systems. The series is fully winterized and features a sloped hull to reduce ice loads in floating mode. These jack-ups could operate in water depths of 20 to 50 meters and in managed ice conditions of up to 2.0 meters first-year ice.
- **The NanuQ drillship series** has been developed based on the same design philosophies as all GustoMSC drillships. The NanuQ 5,000 TM is the most capable Arctic drillship, capable of extended season to year-round operations in up to 4 meters of multi-year ice. This unit is turret moored, with

DP capability for station-keeping during mooring system hook-up. It is self-propelled and offers ice class up to PC2, allowing year-round access to all Arctic areas. The NanuQ drillship series does also consist of DP units.

Huismann has designed the **JBF Arctic drilling unit** to drill wells in Arctic conditions, moored in ice infested waters with ice thickness up to approximately 2.0 meters (Huisman, 2015). Depending on ice conditions, ice breaker support can be required. The unit consists of a round floater, eight columns and a round deckbox. When operating in ice the unit will ballast to ice draft (partly submerged deckbox) to protect the riser against level ice, rubble and ice ridges. The round conical shaped deckbox has a heavily strengthened structure at waterline level to deflect and break the ice. The round floater is also strengthened for transit through broken ice (icebreaker assisted). When no ice is present the unit operates at its operating draft as a conventional semi-submersible unit. Station keeping in ice infested waters is achieved by a heavy 12-point mooring system. The unit can operate in water-depths between 50 and 1,500 meters. If required the design can be customised for setting the unit on the sea bed in shallow water.

Inocean has developed an **Arctic drillship**. The new unit has been named IN-ICE (Inocean, 2015). The ship is completely enclosed and winterized, is environmentally friendly, and has enhanced logistics / storage facilities. The ice class is for a substantially extended drilling season for a large part of the Arctic – with a PC-4 ice class. The drillship is designed with a conventional bow for operations in rough open water wave conditions, as well as to implement a moderate stern for aft-way operations in managed ice. Inocean envisages the stern more optimized for avoiding ice into the moon pool than for ice breaking, but also because drilling operations in Arctic areas are expected to be conducted primarily in ”managed ice”. Positioning will be done through thruster assisted turret mooring in the shallow parts of the operational area, and by DP in the deeper parts.

Moss Maritime is designing floaters with ice-breaking and survival capabilities to withstand the impact of the Arctic extremes such as **drilling platforms for Arctic environment**, icebreaking FPSOs, icebreakers, icebreaking LNG carriers, gravity base barges (Moss Maritime, 2015).

Sevan Marine is developing a **cylindrical floating drilling unit for Arctic environments**. The cylindrically shaped hull is particularly suitable in drifting ice as it will face the ice with the same shape in all directions. The unit is designed for obtaining good performance both in harsh open water wave conditions as well as in drifting ice. Year round operation requires design with sloped sides for breaking heavy ice.

7.11.2 Drilling of exploration and production wells from land

Extended reach drilling (ERD), designed to drill wells at offshore targets from land-based locations or artificial islands, enables drilling in areas with level ice and/or icebergs without other precautions. Wells are drilled with a horizontal reach of more than 10,000 meters. Rosneft and ExxonMobil performed drilling operations from Sakhalin, with a horizontal reach of 12,033 meters and a measured depth of 13,500 meters (Rosneft, 2015).

This technology can be applied whenever close to shore, however, there are some challenges related to permafrost and erosion of the shoreline.

7.11.3 Seabed drilling rigs

Robotic Drilling Systems is developing a drilling rig to be located submerged at the seabed for cost-effective drilling in deep waters and Arctic areas (Robotic Drilling Systems, 2015). The seabed submerged rig is connected to a surface support vessel through an umbilical with power, control and mud flow. All functions on the rig are remotely controlled from a control room on the surface vessel or from land. The rig is made up of modules that can be lowered via a surface vessel and guided in place by means of guide wires. The rig is filled with water, pressure compensated and encapsulated in order to avoid contamination of the surrounding environment.

Badger Explorer has developed a formation and reservoir evaluation tool which drills into the subsurface and buries itself (http://www.bxpl.com/). It features a slim electrically powered drilling system and carries sensors, which continuously record data, producing logs while drilling, and providing continuous, long-term data in surveillance mode. The Badger Explorer consists of a drill bit driven by an electro-motor and gear, cutting transport, deposition and compression, in addition to spooled cable, through which power is supplied to the tool and data transferred to surface. It is a non-reusable exploration tool that remains permanently underground.

Seabed drilling rig technology reduces the impact of weather and ice conditions, and aims to reduce the risk of adverse events that may lead to accidental discharges to the sea. The technology is intended for exploration drilling in all locations.

7.11.4 Subsea production systems

The **Arctic and sub-Arctic subsea technology JIP (2010-2011)** aimed at offering the industry a mechanism for optimising design schemes and field development architecture for the efficient delivery of hydrocarbons in Arctic and sub-Arctic waters. The JIP investigated the conventional, enhanced, and active subsea production technologies including subsea separation, boosting, compression and direct electric heating systems, suitable for stranded and existing field developments. The objective of the JIP was to encourage the use of proven and evolving technologies from deep-water Gulf of Mexico, offshore Brazil and northern North Sea to enhance production in Arctic and sub-Arctic waters.

FMC Technologies are working on developing **subsea production systems for Arctic conditions**. Furthermore, they are working on developing **lubricants and sealing technology for Arctic conditions**.

Kvaerner Concrete Solutions' deep-water Arctic subsea separation & storage systems: Eie (2015) describes solutions on how deep-water subsea separation of hydrocarbons and storage of oil can be achieved in hostile environments enabling close to continuous production also when surface production facilities have to abandon location (Eie, 2015). The description is based on ongoing development of a subsea separation and storage system for application in deep-water Arctic. Furthermore, Eie (2015) presents overall Arctic field development suggestions based on the solutions. Eie (2015) discusses a possible way to develop large reservoirs located in the Arctic by use of a subsea separation and storage unit. The solution depends on further development and qualification of several technologies additional to the actual subsea separation and storage unit, as outlined by Eie (2015).

Statoil's Åsgard subsea compression is one step closer to realizing the vision of a full offshore processing plant subsea. Subsea processing and especially gas compression is a vital technology to develop fields in deep waters and harsh environments (Statoil, 2015a).

Figure 15 Åsgard subsea compression (Photography by: Harald Pettersen / Statoil)

ThyssenKrupp Marine System GmbH has performed a feasibility study for the development of a **multi-purpose submarine** which could be applied to a variety of offshore operations sub-ice and in harsh weather areas (Brandt et al., 2015). The versatile vessel is designed for several key missions. Installation, inspection, maintenance and repair tasks for subsea facilities can be performed in water depths up to 1500 meters by use of an onboard gantry crane, an automatic storage system and two work class ROVs. The submarine can also be used to perform seabed seismic surveys at the same water depth. Furthermore, the submarine offers abilities to respond to sub-ice oil and gas spills (Brandt et al., 2015). Submarines operating submerged are not affected by harsh weather conditions. The subsea environment can be regarded as rather static compared to the surface. Therefore, submarines can operate year-round without the need for weather windows (Brandt et al., 2015). The study by Brandt et al. (2015) indicates that the multi-purpose submarine is technically feasible. Future work will focus on a sound evaluation of the economic performance and detailed technical studies.

7.11.5 Floating production units

Eni's Goliat FPSO is developed with the circular Sevan FPSO 1000 concept. The circular shape implies that the FPSO does not need to be turned up towards the ice drift direction. As of October 2015, the FPSO is being installed at the field, and is preparing for production.

Technip, in a consortium with Aker Solutions and SBM Offshore, was awarded, by Shtokman Development AG, an engineering contract for the **floating production unit (FPU)** for the offshore portion of the first phase of the integrated development of the Shtokman gas condensate field in Russia. The concept included winterization and disconnection options.

Moss Maritime is designing floaters with ice-breaking and survival capabilities to withstand the impact of the Arctic extremes such as drilling platforms for Arctic environment, **icebreaking FPSOs**, icebreakers, icebreaking LNG carriers, **gravity base barges** (Moss Maritime, 2015).

7.11.6 Support vessels for inspection and maintenance activities

Air cushion vehicles (ACVs): An ACV is a craft capable of travelling over land, water, mud or ice and other surfaces. Andrews et al. (2015) set out the current advances in ACV technology and planned future developments including the results of recent trials.

Arctic Construction and Intervention Vessel (CIVARCTIC): The project investigates a dedicated design basis for a vessel operating in the Northern Norwegian waters with seasonal ice. The primary objective of the project is to extend the operational season for installations and maintenance of subsea oil and gas installations in waters with seasonal ice. As a business case the vessel was scheduled to operate on fields off the coast of Northern Norway and east of Svalbard. The project is divided into the following work packages; 1) Intervention philosophies and tasks, 2) Design guide for metocean and ice, 3) Systematic parameter variation and 4) Environmental footprint.

Autonomous Marine Operations and Systems (AMOS, https://www.ntnu.edu/amos/): The centre works to create a world-leading centre for autonomous marine operations and control systems. AMOS will contribute with fundamental and interdisciplinary knowledge in marine hydrodynamics, ocean constructions and control theory. The research results will be used to develop intelligent ships and ocean structures, autonomous unmanned vehicles (under water, on the surface and in air) and robots for high-precision and safety-critical operations in extreme environments. This is necessary in order to meet challenges related to environmental and climate, safe maritime transport, mapping and surveillance of large ocean and coastal regions, offshore renewable energy, fisheries and aquaculture as well as deep-sea and Arctic oil and gas exploration.

Next generation subsea inspection, maintenance and repair (NextGenIMR, 2014-2017): The project will develop novel integrated sensor platforms with robust perception methods and collision-free motion planning algorithms for subsea inspection and light intervention operations (NTNU, 2015). The project will also focus on subsea factory design, and will especially address autonomous platforms. It combines novel concepts for sensor platforms, advanced localisation and perception methods based on vision and acoustic sensors and collision free path planning and high-level task planning for autonomous services. NextGenIMR results will be tested, verified and demonstrated in full scale test beds available to the project. NTNU and SINTEF cooperate on this project which is sponsored by the Norwegian Research Council, FMC Technologies and Statoil.

Eni's autonomous underwater vehicle (AUV) for environmental monitoring and asset integrity: Eni, in cooperation with Tecnomare, have launched the CLEAN SEA project (Continuous Long-term Environmental and Asset iNtegrity monitoring in SEA) with the objective to use a commercially available AUV, properly upgraded with key enabling technologies, for the execution of environmental monitoring and asset integrity in offshore fields where Eni operates. Buffagni et al. (2014) describe how to reach this goal. A custom designed mission payload, arranged as modular and interchangeable pods, has been installed at the AUV. These modules, characterised by a set of sensors, are built to perform different offshore monitoring activities according to specific needs; automatic water samples collection, visual inspection (asset, seabed) and hydrocarbon leakage detection through automatic chemical analyses of trace pollutants and acoustic survey of seabed and pipelines / flowlines.

Subsea 7's autonomous inspection vehicle (AIV) for subsea inspection in Arctic regions: The AIV developed by Subsea 7 enables complete autonomous inspection of a subsea asset (Jamieson and Hopkins, 2015). The system is deployed using a launch and recovery basket, which can be configured to remain on the seabed for significant periods of time. Jamieson and Hopkins (2015) describe the advanced features of the autonomous inspection vehicle (AIV) technology and discuss how it can be effective in the Arctic regions, under ice operations.

8 Standards and guidelines

There are several standards and guidelines in place for design and operations of platforms, rigs and vessels in the Arctic and cold regions. The most relevant standards and guidelines identified have been included in the following sections.

This section assembles the in-depth information gathering, in addition to the information structuring and documentation steps, see Figure 16.

Figure 16 In-depth information gathering and information structuring and documentation

8.1 International standards

Initiatives identified regarding development and improvement of international standards:

- **The Arctic operations handbook JIP (2012-2013)** focused on the operational activities for transport and installation of fixed, floating and subsea units, as well as for dredging, trenching, pipe laying and floating oil and gas production in Arctic and cold weather conditions. The prime purpose of the JIP was to identify gaps in the existing standards and guidelines. Specific recommendations were subsequently proposed with the intention to contribute to the development of internationally accepted standards and guidelines.

  The Arctic marine operations challenges and operations report (2013) documents the output from the JIP, including the results of the gap analysis and of three pilot projects. The report provides the offshore industry an overview of identified gaps and proposes a large number of recommendations in order to close the gaps. The identified gaps and recommendations could support the further development of ISO TC67 SC8 Arctic operations, ISO 19906 SC7 Offshore structures, ISO 19901-6 Marine operations and future JIPs. Wiersema et al. (2014) describe the Arctic operations handbook JIP.

  In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPs. However, only the SALTO JIP was initiated for various reasons.
  - The aim of the **PractICE JIP** would be to provide a real-time simulation platform enabling practical simulations of offshore operations in ice. It would build on previous conceptual studies, initial model work and would comply with training objectives and requirements set by the industry.
  - The **IceStream JIP** would be a follow-up of the pilot IceStream project. A floating structure would be modelled, along with a generated set of ice particles. Additionally, model tests would be carried out in the NRC ice tank, as well as with artificial ice at MARIN.
  - The **IceTower JIP** would have involved the instrumentation of an offloading tower encountering severe ice floes. During three winter seasons, the loads on the tower and the ice conditions would be monitored.

- The **SALTO JIP** will provide a PC simulation tool for risk-based, probabilistic design to help the industry prepare for the environmental conditions (wind, fog, ice, icing) of the Arctic and, henceforth, to optimise operations of ships and offshore constructions. Pre-knowledge of workability, risk and limiting conditions will lead to enhanced safety and reduced environmental impact.

8.1.1 International Standardization Organization (ISO)

8.1.1.1 ISO 19906:2010 Arctic offshore structures (under revision)

The ISO 19906:2010 Arctic offshore structures standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. The objective is to ensure that offshores structures in Arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value to the owner, the industry and to society in general.

ISO 19906:2010 has been adopted as a national standard by Canada, Russia and the European Union (Frederking, 2012). Furthermore, API has adopted a modified edition of ISO 19906:2010, published as API RP 2N:2015, see section 8.3.1.

Blanchet et al. (2011) provide a brief history of the document preparation as it relates to country and industry involvement, development of technical input, editing and review processes undertaken and acceptance of the document by ISO and its participating members.

The standard is currently under revision lead by the convenor, Karen Muggeridge. Draft International Standard (DIS) version is planned for mid-2016.

8.1.1.2 ISO TC67 SC8 Arctic operation standards (under development)

Based on recommendations from the Barents 2020 project, a new international standardisation Arctic operations subcommittee (SC) SC8 was established in 2012. The scope of the SC8 is standardisation of operations associated with exploration, production and processing of hydrocarbons in onshore and offshore Arctic regions, and other locations characterised by low ambient temperatures and the presence of ice, snow and/or permafrost. Requirements for offshore pipelines and offshore structures are excluded from SC8 as they are included under SC2 and SC7, respectively.

A total of six work groups have been established under SC8 developing a new set of standards for Arctic operations including (Johansen, 2014):

1. Working environment (committee draft, CD, submitted for comments in 2015)
2. Escape, evacuation and rescue
3. Environmental monitoring
4. Ice management (committee draft, CD, submitted for comments in 2015)
5. Arctic materials(committee draft, CD, submitted for comments in 2015)
6. Physical environment data for Arctic operations (committee draft, CD, submitted for comments in 2015)

Two of the new standards are described in more detail below.

ISO 35104 Ice management standard (TC67 SC8 WG4)

The overall objective of the standard is to ensure that ice management is planned, engineered and implemented within defined and recognized safety / confidence levels, wherever they are performed. The following in-ice activities and infrastructures which require ice management are covered by this standard; floating moored and/or dynamically positioned drilling vessels, coring vessels, production facilities and work-over vessels, construction and installation (including trenching, dredging, pipe laying), tanker loading and other offloading operations, protecting subsea installations, seismic operations, oil spill response, bottom founded structures (fixed installations). The development of the standard is led by the convenor, Robin Browne.

ISO 35106 Arctic metocean, ice and seabed data (TC67 SC8 WG6)

The standard specifies requirements and provides recommendations and guidance for the collection, analysis and presentation of relevant physical environmental data for Arctic activities of the petroleum and natural gas industries in the Arctic and cold regions. The development of the standard is led by the convenor, Pavel Liferov.

8.1.2 International Maritime Organization (IMO)

8.1.2.1 Polar Code

IMO has adopted the International Code for Ships Operating in Polar Waters (Polar Code) and related amendments to make it mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL). The Polar Code is expected to enter into force on 1 January 2017 (IMO, 2015).

The Polar Code and SOLAS amendments were adopted during the 94th session of IMO's Maritime Safety Committee (MSC), in November 2014; the environmental provisions and MARPOL amendments were adopted during the 68th session of the Marine Environment Protection Committee (MEPC) in May 2015.

The expected date of entry into force of the SOLAS amendments is 1 January 2017, under the tacit acceptance procedure. It will apply to new ships constructed after that date. Ships constructed before 1 January 2017 will be required to meet the relevant requirements of the Polar Code by the first intermediate or renewal survey, whichever occurs first, after 1 January 2018.

Because it contains both safety and environment related provisions, the Polar Code will be mandatory under both SOLAS and the International Convention for the Prevention of Pollution from Ships (MARPOL).

The Polar Code is intended to cover the full range of shipping-related matters relevant to navigation in water surrounding the two poles. Ship-design, construction and equipment, operational and training concerns, search and rescue will be covered by the code, and in addition protection of the environment and eco-systems of the polar regions will be covered. The code includes mandatory measures regarding both safety and pollution prevention. The code requires ships intending to operate in the defined waters of the Antarctic and Arctic to apply for a Polar Ship Certificate.

8.1.2.2 MODU Code

The code for the construction and equipment of mobile offshore drilling units (MODU Code) was adopted by IMO in 2009. The MODU Code is not Arctic specific, but it does recommend design criteria, construction standards and other safety measures for mobile offshore drilling units so as to minimize the risk to such units, to the personnel on board and to the environment.

8.1.2.3 Guidelines for ships operating in polar waters

The guidelines for ships operating in polar waters aim at mitigating the additional risk imposed on shipping due to the harsh environmental and climatic conditions existing in polar waters (IMO, 2010). The polar environment imposes additional demands on ship systems, including navigation, communications, life-saving appliances, main and auxiliary machinery, environmental protection and damage control, and emphasizes the need to ensure that all ship systems both are capable of functioning effectively under anticipated operating conditions and provide adequate levels of safety in accident and emergency situations. In addition, the guideline recognizes that safe operation in such conditions requires specific attention to human factors, including training and operational procedures.

8.2 Arctic Council

The following Arctic Council initiatives have been identified:

- **Arctic offshore oil and gas guidelines (2009):** The Arctic offshore oil and gas guidelines, issued by the Arctic Council – Protection of the Arctic Marine Environment (PAME) are intended to be of use to the Arctic nations in offshore oil and gas activities during planning, exploration, development, production and decommissioning, with the exception of transportation of oil and gas (Arctic Council, 2009). The goal is to assist regulators in developing standards that can be applied and enforced consistently for all offshore Arctic oil and gas operators. The intention of the guidelines is to encourage the highest standards currently available by defining a set of recommended practices and outline strategic actions for consideration by those responsible for regulation of offshore oil and gas activities in the Arctic. The guidelines may be of help to the industry when planning for oil and gas activities and to the public in understanding Arctic environmental concerns and practices during offshore oil and gas activities.
- **Guidelines for transfer of refined oil and oil products in Arctic waters (2004):** The guidelines for transfer of refined oil and oil products in Arctic waters were developed for vessels operating in the Arctic (Arctic Council, 2004). The use of the guidelines is encouraged in all ice-infested waters. The aim is to prevent spillage during cargo / fuel oil transfer. According to the guidelines, cargo / oil fuel spillage can be prevented by: securing that reasonable precautions have been taken; that adequate resources can be deployed if unforeseen problems develop; and making sure that transfer supervisors and their crew are able to work safely and carefully.
- **Overview of standards for petroleum and maritime activities in the Arctic (initiated 2015):** The Arctic Council - Emergency, Prevention, Preparedness and Response (EPPR) has initiated a project with the objective of establishing an overview of standards for petroleum and maritime activities in the Arctic. Through the work, it shall be evaluated how the need for standards is identified, how standards are developed, established and maintained, and who participates in the different phases of the work.

8.3 National standards

An overview of selected national regulators' reference and use of national, regional, international and industry standards in their regulatory documents can be found in IOGP report no. 426 on regulators' use of standards (IOGP, 2010). The IOGP report particularly focuses on standards for materials, equipment, systems and structures for the offshore petroleum industry. Furthermore, the IOGP report attempts to analyse the documents prepared by national and provincial lawmakers and the regulators themselves.

8.3.1 American Petroleum Institute (API)

API RP 2N Recommended practice for planning, designing and constructing structures and pipelines for Arctic conditions

The API RP 2N Recommended Practice for planning, designing and constructing structures and pipelines for Arctic conditions was first published in 1982. API RP 2N served as the basis for ISO 19906 Arctic offshore structures, which was published in 2010. In April 2015, a new edition of API RP 2N was published. The new edition is a modified adoption of the ISO 19906:2010.

The main observed differences between the ISO 19906:2010 and the API RP 2N standards are:

- API RP 2N uses the wording ‘loads’ and ‘loads effects’ rather than ‘actions’ and ‘actions effects’ used by ISO 19906
- API RP 2N does not mention a reliability target expressed as annual failure probability at 1E-5 for L1 structures as given in Table A.7-1 of ISO 19906

API RP 17W:2014 Subsea capping stacks

This recommended practice provides recommended practices for design, manufacture and use of subsea capping stacks. The document applies to the construction of new subsea capping stacks and can be used to improve existing subsea capping stacks. The standard does not include recommendations or procedures nor equipment for containment systems that may be connected to a subsea capping stack.

API RP 96:2013 Deepwater well design and construction

This recommended practice provides engineers a reference for deep-water well design as well as drilling and completion operations. This recommended practice can also be useful to support internal reviews, internal approvals, contractor engagements, and regulatory approvals.

API Specification 4F:2013 Specification for drilling and well servicing structures

This specification states requirements and gives recommendations for suitable steel structures for drilling and well servicing operations in the petroleum industry, provides a uniform method of rating the structures, and provides two Product Specification Levels. This specification that addresses the fabrication of such structures used in cold climate.

8.3.2 Canadian standards

In Canada the ISO 19906:2010 Arctic offshore structures standard has been fully adopted without modification and issued (CAN/CSA-ISO 19906:11).

Frederking (2012) compares standards for predicting ice forces on Arctic offshore structures, amongst others the ISO 19906:2010 standard and the previous Canadian standard CAN/CSA S471-04 General requirements, design criteria, the environment, and loads, published in 2004. ISO 19906:2010 incorporates guidance on ice thickness and geometry effects from the Canadian standard.

8.3.3 Russian standards

Frederking (2012) compares standards for predicting ice forces on Arctic offshore structures, amongst others the ISO 19906:2010 standard and the Russian Federation’s SNiP 2.06.04-82* Loads and effects on hydrotechnical structures (from waves, ice and vessels) , published in 1995 (Note, the * indicates this is the later 1995 edition). ISO 19906:2010 incorporates guidance on ice strength from the Russian standard.

Russia has adopted ISO 19906:2010 Arctic offshore structures as a national standard (Frederking, 2012). However, reference should still be made to the Russian standard VSN 41.88 Design of ice-resistant fixed platforms and SNiP 2.06.04-82 Loads and effects on hydrotechnical structures (from waves, ice and vessels) for design of fixed offshore structures (Barents 2020, 2009).

8.3.4 Norwegian standards

NORSOK D-010 Well integrity in drilling and well operations standard

NORSOK D-2010 (2013) defines the minimum functional and performance oriented requirements and guidelines for well design, planning and execution of safe well operations. The focus of the standard is well integrity.

NORSOK N-003 Actions and action effects

Edition 3 of the NORSOK standard N-003 Actions and action effects is under development, planned to be published in 2015. The standard specifies general principles and guidelines for determination of characteristic actions and action effects for the structural design and assessment and for the design verification of structures. The standard is applicable to the design and assessment of complete structures including substructures, topside structures, vessel hulls, foundations, mooring systems, risers and subsea installations for all types of offshore structures used in the petroleum activities, including bottom-founded structures as well as floating structures. The standard applies for the different stages of construction (namely fabrication, transportation and installation), to the use of the structure during its intended life, and to its abandonment. Aspects related to verification and quality control are also addressed.

The standard is primarily written for facilities on the Norwegian continental shelf (including the continental shelf of Svalbard) as defined by the Norwegian Petroleum Directorate 16 June 2014, but the principles may also be applicable for other areas.

8.4 Classification societies

For drilling rigs, class rules are the basic certification governing design and deployment of an Arctic class drilling rig (NPC, 2015). An Arctic notation will be required for conditions with low temperatures and/or sea ice.

The following initiatives have been identified:

- **IACS Requirements for polar class vessels (2011):** The International Association of Classification Societies (IACS) has published harmonized rules for polar class vessels (IACS, 2011). The IACS unified requirements for polar ships apply to ships constructed of steel and intended for navigation in ice-infested polar waters, except icebreakers.
- **OCIMF Offshore vessel operations in ice and/or severe sub-zero temperatures (2014):** The Oil Companies International Marine Forum (OCIMF) has prepared a report with the purpose of providing guidance to operators and charterers of offshore support vessels employed for use in areas impacted by ice or severe sub-zero temperatures with the aim of encouraging high standards of safety and environmental protection for those operating in Arctic and Sub-Arctic regions (OCIMF, 2014).

The most relevant guidelines, recommended practices and standards regarding operations in the Arctic published by classification societies are described below. The classification societies are presented in alphabetical order, while the documents are listed in chronological order.

8.4.1 American Bureau of Shipping (ABS)

The following ABS notifications have been identified for offshore petroleum activities in Arctic and cold climate regions:

- **Guidance notes on ice class (2014):** The purpose of the guidance notes on ice class is to provide ship designers with a clear guidance on alternative design procedures for hull side structures, on alternative methods for determination of power requirements and on procedures for propeller strength assessment based on the finite element method for Baltic ice class vessels (ABS, 2014a).

- **Guide for vessels operating in low temperature environments (LTE guide, 2014):** ABS issued this guide to assist the marine industry in the operation of merchant vessels in low temperature environments (ABS, 2014b). The operation presents challenges for designers, builders, owners and operators that are related directly to construction, outfitting and operation of vessels and issues pertaining to the ability of the crew to function in a difficult environment. Included in the guide are the ABS criteria that are intended to assist in the design, operation and maintenance of vessels continuously operating in ice, occasionally operating in ice and which are operating in low temperatures in the absence of ice.
- **Guide for ice loads monitoring systems (2011):** The guide provides requirements for the installation of, and the information to be provided by, ice loads monitoring systems fitted on ice classed ABS vessels (ABS, 2011). The systems are intended as an aid when a vessel is operating in ice-infested waters so that appropriate action can be taken to minimize the likelihood of the vessel sustaining structural damage from interaction with the ice.
- **Winterization guidelines for LNG/CNG carriers in Arctic environments (2006):** ABS has prepared a paper discussing ship designs for transportation of oil and gas in the Arctic region and Baltic Sea and operation challenges for this trade from an ABS class perspective (ABS, 2006). The paper focuses on two related perspectives:
    - Winterization of vessels operating in the Arctic environment
    - Implications for design, winterization and operations due to the needs of humans operating under Arctic conditions

8.4.2 Bureau Veritas

The following Bureau Veritas notifications have been identified for offshore petroleum activities in Arctic and cold climate regions:

- **Rule note NR 616 Ice load monitoring system (2015):** The rule note applies to ships which are fitted with equipment continuously monitoring ice loads exerted on ship's hull by ice formations. The rule includes separate sections for design, installation, testing and surveys.
- **Rule note NR 527 Rules for the classification of Polar Class and Icebreaker ships (2013):** The rule note applies to ships constructed of steel and intended for navigation in ice-infested polar waters, including icebreakers. The requirements apply in addition to the applicable requirements of NR 467 Rules for the classification of steel ships. The rule note includes rules regarding material and welding, design ice loads, requirements to machinery and propulsions, auxiliary systems, cooling water, ballast and ventilation system.
- **Guidance note NI 543 Ice reinforcement selection in different world navigation areas (2013):** This guidance note aims to provide advice on the Ice Class or Polar Class notation to be adopted for the navigation in areas such as the Canadian Arctic, the Greenland waters, the Russian Arctic, the Baltic Sea, the Antarctic and some other locations in Central and Eastern Europe. Based on the climatic conditions in a given area at a specific time of the year and the local legislation where applicable, this note allows identifying the most appropriate additional class notation for navigation in ice.
- **Rule note NR 584 Propulsors in ice (2012):** The rule note applies in addition to NR 467 Rules for the classification of steel ships and NR 527 Rules of the classification of Polar Class and icebreaker ships to the following types of propulsors intended for navigation in ice infested waters; a) Podded propulsor, with or without nozzle and b) Geared propulsor, with or without nozzle. The rule includes sections for materials, ice interaction, machinery design and electrical installation.
- **Guidance note NI 565 Ice characteristics and ice / structure interactions (2010):** The purpose of the guidance note is to collect and provide data on the ice (physical and mechanical characteristics) as well as giving some guidance on the calculations of the forces generated by the ice on ships and

offshore structures. The note includes information on different types of ice and on the mechanical properties of these different types of ice, it includes analytical formulae and methods to estimate forces applied on the structures due to ice, with respect to the different modes of failure of the ice. These pressures and loads may be used to assess the strength of the structure.

- **COLD notation** to deal with low ambient temperatures, frozen spray (icing of ships) and reduced effectiveness of components:
    - Material class and grade selection for low air temperatures
    - Decks and superstructures
    - Stability
    - Propulsion and other essential services (e.g. firefighting, lifesaving, mooring equipment)
    - Electricity production
    - Navigation
    - Crew protection and elimination of ice where necessary for safe access
    - Lifting appliances

8.4.3 DNV GL

The following DNV GL notifications have been identified for offshore petroleum activities in Arctic and cold climate regions:

- **DNVGL-OS-A201 Winterization for cold climate operations (2015):** The objective of the standard is to provide general principles for preparation of mobile units and offshore installations for intended operations in cold climate conditions (DNV GL, 2015a). The standard has been developed for general world-wide application. The objective of winterization is ensuring that a vessel is capable of and suitably prepared for operations in cold climates. This is provided for by setting functional requirements to systems and equipment which are intended to be in operation in cold-climate conditions.
- **DNV-OS-F101 Submarine pipeline systems (2013):** The standard gives criteria and recommendations on concept development, design, construction, operation and abandonment of submarine pipeline systems (DNV, 2013a). The objectives of the standard are to ensure that the concept development, design, construction, operation and abandonment of pipeline systems are safe and conducted with due regard to public safety and the protection of the environment, provide an internationally acceptable standard of safety for submarine pipeline systems by defining minimum requirements for concept development, design, construction, operation and abandonment, serve as a technical reference document in contractual matters between purchaser and contractor and serve as a guideline for designers, purchaser and contractors. The standard includes a section on the design of pipelines subjected to potential ice interaction.
- **DNV-RP-A203 Technology qualification (2013):** The objective of this recommended practice is to provide the industry with a systematic approach to technology qualification, ensuring that the technology functions reliably within specified limits (DNV, 2013b). The approach is applicable for components, equipment and systems, which are not already covered by a validated set of requirements (such as an applicable standard). The recommended practice describes the philosophy and principles of technology qualification in addition to the basic technology qualification process.
- **DNV-RP-C209 Arctic environmental conditions, ice loads and load effects (under development):** This recommended practice is under development and expected for hearing in 2015. The development of this RP is based on experiences from the ICESTRUCT JIP. The recommended practice will provide practical and consistent design recommendations for fixed and floating structures in ice. It will provide guidance where existing codes are incomplete, silent or merely provide functional requirements.

- **DNV-RP-F107 Risk assessment of pipeline protection (2010):** The recommended practice presents a risk-based approach for assessing pipeline protection against accidental external loads (DNV, 2010a).
- **DNV-RP-F302:2010 Selection and use of subsea leak detection systems (2010):** The objective of this recommended practice is to summarize industry experiences and knowledge with relevance to selection and use of detectors for a subsea leak detection system (DNV, 2010b). The document is a result of a JIP on leak detection ongoing from 2005 to 2010.

8.4.4 Lloyd’s Register

The following Lloyd’s Register notifications have been identified for offshore petroleum activities in Arctic and cold climate regions:

- **Rules for ice and cold operations (2015):** The rules state the requirements for ships intended for operations in ice and cold conditions. It is included in Lloyd's Register rules and regulations for the classification of ships part 8 (Lloyd’s Register, 2015).
- **Rules for winterization of ships (2015, provisional):** Lloyd’s Register has developed winterization rules which account for the specific nature of operating in low temperature environment. In the development of these rules, they focused on the need to undertake systematic review of the ship and its systems, using a risk assessment approach for material selection of deck equipment and systems as an illustrative example. The winterization rules will provide a level of protection for ships that is commensurate with the envisaged operations and arrangements.

9 R&D centres, forums, portals, projects and programs

Several forums and portals exist where one purpose is to cooperate with other partners to gain and share knowledge and competence regarding Arctic field development and operations. Furthermore, there are several centres, projects and programs focusing on R&D activities related to offshore petroleum development and operations in Arctic and cold climate regions. Some of the identified centres, forums, portals, projects and programs that focus on Arctic field development and operations are listed below, in alphabetic order.

This section assembles the in-depth information gathering, in addition to the information structuring and documentation steps, see Figure 17.

Figure 17 In-depth information gathering and information structuring and documentation

9.1 ABS' Harsh Environment Technology Center (HETC)

In 2009, ABS expanded its polar and harsh environment program located within ABS' Technology Department by creating the ABS Harsh Environment Technology Center (HETC) located on the campus of Memorial University of Newfoundland (MUN) in St. John's Canada (http://ww2.eagle.org/en/what-we-offer/offshore-energy/harsh-environment.html). The centre supports the development of technologies for ships and offshore structures operating in harsh environments, particularly the Arctic. Applied research is conducted to study vessels and units operating in ice covered waters, low temperature environments and severe wave and wind climates.

9.2 Arctic center for unmanned aircraft (ASUF)

The Arctic center for unmanned aircraft (ASUF, http://www.asuf.no/english) is a national and international focal point in the use of unmanned aircraft for emergency preparedness, environmental monitoring and technology development in the Arctic. The center also contributes to increased safety in connection with commercial flights and ambulance, rescue and police operations. ASUF develops communication systems, sensors and instruments, algorithmic and analytical tools and navigation and control systems, as well as testing new materials and adapting these for use in cold and extreme climates.

9.3 ARCtic Petroleum Exploration (ARCEx)

The research centre for ARCtic Petroleum Exploration (ARCEx, http://www.arcex.no/) is a national centre, with several national and international partners, hosted at the Department of Geology at the University in Tromsø, the Arctic University of Norway. The project was initiated in 2014 and has a duration of eight years.

The overarching goal of ARCEx is to create new knowledge about the petroleum resources in the Arctic and to provide essential knowledge and methodology for eco-safe exploration.

Five work packages have been established:

- Basin analysis

- Petroleum systems and play concepts
- Environment risk management
- Technology for eco-safe exploration in the Arctic
- Education

9.4 Arctic Info – Strategic Environmental Impact Assessment of development of the Arctic

The Strategic Environmental Impact Assessment of development of the Arctic strengthens communication and outreach within the EU and between the EU and the Arctic community about the contribution the EU is making to address environmental and other issues raised by the rapid development of the Arctic region as a result of economic and climate change (http://www.arcticinfo.eu/).

The primary objective is to compile stakeholders' knowledge and perspectives on the scientific information about the development of the Arctic as well as increase awareness about the Arctic and its changing political, economic and environmental landscape, and the impact of EU policies. The objective enhances the use of impact assessment and its importance as a tool and a channel to put together information for the use of decision- and policy-makers and the related legal processes.

The secondary objective is to test the effectiveness and sustainability of the network of leading communication and research centres as the basis of a possible future European Arctic Information Centre aiming at facilitating information exchange between the EU institutions, Arctic stakeholders and the general public.

The project is comprised of four work packages:

- EU Arctic information centre feasibility study
- Impact assessment
- Outreach and communication
- Project management

The EU Arctic information centre feasibility study has been included in this report because one of the main activities was to develop an Arctic initiatives compendium. The European Arctic initiatives compendium compiles flagship initiatives undertaken in the Arctic regions by member states and actors operating within states belonging to the European Union (EU) or the European Economic Area. It aims to assist in an Arctic information centre feasibility study; to provide a window into Arctic initiatives that may inform the European Arctic impact assessment which forms part of the preparatory action; and to inform the European Commission on European Arctic initiatives. The compendium provides an overview of existing inventories and reports before proceeding to detail European infrastructural and institutional initiatives in the Arctic. The compendium documents major strategic processes initiated by European bodies in the Arctic. It also outlines initiatives related to monitoring and assessment as well as commercial development.

9.5 Autonomous Marine Operations and Systems (AMOS)

The centre for Autonomous Marine Operations and Systems (AMOS, https://www.ntnu.edu/amos/) works to create a world-leading centre for autonomous marine operations and control systems. AMOS will contribute with fundamental and interdisciplinary knowledge in marine hydrodynamics, ocean constructions and control theory. The research results will be used to develop intelligent ships and ocean structures, autonomous unmanned vehicles (under water, on the surface and in air) and robots for high-precision and safety-critical operations in extreme environments. This is necessary in order to meet challenges related to environmental and climate, safe maritime transport, mapping and surveillance of large ocean and coastal regions, offshore renewable energy, fisheries and aquaculture as well as deep-sea and Arctic oil and gas exploration. AMOS projects are:

- Renewable offshore energy
- Intelligent aquaculture structures
- Autonomous unmanned vehicles
- Autonomous underwater robotics
- Autonomous unmanned aerial vehicles
- Energy and green operations
- Autonomous marine operations
- Accidents and abnormal events
- Subsea intervention

9.6 Barents Sea Exploration and Cooperation (BaSEC)

The BaSEC project (Barents Sea Exploration and Cooperation) is a joint initiative project between the active operators in the Norwegian part of the Barents Sea. The JIP was initiated in 2015 and will initially last for three years (http://www.statoil.com/en/NewsAndMedia/News/2015/Pages/21Apr_Barents_conf.aspx).

The program has formed work groups on several areas to ensure that the expectations that are stated by the governing authorities are met through strengthening of HSE and operational preparedness for exploration activities. The work groups are listed below:

- Metocean and ice
- Environmental and oil spill response
- Logistics and emergency response
- Mobile drilling units
- Health and working environment

9.7 BarentsObserver

http://barentsobserver.com/ is an open internet news service, which offers daily updated news from and about the Barents Region and the Arctic. The site was founded in 2002 and has since 2005 been run by the Norwegian Barents Secretariat. Staff-writers are employees of the secretariat. The news-desk is located in Kirkenes, northern Norway.

The site presents news stories from the northern parts of all the four countries in the region: Russia, Norway, Sweden and Finland. All news stories are published in English and Russian.

All news material is categorized in: Energy, Security, Nature, Business, Arctic, Culture, Borders, Politics and Society. An archive search function gives you full access to the news archive, which presently contains more than 15.000 news reports. BarentsObserver also provides background cross-border information about the Barents cooperation and bilateral contacts between the member regions.

9.8 BarentsWatch

https://www.barentswatch.no/en/ is a comprehensive monitoring and information system for large parts of the world's northern seas.

By coordinating information and developing new services based on the combination of data, BarentsWatch will disseminate a better factual basis and more comprehensive picture of the activities in, and condition of, our seas and coastal areas.

The system will make relevant information and services more easily accessible for authorities, decision-makers and general users. This will simplify access to and ensure the exchange of public information.

An open part of BarentsWatch shall be an information portal available to everyone. This was launched in 2012, and is being developed incrementally. The portal has information about topics such as the climate and environment, marine resources, oil and gas, maritime transport and maritime law, among other things. There are also map services, an overview of ports, and news from about 25 partners.

9.9 Centre for Arctic Resource Development (CARD)

The Centre for Arctic Resource Development (CARD, https://www.card-arctic.ca/) is a medium to long term R&D initiative dedicated to responsible, cost-effective hydrocarbon development in Arctic regions that was established in 2011. Arctic environments present formidable barriers to hydrocarbon development. CARD serves as focal point for planning, coordinating and conducting research to fill gaps in the knowledge, technology, methodology and training needed to remove these barriers. CARD research programs are organized into core areas of:

- Ice Mechanics
- Ice Management and Station-Keeping in Ice
- Floating System Modelling

CARD is located within C-CORE complex of facilities at Memorial University of Newfoundland (MUN) in St. Johns, Canada. It forms part of a well-established and continually evolving Newfoundland research and development community and technology cluster.

CARD is led by C-CORE. Other partners are Hibernia, R&D Corporation of Newfoundland and Labrador, Terra-Nova and MUN.

9.10 Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA)

The centre for integrated remote sensing and forecasting for Arctic operations (CIRFA, https://cirfa.uit.no/) project was started in 2015 and will have a duration of up to eight years. The main objective of the centre is to develop knowledge and technology for the monitoring of maritime conditions and forecasting of weather, emissions and sea and ice conditions in Arctic waters. These factors are essential for the petroleum, shipping and fishing industries to be able to conduct safe and sustainable operations in the northern waters.

Seven work packages have been established:

- Ocean remote sensing
- Sea ice, iceberg and growler remote sensing
- Oil spill remote sensing
- Remotely piloted aircraft systems (RPAS) technologies
- Drift modelling and prediction
- Data collection and field work
- Pilot service demonstration

9.11 Chevron's Arctic Center

Chevron's Arctic Center (http://www.chevron.ca/our-businesses/chevron-arctic-center) is a centralized, multidisciplinary group of Arctic subject matter experts from a wide range of engineering disciplines and operational backgrounds, including; drilling, Arctic oil spill response, facilities and geotechnical engineering, naval architecture, logistics, environmental, regulatory affairs, indigenous and stakeholder consultation, ice regimes/ice management and Master Mariners. Chevron Arctic Center supports all stages of Chevron projects in Arctic and ice-prone regions globally. Chevron Arctic Center specialists play a key role in identifying, and aiding in providing solutions to, a range of specific Arctic issues, including technological research and development.

9.12 ColdTech – Sustainable Arctic Technology

The ColdTech project is a research initiative of the NORDSATSING program of the Research Council of Norway to promote sustainable development in northern Norway (http://www.arctic-technology.com/). Arctic technology covers most aspects of construction, operations and living in the Arctic region. Cold climate technology is technology developed to address challenges and to utilize advantages of cold climate. ColdTech is a platform to support sustainable development of education in the north, networking between research and industry, competence development amongst ColdTech partners (including industry and R&D institutes and universities), and state-of-the-art research activities. It aims to strengthen both research and industry northern Norway.

9.13 DrillWell – Drilling and Well Centre for Improved Recovery

The vision of DrillWell – the Drilling and Well Centre for Improved Recovery is to unlock petroleum resources through better drilling and well technology (http://drillwell.no/).

The Drilling and Well Centre for Improved Recovery was established in 2010 and received status as a Centre for Research Based Innovation (SFI) from the Research Council of Norway in 2011. DrillWell's objective is to improve drilling and well technology, providing improved safety for people and the environment, and value creation through better resource development, improved operational efficiency and reduced costs.

This will be achieved by targeted research and development, focusing on 1) Safe and efficient drilling process, 2) Drilling solutions for improved recovery and 3) Well solutions for improved recovery.

Some research and development activities are Arctic specific.

The developed technology and solutions will be commercially available in the market through cooperation with the service industry.

9.14 High North HSE challenges project by the Norwegian oil and gas association

The initiative "HSE challenges in the High North" was launched by the Norwegian Oil and Gas Association in 2010 as a three part cooperation between the industries organisations, labour unions and authorities (https://www.norskoljeoggass.no/no/HMS-utfordringer-i-nordomradene/).

The purpose of the work was to increase the knowledge and establish a common understanding in the industry on the challenges one may experience with petroleum operations in the High North.

A large volume of literature and other information was gathered, systemized and assessed. These formed the basis for six thematic working seminars with invited delegates and expert keynote speakers. At the seminars a large number of issues were raised and discussed and afterwards systemized by the secretariat.

The themes of the seminars were:

- Climatic conditions and communication
- Health and working environment
- Helicopter logistics and helicopter emergency preparedness
- Risk management and design
- Emergency preparedness (other than helicopter)
- Logistics and ice control

Following the seminars, necessary actions to solve the unsolved issues were identified.

The work was finalized with an open summary conference in November 2014 and a summary report with recommendations for further work under the following headlines (Norwegian Oil and Gas Association, 2015):

- Improved weather forecasts
- Emergency preparedness, clarification on industry and public responsibilities
- Implementation of remote medical support (telemedical communication)
- Satellite communication
- Helicopter safety
- Operational guidelines
- Clothing and work protection equipment
- Contributions to the work on the ISO TC67 SC8 Arctic operation standards
- Recommendations for R&D programmes

9.15 INTSOK

INTSOK – Norwegian oil and gas partners – was established in 1997 as an independent non-profit foundation to strengthen the long-term basis for value-creating and employment in the Norwegian oil and gas industry through expanding the industry's international business activities (http://www.intsok.com/). The objective is to promote the Norwegian oil and gas industry's leading expertise, technology and experience to key clients in international markets and to provide market information to partners.

INTSOK led the RU-NO Barents Project; a Russian – Norwegian oil & gas industry cooperation project that assessed the gap between the technology currently available and the technology needed for extracting oil and gas resources in the Barents, Pechora and Kara Seas in an environmentally sound and safe way. See section 6.4.

INTSOK has recently initiated a new project that is a spin-off from the RU-NO Barents project. A catalogue of Norwegian Arctic and cold climate technology and experience was published in February 2015. The new project will further develop this catalogue, mapping industry capabilities, and publishing the Norwegian capabilities on the web and in printed catalogues. Both offshore maritime and petroleum industry will be covered.

9.16 Lloyd's Register applied technology group; polar technologies

Lloyd's Register has an applied technology group. The group provides multidisciplinary consulting services, engineering analysis software and contract research services to clients in industry and government worldwide. The group has capabilities within the following areas:

- Public Safety
- Survivability
- Life-cycle management
- Polar technologies
- Advances tools
- Emerging technologies

Within polar technologies, the group work to progress regulatory development hand-in-hand with commercial and government asset development (http://www.lr.org/en/marine/technology-and-innovation/AppliedTechnologyGroup/polartechnologies.aspx). The specialist areas of expertise are:

- Polar code development

- Ice and cold operations
- Ice damage assessment
- Structural analysis
- Strength assessment
- Risk assessment
- Vessel reliability studies

9.17 LOOKNorth

LOOKNorth (Leading Operational Observations and Knowledge for the North, https://www.looknorth.org/) is a national (Canadian) centre of excellence for commercialization and research hosted by C-CORE. In collaboration with a broad network of industry, northern, business and research partners, LOOKNorth validates and drives commercialization of satellite and other monitoring technologies for use in these challenging and environmentally sensitive environments to support safe and sustainable development of Canada's northern natural resources. It promotes the use of remote sensing technologies in environmental monitoring for northern stakeholder groups.

9.18 Maritime Surveillance in the Northern Sea Basins (MARSUNO)

The Maritime Surveillance in the Northern Sea Basins (MARSUNO) project was a pilot project initiated by the European Commission. 24 authorities from 10 countries are partners in the project, which aimed to achieve a higher degree of interoperability among existing monitoring and tracking systems in order to improve maritime surveillance in the Baltic Sea and the North Sea area. The main purpose of the pilot project was to create a common information sharing environment for the EU maritime domain in order to optimize the efficiency and the cost of maritime surveillance throughout the EU.

The work was divided into six work groups:

- Integrated border management – law enforcement
- Vessel traffic monitoring information system
- Maritime pollution response
- Search and rescue
- Fisheries control
- Maritime situational awareness

(http://ec.europa.eu/newsroom/mare/itemdetail.cfm?subweb=342&lang=en&item_id=8669)

The project covered the Baltic Sea and North Sea. It is suggested that this project could be extended to include other cold region areas such as the Barents Sea.

9.19 NRC's Arctic program

The National Research Council of Canada (NRC) has a research program dedicated to the Arctic (http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/arctic.html). By partnering with the northern shipping and mining industries, as well as with government regulators and operators, the program develops technologies that will result in safer and more efficient shipping operations in ice-covered waters. The Arctic program also works to improve petroleum development by optimising ice management, investigating ice loads on offshore structure, developing oil spill solutions and improving the performance of life-saving appliances (LSA) in extreme and remote environments.

9.20 Petro Arctic

Petro Arctic is an interest organization for companies wishing to position themselves as suppliers to the development and operation of petroleum projects on the northern Norwegian shelf (http://www.petroarctic.no/). The main objective of Petro Arctic is to get as large deliveries of goods and services as possible from the member companies to producing fields or fields under development in the Norwegian Sea North and Barents Sea. This is achieved by marketing the member companies to operators and builders, as well as through motivating and preparing members through participation in networking and skills development program. Petro Arctic was established in 1997. Operation of association funded by the association's members, main partners Statoil and Eni Norway, other partners are OMV, Lundin, Total, Dong, Det Norske and GDF SUEZ.

9.21 Petroleum Research Newfoundland & Labrador (PRNL)

The Petroleum Research Newfoundland & Labrador (PRNL, http://pr-ac.ca/) is a federally-incorporated, member based, non-for-profit organization that facilitates research and technology development and delivers value to members by identifying opportunities, developing proposals, and funding and managing the execution of projects on behalf of the Newfoundland and Labrador offshore oil and gas industry (PRNL, 2015). PRNL seeks proposals for research and technology development projects that address the operational, technical and business of its members. The members are Chevron Canada Resources, ExxonMobil Canada, Husky Energy, Statoil Canada and Suncor Energy.

9.22 Polar View

Polar View (http://www.polarview.org/) is a global organization providing satellite-based information and data services in the polar regions and the cryosphere. Their services include enhanced sea ice information (charts and forecasts) as well as ice-edge and iceberg monitoring data. They also provide monitoring services for lake and river ice, snow cover maps and glacier monitoring and assessment.

The Polar View team is comprised of a dynamic group of service providers, government agencies, research institutes, system developers and universities from over 9 countries across Europe and Canada. Each organization brings diverse and complementary skills and world-renowned expertise in polar earth observation technologies, applications and research. The team delivers data and information services for addressing polar issues that meet the ongoing needs of its user sectors, including marine transportation, oil and gas, emergency management and fishing.

9.23 Shell Ice and Weather Advisory Center (SIWAC)

In the absence of pooled forecasting services and operational-grade forecasting capacity by public weather services, Shell has developed and operates an in-house, Anchorage based, forecasting program designed specifically for the demands and requirements of Shell's Alaska operations. Shell Ice and Weather Advisory Center (SIWAC, http://www.siwac.com/) is a focused ice and weather forecast operation covering the offshore and coastal areas from the Gulf of Alaska to the Canadian Beaufort Sea. SIWAC consists of a team of fulltime Arctic experienced forecasters working in a 24/7 rotation schedule and are fully integrated into the operations process, directly engaging with field personnel and decision makers.

Development of differentiating forecast products and services depends not only on an expert team, but also a robust observation program consisting of contracted and public satellite imagery, a network of metocean buoys, satellite-tracked ice movement beacons, and steady stream of field observations from specially trained personnel abroad marine and aviation assets. The SIWAC forecasters develop numerous daily products including site-specific, wide-area, vessel routing, and weather window forecasts that are delivered to end users through websites and live briefings. To aid in improving forecasting performance and research across the board, Shell entered into a Memorandum of Agreement with the National Oceanic and

Atmospheric Administration (NOAA) in 2012. This collaborative agreement makes Shell's Arctic metocean data and ice charts publically available through NOAA and fosters dialog between the SIWAC and NOAA forecasters.

9.24 Sustainable Arctic Marine and Coastal Technology (SAMCoT)

SAMCoT (Sustainable Arctic Marine and Coastal Technology, https://www.ntnu.edu/samcot) is a centre for research based innovation for the development of robust technology needed by the industry for sustainable exploration and exploitation of the Arctic region (NTNU, 2015). SAMCoT started in 2011, and is tasked to meet the engineering challenges due to ice, permafrost and changing climate for the benefit of the energy sector and society. The objectives of SAMCoT are to provide the research based knowledge necessary in order for the industry to develop Arctic technology for the energy sector, to address the implications of the presence of ice and permafrost and to produce knowledge that will ensure sustainable and safe exploration, exploitation and transport from and within the Arctic region and to provide the foundation for further development of environmentally adapted coastal infrastructure.

10 Conclusions and recommendations for further work

This report establishes 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. A comprehensive overview of measures has been established based on contributions from the industry and R&D institutions through a baseline survey in addition to reviewing open sources.

This report was prepared by Proactima for the Norwegian Petroleum Safety Authority acting on behalf of the Norwegian Ministry of Foreign Affairs. The development of the report has been financed by the Norwegian Ministry of Foreign Affairs. The final report will be delivered to the Ministry of Foreign Affairs for further processing with regard to the Arctic Council.

To be able to focus the work towards the areas that have a high impact on the risk for acute oil pollution, a risk-based approach, focusing on measures that affect the undesirable events that have the highest impact on the risk for oil pollution in the Arctic marine environment, has been applied in this project. At a high level, the following undesirable events that may result in acute pollution have been considered relevant for Arctic offshore petroleum activity:

1. Process leak
2. Blowout
3. Riser / pipeline / subsea structure leak
4. Object on collision course
5. Damage to structure
6. Leak during loading / offloading

These undesirable events have formed the foundation for prioritising and structuring measures identified through this project. The measures have been structured according to the following themes:

- Metocean 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

The report endeavours to provide a broad overview, covering the most important areas subject to the scope of work. This is achieved by the approach taken, however, due to the extent of the issues that have been investigated, the report may not have managed to capture all existing, ongoing or planned initiatives.

The report demonstrates that extensive research and development initiatives have been ongoing for several decades related to enhancing the safety of offshore petroleum activities in the Arctic and cold climate regions. Some observations, recommendations and suggestions for further work have been provided for each of the themes covered by the report.

Metocean and ice conditions

Information on metocean and ice conditions is vital for safe design and operations in the offshore Arctic environment. The following observations, recommendations and suggestions for further work are made for metocean and ice conditions, including weather forecasting:

- Metocean and ice conditions:
  - Several initiatives have been identified regarding collecting and understanding metocean and ice conditions for Arctic and cold climate areas.
  - Over the years, the metocean and ice conditions for an area may change and the ice cap may be reduced. However, years with severe ice conditions cannot be neglected in the future and the importance of taking these conditions into account in the design and choice of technology and equipment is highlighted. The importance of systems for detecting ice in areas where this is no longer common or expected is highlighted.
  - Reduction of the ice cap may lead to an increase in the occurrence of significant waves. This may impose new challenges that should be studied.
  - A new ISO standard (ISO 35106 Arctic metocean, ice and seabed data) setting requirements to metocean and ice data is under development. The importance of adhering to such standards is highlighted.
- Weather forecasting:
  - Improved weather forecasting methods are recommended for polar regions, in particular related to forecasting of polar lows (wave conditions and trajectory paths). This may be achieved by higher resolution meteorological models and improved data collection methods.

Ice management

The following observations, recommendations and suggestions for further work are made regarding ice management, including forecasting, detection and monitoring of ice, station-keeping in ice, physical ice management and disconnection:

- Forecasting, detection and monitoring in ice:
  - Through the work identified in this report, it has not been possible to identify the limit of objects that currently is detectable. However, it is suggested that research regarding detecting smaller icebergs or ice floes should be a focus area. Such ice features are important for many offshore petroleum activities, amongst others exploration drilling, construction work and well maintenance.
- Physical ice management:
  - Physical ice management by towing icebergs is a known method for open water areas on the Grand Banks, offshore Newfoundland.
  - It seems as though there is limited research related to physical ice management for ice broken into multiple smaller pieces. When ice is broken into multiple smaller pieces, these pieces, when floating on waves, may represent a threat to the facility. Through the work in this report, no physical ice management methods for ice broken into multiple smaller pieces has been identified. The importance of considering this when designing equipment and facilities is highlighted.
  - The importance of a holistic ice management strategy for ship-shaped production units, such as FPSOs and FPUs, is highlighted. It is recommended that a holistic ice management strategy includes dynamic positioning in ice (vessel vaning and drift), ice loads exerted on the production facility, disconnection requirements and subsequently reconnection possibilities.
- Station-keeping in ice:

- o Through the work identified in this report, it seems as though research related to dynamic positioning in pack ice is promising, but not yet proven.
- Disconnection:
  - o To a large extent, the work identified related to disconnection and subsequently reconnection is applicable for units with a few risers. Even though disconnection possibilities exist for floating production units with several risers, practical reconnection possibilities are limited. There may be hesitation to disconnect if it is not practical or it is complicated to reconnect. It is suggested that technology for disconnection and subsequently reconnection of several risers should be developed.
  - o The importance of implementing operational limitations, e.g. regarding drilling and well intervention activities, loading / offloading activities and marine operations, is highlighted.

Drilling technology, well integrity and well control

The following observations, recommendations and suggestions for further work are made:

- The industry is conducting work to develop new technology for providing barriers in a well control situation. It is suggested that this work is continued to fully verify, validate and document the measures.
- It is suggested that research should emphasise measures to reduce the probability of encountering a well control situation.

Pipelines and subsea structures

The following observations, recommendations and suggestions for further work are made:

- Much research is performed on protection of pipelines and subsea structures exposed to loading from the keel of ridges and icebergs.
- It is suggested that there is still a need for work to be carried out to ensure that pipelines and subsea structures will not be damaged by ice ridges and icebergs.
- It is suggested that there is still a need for work to be carried out to detect leaks in pipelines and subsea structures.

Facility design

The following observations, recommendations and suggestions for further work are made regarding facility design issues:

- Ice loads:
  - o Much research has been performed related to ice loads on facilities. At this stage, it is not possible to conclude whether all these research activities will result in development of an inherently safe design. It is recommended that the need for disconnection options are always evaluated for floating units in ice loading situations.
  - o The importance of identifying which ice features represent the design ice loads is highlighted. Through the work identified in this report it is not clear whether the above-mentioned R&D activities cover all types of relevant ice features such as ridges, multi-year ice, ice islands, ice floes, growlers and bergy bits frozen into the ice cover.
  - o The importance of dimensioning the structure both globally (for the total loads) and locally (for high local ice load pressures caused by the different ice features) is highlighted.
- Ice model testing
  - o It is suggested to continue focusing on ice tank testing in order to ensure that failure modes are detected and that the associated loads are included in the design basis.
- Material selection

- Regarding material selection, the importance of choosing materials fit for purpose in accordance with standards, such as the ISO 19906:2010 Arctic offshore structures, is highlighted. API RP 2N is also relevant in this aspect. Furthermore, the new initiative under ISO TC67 SC8 regarding Arctic materials is relevant.

- Winterization
  - Focus on winterization is necessary to ensure safe working conditions, avoid gas build-up in closed rooms and to reduce energy consumption needs for heating and ventilation.

Loading and offloading

This report has identified some initiatives regarding offshore loading / offloading and the following observations, recommendations and suggestions for further work are made:

- Offshore loading systems that can operate during normal ice drift conditions have been identified. It is, however, noted that during strong ice drift the loading operations can be disrupted.
- Based on the information identified, it seems as though offshore loading systems that can operate during icing conditions do not exist.
- With the present status, it is recommended that loading is delayed until suitable weather conditions are identified for the operations.

Communication solutions

The following observations, recommendations and suggestions for further work are made:

- The current communication infrastructure is inadequate for the operational requirements of expected future maritime activities in the Arctic (SINTEF, 2015b).
- Improved communication solutions for the Arctic like the Iridium NEXT are currently being deployed.
- Further improved communication solutions for the Arctic like HEO satellites are being developed. This will improve the communication services in the Arctic.

Human resources and competence

The following suggestions are made:

- It is suggested that training programs for those involved in cold climate operations offshore should include realistic training under cold weather conditions, relevant simulator training as well as relevant fitness training to ensure prudent operations particular in case of emergencies.

Management

The following observations, recommendations and suggestions for further work are made:

- For companies involved in cold climate operations, the importance of relevant management levels preparing themselves for the work is highlighted.
- It is suggested that line managers directly involved in operational decisions should participate in realistic training courses under cold weather conditions.

Oil spill detection

Detecting an oil spill in remote location, and under ice, is a challenge. Two major industry JIPs have been conducted regarding detection of oil spill in the Arctic. However, there is still uncertainty regarding the detection methods and it is suggested that there is a need for more research on this matter.

Development of new concepts for exploration and production activities

Several initiatives regarding development of new concepts for exploration and production have been identified. The importance of acknowledging that development of new concepts is a process that takes considerable time, from the concept / feasibility phase, design phase, demonstration and qualification phase through to a new product, is highlighted.

It is suggested to continue the development of concepts for rendering the following exploration and production activities in offshore Arctic and cold climate regions possible:

- Qualification of a full subsea production solution for the Arctic in order to adapt for production in ice-covered waters. This could be achieved by evaluating and documenting that known deep-water technology can be transferred to Arctic operations.
- Improving maintenance and inspection methods for cold climate regions.

Standards and guidelines

The following observations, recommendations and suggestions for further work are made:

- Internationally acknowledged standards for design and construction of Arctic offshore structures exist and standards regarding Arctic petroleum operations are currently under development.
- For ships operating in polar waters the Polar Code has recently been acknowledged by IMO and is expected to enter into force on 1 January 2017.
- The importance of applying the standards that exist when choosing and qualifying technology is highlighted.
- It is recommended to further develop standards and ensure consistent use of standards across borders, for example in the Barents Sea.

R&D centres, projects and forums

A number of R&D centres, projects and forums are focusing on Arctic specific issues, enhancing the safety of Arctic operations. In this report a selection of these has been described. The importance of maintaining competence and expertise, amongst others through research and development published at conferences and in journals, is highlighted.

11 References

ABS, 2014a. Guidance notes on ice class. Houston, Texas, USA.

ABS, 2014b. Guide for vessels operating in low temperature environments. Houston, Texas, USA.

ABS, 2011. Guide for ice loads monitoring system. Houston, Texas, USA.

ABS, 2006. Winterization guidelines for LNG / CNG carriers in Arctic environments. ABS technical paper, USA.

AMAP, 2010. Assessment 2007: Oil and Gas Activities in the Arctic – Effects and Potential Effects. Volume 2. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Andrews, D. (Shell) and Coveney, M. (Griffon Hoverwork), 2015. ACVs in the Arctic. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25503.

API RP 2N:2015. API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions. Third edition.

API RP 17W:2014. API RP 17W Subsea capping stacks. First edition.

API RP 96:2013. API RP 96 Deepwater well design and construction. First edition.

API Specification 4F:2013. API Specification 4F Specification for drilling and well servicing structures. Fourth edition.

Arctic Council, 2009. Arctic offshore oil and gas guidelines.

Arctic Council, 2004. Guidelines for transfer of refined oil and oil products in Arctic waters.

Arctic operations handbook, 2013. Arctic marine operations challenges & recommendations. Final report of the Arctic operations handbook JIP.

Barents 2020, 2012. Barents 2020. Assessment of international standards for safe exploration, production and transportation of oil and gas in the Barents Sea. Final Report Phase 4. DNV Report 2012-0690, Høvik, Norway.

Barents 2020, 2009. Barents 2020. Assessment of international standards for safe exploration, production and transportation of oil and gas in the Barents Sea. Final Report Phase 3. DNV Report 2009-1626, Høvik, Norway.

Barker, A. (NRC CHC) and Timco, G. (NRC CHC), 2005. Ice rubble generation for offshore production structures: Current practices overview. NRC technical report CHC-TR-030. DOI: http://doi.org/10.4224/12340901

Battelle, 2014. Capabilities and Uses of Sensor-Equipped Ocean Vehicles for Subsea and Surface Detection & Tracking of Oil Spills. OGP-IPIECA Oil Spill Response Joint Industry Project. Surveillance, Modelling & Visualization. Work Package 1: In Water Surveillance.

Bauduin, C., Boulard, R., Caille, F. and Newport, A. (SBM Offshore), 2015. Disconnectable mooring systems for Arctic conditions. Presented at the Offshore Technology Conference, 4-7 May 2015, Houston, Texas, USA. OTC 25910.

Bekkadal, F., 2014. Arctic communications challenges. Marine Technology Society Journal 48(2), pp. 8-16. DOI: 10.4031/MTSJ.48.2.9.

Bekkadal, F. and Fjørtoft, K.E., 2014. COINOR - Communications in the High North and other remote areas. Presented at Arctic Frontiers, 19-24 January 2014, Tromsø, Norway. Publication ID: CRIStin 1182304.

Blanchet, D. (BPXA Alaska), Spring, W. (Bear Ice Technology Inc.), McKenna, R.F. (McKenna and Associates) and Thomas, G.A.N. (BP), 2011. ISO 19906: An international standard for Arctic offshore structures. Presented at the Offshore Technology Conference, 7-9 February 2011, Houston, Texas. OTC 22068.

Bonnemaire, B. (NTNU), 2005. Arctic Offshore Loading: Submerged Turret Loading and Loading Downtime in Drifting Ice. PhD thesis NTNU, Trondheim, Norway.

Bonnemaire, B. (Barlindhaug Consult), Jensen, A. (Barlindhaug Consult), Gudmestad, O.T. (NTNU / Statoil), Lundamo, T. (Barlindhaug Consult) and Løset, S. (NTNU), 2007. Challenges related to station-keeping in ice. 9th annual INTSOK conference, March 2007, Houston, Texas.

Bourmistrov, A., Mellemvik, F., Bambulyak, A., Gudmestad O.T., Overland, I. and Zolotukhin, A., 2015. International Arctic Petroleum Cooperation. Barents Sea Scenarios. Routledge. ISBN: 978-1-13-878326-3.

Brandt, H., Frühling, C., Hollung, A., Schiemann, M, Voß, T. (ThyssenKrupp Marine Systems GmbH), 2015. A multi-purpose submarine concept for Arctic offshore operations. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25501.

Bruun, P.K. (Aker Solutions), Ågedal, B. (Aker Solutions) and Matala, R. (Aker Arctic), 2015. Arctic drillship design for severe ice conditions. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-187.

Bruun, P.K. (Aker Solutions), Løset, S. (NTNU), Gürtner, A. (Statoil), Kuiper, G. (Shell), Kokkinis, T. (ExxonMobil), Sigurdsen, A. (Chevron) and Hannus, H. (Aker Solutions), 2011. Ice model testing of structures with a downward breaking cone at the waterline JIP; presentation, set-up & objectives. Proceedings of the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering, 19-24 June 2011, Rotterdam, the Netherlands. OMAE2011-49380.

Bruun, P.K. (Aker Engineering & Technology), Husvik, J. (Aker Engineering & Technology), Le-Guennec, S. (Total) and Hellmann, J.H. (HSVA), 2009. Ice model test of an Arctic SPAR. Proceedings of the POAC 2009 20th international conference on Port and Ocean Engineering under Arctic Conditions, 9-12 June 2009, Luleå, Sweden. POAC09-136.

BSEE, 2015a. BSEE Oversees Testing of Shell Arctic Drilling Well Containment Equipment, BSEE News Briefs 18 June 2015. http://www.bsee.gov/BSEE-Newsroom/BSEE-News-Briefs/2015/BSEE-Oversees-Testing-of-Shell-Arctic-Drilling-Well-Containment-Equipment/

BSEE, 2015b. BSEE Observes Demonstration of Containment Dome Deployment, BSEE News Briefs 4 June 2015. http://www.bsee.gov/BSEE-Newsroom/BSEE-News-Briefs/2015/BSEE-Observes-Demonstration-of-Containment-Dome-Deployment/

Buffagni, M., Gasparoni, F., Bergseth, N.H., Bjørnbom, E. and Broccia, P. (Eni), 2014. Development and test of an AUV for environmental monitoring and asset integrity in offshore O&G scenarios: CLEAN SEA project. Presented at the SPE International Conference on Health, Safety and Environment, 17-19 March 2014, Long Beach, California, USA.

CAN/CSA-ISO 19906:11. Petroleum and natural gas industries - Arctic offshore structures (Adopted ISO 19906:2010, first edition, 2010-12-15).

CARD, 2015. Station-keeping in Ice. Existing solutions. https://www.card-arctic.ca/station-keeping-solutions

Chevron Canada Limited, 2010. Submission to National Energy Board policy hearing for same season relief well capability for drilling in the Beaufort Sea.

CHNL, 2015. Centre of High North Logistics Arctic 2030 Project. http://www.chnl.no/?page=4&show=90&news=68&title=Research%3A+CHNL%92s+Arctic+2030+Project

C-CORE, 2014. Guidelines for the use of satellite-based ice information in the oil and gas sector. A project supported by the ESA and IOGP. Presented at the 15th International Ice Charting Working Group Meeting, 20-25 October 2014, Punta Arenas, Chile.

C-CORE, 2005. Stability and drift of icebergs under tow. C-CORE Report R-04-072-216 v1. Draft report. St. John's, Newfoundland and Labrador, Canada.

ConocoPhillips and Lundin, 2013. Arctic approach.

Daley, C., Alawneh, S., Peters, D., Blades, G. and Colbourne, B. (MUN), 2014. Simulation of managed sea ice loads on a floating offshore platform using GPU-event mechanics. ICETECH 2014, 28-31 July 2014, Banff, Alberta, Canada.

Dalheim, J. Nodland, S. and Pappas, J. (Scandpower), 2012. Explosion safety drivers in Arctic platform design. Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering, 10-15 June 2012, Rio de Janeiro, Brazil. OMAE2012-83026.

DNV GL, 2015a. Offshore standard DNVGL-OS-A201 Winterization for cold climate operations.

DNV GL, 2015b. SAFEARC – Safe Arctic Marine Operation. http://www.dnvgl-source.com/assets/documents/src/safearc_twopager_2015_05_l0x.pdf

DNV GL, 2015c. Technology challenges for year-round oil and gas production at 74°N in the Barents Sea. DNV GL Report no. 2015-0925, draft edition, Høvik, Norway.

DNV, 2014. MARICE project summary. DNV report 2014-0096, Rev. 01, Høvik, Norway. http://www.nsd.uib.no/data/individ/publikasjoner/NSD2117/NSD2117_Project%20Summary.pdf

DNV, 2013a. Offshore standard DNV-OS-F101 Submarine pipeline systems. Høvik, Norway.

DNV, 2013b. Recommended practice DNV-RP-A203 Technology qualification. Høvik, Norway.

DNV, 2010a. Recommended practice DNV-RP-F107 Risk assessment of pipeline protection. Høvik, Norway.

DNV, 2010b. Recommended practice DNV-RP-F302 Selection and use of subsea leak detection systems. Høvik, Norway.

DNV, 2008. State of the art review, Arctic specific hazards to the design of Arctic offshore pipelines, Energy Report ICE PIPE JIP, Report no./DNV reg. no.: 2008-1267/121CU6F-54, Rev. 02, Høvik, Norway.

Dudal, A. (Bureau Veritas), Septseault, C. (Cervval), Beal. P.A. (Cervval), Yaouanq, S.L. (Cervval) and Roberts, B. (Technip), 2015. A new Arctic platform design tool for simulating ice-structure interaction. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-066.

Eie, R. (Kværner Concrete Solutions), 2015. Deepwater Arctic subsea separation & storage systems. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25526.

Eik, K.J. (NTNU), 2010. Ice management in Arctic offshore operations and field developments. PhD thesis at NTNU, Trondheim, Norway.

El-Gebaly, S., Paulin, M., Lanan, G. and Cooper, P. (INTECSEA), 2012. Ice gouge interaction with buried pipelines assessment using advanced coupled Eulerian Lagrangian. Presented at the Arctic Technology Conference, 3-5 December 2012, Houston, Texas, USA. OTC 23764.

FMC Technologies, 2015. FMC Technologies' solutions to harsh environment. Presented at INTSOK's 13th Annual Russian-Norwegian Oil & Gas Conference, 28 January 2015.

Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia.

Frederking, R. (NRC) and Sudom, D. (NRC), 2006. Maximum ice force on the Molikpaq during the April 12, 1986 event. Cold Regions Science and Technology 46(3), pp. 147-166. DOI: 10.1016/j.coldregions.2006.08.019.

Georghiou, A.E., Davis, A., Eskandari, F. and Paulin, M. (INTECSEA), 2015. Extending conventional pipe-soil interaction models to include bundle effects for Arctic subsea pipeline design. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25524.

Gudmestad, O.T. (UiS) & Quale, C. (IRIS), 2011. Technology and Operational challenges for the High North.

Gudmestad, O.T., Zolotukhin, A.B. and Jarlsby, E., 2010. Petroleum resources with emphasis on offshore fields. WIT Press, Southampton, UK. ISBN-10: 1845644786, ISBN-13: 978-1845644789.

Gudmestad, O.T., Zolotukhin, A.B., Ermakov, A.I., Jakobsen, R.A., Michtchencko, I.T., Vovk, V.S., Løset, S. and Shkhinek, K.N., 1999. Basics of offshore petroleum engineering and development of marine facilities. ISBN: 5-7246-0100-1.

Gudmestad, O.T. (UiS / NTNU), Dalane, O. (NTNU) and Aksnes, V. (NTNU), 2009. Design of floating production systems in the Arctic. On the requirement to disconnection for a moored floater in hard ice conditions. Proceedings of the POAC 2009 20th International

Conference on Port and Ocean Engineering under Arctic Conditions, 9-12 June 2009, Luleå, Sweden. POAC09-137.

Hamilton, J.M. (ExxonMobil), 2011. The challenges of deep-water Arctic development. International Journal of Offshore and Polar Engineering by the International Society of Offshore and Polar Engineers, 21(4), pp. 241-247. ISOPE-11-21-4-241.

Hansen, F.S. (UNIS), 2014. Menneskelige faktorer og beredskap. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 5 on emergency preparedness, 2-3 June 2014 (in Norwegian).

Hassel, M. (NTNU), Utne, I.B. (NTNU) and Vinnem, J.E. (NTNU), 2015. Challenges with bringing collision risk models used in the North Sea and Norwegian Sea to the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-017.

Heinicke, C. (Aalto University), Polojärvi, A. (Aalto University / SAMCoT, NTNU) and Tuhkuri, J. (Aalto University / SAMCoT, NTNU), 2015. Preliminary results of 3D simulations of a failing ice sheet. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-119.

Huaiyin, L., Xuebo, D. and Kai, Z. (Sinopec Exploration & Production Research Institute), 2015. Review and outlook on Arctic offshore facilities & technologies. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25541.

Huisman, 2015. JBF Arctic. http://www.huismanequipment.com/en/products/drilling/jbf_14000/jbf_arctic

Høyland, K.V. (UNIS), 2002. Consolidation of first-year sea ice ridges. Journal of Geophysical Research 107(C6), pp. 15.1-15.16. DOI: 10.1029/2000JC000526.

IACS, 2011. Unified requirements I. Requirements concerning polar class.

IMO, 2015. Polar Code. http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx

IMO, 2010. Guidelines for ships operating in polar waters. Sales number E190E. 2010 edition. London, UK.

Inocean, 2015. Arctic drillship. http://www.inocean.no/inocean-goes-in-ice

INTECSEA, 2015 2015 Arctic map http://www.intecsea.com/our-business/arctic-development/

IOGP, 2015. Metocean industry projects. http://www.iogp.org/Technical-expertise/Metocean/Industry-projects

IOGP, 2010. Regulators' use of standards. IOGP Report no. 426. http://www.ogp.org.uk/pubs/426.pdf

IPIECA & OGP, 2009. The health aspects of work in extreme climates. A guide for oil and gas industry managers and supervisors. Report no. 398. London, UK. http://www.ogp.org.uk/pubs/398.pdf

Irmer, M. (Fraunhofer), Glück, N. (Fraunhofer) and Momber, A. (Muehlan), 2013. Performance characteristics of surface protection coating systems for offshore structures under Arctic conditions. Presented at the Offshore Technology Conference, 6-9 May 2013, Houston, Texas, USA. OTC 23936.

ISO 11079:2007. ISO 11079 Ergonomics of the thermal environment – Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects, International Standardisation Organisation, Geneva, Switzerland.

ISO 19906:2010. ISO 19906 Petroleum and natural gas industries – Arctic offshore structures. First edition, International Standardisation Organisation, Geneva, Switzerland.

Jamieson, J. and Hopkins, D. (Subsea 7), 2015. The potential benefits autonomous underwater vehicles bring to subsea inspection in Arctic regions. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25540.

Jensen, A. (NTNU), 2002. Evaluation of Concepts for Loading of Hydrocarbons in Ice-infested Waters. PhD thesis at NTNU, Trondheim, Norway.

Johansen, O.H. (Statoil), 2014. International standardisation Arctic operations (ISO TC67 SC8). Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 6 on maritime logistics, infrastructure and ice management, 17-18 June 2014.

Jordaan, I. (Ian Jordaan & Associates Inc. / C-CORE), Bruce, J. (C-CORE), Hewitt, K. (K.J. Hewitt & Associates Ltd.) and Frederking, R. (Canadian Hydraulics Centre), 2011. Re-evaluation of ice loads and pressures measured in 1986 on the Molikpaq structure. Proceedings of the POAC 2011 21st International Conference on Port and Ocean Engineering under Arctic Conditions, 10-14 June 2011, Montréal, Canada. POAC11-130.

Juurmaa, K., Mattsson, T., Sasaki, N., Wilkman, G., 2002. The development of the double acting tanker for ice operation. Proceedings of the 17th International Symposium on Okhotsk Sea & Sea Ice, 24-28 February 2002, Mombetsu, Hokkaido, Japan.

Kärnä, T. (NTNU), Gravesen, H. (Technical University of Denmark), Fransson, L. (Luleå University of Technology) and Løset, S. (NTNU), 2010. Simulation of multi-modal vibrations due to ice actions. IAHR 20th International Symposium on Ice, 14-18 June 2010, Lahti, Finland.

Keinonen, A. (AKAC Inc.), Martin, E. (AKAC Inc.), Neville, M. (AKAC Inc.) and Gudmestad, O.T. (Statoil), 2007. Operability of an Arctic drill ship in ice with and without ice management. Proceedings of the DOT 2007 Deep Offshore Technology, 10-12 October 2007, Stavanger, Norway. On CD.

Keinonen, A. (AKAC Inc.), Wells, H. (Sakhalin Energy Investment Company), Dunderdale, P. (P.E. Dunderdale and Associates Inc.), Pilkington, R. (Canatec), Miller, G. (Coflexip Stena Offshore) and Brovin, A. (Calgary, Canada), 2000. Dynamic positioning operation in ice, offshore Sakhalin, May-June 1999. Proceedings of the ISOPE 2000 10th International Offshore and Polar Engineering Conference, 28 May-2 June 2000, Seattle, USA. ISOPE-I-00-102.

Kerkeni, S. (DCNS-Research/Sirehna), dal Santo, X. (DCNS-Research/Sirehna), Doucy, O. (DCNS-Research/Sirehna), Jochmann, P. (HSVA), Haase, A. (HSVA), Metrikin, I. (NTNU / Statoil), Løset, S. (NTNU), Jenssen, N.A. (Kongsberg Maritime), Hals, T. (Kongsberg Maritime), Gürtner, A. (Statoil), Moslet, P.O. (DNV) and Støle-Hentschel, S. (DNV),

2014. DYPIC project: technological and scientific progress opening new perspectives. Proceedings of the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24652.

Kim, E. (SAMCoT / AMOS, NTNU), Lu, W. (SAMCoT, NTNU), Lubbad, R. (SAMCoT, NTNU), Løset, S. (SAMCoT, NTNU) and Amdahl, J. (SAMCoT / AMOS, NTNU), 2015. Toward a holistic load model for structures in broken ice. Proceedings at the POAC 2015 23rd International Conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-255.

King, T. (C-CORE), Wright, R. (Nalcor Energy), Drover, K. (Nalcor Energy), Fleming, G. (Nalcor Energy) and Gillis, E. (Nalcor Energy), 2015. Offshore Newfoundland and Labrador metocean study. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25495.

Kwan, C.T.T. (Kwan Engineering Services), Bond, J. (ABS), Yu, H. (ABS) and Morandi, A. (Global Maritime), 2014. Arctic mooring systems – the past, present and future. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24581.

Kuiper, G. (Shell) and Løset, S. (SAMCoT, NTNU), 2015. SAMCoT: Leveraging cross sector collaboration to drive sustainable energy developments in the Arctic. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25494.

Liferov, P. (NTNU), 2005. First-year ice ridge scour and some aspects of ice rubble behaviour. PhD thesis at NTNU, Trondheim, Norway.

Lloyd's Register, 2015. Rules and regulations for the classification of ships. Part 8: Rules for ice and cold operations.

Lochte, G. (Trendsetter Engineering), Lingo, D. (Trendsetter Engineering), Matson, A. (Trendsetter Engineering), 2015. Case study – a mudline closure device as a pre-installed well control system. Presented at the AOGP 2015 Arctic Oil & Gas North America, 14-15 April 2015, St. John’s, Canada.

LOOKNorth, 2014. Oil spill detection and modelling in the Hudson and Davis Straits. LOOKNorth Report R-13-087-1096. Rev. 2.0. St. John's, Newfoundland and Labrador, Canada.

Løset, S., Shkhinek, K.N., Gudmestad, O.T. and Høyland, K.V., 2006. Actions from ice on Arctic offshore and Coastal Structures. LAN. ISBN: 5-8114-0703-3.

Madrid, M. (Trendsetter Engineering) and Matson, A. (Trendsetter Engineering), 2014. How Offshore Capping Stacks Work. SPE-0114-025-TWA, The Way Ahead 10(01), pp. 25-27. DOI: 10.2118/0114-025-TWA.

Magnell, B. (Woods Hole Group Inc.), Ivanov, L. (Woods Hole Group Inc.) and Siegel, E. (Nortek), 2010. Measurements of ice parameters in the Beaufort Sea using the Nortek AWAC acoustic doppler current profiler. OCEANS 2010, 20-23 September 2010, Seattle, Washington, USA. DOI: 10.1109/OCEANS.2010.5664016.

Marchenko, N. (UNIS), 2014. Floating ice induced ship casualties. Proceedings of the 22nd IAHR International Symposium on Ice, 11-15 August 2014, Singapore.

Markeset, T., Sæland, A., Gudmestad, O. and Barabady, J., 2015. Petroleum production facilities in Arctic operational environments. In: Bourmistrov, B., Mellemvik, F., Bambulyak, A. Gudmestad, O., Overland, I. and Zolotukhin, A. (editors), 2015: International Arctic Petroleum Cooperation, Barents Sea Scenarios. ISBN 978-1-13-878326-3, Routledge Series in Environmental Policy.

MET Norway, 2012. Kunnskap om vind, bølger, temperatur, isutbredelse, siktforhold m.v. – «Barentshavet SØ». Bistand til OEDs åpningsprosesser for petroleumsvirksomhet i nord. Met.no report no. 11/2012, Oslo, Norway (in Norwegian).

Metrikin, I. (NTNU / Statoil), Kerkeni, S. (DCNS Research / Sirehna), Jochmann, P (HSVA), and Løset, S. (NTNU), 2015. Experimental and numerical investigation of dynamic positioning in level ice. Journal of Offshore Mechanics and Arctic Engineering, 137(3), 031501. DOI: 10.1115/1.4030042.

Moss Maritime, 2015. Arctic environment units. http://www.mossww.com/technologies/arctic.php

NEB, 2014. National Energy Board filing requirements for offshore drilling In the Canadian Arctic. https://www.neb-one.gc.ca/bts/ctrg/gnthr/rctcrvwflngrqrmnt/index-eng.html#s4c

NEB, 2011. Public review of Arctic safety and environmental offshore drilling requirements. NEB file OF-EP-Gen-AODR 01.

NEB, 2015. ARCHIVED - Chevron Canada Limited - exploration license EL 481 - Same season relief well technical proceeding.

NSIDC, 2006. Submarine upward looking sonar ice draft profile data and statistics. Boulder, Colorado USA. DOI: 10.7265/N54Q7RWK.

Nikolaisen, Ø. (UiT), Sunde, J. (Teekay Shipping Norway) and Gudmestad, O.T. (UiS), 2015. Winterization of bow loading systems on shuttle tankers. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25568.

Nikitin, M.A. (The Hydrometcentre of Russia) and Chumakov, M.M. (LLC Gazprom VNIIGAZ), 2015. Case study of polar lows in Barents and Kara Seas during 2014. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-070.

NORSOK D-010, 2013. Well integrity and drilling and well operations. Edition 4. Standards Norway, Oslo, Norway.

NORSOK N-003, 2015. Actions and action effects. Edition 3 (draft version). Standards Norway, Oslo, Norway.

Norwegian Oil and Gas Association, 2015. HSE challenges in the High North summary report (in Norwegian).

NPC, 2015. Arctic Potential – Realizing the promise of U.S. Arctic oil and gas resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org/

NTNU, 2015. NTNU Oceans - into the deep ocean. https://www.ntnu.edu/oceans/into-the-deep-ocean

Oceaneering, 2014. Capabilities and uses of sensor and video-equipped waterborne surveillance-ROVs for subsea detection and tracking of oil spills. OGP-IPIECA Oil spill response joint industry project. Surveillance, modelling & visualization. Work package 1: In water surveillance.

OCIMF, 2014. Offshore vessel operations in ice and /or severe sub-zero temperatures. First edition. London, England. http://www.ocimf.org/media/53160/Offshore_Vessel_Operations_in_Ice_and_or_Severe_Sub-Zero_Temperatures_in_Arctic_and_Sub-Arctic_Regions.pdf

Offshore, 2014 2014 Survey of Arctic & cold region technology for offshore field development http://www.offshore-mag.com/content/dam/offshore/print-articles/volume-74/02/0214ArcticPoster-012014Ads.pdf

Onishchenko, D. (Gazprom VNIIGAZ LLC / A. Yu. Ishlinsky for Problems in Mechanics RAS), Marchenko, A. (UNIS), 2015. Analytical estimation of maneuverability of moored FPU with internal turret in close ice. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-082.

Orimolade, P.O., Haver, S., Gudmestad, O.T. (UiS), 2015. Estimation of extreme significant wave heights and the associated uncertainties: A case study using NORA10 hindcast data for the Barents Sea. Submitted to Journal of Marine Structures, August 2015.

Palmer A. and Croasdale, K., 2012. Arctic Offshore Engineering. World Scientific Publishing Co. Pte. Ltd. ISBN: 978-981-4368-77-3.

Paulin, M., Cocker, J., Humby, D., Lanan, G. (INTECSEA), 2014a. Trenching considerations for Arctic pipelines. ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, California, USA. OMAE2014-23116.

Paulin, M., DeGeer, D., Cocker, J. and Flynn, M. (INTECSEA), 2014b. Arctic offshore pipeline design and installation challenges. ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, California, USA. OMAE2014-23117.

Polar Imaging Ltd., 2015a. An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Airborne Remote Sensing. Provided for IPIECA and OGP. PIL-4000-38-TR-1.1.

Polar Imaging Ltd., 2015b. Surface Surveillance Capabilities for Oil Spill Response using Remote Sensing. JIP SMV: WP 2 Final Report. Provided for IPIECA and OGP. PIL-4000-39-TR-1.2.

Polar Imaging Ltd., 2014. An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Satellite Remote Sensing. Provided for IPIECA and OGP. PIL-4000-35-TR-1.2.

Pour, F.S., Naseri, M. and Barabadi, J. (UiT), 2015. Drill cutting and waste injection assurance in the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-180.

PRNL, 2014. Joint industry program: Development of improved ice management capabilities for operations in Arctic and harsh environments. http://petroleumresearch.ca/index.php?id=166

PRNL, 2015. Petroleum Research Newfoundland & Labrador. http://pr-ac.ca/

PSA, UiS & IRIS, 2010. Teknologi- og kunnskapsstatus av betydning for å redusere risiko for uønskede hendelser som kan føre til akutte utslipp til sjø i forbindelse med petroleumsvirksomhet i Nordområdene. Stavanger, Norway (in Norwegian).

Puestow, T. (C-CORE), Parsons, L. (C-CORE), Zakharov, I. (C-CORE), Cater, N. (C-CORE), Pradeep, B. (C-CORE), Fuglem, M. (C-CORE), Parr, G. (C-CORE), Jayasin, A. (C-CORE), Warren, S. (C-CORE) and Warbanski, G. (Emergency Spill and Consulting Inc.), 2013. Oil spill detection and mapping in low visibility and ice: Surface remote sensing. Final report 5.1.

Raye, R. (Shell), 2015. Forecasting ice and weather conditions for field operations in Alaska. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25497.

Reed, I. (Shell), 2014. Oil exploration and production offshore Sakhalin island. Ice management and marine operations. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 6 on maritime logistics, infrastructure and ice management, 17-18 June 2014.

Robotic Drilling Systems, 2015. Seabed rig. http://www.rds.no/seabed-rig/about-seabed-rig

Rosneft, 2015. Sakhalin-1 Sets Another Extended Reach Drilling Record. Rosneft press release 14 April 2015.

RU-NO Barents Project, 2015. RU-NO Barents project reports. http://www.intsok.com/Market-info/Markets/Russia/RU-NO-Project/Project-Reports

Samuelsen, E.M. (UiT / MET Norway), Løset, S. (SAMCoT, NTNU / UNIS) and Edvardsen, K. (UiT), 2015. Marine icing observed on KV Nordkapp during a cold air outbreak with a developing polar low in the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-087.

Sayed, M. (NRC), Kubat, I. (NRC), Watson, D. (NRC), Wright, B. (B. Wright and Associates Ltd.), Gash, R. (NRC) and Millan, J. (NRC), 2015. Simulations of the stationkeeping of drillships under changing direction of ice movement. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25565.

Scott, B. (Chevron) and Denstedt, S. (Osler, Hoskin & Harcourt LLP), 2015. Equivalency: regulatory flexibility in a changing world. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25486.

Shafer, R.S. (ConocoPhillips), Noble, P.G. (ConocoPhillips), Cheung, T.O. (Keppel Offshore and Marine), Chow, Y.Y. (Keppel Offshore and Marine), Quah, M. (Keppel Offshore and Marine), Foo, K.S. (Keppel Offshore and Marine), Wang, C.D. (Keppel Offshore and Marine) and Perry, M.J. (Keppel Offshore and Marine), 2013. Basis of design and specifications for shallow water Arctic MODU for year-round operation, development and exploration. Presented at the SPE/IADC Drilling Conference and Exhibition, 5-7 March 2013, Amsterdam, The Netherlands. SPE/IADC 163429.

Shell, 2012. Royal Dutch Shell Alaska drilling update. http://www.shell.com/global/aboutshell/media/news-and-media-releases/2012/alaska-drilling-update-17092012.html

Siebenaler, S. (SwRI), Iyer, M. (Shell), Kulkarni, M. (ExxonMobil), Salmatanis, N. (Chevron), 2015. Thermal characterization of potential leaks in offshore pipelines. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25515.

SINTEF, 2015a. Durable advanced concrete solutions (DACS). http://www.sintef.no/prosjekter/byggforsk/dacs--durable-advanced-concrete-structures/

SINTEF, 2015b. What is the problem with communication in the Arctic? http://www.sintef.no/home/marintek/projects/maritime/what-is-the-problem-with-communication-in-the-arctic/

Statoil, 2015. Åsgard subsea compression project. http://www.statoil.com/no/technologyinnovation/fielddevelopment/aboutsubsea/Pages/The%C3%85sgardComplex.aspx

Statoil, 2014. Rig positioning in the High North. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 1 on climatic conditions and communication, 24-25 March 2014 (in Norwegian).

Subbotin, E., 2015. Oil offloading solutions for the Pechora Sea exemplified by the Prirazlomnoye field. MSc thesis Gubkin University of Oil and Gas in Moscow, Russia / UiS, Norway.

Tangvald, T.B. (Navion), Wiik, E. (Advanced Production Systems) and Boge, H. (Statoil), 2000. Operating experience with Navion Munin FPSO at the Lufeng field. Presented at the Offshore Technology Conference, 1-4 May 2000, Houston, Texas, USA. OTC 12057.

Taylor, R. (MUN / CARD), Turnbull, I. (CARD), Slaney, A. (Department of Fisheries and Oceans), 2015. Field data for sea ice and iceberg drift offshore Newfoundland and Labrador. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25575.

Taylor, R.S. (CARD), Murrin, D.C. (CARD), Kennedy, A.M. (C-CORE) and Randell, C.J. (C-CORE), 2012. Arctic development roadmap: Prioritization of R&D. Presented at the Offshore Technology Conference, 30 April-3 May 2012, Houston, Texas, USA. OTC 23121.

Telenor Satellite Broadcasting, 2014. Satellite communication in the High North - challenges and solutions. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 4 on risk management and design, 20-21 May 2014 (in Norwegian).

Thodi, P., Paulin, M., DeGeer, D. and Squires, M. (INTECSEA), 2015. Real-time Arctic pipeline integrity and leak monitoring. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25604.

Tiffin, S. (Canatec), Pilkington, R. (Canatec), Hill, C. (Canatec), Debicki, M. (Canatec), McGonigal (Glacialis Ice Consulting) and Jolles, W. (Canatec), 2014. A decision-support system for ice / iceberg surveillance, advisory and management activities in offshore petroleum operations. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24657.

Tijsen, J. (TU Delft), Bruneau, S. (MUN) and Colbourne, B. (MUN), 2015. Laboratory examination of ice loads and effects on concrete surfaces from bi-axial collision and adhesion events. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-36.

Torsæter, M. (SINTEF Petroleum Research) and Cerasi, P. (SINTEF Petroleum Research), 2015. Mud weight control during Arctic Drilling Operations. 23-25 March 2015, Copenhagen, Denmark. OTC 25481

Torsæter, M. (SINTEF Petroleum Research) and Vrålstad, T. (SINTEF Petroleum Research), 2014. Drilling and well challenges in the Arctic. Marine Technology Society Journal, 48(5), pp. 76-80.

Trendsetter Engineering, 2014. HPHT Capping stacks and new technology for subsea well control. http://www.trendsetterengineering.com/media/files/files/f2d8d560/Clean_Gulf_Trendsetter_Subsea_Well_Control_Equipment_Capping_Stack_MCD_Kill_Manifold_.pdf

Trendsetter Engineering, 2012. Arctic capping stack. http://www.trendsetterengineering.com/news/trendsetter-completes-arctic-capping-stack/

Vershinin, S.A., Truskov, P.A., Liferov, P.A., 2007. Ice features action on seabed. IPK “Russkaya kniga”, Moscow, Russia, 196 p. (in Russian).

Wang, C. (Keppel Offshore & Marine Technology Centre), Quah, M. (Keppel Offshore & Marine Technology Centre), Noble, P.G. (ConocoPhillips), Shafer, R. (ConocoPhillips), Soofi, K.A. (ConocoPhillips), Alvord, C. (ConocoPhillips) and Brassfield, T. (ConocoPhillips), 2012. Use of jack-up drilling units in Arctic seas with potential ice incursions during open water season. Presented at the Arctic Technology Conference, 3-5 December 2012, Houston, Texas. OTC 23745.

Wassink, A., and List, R. van der (GustoMSC), 2015. Development of solutions for Arctic offshore drilling. Presented at the SPE Arctic and Extreme Environments Conference & Exhibition, 15-17 October 2013, Moscow, Russia. SPE 166848.

Wiersema, E. (Heerema Marine Contractors), Lange, F. (Shell), Cammaert, G. (TU Delft), Sliggers, F. (TU Delft), Jolles, W. (Canatec) and van der Nat, C. (Bluewater), 2014. Arctic operations handbook JIP. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24545.

Wilkinson, J. (Polar Ocean Services), Maksym, T. (Woods Hole Oceanographic Institution) and Hanumant, S. (Woods Hole Oceanographic Institution), 2013. Capabilities for detection of oil spills under sea ice from autonomous underwater vehicles. Final report 5.2.

Wilkman, G. (Wilkman Arctic Advisor), 2015. Development of icebreaking ships with ice model tests. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25532.

Winkler, M. (Shell), Jahre-Nilsen, C. (Statoil), Blaauw, R. (Shell) and Dyve-Jones, R. (Statoil), 2015. Arctic oil spill prevention and response: working collaboratively to improve and extend safe practice. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25485.

WMO, 2014. Sea Ice Nomenclature.

Wright, J. (Chevron Arctic Center), Hammeken-Holm, J. (BMP), Renganathan, V. (Chevron Arctic Center) and Robertson, S. (Chevron Arctic Center), 2014. NE Greenland ice study group and recent project work. Arctic Technology Conference, 10-12 February, Houston, Texas, USA. OTC 24596.

Yang, M. (MUN), Khan, F.I. (MUN), Lye, L. (MUN), Sulistiyono, H. (MUN), Dolny, J. (HETC) and Oldford, D. (HETC), 2013. Risk-based winterization for vessels operations in Arctic environments. Journal of Ship Production and Design 29(4), pp. 199-210.

Zakharov, I., Bobby, P., Power, D., Saunders, K. and Warren S. (C-CORE), 2015. Monitoring hazardous sea ice features using satellite imagery. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25570.

Appendix 1 Abbreviations

ABS	American Bureau of Shipping
ACV	Air Cushion Vehicles
AID	Altimeter Ice Detection
AIS	Automatic Identification System
AIV	Autonomous Inspection Vehicle
AMAP	Arctic Monitoring and Assessment Programme
AMOS	Autonomous Marine Operations and Systems
AOOS	Alaska Ocean Observing System
AORF	Arctic Offshore Regulators Forum
AOSL	Autonomous Oceans Systems Laboratory
API	American Petroleum Institute
ARCEx	ARCtic Petroleum Exploration
ART JIP	Arctic Response Technology Joint Industry Project
ARTES	Advanced Research in Telecommunications Systems
ASID	Auxiliary Safety Isolation Device
ASME	American Society of Mechanical Engineers
ASUF	Arctic Centre for Unmanned Aircraft
ATC	Arctic Technology Conference
AUV	Autonomous Underwater Vehicle
AWAC	Acoustic Wave And Current
AWKS	Alternative Well Kill System
BaSEC	Barents Sea Exploration and Cooperation
BaSMIN	Barents Sea Metocean and Ice data Network
BOEM	Bureau of Ocean Energy Management (USA)
BOP	Blowout Preventer
BMP	Bureau of Minerals and Petroleum (Greenland)
BSEE	Bureau of Safety and Environmental Enforcement (USA)
CARD	Centre for Arctic Resource Development

CASMOS	Caspian Sea Metocean Study
CD	Committee Draft
CHNL	Centre of High North Logistics
CIRFA	Centre for Integrated Remote Sensing and Forecasting for Arctic Operations
CMEMS	Copernicus Marine Environment Monitoring Service
CNG	Compressed Natural Gas
CNLOPB	Canada Newfoundland Labrador Offshore Petroleum Board
COINOR	Communications in the High North and other remote area
CSA	Canadian Standards Association
DACS	Durable Advanced Concrete Solutions
DAS	Distributed Acoustic Sensing
DAT	Double Acting Tanker
DFC	Divert / Flow Control
DIRKS	Development of Ice Ridge Keel Strength
DIS	Draft International Standard
DP	Dynamic Positioning
DTS	Distributed Temperature Sensing
DYPIC	Dynamic positioning in ice
ERD	Extended Reach Drilling
ESA	European Space Agency
ESG	Environmental Safe Guard
ESP	Environmental Sampling Processor
EU	European Union
EUMETSAT	Exploitation of Meteorological Satellites
FEED	Front End Engineering Design
FOIROT	Fixed Offshore Ice Resistant Offloading Terminal
FPSO	Floating, Production, Storage and Offloading
FPU	Floating, Production Unit
FSO	Floating, Storage and Offloading

GBS	Gravity Based Structure
GEM	GPU based event mechanics
GEO	Geostationary
GFA	GROW Fine Arctic
GIS	Geographic Information Sysstem
GNSS	Global Navigation Satellite System
GLONASS	GLObal NAvigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
HEO	Highly Elliptical Orbit
HETC	Harsh Environment Technology Center
HF	High Frequency
HSE	Health, Safety and Environment
HSVA	Hamburgische Schiffbau-Versuchsanstalt
HVAC	Heating, Ventilation and Air Conditioning
IACS	International Association of Classification Societies
IADC	International Association of Drilling Contractors
IAHR	International Association for Hydro-Environment Engineering and Research
ICETECH	International Conference and Exhibition on Ships and Structures in Ice
IMO	International Maritime Organisation
IODP	International Ocean Development Program
IOGP	International Association of Oil and Gas Producers
IPIECA	The global oil and gas industry association for environmental and social issues
IRIS	International Research Institute of Stavanger
ISO	International Standardisation Organisation
ISOPE	International Society of Offshore and Polar Engineers
JIP	Joint Industry Project
JITF	Joint Industry Task Force
KARBIAC	Kara and Barents Sea Ice and Currents

KOMtech	Keppel Offshore & Marine Technology Centre
KSAT	Kongsberg Satellite Services
LME	Large Marine Ecosystem
LNG	Liquefied Natural Gas
LTE	Low Temperature Environment
LWAC	Ductile Lightweight Aggregate Concrete
MAIRES	Monitoring Arctic land and sea ice using Russian and European satellites
MARENOR	Maritime Radio system performance in the High North
MARICE	Marine Icing
MARIN	Maritime Research Institute Netherlands
MARSUNO	Maritime Surveillance in the Northern Sea Basins
MCD	Mudline Closure Device
MET Norway	Norwegian Meteorological Institute
MIR	Mechanics of Ice Rubble
MODU	Mobile Offshore Drilling Unit
MUN	Memorial University of Newfoundland
MUN OERC	Memorial University of Newfoundland – Ocean Engineering Research Centre
NEB	National Energy Board (Canada)
NEN	Netherlands Standardization Institute
NESS	Nalcor Exploration Strategy System
NOAA	National Oceanic and Atmospheric Administration
NORUT	Northern Research Institute
NPC	National Petroleum Council (USA)
NRC	National Research Council (Canada)
NRC CHC	National Research Council – Canadian Hydraulics Centre
NRC IOT	National Research Council – Institute for Ocean Technology
NRC OCRE	National Research Council – Ocean, Coastal and River Engineering
NSIDC	National Snow and Ice Data Center
NSRA	Northern Sea Route Administration

NTNU	Norwegian University of Science and Technology
OCIMF	Oil Companies International Marine Forum
OG21	Oil and Gas in the 21 century
OMAE	Ocean, Offshore and Arctic Engineering
OSI	Ocean and Sea Ice
OSR JIP	Oil Spill Response Joint Industry Project
OTC	Offshore Technology Conference
PAME	Protection of the Arctic Marine Environment
PAMOS	Pan Arctic Metocean Study
PERD	Program of Energy Research and Development
PIRAM	Pipeline Ice Risk Assessment and Mitigation
POAC	Port and Ocean Engineering under Arctic Conditions
PRAC	Petroleum Research Atlantic Canada
PRNL	Petroleum Research Newfoundland and Labrador
PSA	Petroleum Safety Authority (Norway)
PSV	Platform Supply Vessel
QDR	Quick Disconnect Reconnect
ROV	Remotely Operated Vehicle
RP	Recommended Practice
RU-NO Barents Project	The Russian – Norwegian Oil and Gas industry cooperation in the High North Project
R&D	Research and Development
SAF	Satellite Application Facilities
SAFEARC	Safe Arctic Marine Operation
SALM	Single Anchor Leg Mooring
SALTO	Safe Arctic Logistics, Transport and Operations
SAM	Subsea Accumulator Module
SAMCoT	Sustainable Arctic Marine and Coastal Technology
SAR	Synthetic Aperture Radar
SC	Sub-Committee

SIRAM	Subsea Ice Risk Assessment and Mitigation
SIWAC	Shell Ice and Weather Advisory Center
SOLAS	Safety of Life at Sea
SSRW	Same Season Relief Well
STePS2	Sustainable Technology for Polar Ships and Structures
STP	Submerged Turret Production
SwRI	Southwest Research Institute
TAM	Thruster-Assisted Mooring
TFOPP	Task Force on Arctic Marine Oil Pollution Prevention
THREDDS	THematic Real-time Environmental Distributed Data Services
TLP	Tension Leg Platform
TLU	Tanker Loading Unit
TREC	Thermo Responsive Elastomer Composites
TU Delft	Technical University of Delft
UAV	Unmanned Aerial Vehicle
UiB	University of Bergen
UiO	University of Oslo
UiS	University of Stavanger
UiT	University of Tromsø – the Arctic university of Norway
ULS	Upward-Looking Sonar
UNIS	University Centre in Svalbard
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WG	Work Group
WMO	World Meteorological Organisation

Appendix 2 Cover letter

Proactima Stavanger
Postboks 8034
4068 Stavanger
Norway

Proactima Oslo
Postboks 2988 Solli
0230 Oslo
Norway

Proactima Bergen
Kong Christian Frederiks plass 3
BI-bygget, 5006 Bergen
Norway

Proactima Trondheim
Abelsgate 5
7030 Trondheim
Norway

t: +47 40 00 19 33 · f: +47 51 87 57 41 · org.no. 985 892 555 · post@proactima.com · proactima.com

Letter sent to:
Industry and R&D institutions
within the Arctic Petroleum
Industry

Our ref.: 1071842

Stavanger, 27 April 2015

Overview of measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activity

Proactima (located in Stavanger, Norway) is currently conducting a project on behalf of the Norwegian Petroleum Safety Authority (PSA) to map measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activity. The assignment is an action identified by Task Force on Arctic Marine Oil Pollution Prevention (TFOPP) working within the Arctic Council. The assignment is financed by the Norwegian Ministry of Foreign Affairs.

The assignment covers all measures to prevent oil pollution in the Arctic marine environment from offshore petroleum activities. The mapping shall focus especially on technical conditions, but also operational conditions are relevant. Technology, research and development, standards, procedures and guidelines are among the topics to be mapped – both established, ongoing and proposed new activities. Oil spill response, in addition to shuttle tankers and vessels operating on the open sea are not a part of the assignment.

The results from the work will be documented in an open report, which will be published by the Arctic Council. The PSA will present the results from the work at the Arctic Safety Summit 2015 in Tromsø in October 2015.

As a part of the mapping activity, we solicit your organisation's response to the enclosed questionnaire. If you for some reason choose not to answer certain questions, this will of course be respected. However, we will ensure that we will deal with information received in a responsible and restricted manner, and any requirements to sensitivity or confidentiality that you may add, will be complied with.

A follow-up dialogue may be required with some of the recipients of this letter. Contact for such follow-up arrangements will be made in due course.

Questions regarding the survey may be directed to Proactima project manager Karianne Haver, phone +47 957 34 291 or e-mail karianne.haver@proactima.com or PSA contact person Sigurd R. Jacobsen, phone +47 957 08 834 or e-mail sigurd.jacobsen@ptil.no, alternatively Øyvind Tuntland, phone +47 906 83 593 or e-mail oyvind.tuntland@ptil.no.

We appreciate your assistance and look forward to receiving a reply within 8 May 2015.

Best regards
Proactima AS

Hermann S. Wiencke
Managing director

Appendix 3 Questionnaire

Proactima (located in Stavanger, Norway) is currently conducting an assignment on behalf of the Norwegian Petroleum Safety Authority (PSA) to map measures specifically designed to prevent or contain the escape of fluids into the marine environment from offshore petroleum activities in the Arctic. The assignment is an action identified by Task Force on Arctic Marine Oil Pollution Prevention (TFOPP) working within the Arctic Council.

Our focus is technical and operational measures to enhance the safety related to offshore petroleum activities in the Arctic. The scope includes, but is not limited to, field development concepts, well integrity incl. capping and containment, process systems, risers, pipeline transportation, loading / offloading systems, ice surveillance and ice management.

Technology, research and development, standards, procedures and guidelines are among the topics to be mapped – both established, ongoing and proposed new activities.

1.	**TECHNOLOGY, RESEARCH AND DEVELOPMENT** **Do you participate in technology, research and development activities related to offshore petroleum operations in the Arctic?** Yes / No
	If 'Yes', please indicate topics being addressed
2.	**STANDARDS, PROCEDURES AND GUIDELINES** **Do you participate in development of standards, procedures and guidelines related to offshore petroleum activities in the Arctic?** Yes / No
3.	**TECHNOLOGICAL AND OPERATIONAL CHALLENGES** **What do you consider to be the most critical technological or operational challenges for exploitation of petroleum resources in Arctic regions?** Please specify
3.	**TECHNOLOGY, RESEARCH AND DEVELOPMENT PROJECTS** **If you undertake technology, research and development projects (ref. question no. 1 above), has information about such activities or concepts been announced or published at conferences, in technical publications or in the press?** Yes / No
	If 'Yes', please refer to relevant sources

4.	**IMPACT ON HSE** **Will the technical solution(s) you work on have impact on the probability of unwanted incidents occurring and / or the consequences of an incident taking place?** Yes / No
	If 'Yes', please indicate the effects you foresee
6.	**ENVIRONMENTAL AND METOCEAN DATA** **Do you carry out collection and / or registration of relevant data for the Arctic regions?** Yes / No
	If 'Yes', we would appreciate information regarding availability of the data
7.	**TECHNOLOGY, RESEARCH AND DEVELOPMENT PARTNERS** **If you are in position to provide names, we would appreciate to know of key partners in your Arctic projects.**
	Technology, research and development partners

Appendix 4 Overview of respondents to the baseline survey

Respondents to the baseline survey, in terms of responding to the baseline questionnaire request or through direct contact, are presented in Table 1. The organisation and location of the contact point, in addition to organisation type, are presented.

Table 1 Contributors to the baseline survey

Organisation	Location	Organisation type
Aker Solutions	Norway	Industry
American Bureau of Shipping (ABS) - Harsh Environment Technology Center (HETC)	Canada	Classification society
American Petroleum Institute (API)	USA	Industry
Bayerngas Norway	Norway	Operator
BG Group E&P Europe	Norway	Operator
BP Norway	Norway	Operator
Bureau Veritas	Norway	Classification society
Canada Newfoundland Labrador Offshore Petroleum Board (CNLOPB)	Canada	Authorities
Canatec Europe	The Netherlands	Industry
C-CORE**in**	Canada	Industry
Chevron Arctic Center	Canada	Operator
ConocoPhillips Norway	Norway	Operator
COSL Drilling Europe	Norway	Industry
DEA Norway	Norway	Operator
Det Norske	Norway	Operator
DNV GL	Norway	Classification society
Dolphin Drilling	Norway	Industry
Dong Energy E&P Norway	Norway	Operator
Dr.tech. Olav Olsen	Norway	Industry
E.ON E&P Norway	Norway	Operator
Edison Norway	Norway	Operator
Eni Norway	Norway	Operator
ExxonMobil E&P Norway	Norway	Operator
Faroe Petroleum	Norway	Operator
FMC Technologies	Norway	Industry
GDF SUEZ E&P Norway	Norway	Operator
Graham Thomas	England	Independent
GustoMSC	The Netherlands	Industry
Halliburton	USA	Industry
Henrik Carlsen	Stavanger	Independent
HSVA	Germany	Industry
Inocean	Norway	Industry
Institute for Energy Technology	Norway	Research

Organisation	Location	Organisation type
INTECSEA	Canada	Industry
INTSOK	Norway / Russia	Industry
IOGP	Norway	Industry
ISPAS	Norway	Industry
Keppel Offshore & Marine Technology Centre (KOMtech)	Singapore	Industry
KUFPEC Norway	Norway	Industry
Kværner Concrete Solutions	Norway	Industry
Lloyd's Register	Norway	Classification society
Lundin Norway	Norway	Operator
Machine Technology Center	Finland	Research
Marin	The Netherlands	Research
MARINTEK	Norway	Research
MET Norway	Norway	Research
Mike Maguire	Canada	Independent
Moss Maritime	Norway	Industry
National Energy Authority (Iceland)	Iceland	Authorities
National Energy Board (Canada)	Canada	Authorities
National Institute Of Occupational Health (Norway)	Norway	Research
National Oilwell Varco	USA	Industry
National Research Council (Canada)	Canada	Research
North Energy	Norway	Operator
NORUT	Norway	Research
Norwegian Petroleum Directorate	Norway	Authorities
NTNU (SAMCoT)	Norway	Research
Nuna Oil	Greenland	Operator
The Research Council of Norway	Norway	Industry
OMV Norway	Norway	Operator
Peter Noble	USA	Independent
Petro Arctic	Norway	Industry
PGNiG Upstream International	Norway	Operator
Preventor	Trondheim	Industry
Prosafe	Norway	Industry
Rutter	Canada	Industry
SAFETEC	Norway	Industry
Saipem Italy	Italy	Industry
Shell International E&P	USA	Operator
SINTEF Petroleum Research	Norway	Research
SINTEF Safety Research	Norway	Research
Southwest Research Institute (SwRI)	USA	Research
Statoil	Norway	Operator
Stena Drilling	Norway	Industry
Subsea 7 Canada	Canada	Industry
Subsea 7 Norway	Norway	Industry
Suncor Energy Norway	Norway	Operator

Organisation	Location	Organisation type
Technip Norway	Norway	Industry
Telenor Satellite Broadcasting	Norway	Industry
The Research Council of Norway	Norway	Industry
ThyssenKrupp Marine Systems	Germany	Industry
Total E&P Norway	Norway	Operator
Transocean Services	Norway	Industry
Trendsetter Engineering	USA	Industry
Viking Ice Consultancy	Norway	Industry
Wintershall Norway	Norway	Operator

Appendix 5 Technology implemented in Arctic areas

Introduction

Overview of Arctic areas

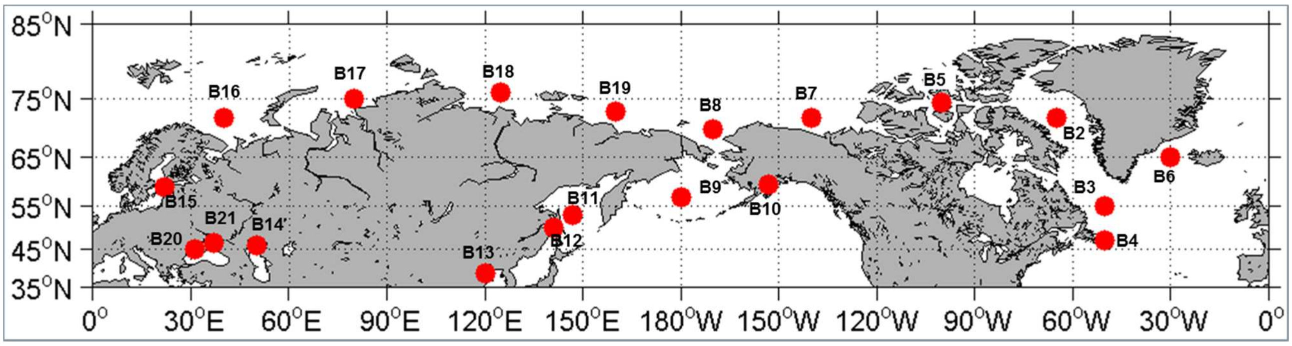


Figure 18 Arctic areas as defined in ISO 19906:2010.

In ISO 19906 (ISO 19906:2010) twenty Arctic areas (roughly displayed in Figure 18) are defined, and area specific Arctic challenges are described in depth in Annex B of the document. Some of the main Arctic challenges and characteristics for this report are described in Table 2, and a summary of important characteristics are found in the overview matrix presented later. Table 2 also displays an overview of the number of offshore installations located in these areas, while Table 3 displays an overview of the installation types found in each area (INTECSEA, 2015 & Offshore, 2014).

Table 2 Arctic areas in ISO 19906 and their main characteristics.

Arctic areas[1]	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
B.2 Baffin Bay and Davis Strait	🔴	🔴	🔴	-41		
B.3 Labrador	🔴		🔴	-40	~200	1 future
B.4 Newfoundland	🔵		🔴	-19	80-122	4 existing
B.5 Canadian Arctic Archipelago	🔴	🔴	🔴	-45	0, 55	1 former 1 future
B.6 Greenland	🔴	🔴	🔴	-35		
B.7 Beaufort Sea	🔴	🔴	🔵 / 🔴	-40	2-34	4 existing 4 future
B.8 Chukchi Sea	🔴	🔴		-50	40-50	4 future
B.9 Bering Sea	🔴			-40		
B.10 Cook Inlet	🔴			-43	14-56	16 existing
B.11 Okhotsk Sea	🔴			-44	0, 15-35, 90	8 existing
B.12 Tatar Strait	🔴	🔵		-42	22	1 existing
B.13 Bohai Sea	🔴			-25	~20, <85	6 existing[2]
B.14 North Caspian	🔵 / 🔴			-30	3-6	1 existing
B.15 Baltic Sea	🔵 / 🔴			-25	25-35	2 existing

Arctic areas[1]	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
B.16 Barents Sea[3]						
Regions III, IV, V (Russia N.E.)	🔴	🔵		-39	320	2 existing
Regions VI, VII, VIII (Russia S.E.)	🔵		🔴	-20	17-20	1 future
Regions I, II (Norway)				-25/-12	250-400	2 existing
B.17 Kara Sea	🔴	🔴	🔵	-48		
B.18 Laptev Sea	🔴	🔴	🔵	-53		
B.19 East Siberian Sea	🔴	🔴	🔵	-51		
B.20 Black Sea	🔵			-27		
B.21 Sea of Azov	🔵			-30		

[1] Arctic areas as defined in ISO 19906:2010. Letter and number in front of name refers to the chapter describing the actual area.
[2] Uncertain numbers
[3] Regions in the Barents Sea as defined in Barents 2020 (Barents 2020, 2012).
🔵 Moderate / minor
🔴 Severe

Overview of installations in Arctic areas

Table 3 Overview of installation types in the various Arctic areas.

Arctic area	GBS	FPSO	Subsea	Artificial island	Open leg	Other
B.3 Labrador						1 future
B.4 Newfoundland	2 existing	2 existing				
B.5 Canadian Arctic Archipelago			1 future			1 former
B.7 Beaufort Sea	1 future			4 existing + 1 future		3 future
B.8 Chukchi Sea						4 future
B.10 Cook Inlet					15 existing	1 existing
B.11 Okhotsk Sea	5 existing		1 existing			2 existing
B.12 Tatar Strait						1 existing
B.13 Bohai Sea					5 existing[1]	1 existing[1]
B.14 North Caspian				1 existing		
B.15 Baltic Sea					2 existing	
B.16 Barents Sea	1 existing	1 existing +1 future	1 existing			1 existing

[1] Uncertain numbers

Overview of general ice protection technologies

Multiple technology solutions empower year around drilling and oil production, also when exposed to extreme temperatures and strong forces from for instance multi-year ice and icebergs. The main solutions in use are described in the sections below. In the subsequent chapter, the technology implemented for the installations currently being in operation or future planned installations is presented for each of the Arctic areas.

Artificial islands

By constructing artificial islands in areas with shallow water, it is possible to utilize technical solutions both from land and offshore based oil and gas installations and at the same time be able to withstand the forces from level ice and icebergs. Boreholes connecting the installation to the reservoirs often go from the “center” of the island and down into the under burden. Wells can also be connected to an artificial island via subsea installations and buried pipelines. Oil and gas are then typically transported from the artificial island and onshore, or to an offloading system, in buried pipelines or pipelines protected above sea level. Artificial islands are used both for drilling and/or production installations.

Buried pipelines and umbilicals

Pipelines and umbilicals, to/from shore or connecting offshore installations, are buried in the seabed for protection against the dangers of mechanical damage at shallow waters. Whenever the term buried pipelines / umbilical appears in this document without any other information the pipeline / umbilical is buried in the seabed.

Disconnectable solutions

For some installations, particularly those with permanent ice management or in areas where level ice and/or icebergs is a potential threat, various disconnectable solutions are used for risers, umbilicals and offloading systems. The installation is then able to disconnect from these systems in a case of emergency. Disconnection is usually possible to perform within minutes, while reconnection may take very long time (weeks / months in case of level ice).

Encapsulated subsea connections

Common protection of subsea connections (risers and umbilicals) and borestrings, using open channels inside platform legs or inside the GBS body to protect the connections from the forces of, for instance, level ice and minor icebergs.

Heated and mechanically ventilated process area

Using heated and mechanically ventilated process areas on installations in areas with low (-15°C – -30°C) to extreme (< -30°C) temperatures make it possible to utilize processing and working areas designed for work under normal temperature conditions. The systems must be enabled to withstand extreme temperatures when/if shut down.

Horizontal drilling from shore

Extended Reach Drilling (ERD), designed to drill wells at offshore targets from land-based locations / artificial islands, enables drilling in areas with level ice and/or icebergs without other precautions. Wells are drilled with a horizontal reach of more than 10,000 meters; some with a total depth of more than 12,300 meters out from the land-based rig. The technique is particularly suited for large targets, but as new technics are enabling increased precision it is also being used for smaller targets.

Ice management

By utilizing icebreakers and/or ice classed vessels and various monitoring systems in a systematical way, it is possible to have year round working installations in areas with level ice and icebergs. Icebreakers can then prevent level ice to form around the installation and keep fare ways open for shuttle tankers, service vessels and emergency preparedness. Furthermore, icebergs can be forced away from the installation by the vessels involved in the ice management.

Ice reinforced installations

In many cases it is possible to meet challenges from level ice, smaller icebergs, icing and heavy sea by using conventional installations with reinforced concrete / steel structures which are designed to withstand sea ice, icebergs and various meteorological and oceanographic conditions. This applies to all types of installations (GBS, jacket, FPSO, artificial island etc.).

Ice resistant offloading systems

Various ice resistant offloading systems are in use, often in connection with ice management:

- Turrets are used for tankers to "dock in" the offloading connections from underneath its hull. Tankers are able to weathervane around the turret when loading. When not in use the turret has the ability to be positioned deep enough under water to avoid level ice and icebergs. Other submerged offloading systems do also exist.
- Towers connected to onshore terminals or offshore installations with pipelines at / buried in the seabed, allowing tankers to weathervane when loading.
- Buoys connected to onshore terminals or offshore installations with pipelines at / buried in the seabed, allowing tankers to weathervane when loading.
- Tandem offloading, connecting the installation through a hose to a nearby tanker.

Subsea installations

Subsea production facilities connected to shore make it possible to produce hydrocarbons in the harshest climates and ice conditions, with no platforms or other offshore constructions required. Subsea installations can also be connected to other offshore installations. The subsea installations are connected with each other and to shore / other installations through pipelines and umbilicals at, or buried in, the seabed. Normally they are designed with anti-sweep constructions protecting them from mechanical damage like vessels, trawlers and icebergs.

Installations in Arctic areas

B.3 Labrador

Table 4 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
	1st year	Multi-year				
Bjarni / North Bjarni area	●		●	-40	~200	1 future

• Moderate / minor
• Severe

There is no available information on ice protection technologies.

Relevant installations

Future		
Operator	Suncor Energy (http://www.suncor.com/default.aspx)	**No picture available**
1st production year	Future: 2019 (expected)	
Design	To be decided	
Type	To be decided	
Environment	• Extreme temperatures • Icebergs • High wave heights • Level ice • Short distance to shore	
Technology	To be decided	
Fact pages	No specific information available. Newfoundland and Labrador, Dep. of Finance: • http://www.economics.gov.nl.ca/e2012/oilandgas.pdf	

B.4 Newfoundland

Table 5 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
	1st year	Multi-year				
Grand Banks	●		●	-19	80-122	4 existing

• Moderate / minor
• Severe

List of ice protection technologies

- Disconnectable solutions
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Ice management
- Ice reinforced installations
- Ice resistant offloading systems

Relevant installations

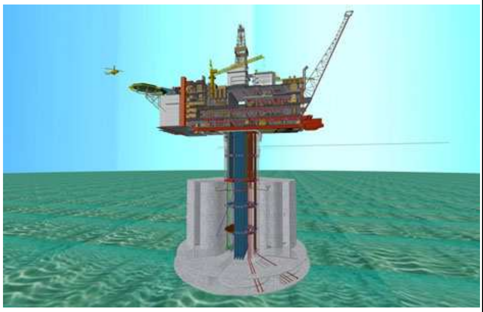
<table>
<tr><th colspan="3">White Rose</th></tr>
<tr><td>Operator</td><td>Husky Energy (http://www.huskyenergy.com/)</td><td rowspan="5">
Source: Husky Energy (huskyenergy.com, http://www.huskyenergy.com/)</td></tr>
<tr><td>1st production year</td><td>2005</td></tr>
<tr><td>Design</td><td>Aker Solutions (http://www.akersolutions.com/) and Peter Kiewit & Sons Co (http://www.kiewit.com/)</td></tr>
<tr><td>Type</td><td>Ship-shaped FPSO</td></tr>
<tr><td>Environment</td><td>• Level ice
• Icebergs
• Strong winds
• Icing
• High waves</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; flow-lines and risers from seabed to FPSO, stable oil from FPSO to shuttle tankers, re-injection of produced gas to reservoir
• Tandem offloading from FPSO to ice strengthened shuttle tankers
• Trenched subsea wells
• Ice management
• Quick-disconnect flow-lines and risers
• Subsea flowlines exposed to iceberg actions; calculated risk for damage and renewal</td></tr>
<tr><td>Fact pages</td><td colspan="2">Husky Energy on White Rose:
• http://wrep.huskyenergy.com/Project_overview

Offshore Technology on White Rose:
• http://www.offshore-technology.com/projects/white_rose/

Aker Solutions on White Rose:
• http://www.akersolutions.com/en/Global-menu/Projects/Engineering/Floater-designs/White-Rose-FPSO-Meeting-the-harsh-environment-on-the-Grand-Banks/</td></tr>
</table>

	Newfoundland and Labrador, Dep. of Finance: • http://www.economics.gov.nl.ca/e2012/oilandgas.pdf

Terra Nova		
Operator	Suncor Energy (http://www.suncor.com/default.aspx)	
1st production year	2002	
Design	Daewoo Shipbuilding and Marine Engineering (http://www.dsme.co.kr/epub/main/index.do)	
Type	Ship-shaped FPSO	
Environment	• Level ice • Icebergs • Strong winds • Icing • High waves	Source: Suncor Energy Inc. (suncor.com, http://www.suncor.com/default.aspx)
Technology	• Production system; flow-lines and risers from seabed to FPSO, stable oil from FPSO to shuttle tankers • Tandem offloading from FPSO to ice strengthened shuttle tankers • Trenched subsea wells • Ice management • Quick-disconnect flow-lines and risers	
Fact pages	*Suncor Energy* on Terra Nova: • http://www.suncor.com/en/about/4001.aspx *Offshore Technology* on Terra Nova: • http://www.offshore-technology.com/projects/terra_nova/ Newfoundland and Labrador, Dep. of Finance: • http://www.economics.gov.nl.ca/e2012/oilandgas.pdf	

Hebron		
Operator	ExxonMobil [(http://corporate.exxonmobil.com/)](http://corporate.exxonmobil.com/)	
1st production year	Future: 2017	
Design	Kiewit-Kvaerner Contractors [(http://www.kkc-gbs.com/)](http://www.kkc-gbs.com/)	
Type	Concrete GBS	
Environment	• Level ice • Icebergs • Strong winds • Icing • High waves	Source: ExxonMobil (exxonmobil.com, http://corporate.exxonmobil.com/)
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, stable oil from GBS to shuttle tankers • Reinforced concrete GBS • Encapsulated subsea connections • Offloading from GBS to ice strengthened shuttle tankers • Ice management • Quick-disconnect offshore loading subsea system pipelines	
Fact pages	*The Hebron project*: • http://www.hebronproject.com/ *Kvaerner* on the Hebron GBS: • http://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/Hebron-GBS-Project/ Newfoundland and Labrador, Dep. of Finance: • http://www.economics.gov.nl.ca/e2012/oilandgas.pdf *Kiewit-Kvaerner* on the Hebron project: • http://www.kkc-gbs.com/project	

Hibernia		
Operator	Hibernia Management and Development Company [(http://www.hibernia.ca/)](http://www.hibernia.ca/)	
1st production year	1997	
Design	Newfoundland Offshore Development Constructors (Nodeco) and Doris Development Canada (DDC).	
Type	Block type GBS	
Environment	• Level ice • Icebergs • Strong winds • Icing • High waves	Source: ExxonMobil (exxonmobil.com, http://corporate.exxonmobil.com/)
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, stable oil from GBS to shuttle tankers • Offloading from GBS to ice strengthened shuttle tankers • Encapsulated subsea connections • Ice management • Quick-disconnect offshore loading subsea system pipelines and water injection flowlines • Planned trenched subsea water injection well	
Fact pages	*Offshore Technology* on Hibernia: • http://www.offshore-technology.com/projects/hibernia/ • http://www.offshore-technology.com/projects/hibernia-a-timeline/ Newfoundland and Labrador, Dep. of Finance: • http://www.economics.gov.nl.ca/e2012/oilandgas.pdf	

B.5 Canadian Arctic Archipelago

Table 6 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
	1st year	Multi-year				
Bent Horn	●	●	●	-45	0	1 former
Drake Point	●	●	●	-45	55	1 future

● Moderate / minor
● Severe

List of ice protection technologies

- Former installation, Bent Horn: Onshore installations. Tanker loading only during summer months.
- Future installation, Drake Point: Subsea installations. Very little specific additional information available.

Relevant installations

Bent Horn		
Operator	Panarctic Oils	**No picture available**
1st production year	Former: 1985-1996	
Design	No information found	
Type	Onshore production and terminal	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters • Seismic activity	
Technology	• Production system; onshore production, stable oil from terminal to shuttle tankers • Summer tanker loading via flexible hose to icebreaking tanker, M/V Arctic	
Fact pages	*SNAME Arctic 2010*, presentation: • http://higherlogicdownload.s3.amazonaws.com/SNAME/3383113f-3070-4ddd-acd4-504418eb35a9/UploadedImages/Files/2010/2010-Apr21-Presentation.pdf *Norwegian oil and gas association*, paper: • http://www.norskoljeoggass.no/Global/HMS-utfordringer%20i%20nordomr%C3%A5dene/Underlagsmateriale/Generelt/The%20Arctic%20Islands%20Adventure%20and%20Panarctic%20Oils%20Ltd%20.pdf Bent Horn in a historical setting: • http://en.wikipedia.org/wiki/History_of_the_petroleum_industry_in_Canada_(frontier_exploration_and_development)	

Drake Point		
Operator	Suncor Energy (http://www.suncor.com/default.aspx)	**No picture available**
1st production year	Future: No information available	
Design	No information available	
Type	Subsea	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters • Seismic activity	
Technology	• Subsea installation • No further information is currently found	
Fact pages	*Offshore* on Drake Point, poster: • http://www.offshore-mag.com/content/dam/offshore/print-articles/volume-74/02/0214ArcticPoster-012014Ads.pdf *Franco Nevada* on Drake Point: • http://www.franco-nevada.com/royalties/our-royalties/oil-gas-interests/advanced/arctic-gas-nwt-and-nunavut	

B.7 Beaufort Sea

Table 7 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
	1st year	Multi-year				
Ooguruk (Alaska)	•	•	• / •	-40	2	1 existing
Northstar (Alaska)	•	•	• / •	-40	12	1 existing
Nikaitchuq (Alaska)	•	•	• / •	-40	2	1 existing
Endicott (Alaska)	•	•	• / •	-40	4	1 existing
Liberty (Alaska)	•	•	• / •	-40	6	1 future
Kuvlum (Alaska)	•	•	• / •	-40	34	1 future
Sivulliq (Alaska)	•	•	• / •	-40	34	1 future
Amauligak (Canada)	•	•	• / •	-40	26-32	1 future

• Moderate / minor
• Severe

List of ice protection technologies

- Artificial islands
- Buried pipelines and umbilicals
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Horizontal drilling from shore
- Ice reinforced installations

Relevant installations

Endicott		
Operator	Hilcorp Energy (http://www.hilcorp.com/)	**No picture available**
1st production year	1987	
Design	Alaska Frontier Constructors (http://www.akfrontier.com/index_b.html) (island) Parker Drilling (http://www.parkerdrilling.com/) (drilling rig)	
Type	Artificial island	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	• Production system; onshore production, internal flow-lines and risers “inside” artificial island, offloading to shore through pipelines on gravel causeway • Gravel island • Gravel causeway with pipelines to shore • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*McKinstry* on Endicott: • http://www.mckinstry.com/projects/146/BP-Endicott-Facility *Hilcorp* buys Northstar, Endicott, Milne Point and Liberty: • http://www.alaskajournal.com/Alaska-Journal-of-Commerce/March-Issue-2-2015/Hilcorp-Energy-keeps-up-spending-despite-oil-price-slide/	

Northstar		
Operator	Hilcorp Energy (http://www.hilcorp.com/)	**No picture available**
1st production year	2001	
Design	Alaska Frontier Constructors (island) (http://www.akfrontier.com/index_b.html)	
Type	Artificial island	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	• Production system; onshore production, internal flow-lines and risers "inside" artificial island, offloading to shore through pipeline buried in seabed • Gravel island with concrete mat and rock armour • Buried pipelines to shore • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*Hydrocarbons-Technology* on Northstar • http://www.hydrocarbons-technology.com/projects/northstar/ *Hilcorp* buys Northstar, Endicott, Milne Point and Liberty: • http://www.alaskajournal.com/Alaska-Journal-of-Commerce/March-Issue-2-2015/Hilcorp-Energy-keeps-up-spending-despite-oil-price-slide/ *Wikipedia* on Northstar • http://en.wikipedia.org/wiki/Northstar_Island	

<table>
<tr><th colspan="3">Nikaitchuq</th></tr>
<tr><td>Operator</td><td>ENI Petroleum
(http://www.eni.com/en_IT/home.html)</td><td rowspan="5">
Source: Eni (eni.com, http://www.eni.com/en_IT/home.html)</td></tr>
<tr><td>1st production year</td><td>2011</td></tr>
<tr><td>Design</td><td>• Nanuq (island)
    • INTECSEA (http://www.intecsea.com/) (subsea pipeline)
• HC Price (pipelines)</td></tr>
<tr><td>Type</td><td>Artificial island</td></tr>
<tr><td>Environment</td><td>• Level ice
• Icebergs
• Extreme temperatures
• Shallow waters</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; onshore production, internal flow-lines and risers “inside” artificial island, offloading to shore through pipeline buried in seabed
• Gravel island with gravel bag armour
• Buried pipelines to shore
• Encapsulated subsea connections
• Heated and mechanically ventilated process area</td></tr>
<tr><td>Fact pages</td><td colspan="2">Offshore Technology on Nikaitchuq:
• http://www.offshore-technology.com/projects/nikaitchuqoilfieldal/

Offshore Energy Today on Nikaitchuq:
• http://www.offshoreenergytoday.com/eni-reaches-25-000-bopd-production-goal-at-nikaitchuq-field-alaska/

ENI on Nikaitchuq:
• https://www.eni.com/en_IT/media/press-releases/2014/06/2014-06-19-Nikaitchuq.shtml</td></tr>
</table>

Ooguruk		
Operator	Caelus Energy (http://caelusenergy.com/)	**No picture available**
1st production year	2008	
Design	Nabors (http://www.nabors.com/) (rig) Alaska Frontier Constructors (http://www.akfrontier.com/index_b.html) (island)	
Type	Artificial island	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	• Production system; onshore production, internal flow-lines and risers “inside” artificial island, offloading to shore through pipeline buried in seabed • Gravel island with gravel bag armour • Buried pipelines to shore • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*Offshore Technology* on Oooguruk: • http://www.offshore-technology.com/projects/premier_ooguruk/ *Offshore* on Oooguruk: • http://www.offshore-mag.com/articles/print/volume-68/issue-8/arctic-frontiers/oooguruk-project-offshore-alaska.html *Rigzone* on Oooguruk: • http://www.rigzone.com/news/oil_gas/a/62820/Pioneer_Starts_Up_Ooguruk_Production_in_Alaska	

Liberty		
Operator	Hilcorp Energy (http://www.hilcorp.com/)	**No picture available**
1st production year	Future: 2019	
Design	Parker Drilling (http://www.parkerdrilling.com/) (rig) Alaska Frontier Constructors (island) http://www.akfrontier.com/index_b.html	
Type	Artificial island	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	• Production system; onshore production, internal flow-lines and risers “inside” artificial island, offloading to shore through pipelines on gravel causeway • Gravel island • Gravel causeway with pipelines to shore • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*Alaska Journal of Commerce* on Liberty: • http://www.alaskajournal.com/Alaska-Journal-of-Commerce/January-Issue-2-2015/Hilcorp-files-plan-for-Liberty-field-development/ *Alaska Dispatch News* on Liberty: • http://www.adn.com/article/20140109/bp-returns-traditional-concepts-long-delayed-liberty-oil-field • http://www.adn.com/article/20141230/hilcorp-files-new-development-plan-offshore-liberty-prospect *Offshore Technology* on Liberty • http://www.offshore-technology.com/projects/liberty-project/ *Hilcorp* buys Northstar, Endicott, Milne Point and Liberty: • http://www.alaskajournal.com/Alaska-Journal-of-Commerce/March-Issue-2-2015/Hilcorp-Energy-keeps-up-spending-despite-oil-price-slide/	

Kuvlum		
Operator	Shell (https://www.shell.com/)	No picture available
1st production year	Future: To be decided	
Design	No information available	
Type	To be decided	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	To be decided	
Fact pages	*Offshore* on Kuvlum, poster: • http://www.offshore-mag.com/content/dam/offshore/print-articles/volume-74/02/0214ArcticPoster-012014Ads.pdf	

Sivulliq (previously Hammerhead)		
Operator	Shell (https://www.shell.com/)	No picture available
1st production year	Future: To be decided	
Design	No information available	
Type	Conical GBS	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	• Conical GBS • No further information is currently found	
Fact pages	*Petroleum News* on Sivulliq: • http://www.petroleumnews.com/pntruncate/630112852.shtml	

Amauligak		
Operator	ConocoPhillips (http://www.conocophillips.com/)	**No picture available**
1st production year	Future: To be decided	
Design	No information available	
Type	To be decided	
Environment	• Level ice • Icebergs • Extreme temperatures • Shallow waters	
Technology	To be decided	
Fact pages	*Oil & Gas Eurasia* on Amauligak: • https://www.oilandgaseurasia.com/en/news/canadian-arctic-next-destination-global-majors	

B.8 Chukchi Sea

Table 8 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
Northwest Alaska, 90 km offshore	●	●		-50	40-50	4 future

● Moderate / minor
● Severe

There is no available information on ice protection technologies.

Relevant installations

No detailed information about installations is currently available.

Shell (https://www.shell.com/) plans to develop four fields in the area (the Burger prospect). Oil and associated gas will be produced from fields one, two and four. Natural gas and condensate will be produced from field 3.The development plan covers the construction of four offshore production platforms, offshore subsea pipelines, onshore pipelines across the National Petroleum Reserve Alaska to link to the Trans-Alaska system and a future gas pipeline from the North Slope. An onshore facility is also being planned to assist offshore exploration and drilling activities. The first oil field is expected to come on-stream in 2022, the second in 2036.

Offshore Technology on Burger:

- http://www.offshore-technology.com/projects/chukchiseapermit/

B.10 Cook Inlet

Table 9 Site specific challenges at the various locations.

	Level ice 1st year	Level ice Multi-year	Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
Cook Inlet	●			-43	14-56	16 existing

● Moderate / minor
● Severe

List of ice protection technologies

- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Ice reinforced installations

Relevant installations

Osprey		
Operator	Cook Inlet Energy (Miller Energy Resources - http://www.millerenergyresources.com/)	**No picture available**
1st production year	2000, reactivated in 2011	
Design	Hyundai (platform) Veco (Living quarter)	
Type	Open-legged	
Environment	• Level ice • Strong tides / currents • Extreme temperatures • Shallow waters (14 m)	
Technology	• Production system; internal flow-lines and risers inside platform leg(s), offloading to shore through pipeline(s) on seabed • Ice reinforced open-legged platform • Subsea pipelines (on seabed) • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*Petroleum News* on Osprey: • http://www.petroleumnews.com/pntruncate/288482892.shtml *Marine Exchange of Alaska* on the installation of the Osprey platform: • http://www.mxak.org/community/osprey/osprey.html • http://www.mxak.org/community/osprey/osprey%20info.pdf	

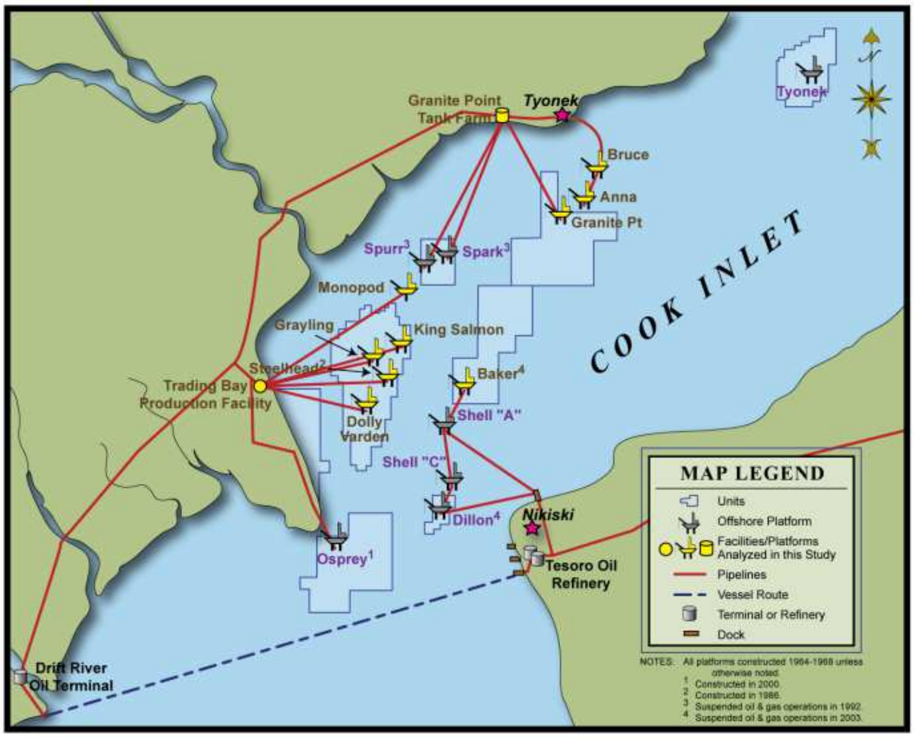


Figure 19 Offshore installations at the Cook Inlet (Nuka Research & Planning Group).

Other platforms at the Cook Inlet		
Operator	Chevron (http://www.chevron.com/), Cross Timbers (http://crosstimbersenergy.com/), ConocoPhillips (http://www.conocophillips.com/), Forest Oil (http://www.bizjournals.com/denver/blog/earth_to_power/2014/12/forest-oil-sabine-complete-merger-hq-to-be-in.html), Shell (https://www.shell.com/)	**No picture available**
1st production year	14 in 1964-1968, 1 in 1986	
Design		
Type	Open-legged (large diameter), one mono-pod	
Environment	• Level ice • Strong tides • Extreme temperatures • Shallow waters	
Technology	Due to their high age these platforms are not investigated any further in this report.	
Fact pages	*Alaska Dispatch News*, photo slideshow on platforms at the Cook Inlet: • http://www.adn.com/slideshow/photos-cook-inlet-offshore-oil-production *Oilprice.com* – “A History of Oil and Gas in Southern Alaska”:	

	• http://oilprice.com/Energy/Energy-General/A-History-Of-Oil-And-Gas-In-Southern-Alaska.html

B.11 Okhotsk Sea and B.12 Tatar Strait

Table 10 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp. [°C]	Sea depth at installations [m]	# installations
	1st year	Multi-year				
North eastern Sakhalin Island coast	●			-44	15-90	6 existing
South Sakhalin Island coast					20	2 existing
Tatar Strait, North	●	●		-42	22	1 existing

● Moderate / minor
● Severe

List of ice protection technologies

- Buried pipelines and umbilicals
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Horizontal drilling from shore[1]
- Ice management
- Ice reinforced installations
- Ice resistant offloading systems
- Subsea installations

[1] Several wells are drilled at this location with a horizontal reach of more than 10 000 m, some with a total depth of more than 12 300 m out from the land-based rig.

Relevant installations

<table>
<tr><td colspan="3">Yastreb (Sakhalin-1)</td></tr>
<tr><td>Operator</td><td>Exxon Neftegas (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td><td rowspan="5">
Source: Exxon Neftegas Ltd. (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td></tr>
<tr><td>1st production year</td><td>2002</td></tr>
<tr><td>Design</td><td>Parker Drilling (http://www.parkerdrilling.com/)</td></tr>
<tr><td>Type</td><td>Onshore ERD rig</td></tr>
<tr><td>Environment</td><td>• Level ice
• Extreme temperatures
• Shallow waters
• Seismic activity
• High waves</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; onshore production, stable oil thorough onshore pipelines to offloading terminal.
• Extended Reach Drilling (ERD)
• Onshore rig and facilities</td></tr>
<tr><td>Fact pages</td><td colspan="2">Sakhalin-1 on the Yastreb rig:
• http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/about_phases_chayvo1_yastreb.aspx

Offshore on the Yastreb rig and extended-reach drilling:
• http://www.offshore-mag.com/articles/print/volume-72/issue-9/drilling-and-completion/extended-reach-drilling-advances-to-meet-industry-need.html

Offshore Technology on the Yastreb rig and Sakhalin-1:
• http://www.offshore-technology.com/features/feature1089/</td></tr>
</table>

Orlan (Sakhalin-1)		
Operator	Exxon Neftegas (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)	 Source: Exxon Neftegas Ltd. (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)
1st production year	2005	
Design	Global Marine Concrete Island Drilling Systems	
Type	Block type GBS	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity • High waves	
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shore through pipeline buried in seabed • Block type GBS / Concrete Island Drilling Structure (CIDS) • Heated work areas / HVAC plant • Internal risers / drill string • Wave deflectors toward windward sides • Continuous steel skirt to manage water intrusion and potential freeze impact • Buried pipeline to shore	
Fact pages	*Offshore* on the Orlan platform • http://www.offshore-mag.com/articles/print/volume-67/issue-9/arctic-frontiers/braving-the-bitter-cold.html *Offshore Technology* on the Orlan platform and Sakhalin-1: • http://www.offshore-technology.com/features/feature1089/ *Rigzone* on the Orlan platform • http://www.rigzone.com/data/offshore_drilling_rigs/628/Drill_Barge/Exxon_Neftgaz/Orlan	

<table>
<tr><td colspan="3">Berkut (Sakhalin-1)</td></tr>
<tr><td>Operator</td><td>Exxon Neftegas (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td><td rowspan="5">
Source: Exxon Neftegas Ltd. (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td></tr>
<tr><td>1st production year</td><td>2014</td></tr>
<tr><td>Design</td><td>Kvaerner (https://www.kvaerner.com/) and Daewoo Shipbuilding and Marine Engineering (http://www.dsme.co.kr/epub/introduction/introduction0101.do)</td></tr>
<tr><td>Type</td><td>Multi-column concrete GBS</td></tr>
<tr><td>Environment</td><td>• Level ice
• Extreme temperatures
• Shallow waters
• Seismic activity
• High waves</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shore through pipeline buried in seabed
• Ice resistant fixed platform, for sea ice up to two meters thickness
• Buried pipeline to shore
• Designed for a seismically active area</td></tr>
<tr><td>Fact pages</td><td colspan="2">Offshore Technology on the Berkut platform
• http://www.offshore-technology.com/projects/arkutun-dagi-oil-gas-field/

Rosneft on the Berkut platform:
• http://www.rosneft.com/news/news_in_press/23062014.html

Kvaerner on the Berkut platform
• https://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/The-Sakhalin-1-GBS-completed/</td></tr>
</table>

<table>
<tr><td colspan="3">De-Kastri oil export terminal (Sakhalin-1)</td></tr>
<tr><td>Operator</td><td>Exxon Neftegas (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td><td rowspan="5">
Source: Exxon Neftegas Ltd. (http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx)</td></tr>
<tr><td>1st production year</td><td>2006</td></tr>
<tr><td>Design</td><td>Bluewater (http://www.bluewater.com/)</td></tr>
<tr><td>Type</td><td>Single Point Mooring (SPM) loading tower</td></tr>
<tr><td>Environment</td><td>• Level ice
• Extreme temperatures
• Shallow waters
• Seismic activity</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; buried pipelines from oil terminal to offloading tower, flexible hose from offloading tower to tankers
• Weather-vaning offshore offloading
• Ice resistant Single Point Mooring (SPM) loading tower
• Buried pipeline from shore
• Serving a specifically designed fleet of double hull Aframax class tankers, escorted by ice-breaking vessels</td></tr>
<tr><td>Fact pages</td><td colspan="2">About the De-Kastri terminal
• http://www.vostokmedia.com/n64483.html?print

European Oil & Gas on the De-Kastri terminal
• http://www.europeanoilandgas.co.uk/article-page.php?contentid=5775&issueid=209

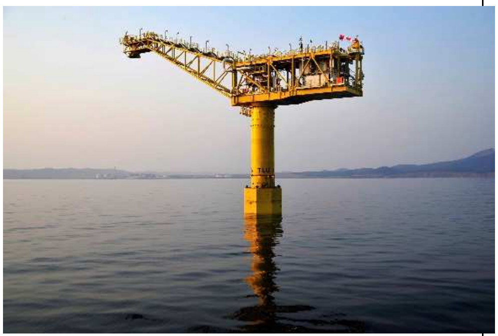
decarboni.se on SPMs
• http://decarboni.se/publications/co2-liquid-logistics-shipping-concept-llsc-overall-supply-chain-optimization/56-ship</td></tr>
</table>

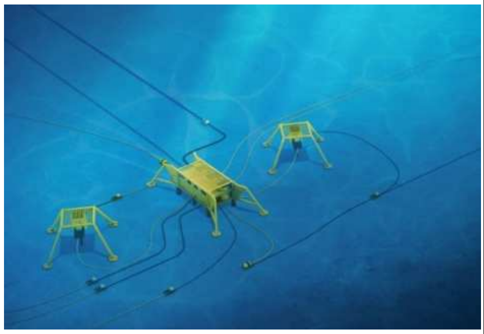
Molikpaq (PA-A) (Sakhalin-2)		
Operator	Sakhalin Energy (http://www.sakhalinenergy.com/en/index.wbp)	
1st production year	1999 (tanker offloading), 2008 (pipeline)	
Design	Sandwell/IHI (now part of Ausenco (http://www.ausenco.com/))	
Type	Block type GBS	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity • High waves	Courtesy of Sakhalin Energy Investment Company Ltd. (http://www.sakhalinenergy.com/en/index.wbp)
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shore through pipeline buried in seabed • Block type GBS / Steel Island Drilling Structure (SIDS) • Steel caisson with an annular hull, ballasted down to the seabed • Internal risers / drill string • 1999-2008: Single Anchor Leg Mooring (SALM) buoy, enabling offloading to tankers in ice free periods • 2008-: Year round offloading through buried pipeline to shore	
Fact pages	*Phoenix & Hodge* on the design and history of the Molikpaq platform • http://phoenix-hodge.com/Molikpaq.html *Offshore Technology* on the Molikpaq platform and Sakhalin-2 • http://www.offshore-technology.com/projects/sakhalin/	

Piltun-Astokhskoye-B (PA-B) (Sakhalin-2)		
Operator	Sakhalin Energy (http://www.sakhalinenergy.com/en/index.wbp)	
1st production year	2007	
Design	Kvaerner (https://www.kvaerner.com/) and Quattrogemini OY	
Type	Multi-column concrete GBS	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity • High waves	Courtesy of Sakhalin Energy Investment Company Ltd. (http://www.sakhalinenergy.com/en/index.wbp)
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shore through pipeline buried in seabed • Ice resistant fixed platform, for sea ice up to two meters thickness • Buried pipeline to shore • Designed for a seismically active area	
Fact pages	*Kvaerner* on the GBS on Sakhalin • https://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/Concrete-references/	

Lunskoye-A (LUN-A) (Sakhalin-2)		
Operator	Sakhalin Energy (http://www.sakhalinenergy.com/en/index.wbp)	 Courtesy of Sakhalin Energy Investment Company Ltd. (http://www.sakhalinenergy.com/en/index.wbp)
1st production year	2008	
Design	Kvaerner (https://www.kvaerner.com/) and Quattrogemini OY	
Type	Multi-column concrete GBS	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity • High waves	
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shore through pipeline buried in seabed • Ice resistant fixed platform, for sea ice up to two meters thickness • Buried pipeline to shore • Designed for a seismically active area	
Fact pages	*Kvaerner* on the GBS on Sakhalin • https://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/Concrete-references/	

LNG plant at the Prigorodnoye Production Complex (Sakhalin-2)		
Operator	Sakhalin Energy (http://www.sakhalinenergy.com/en/index.wbp)	
1st production year	2009	
Design		
Type	Offloading jetty for LNG to tankers	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity	Courtesy of Sakhalin Energy Investment Company Ltd. (http://www.sakhalinenergy.com/en/index.wbp)
Technology	• Production system; pipelines from gas terminal on jetty to offloading system for tankers • Special designed loading jetty, handling custom-designed LNG carriers • Pipeline from shore, above sea level	
Fact pages	*Sakhalin Energy* on the LNG plant: • http://www.sakhalinenergy.ru/en/company/company_assets/industrial_complex_prigorodnoe.wbp *Hydrocarbons Technology* on the LNG plant: • http://www.hydrocarbons-technology.com/projects/sakhalin2/	

Oil export terminal at the Prigorodnoye Production Complex (Sakhalin-2)		
Operator	Sakhalin Energy (http://www.sakhalinenergy.com/en/index.wbp)	
1st production year	2009	
Design	Ausenco (http://www.ausenco.com/)	
Type	Offshore oil loading tower	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity	Courtesy of Sakhalin Energy Investment Company Ltd. (http://www.sakhalinenergy.com/en/index.wbp)
Technology	• Production system; pipelines on seabed from oil terminal to offloading tower, flexible hose from offloading tower to tankers • Subsea offloading pipeline from shore • Single Point Mooring (SPM) Tanker Loading Unit (TLU), allowing tankers to weathervane according to wind, current, waves and ice conditions • TLU designed to resist severe ice, wave, wind, seismic and vessel collision loads	
Fact pages	*Gazprom* on the oil export terminal • http://gazprom-sh.nl/oil/ *Ausenco* on the TLU • http://www.ausenco.com/case-studies/tanker-loading-unit# *decarboni.se* on TLUs • http://decarboni.se/publications/co2-liquid-logistics-shipping-concept-llsc-overall-supply-chain-optimization/56-ship *Sakhalin Energy* on the production complex: • http://www.sakhalinenergy.ru/en/company/company_assets/industrial_complex_prigorodnoe.wbp *Hydrocarbons Technology* on the production complex: • http://www.hydrocarbons-technology.com/projects/sakhalin2/	

Kirinsky gas and condensate field (Sakhalin-3)		
Operator	Gazprom (http://www.gazprom.com)	 Source: Gazprom (http://www.gazprom.com)
1st production year	2014	
Design	Saipem (http://www.saipem.com/sites/SAIPEM_en_IT/home/saipem-homepage.page) and Mezhregiontruboprovostroy (MRTS) (http://www.mrts.ru/en/)	
Type	Subsea	
Environment	• Level ice • Extreme temperatures • Shallow waters • Seismic activity • High waves	
Technology	• Production system; subsea production facility, connected with buried umbilicals and pipelines to/from shore • Manifold at seabed intakes gas from several wells • Manifold and wells secured by special anti-sweep constructions • Buried pipeline for gas transport to shore • Buried pipeline for anti-freeze from shore to field, preventing formation of hydrates • Buried umbilical line for subsea production system control • Seismic resistant for earthquakes with magnitudes of up to 9 points	
Fact pages	*Gazprom* on the Kirinskoye field • http://www.gazprom.com/about/production/projects/deposits/sakhalin3/kirinskoye/ *Offshore Technology* on the Kirinskoye field • http://www.offshore-technology.com/projects/kirinskoye-gas-condensate-field-russia/	

General references on Sakhalin

Sakhalin-1 home page:

- http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx

Exxon Mobil on Sakhalin-1:

- http://corporate.exxonmobil.com/en/energy/arctic/presence/our-arctic-presence

Sakhalin-2 home page:[1]

[1] All assets of Sakhalin Energy Investment Company Ltd. / Sakhalin-2 project are located to the South of the Arctic Circle.

- http://www.sakhalinenergy.com/en/index.wbp

Gazprom on the Sakhalin-2 project:

- http://www.gazprom.com/about/production/projects/deposits/sakhalin2/

Offshore Technology on the Sakhalin-2 project:

- http://www.offshore-technology.com/projects/sakhalin-ii-a-timeline/sakhalin-ii-a-timeline3.html

Gazprom on the Sakhalin-3 project:

- http://www.gazprom.com/about/production/projects/deposits/sakhalin3/

Kvaerner on concrete solutions for Arctic installations (PDF):

- http://www.intsok.com/content/download/20055/125757/version/2/file/Kvaern_PDF_007.+Kvaerner+Concre.pdf

B.13 Bohai Sea

The Bohai Sea is an "odd" Arctic area, with spars information available. However, this is probably not the most relevant technology available, so neither a complete overview of the installations nor detailed information about them has been traced down.

Table 11 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
B.13 Bohai Sea	●			-25	~20, <85	6 existing[1]

● Moderate / minor
● Severe
[1]Uncertain numbers

List of ice protection technologies

- Buried pipelines and umbilicals
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Ice reinforced installations

Relevant installations

<table>
<tr><th colspan="3">6 platforms, named A-F</th></tr>
<tr><td>Operator</td><td>China National Offshore Oil Corporation (CNOOC) (http://www.cnoocltd.com/), ConocoPhillips (http://www.conocophillips.com/), others</td><td rowspan="5">
Source: China National Offshore Oil Corporation (http://www.cnoocltd.com/)</td></tr>
<tr><td>1st production year</td><td>2004-2011</td></tr>
<tr><td>Design</td><td></td></tr>
<tr><td>Type</td><td>Open-legged and mono-pile</td></tr>
<tr><td>Environment</td><td>• Level ice
• Low temperatures
• Shallow waters</td></tr>
<tr><td>Technology</td><td colspan="2">• Ice reinforced open-legged platform, some with ice cones
• Heated and mechanically ventilated process area
• Buried pipelines to shore</td></tr>
<tr><td>Fact pages</td><td colspan="2">Offshore Technology on the Bohai Bay Field:
• http://www.offshore-technology.com/projects/bohai-bay/</td></tr>
</table>

B.14 North Caspian

Table 12 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
North Caspian	● / ●			-30	3-6	1 existing

● Moderate / minor

● Severe

List of ice protection technologies:

- Artificial islands
- Buried pipelines and umbilicals
- Encapsulated subsea connections
- Heated and mechanically ventilated process area

Relevant installations

<table>
<tr><th colspan="3">Kashagan</th></tr>
<tr><td>Operator</td><td>North Caspian Operating Company (http://www.ncoc.kz/en/default.aspx)</td><td rowspan="5">
Courtesy of North Caspian Operating Company (http://www.ncoc.kz/en/default.aspx)</td></tr>
<tr><td>1st production year</td><td>2013</td></tr>
<tr><td>Design</td><td>Aker Solutions (https://www.akersolutions.com/), WorleyParsons (http://www.worleyparsons.com/Pages/Default.aspx), CB&I (http://www.cbi.com/) and Saipem (http://www.saipem.com/sites/SAIPEM_en_IT/home/saipem-homepage.page)</td></tr>
<tr><td>Type</td><td>Artificial island</td></tr>
<tr><td>Environment</td><td>• Level ice
• Extreme temperatures
• Shallow water</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; onshore production, internal flow-lines and risers “inside” artificial island, offloading to shore through pipeline buried in seabed
• Rock-filled cofferdam island, gravel islands
• Dry trees
• Full well stream flow lines to offshore processing facilities
• Buried oil pipeline to shore
• Encapsulated subsea connections
• Heated and mechanically ventilated process area</td></tr>
<tr><td>Fact pages</td><td colspan="2">North Caspian Operating Company, homepage:
• http://www.ncoc.kz/en/default.aspx

Offshore Technology on Kashagan:
• http://www.offshore-technology.com/projects/kashagan/

Society of Petroleum Engineers on Kashagan:
• http://www.spe.org/news/article/the-mystery-of-the-kashagan</td></tr>
</table>

B.15 Baltic Sea

Table 13 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
Kurshsky Gulf	● / ●			-25	25-35	2 existing

● Moderate / minor
● Severe

List of ice protection technologies:

- Buried pipelines and umbilicals
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Ice reinforced installations

Relevant installations

Kravtsovskoye D-6		
Operator	Lukoil (http://www.lukoil.com/)	 Source: Lukoil (http://www.lukoil.com/)
1st production year	2004	
Design	Corall Central Design Bureau (living quarter) Krein-Shelf (jacket) HRI-Oilfield (drilling rig)	
Type	Open-leg platforms	
Environment	• Level ice • Low temperatures • Shallow water	
Technology	• Production system; flow-lines and risers inside platform leg(s), offloading to shore through (partly) buried pipeline • Two gangway connected ice reinforced open-leg jacket platforms • Subsea oil / gas pipelines to shore, partly buried and partly active anode protected • Encapsulated subsea connections • Heated and mechanically ventilated process area	
Fact pages	*Offshore Technology* on Kravtsovskoye: • http://www.offshore-technology.com/projects/kravtsovskoye/	

B.16 Barents Sea

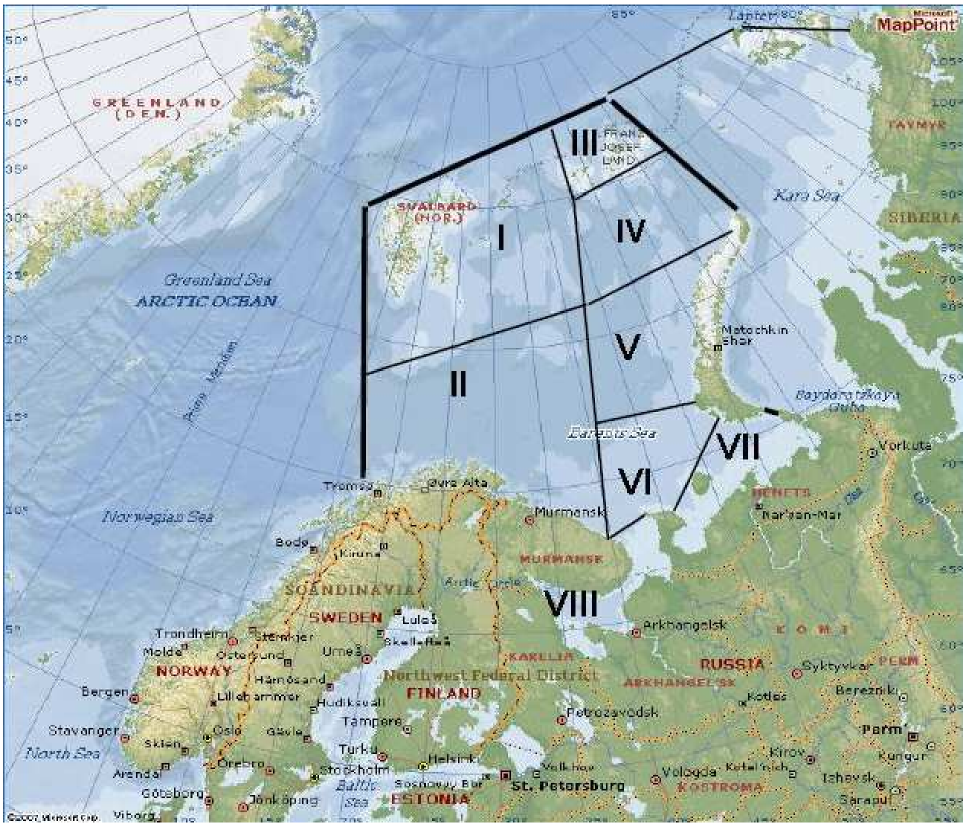


Figure 20 The Barents Sea, with the eight regions as defined in Barents 2020 (Barents 2020, 2012).

In this report, the Barents Sea is divided into eight regions, Figure 20, as defined in Barents 2020 (Barents 2020, 2012). In ISO 19906 the Barents Sea is divided into three regions: 1) The western region, more or less corresponding to regions I and II. 2) The north-eastern region, more or less corresponding to the regions III, IV and V. 3) The south-eastern region, more or less corresponding to the regions VI, VII and VIII. Currently, there are oil and gas installations only in regions II and VII. A future installation is planned at the Shtokman field in region V, close to the border of region II.

Table 14 Site specific challenges at the various locations.

	Level ice		Ice-bergs	Min. temp.	Sea depth at installations	# installations
	1st year	Multi-year		[°C]	[m]	
Region II (Norway)				-12	250-400	2 existing
Region VIII (Russia)	●	●		-20	17-20	2 existing
Region V (Russia)	●		●	-39	320	1 future

● Moderate / minor
● Severe

List of ice protection technologies

- Buried pipelines and umbilicals
- Disconnectable solutions
- Encapsulated subsea connections
- Heated and mechanically ventilated process area
- Ice management
- Ice reinforced installations
- Ice resistant offloading systems
- Subsea installations

Relevant installations

Snøhvit (Region II)		
Operator	Statoil (http://www.statoil.com/no/Pages/default.aspx)	 Source: Øyvind Hagen / Statoil (http://www.statoil.com/no/Pages/default.aspx)
1st production year	2007	
Design	Aker Solutions (http://www.akersolutions.com/)	
Type	Subsea	
Environment	• Medium water depth • Rapid changing weather • Sea spray icing (gas terminal)	
Technology	• Production system; subsea production facility, connected with umibilicals and pipelines at seabed to shore • Subsea installation with anti-sweep protection: templates with manifolds, trees, control system • Subsea gas / condensate pipelines to shore	
Fact pages	*Statoil* on Snøhvit: • http://www.statoil.com/en/OurOperations/ExplorationProd/ncs/snoehvit/Pages/default.aspx *Offshore Technology* on Snøhvit: • http://www.offshore-technology.com/projects/snohvit-field/	

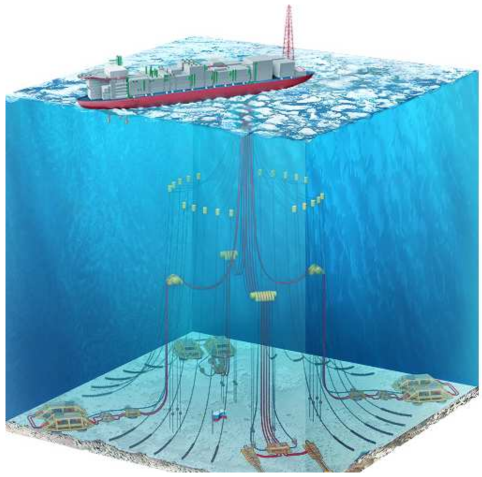
Goliat (Region II)		
Operator	ENI Norge AS (http://www.eninorge.com/)	 Source: Eni Norge (http://www.eninorge.com/)
1st production year	2015/2016	
Design	Sevan Marine (http://www.sevanmarine.com/)	
Type	FPSO + subsea	
Environment	• Medium water depth • Rapid changing weather • Sea spray icing	
Technology	• Production system; flow-lines and risers from seabed inside FPSO, stable oil from FPSO to shuttle tankers, reinjection of gas to reservoir. • Sevan 1000 FPSO • Subsea installation with anti-sweep protection: templates with manifolds, trees, control system • Flexible risers • Encapsulated subsea connections • Heated and mechanically ventilated process area • Offloading from FPSO to shuttle tankers	
Fact pages	*ENI* on Goliat: • http://www.eninorge.com/en/Field-development/Goliat/ *Offshore Technology* on Goliat: • http://www.offshore-technology.com/projects/goliat/	

<table>
<tr><td colspan="3">Varandey oil export terminal (Region VII)</td></tr>
<tr><td>Operator</td><td>Lukoil (http://www.lukoil.com/) / ConocoPhillips (http://www.conocophillips.com/)</td><td rowspan="5">
Source: Lukoil (http://www.lukoil.com/)</td></tr>
<tr><td>1st production year</td><td>2008</td></tr>
<tr><td>Design</td><td>Aker Solutions (http://www.conocophillips.com/)</td></tr>
<tr><td>Type</td><td>Offshore oil loading structure</td></tr>
<tr><td>Environment</td><td>• Level ice
• Low temperatures
• Shallow waters</td></tr>
<tr><td>Technology</td><td colspan="2">• Production system; buried pipelines in seabed from oil terminal to offloading tower, flexible hose from offloading tower to tankers
• Fixed Offshore Ice Resistant Offloading Terminal (FOIROT); steel piled loading structure with loading arm
• Buried oil pipeline from shore
• Ice management</td></tr>
<tr><td>Fact pages</td><td colspan="2">Lukeoil on Varandey:
• http://www.lukoil.com/materials/doc/img_pr/3.htm

Oil of Russia on Varandey:
• http://www.oilru.com/or/45/937/

Aker Solutions on Varandey:
• http://www.akersolutions.com/en/Global-menu/Media/Press-Releases/All/2008/Successful-offloading-operations-in-Russia-using-Aker-Solutions-environmental-friendly-offloading-system/</td></tr>
</table>

Prirazlomnoye (Region VII)		
Operator	Gazprom neft shelf (former Sevmorneftegaz) (http://www.gazprom-neft.com/)	
1st production year	2014	
Design	Sevmash Production Association (http://www.sevmash.ru/eng/)	
Type	Block type GBS	
Environment	• Level ice • Low temperatures • Shallow waters	Source: Gazprom (http://www.gazprom-neft.com/)
Technology	• Production system; internal flow-lines and risers from seabed inside GBS, offloading to shuttle tankers • Block type GBS • Ice resistant body • Encapsulated subsea connections • Heated and mechanically ventilated process area • Offloading from GBS to ice strengthened shuttle tankers • Ice management	
Fact pages	*Gazprom* on Prirazlomnoye: • http://www.gazprom.com/about/production/projects/deposits/pnm/ *Offshore Technology* on Prirazlomnoye: • http://www.offshore-technology.com/projects/prirazlomnoye/	

<table>
<tr><td colspan="3">The Shtokman FPSO (Region V)</td></tr>
<tr><td>Operator</td><td>Shtokman Development
(http://www.shtokman.ru/en/)</td><td rowspan="5">
Source: Shtokman Development
(http://www.shtokman.ru/en/)</td></tr>
<tr><td>1st production year</td><td>Future: 2022 (estimated)</td></tr>
<tr><td>Design</td><td>No information available</td></tr>
<tr><td>Type</td><td>FPSO</td></tr>
<tr><td>Environment</td><td>• Level ice
• Icebergs
• Extreme temperatures</td></tr>
<tr><td>Technology</td><td colspan="2">Likely technology:
• Ship-shaped FPSO
• Subsea installations
• Disconnectable flexible risers from subsea installations to FPSO
• Subsea pipeline from subsea templates to shore
• Ice management</td></tr>
<tr><td>Fact pages</td><td colspan="2">Shtokman Development on Shtokman:
• http://www.shtokman.ru/en/

Gazprom on Shtokman:
• http://www.gazprom.com/about/production/projects/deposits/shp/

Offshore Technology on Shtokman:
• http://www.offshore-technology.com/projects/shtokman/</td></tr>
</table>

Overview matrix – technological solutions

Table 15 contains a summary / overview of the technologies at the various locations discussed in this report.

Table 15 Overview over installations evaluated in this report.

Technology	Area	Installation	Special protection
Ship-shaped FPSO	Newfoundland	White Rose	Tandem offloading to ice strengthened shuttle tankers Trenched subsea wells Ice management Quick-disconnect flow-lines
Ship-shaped FPSO	Newfoundland	Terra Nova	Tandem offloading to ice strengthened shuttle tankers Trenched subsea wells Ice management Quick-disconnect flow-lines
Concrete GBS	Newfoundland	Hebron (future)	Reinforced concrete GBS Encapsulated subsea connections Offloading from GBS to ice strengthened shuttle tankers Ice management Quick-disconnect offshore loading system pipelines
Block type GBS	Newfoundland	Hibernia	Offloading from GBS to ice strengthened shuttle tankers Encapsulated subsea connections Iceberg management Quick-disconnect offshore loading systems pipelines and water injection flowlines Planned trenched subsea water injection well
Onshore production / terminal	Canadian Arctic Archipelago	Bent Horn (former)	Onshore production Offloading only in summer months
Gravel island	Beaufort Sea	Endicott	Gravel island Gravel causeway with pipelines to shore Encapsulated subsea connections Heated and mechanically ventilated process area
Gravel island	Beaufort Sea	Northstar	Gravel island with concrete mat and rock armour Buried pipelines to shore Encapsulated subsea connections Heated and mechanically ventilated process area
Gravel island	Beaufort Sea	Nikaitchuq	Gravel island with gravel bag armour Buried pipelines to shore Encapsulated subsea connections Heated and mechanically ventilated process area
Gravel island	Beaufort Sea	Oooguruk	Gravel island with gravel bag armour Buried pipelines to shore Encapsulated subsea connections Heated and mechanically ventilated process area

Technology	Area	Installation	Special protection
Gravel island	Beaufort Sea	Liberty	Gravel island Gravel causeway with pipelines to shore Encapsulated subsea connections Heated and mechanically ventilated process area
Open-legged	Cook Inlet	Osprey	Ice reinforced open-legged platform Subsea pipelines (on seabed) Encapsulated subsea connections Heated and mechanically ventilated process area
Open-legged and mono-pod	Cook Inlet	15 other installations	Old installations: 14 started production in 1964-1968, 1 in 1986
ERD	Okhotsk Sea	Yastreb	Extended Reach Drilling (ERD) Onshore rig and facilities
GBS CIDS	Okhotsk Sea	Orlan	Heated work areas / HVAC plant Internal risers / drill string Wave deflectors toward windward sides Continuous steel skirt to manage water intrusion and potential freeze impact Buried pipeline to shore
Multi-column concrete GBS	Okhotsk Sea	Berkut	Ice resistant fixed platform, for sea ice up to two meters thickness Buried pipeline to shore Designed for a seismically active area
SPM loading tower	Tatar Strait	De-Kastri	Weather-vaning offshore offloading Ice resistant Single Point Mooring (SPM) loading tower Buried pipeline from shore Serving a specifically designed fleet of double hull Aframax class tankers, escorted by ice-breaking vessels
GBS SIDS	Okhotsk Sea	Molikpaq PA-A	Steel caisson with an annular hull, ballasted down to the seabed Internal risers / drill string 1999-2008: SALM buoy, enabling offloading to tankers in ice free periods 2008-: Buried pipeline to shore
Multi-column concrete GBS	Okhotsk Sea	Piltun-Astokhskoye-B (PA-B)	Ice resistant fixed platform, for sea ice up to two meters thickness Buried pipeline to shore Designed for a seismically active area
Multi-column concrete GBS	Okhotsk Sea	Lunskoye-A (LUN-A)	Ice resistant fixed platform, for sea ice up to two meters thickness Buried pipeline to shore Designed for a seismically active area
LNG loading jetty	Okhotsk Sea	Prigorodnoye LNG-plant	Special designed loading jetty, handling custom-designed LNG carriers Pipeline from shore above sea level

Technology	Area	Installation	Special protection
Oil loading TLU	Okhotsk Sea	Prigorodnoye oil export terminal	Offloading pipeline from shore 74 m high Tanker Loading Unit (TLU), allowing tankers to weathervane according to wind, current, waves and ice conditions TLU designed to resist severe ice, wave, wind, seismic and vessel collision loads
Subsea	Okhotsk Sea	Kirinsky field	Subsea production facility Manifold at seabed intakes gas from several wells Manifold and wells secured by special anti-sweep constructions Buried pipeline for gas transport to shore Buried pipeline for anti-freeze from shore to field, preventing formation of hydrates Buried umbilical line for subsea production system control Seismic resistant for earthquakes with magnitudes of up to 9 points
Open-legged and mono-pile	Bohai Sea	6 installations	Ice re-inforced open-legged platform, some with ice cones Heated and mechanically ventilated process area Buried pipelines to shore
Gravel islands	North Caspian	Kashagan	Rock-filled cofferdam island, gravel islands Dry trees Full well stream flow lines to offshore processing facilities Buried oil pipeline to shore Encapsulated subsea connections Heated and mechanically ventilated process area
Open-leg jacket	Baltic Sea	Kravtsovskoye D-6	Two gangway connected ice reinforced open-leg jacket platforms Pipelines to shore, partly buried and partly active anode protected Encapsulated subsea connections Heated and mechanically ventilated process area
Subsea	Barents Sea, II	Snøhvit	Subsea installation with anti-sweep protection: templates with manifolds, trees, control system Pipelines to shore
FPSO + subsea	Barents Sea, II	Goliat	Sevan 1000 FPSO Subsea installation with anti-sweep protection: templates with manifolds, trees, control system Flexible risers Encapsulated subsea connections Heated and mechanically ventilated process area Offloading from FPSO to shuttle tankers
Oil loading unit	Barents Sea, VII	Varandey	Fixed Offshore Ice Resistant Offloading Terminal (FOIROT);steel piled loading structure with loading arm Buried pipeline from shore Ice management

Technology	Area	Installation	Special protection
Block type GBS	Barents Sea, VII	Prirazlomnoye	Block type GBS Ice resistant body Encapsulated subsea connections Heated and mechanically ventilated process area Offloading from GBS to ice strengthened shuttle tankers Ice management

Overview matrix – environmental conditions

This matrix contains a summary of some of the information available in appendix B in ISO 19906:2010. This is general characteristics of the entire areas.

Table 16 Coarse summery / overview of environmental conditions for Arctic areas in ISO 19906:2010.

Arctic areas in ISO 19906	Water depth [m]	Level ice 1st year: [m] 2nd/multi-year [m]	Icebergs season # / year mass [tonnes]	Temperature min – max [°C]	Other
B.3 Labrador	20 – 1000	1st: 0.8-1.2 2nd: 2.0-8.0	All year 500 – 5000 > 20 · 10^6	-40 to 27	• High wave height during summer, up to 14 m.
B.4 Newfoundland	75 – 1000	1st: 0.6-1.0 2nd: 1.0-2.0	All year 450 – 2200 Up to 6 ·10^6	-19 to 25	• Superstructure icing, December – March. • Fog in spring and summer. Snow, fog and mist in winter. • High winds / storms during winter, hurricanes in autumn. • Extreme wave heights, up to 30 m.
B.5 Canadian Arctic Archipelago	100 – 500	1st: 1.8-2.6 2nd: 3.0-5.0	All year Few 10-600 ·10^6	-45 to 11	• Earthquake epicentre northwest of Melville Island
B.7 Beaufort Sea	2 – 90 90 – ~10^3	1st: 1.5-2.3 2nd: 2.0-20.0	Unknown Unknown ~10 ·10^6	-40 to 30	• Large areas with large variations! • Sea depth varies from shallow areas to areas with several thousand meters depth. • Seasonal dependency and frequency for icebergs are poorly known. • Ice islands up to 697 km^2 and a thickness of up to 60 m have been documented.

Arctic areas in ISO 19906	Water depth [m]	Level ice 1st year: [m] 2nd/multi-year [m]	Icebergs season # / year mass [tonnes]	Temperature min – max [°C]	Other
B.8 Chukchi Sea Areas: 1 – 4	1,3,4 0 - 50 2 50 - 100	1st: 1.5-2.0 2nd: 2.-6.0	No icebergs?	-50 to 30	• Large areas with large variations! • ISO 19906 does NOT mention icebergs, but the ice islands from the Beaufort Sea should end up somewhere? • Winter: 3-4 storms / month. Spring and summer: 1-2 / month. • Strong currents, more than 50 m/s some places. • Level ice varies with areas (1 – 4).
B.10 Cook Inlet	0 – 100	1st: 0.2-0.6	No icebergs	-43 to 30	• Very dynamic and drifting sea ice.
B.11 Okhotsk Sea Areas: 1 – 3	30 – 90 90 – 3300	1 1st: 1.1-1.6 2 1st: 1.1-1.2 3 1st: 0.5-0.9	No icebergs	1 -51 to 31 2 -44 to 34 3 -42 to 36	• Wave heights reaching 12-20 m during autumn and early winter. • Possibilities for earthquakes and tsunamis.
B.12 Tatar Strait Areas: Russia (R), Sakhalin (S)	10 – 400 >1000 in south	R 1st: 0.7-1.2 S 1st: 0.7-1.1	No icebergs	R -42 to 39 S -41 to 30	• Water depth generally in range 10-400, but very deep at the south tip of Sakhalin: more than 1000 m.
B.13 Bohai Sea	< 85	1st: 0.1-0.6	No icebergs	-25 to N.A.	• Floating pack ice, vary significantly from north to south-east
B.14 North Caspian	0 – 10	1st: ~0.8	No icebergs	-30 to 40	• Large differences due to several climate zones. • Mainly the northern part affected by ice.
B.15 Baltic Sea Areas: 1 – 4, 1 = Gulf of Bothnia, 2 =Gulf of Finland and Riga, 3 = Baltic Sea proper, 4 = Danish Belt	1 0 – 130 2 0 – 120 3 0 – 80 4 0 – 50	1st: 1 0.4-0.9 1st: 2 0.4-0.8 1st: 3 0.3-0.7 1st: 4 0.3-0.7	No icebergs	1 -25 to 24 2 -18 to 25 3 -20 to 24 4 -18 to 23	• Level ice, floating pack ice, vary significantly over the area.

Arctic areas in ISO 19906	Water depth [m]	Level ice 1st year: [m] 2nd/multi-year [m]	Icebergs season # / year mass [tonnes]	Temperature min – max [°C]	Other
B.16 Barents Sea Areas: 1 – 3, 1 = West (I, II Barents 2020) 2 = North E (III, IV, V Barents 2020) 3 = South E (VI, VII, VIII Barents 2020)	1 < 600 2 < 100 3 < 100 Mean: 222 Min: 0 Max: 600	1st: 1 1.2-1.5 2nd: 1 2.5-3.0 1st: 2 1.4-1.6 2nd: 2 2.5-3.0 1st: 3 0.7-1.1	1 6 months 10-40 Up to $10 \cdot 10^6$ 2 All year Unknown Up to $5 \cdot 10^6$ 3 Infrequent Unknown Unknown	1 -12 to 7 2 -39 to 9 3 -20 to 10	• Large areas with large variations!
B.17 Kara Sea	< 600 Mean: 111	1st: 1.4-1.8 2nd: 1.8-2.2	No data*	-48 to 31	• Large areas with large variations! * Icebergs are mainly centred near the northeast coast of Novaya Zemlya and the west coast of the Severnaya Zemlya archipelago. Icebergs have not been sighted in the southern coastal areas.
B.18 Laptev Sea	S: 0-25 N: < 3000 ~50% < 50	1st: 1.6-2.4 2nd: 2.8-3.2	All year Few Small icebergs	-53 to 32	• Large areas with large variations! • Icebergs occur mainly in the western part.
B.19 East Siberian Sea	W: 10 – 20 E: 30 – 40	1st: 1.6-2.4 2nd: 2.8-3.2	Some times Few	-51 to 30	• Sometimes small icebergs, floebergs and ice islands occur in the East Siberian Sea.
B.20 Black Sea	50 – 70	No data	No icebergs	-27 to 40	• Sea ice, only in northwest, covers less than 5% of the Black Sea in sever winters.
B.21 Sea of Azov	0 – 13	1st: 0.2-0.4	No icebergs	-30 to 40	• Sea ice covers most of the sea, and all in sever winters.

Appendix 6 Undesirable events

For each of the undesirable events listed in section 5.3 of the main report, high level barrier functions in addition to an overview of possible risk reducing measures on a generic level (i.e. barrier elements) have been mapped. This has been used for structuring the information gathered through this work. Barrier functions and corresponding measures are presented in event sequences for each of the undesirable events.

Process leak

Prevent process leak
- Prevent technical degradation
- Ensure sufficient design basis
- Prevent process disturbance
- Prevent leakage through human intervention
- Prevent external events

Reduce leak
- Detect leak
- Ensure process segregation and depressurization
- Ensure shutdown

Prevent escalation
- Prevent ignition
- Prevent damage to HC equipment

Prevent oil to sea
- Ensure containment on installation
- Ensure subsea encapsulation

Blowout

Prevent blowout
- Ensure primary well control barrier
- Ensure secondary well control barrier
- Prevent external events

Reduce leak
- Detect leak
- Ensure reduced flow through well design

Prevent escalation
- Prevent ignition
- Prevent damage to HC equipment

Prevent oil to sea
- Ensure capping
- Ensure containment
- Ensure drilling of relief well

Riser / pipeline / subsea structure leak

Prevent riser / pipeline / subsea leak
- Prevent technical degradation
- Ensure sufficient design basis
- Prevent external events

Reduce leak
- Detect leak
- Ensure riser / pipeline / production shutdown

Prevent escalation
- Prevent ignition
- Prevent damage to other HC equipment

Prevent oil to sea
- Ensure capping of leakage point

Object on collision course

Prevent impact with structure
- Detect / forecast / monitor object
- Maintain position
- Deter object
- Disconnect / move off location

Prevent damage to structure
- See damage to structure

Damage to structure

Prevent damage to structure
- Prevent technical degradation
- Ensure sufficient design basis
- Prevent fire / explosion loads
- Prevent external events

Prevent and reduce leak
- Prevent leak from HC containing equipment
- Ensure segregation and depressurisation of process / production pipes
- Ensure production shutdown

Prevent escalation
- N/A

Prevent oil to sea
- N/A

Leak during loading / offloading

Prevent loading / offloading leak
- Prevent technical degradation
- Ensure sufficient design basis
- Prevent leak through human intervention
- Prevent external events

Reduce leak
- Detect leak
- Ensure segregation
- Ensure shut down

Prevent escalation
- N/A

Prevent oil to sea
- N/A

Appendix 7 Catalogue overview of measures identified

Metocean and ice conditions

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Arctic Centre for Unmanned Aircraft (ASUF)	NORUT, UiT, Lufttransport	The Arctic Centre for Unmanned Aircraft (ASUF) is a national and international focal point in the use of unmanned aircraft for emergency preparedness, environmental monitoring and technology development in the Arctic. The centre will also contribute to increased safety in connection with commercial flights and ambulance, rescue and police operations. ASUF offers education, training, research and operational services. The centre spans the entire value chain from education and basic research to innovation and commercial activities. ASUF develops communication systems, sensors and instruments, algorithmic and analytical tools and navigation and control systems, as well as testing new materials and adapting these for use in cold and extreme climates. Particularly in the Arctic, unmanned aircraft are extremely well suited given the long distances and the unique weather, light and environmental conditions, as well as the increasing level of international commercial activity.	http://www.asuf.no/english/	Metocean data collection technology	R&D centre established in 2015
Arctic Portal	AOOS	This portal focuses on the northern Bering, Chukchi and Beaufort Seas. It integrates several hundred layers ranging from habitat type, climatic regimes, tagged animal locations, current weather conditions, political and ecological boundaries, and research instruments. A data layer catalogue enables users to browse data and metadata by category or keyword. The development of this portal was supported by the STAMP project.	http://www.aoos.org/aoos-data-resources/	Metocean and ice data - Bering, Chukchi and Beaufort Seas	Portal
ArcticWeb	Aker Solutions	Obtaining information about offshore Arctic areas is a challenge. The problem in many cases is not the lack of information, but an inability to easily access information and determine its reliability and quality. Seven operators on the Norwegian continental shelf initiated a JIP to tackle this challenge, and together with KADME and Acona developed the ArcticWeb to simplify access to public data sources in the Arctic region. ArcticWeb is currently owned and administrated by Aker Solutions. The technological platform, Where oil, is supplied and hosted by the Norwegian data solutions firm KADME. The information is used by oil and service companies for the purpose of exploration, early field development, environmental risk analysis, emergency preparedness, safety assessments and more. Information is presented to the users via search and map interfaces, for exploration and analysis. Information can also be exported to Excel and Shapefile format for use in corporate data systems. ArcticWeb covers the entire Norwegian continental shelf with data from a wide-range of Norwegian key data owners. These are amongst others Institute of Marine Research, Geological Survey of Norway, Norwegian Meteorological Institute, Norwegian Directorate of Fisheries, Norwegian Coastal Administration and Norwegian Petroleum Directorate.	http://www.arcticweb.com	Metocean and ice data - Norwegian Continental Shelf	Portal
Autonomous aerial systems for marine monitoring and data collection	AMOS	The centre for Autonomous Marine Operations and Systems (AMOS) conducts a project on autonomous aerial systems for marine monitoring and data collection. The research focuses on operations with unmanned aerial vehicles (UAVs) that have the capability to handle a number of operational events without operator input, including intelligent command execution with path re-planning, energy management, fault-tolerant control, automatic launch and recovery from ships, operational safety and collision avoidance, management of communication quality of service, and online pursuit of mission objectives based on real-time payload sensor data information processing such as object tracking and obstacle avoidance, as well as optimal trajectory planning for updating estimates of distributed parameter phenomena being observed.	https://www.ntnu.edu/amos/	Metocean data collection technology	Project 2012-2022
Autonomous surface vessel	MUN AOSL	The purpose of the autonomous surface vessel is to provide the AOSL with an unmanned vessel to: ▪ Support research on autonomous underwater vehicles (AUVs) ▪ Serve as a research and development platform for - Vehicle control algorithms - Autonomous sampling algorithms	http://www.engr.mun.ca/aosl/projects.html	Metocean data collection technology	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		- Multi-vehicle networks ▪ Support undergraduate and graduate learning in the fields of system design, dynamics and control. A catamaran has been designed and the hulls have been completed in October 2010. The vessel's control and communication software is currently under development.			
Autonomous underwater vehicle based research	MUN	MUN is conducting interdisciplinary autonomous underwater vehicle (AUV) based research. A part of this is the MUN Explorer AUV which is a 4.5 meters ocean-going AUV with a 3,000 meters depth capability built by International Submarine Engineering Ltd. In the lab and while fully ocean capable it is being operated initially in coastal areas of Newfoundland for environmental monitoring, seabed imaging and vehicle dynamics testing. Work is on-going to develop the payload of the vehicle to include conductivity-temperature-depth (CTD), sonar and camera devices giving it more versatility and capabilities.	https://www.mun.ca/research/resources/creait/engineering/merlin/auv.php	Metocean data collection technology	R&D ongoing
Barents Sea Metocean and Ice Network (BaSMIN) JIP	Statoil, ConocoPhillips, Det Norske, Dong Energy, E.ON, Eni Norge, Engie, KUFPEC, Lukoil, Lundin, OMV, Repsol, Shell, Total and Wintershall	Today, there is no observational data available for the Central and Eastern Barents Sea. There are only two official weather stations covering the Barents Sea; Bear Island and Hopen. The BaSMIN JIP consists of a metocean observation system and deployment of ice and ocean current moorings: - 5 moorings with ice sensors and current profiler deployed during the 2015-2016 winter season with a potential and likely 1-year extension - 5 moored surface buoys for a minimum of 3 years Met Norway and StormGEO will have access to the data in order to improve and validate weather forecasting / hindcasting for the area. The objective is to increase data, competence and quality in weather forecasting / hindcasting for the area to increase safety related to weather limitations for operations and activity.	-	Metocean and ice data - Barents Sea	JIP 2015-2018
BarentsWatch	A cooperation between ministries, state agencies and research institutes	BarentsWatch is a comprehensive monitoring and information system for large parts of the world's northern seas.By coordinating information and developing new services based on the combination of data, BarentsWatch will disseminate a better factual basis and more comprehensive picture of the activities in, and condition of, our seas and coastal areas.The system will make relevant information and services more easily accessible for authorities, decision-makers and general users. This will simplify access to and ensure the exchange of public information.An open part of BarentsWatch shall be an information portal available to everyone. This was launched in 2012, and is being developed incrementally. The portal has information about topics such as the climate and environment, marine resources, oil and gas, maritime transport and maritime law, among other things. There are also map services, an overview of ports, and news from about 25 partners.	https://www.barentswatch.no/en/	Metocean and ice data	Portal launched in 2012. Incrementally developed
CAspian Sea MetOcean Study (CASMOS)	IOGP	The CAspian Sea Metocean Study (CASMOS) JIP was initiated in 2001 with the objective to establish reliable normal and extreme wind, wave, surge and current climate data. A hindcast study has been performed, which included 100 storms over a 52-year period 1948-2000 and covered a 10-year continuous period 1991-2000. Oceanweather's 3rd generation wave model and 3-D hydrodynamical model were used to produce a wind, wave, current, and surge climatology. CASMOS-2 extends the continuous hindcast to 50 years, adds 25 more storms, and through the Danish Hydraulics Institute (DHI) includes new 3-D current and 2-D hydrodynamic model results. A new phase of the JIP focused on high-resolution wind modelling with StormGEO, to account for katabatic winds.	IOGP, 2015. Metocean industry projects. http://www.iogp.org/Technical-expertise/Metocean/Industry-projects. http://www.iogp.org/Technical-expertise/Metocean/Industry-projects#45017-casmos-caspian-sea-metocean-study	Metocean and ice data - Caspian Sea	JIP 2001-ongoing
Centre for Integrated Remote Sensing and Forecasting for Arctic	UiT Research partners: NORUT (MET Norway), Norwegian Polar Institute, NTNU, Nansen Environmental	The centre for integrated remote sensing and forecasting for Arctic operations (CIRFA) project was started in 2015 and will have a duration of up to eight years.The main objective of the centre is to develop knowledge and technology for the monitoring of maritime conditions and forecasting of weather, emissions and sea and ice conditions in Arctic waters. These factors are	http://cirfa.uit.no/	Metocean and ice data	R&D centre 2015-2023

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Operations (CIRFA)	and Remote Sensing Centre, researchers from different international research institutions	essential for the petroleum, shipping and fishing industries to be able to conduct safe and sustainable operations in the northern waters. Seven work packages have been established: - Ocean remote sensing - Sea ice, iceberg and growler remote sensing - Oil spill remote sensing - Remotely piloted aircraft systems technologies - Drift modelling and prediction - Data collection and field work - Pilot service demonstration			
Cook Inlet Response Tool	AOOS	This data visualization tool incorporates multiple types of data (real-time sensors, model output, GIS layers, etc.) on a single screen. The tool was developed in collaboration with the Cook Inlet Regional Citizens Advisory Council to assist emergency responders in the event of an oil spill or other event. Unique to this tool is the ability to view video imagery and still photos for the entire coastline, drawing from the ShoreZone project. This allows users to virtually "fly the coast", and integrate that information visually and spatially with other types of data.	http://www.aoos.org/aoos-data-resources/	Metocean and ice data - Cook Inlet	Portal
Copernicus Marine Environment Monitoring Service (CMEMS)	EU	The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic reference information on the state of the physical oceans and regional seas. The observations and forecasts produced by the service support all marine applications. The provision of data on currents, winds and sea ice help to improve ship routing services, offshore operations or search and rescue operations, thus contributing to marine safety. CMEMS is part of the European Earth observation programme, Copernicus (formerly named GMES, for Global Monitoring for Environment and Security).	http://marine.copernicus.eu/	Metocean and ice data	R&D programme
eKlima	MET Norway	eKlima is a web portal which gives free access, available to everyone, to weather and climate data from the Norwegian Meteorological Institute. The climate database contains data from all present and past weather stations of the Norwegian Meteorological institute, as well as data from other institutions (owners) that are allowed to be distributed. This includes data from a number of weather stations in the Norwegian Arctic, including Svalbard, Bjørnøya, Hopen and Jan Mayen.	http://eklima.met.no	Metocean and ice data - Norwegian Arctic, including Svalbard, Bjørnøya, Hopen and Jan Mayen	Portal
Forecasting of polar lows	MET Norway	The Norwegian Meteorological Institute has developed new forecasting methods for polar lows, including probability for occurrence and wind strength for the Barents Sea (BarentsWatch, 2015). The forecasting method is based on an ensemble prediction system (ESP), that is the forecast model is run several times for the same weather situation using slightly different starting conditions to produce a similar number of forecasts conditions. The Norwegian Meteorological Institute is working to develop new models for prediction of Polar low trajectories. A reliable prediction would, however, require a higher resolution model of the area of concern.	www.barentswatch.no	Weather forecasting - Barents Sea	Portal launched in 2012
Forecasting polar lows in Barents and Kara Seas during 2014 - a case study	The Hydrometcentre of Russia State Institution, Gazprom VNIIGAZ LLC	Nikitin and Chumakov (2015) have conducted a case study of polar lows in Barents and Kara Seas during 2014 on the basis of forecasts produced by the atmospheric model COSMO-Ru. Satellite data and observational data from coastal hydrometeorological stations were used for verification of the forecast. Nikitin and Chumakov show that the model reproduces wind gusts speed rather accurately. Comparing the results with calculations based on the methods recommended by ISO 19901 standard shows some discrepancies due to neglecting unstable air stratification in the latter case.	Nikitin, M.A. (The Hydrometcentre of Russia) and Chumakov, M.M. (Gazprom VNIIGAZ LLC), 2015. Case study of polar lows in Barents and Kara Seas during 2014. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-070.	Weather forecasting - Barents Sea and Kara Sea	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Goliat metocean data	Eni Norge	For the Goliat development project in the Norwegian part of the Barents Sea Eni Norge has collected metocean data with buoys and will, during production, measure a number of metocean parameters from meteorological stations on the Goliat FPSO and with buoys, which will be reported to the Norwegian Meteorological Institute. Some of the metocean data will be available through Norwegian Meteorological Institute data series, while part of the data can be requested through the Goliat license.		Metocean and ice data - Barents Sea	Ongoing
GROW Fine Arctic (GFA)	Oceanweather	The GROW Fine Arctic (GFA) hindcast is Oceanweather's metocean study of the Arctic Sea. The standard continuous hindcast covers 29 years (1983-2011) of data. Spectra is also archived and available at select locations.	http://www.oceanweather.com/metocean/arcticsea/index.html	Metocean and ice data - Arctic Sea	Study
High frequency radar	-	High frequency (HF) radar is a shore- or ship-based measurement system used to quantify the speed and direction of surface ocean currents. One station transmits radio waves that travel several kilometres in all directions.As each radio wave reflects off the ocean and returns to the receiver, the signal is shifted by a process known as the Doppler effect: the change in frequency of a wave for an observer (here, the receive antenna) moving relative to the source of the wave (here, the ocean). Knowing the amount of Doppler shift tells us how fast the currents are moving offshore.HF radar also helps to understand local ocean current phenomena that are hard to detect by other methods because these ocean features are relatively small.	http://www.aoos.org/arctic-hf-radar/	Metoce and ice data	Technology developed
High frequency radars in Alaska	AOOS, University of Alaska Fairbanks, BOEM, ConocoPhillips and Shell	High frequency (HF) radar deployments in Alaska. From 2011, HF radar stations have been located in the Chukchi Sea, Alaska. Project data is available in near real time through the AOOS data portal, and through the University of Alaska Fairbanks.	http://www.aoos.org/arctic-hf-radar/	Metocean and ice data - Alaska	Ongoing
High frequency radars in the Barents Sea	MET Norway, Eni, Shell, Statoil	High frequency radar deployments at the coast of Northern Norway. These will measure radial components of the surface currents. The project will improve the current forecasts and increase the oil spill modelling capability in the Barents Sea. Data (both raw and model) will be made available to the public via the THREDDS server hosted by MET Norway.		Metocean and ice data - Barents Sea	Ongoing
International Arctic buoy program	Polar Science Center, Applied physics laboratory, University of Washington	The participants of the program work together to maintain a network of drifting buoys in the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes including supports to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) programme. Data from the program have many uses. For example: 1. Research in Arctic climate and climate change 2. Forecasting weather and ice conditions 3. Validation of satellites 4. Forcing, validation and assimilation into numerical climate models 5. Tracking the source and fate of samples taken from the ice	http://iabp.apl.washington.edu/	Metocean and ice data - Arctic Sea	R&D programme
ISO 35106 Arctic metocean, ice and seabed data (TC67 SC8 WG6)	ISO	The standard specifies requirements and provides recommendations and guidance for the collection, analysis and presentation of relevant physical environmental data for Arctic activities of the petroleum and natural gas industries in the Arctic and cold regions.This standard has a separate section regarding physical environment data for Arctic operations and will require collection of ice and metocean data for operations and Arctic and cold climate areas.The development of the standard is led by the convenor, Pavel Liferov.	-	Metocean and ice data	International standard under development, committee draft, CD, submitted for comments in 2015
Kara and Barents Sea Ice and Currents (KARBIAC)	IOGP	To prepare for oil and gas exploration in the Kara and Barents Seas, it is of general importance to get a good understanding of the environment. In particular, it is of interest to get insight into the meteorological and oceanographic variables such as winds, waves, water level (tidal height and storm surge) and currents to design offshore structures that are both safe and cost efficient. Accordingly, the overall objective of the Kara and Barents Sea Ice and Currents (KARBIAC) JIP was to produce sufficiently accurate information about long-term cycles and trends, in particular with	IOGP, 2015. Metocean industry projects. http://www.iogp.org/Technical-expertise/Metocean/Industry-projects	Metocean and ice data - Kara and Barents Sea	JIP 1987-2011

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		regard to currents and sea ice. The only means by which such time series can be provided is by performing long-term hindcasts using numerical ocean models. Before embarking on such an endeavour it is of considerable interest to assess the skill of the ocean model to be employed. The KARBIAC JIP therefore decided to perform a project (KARBIAC Phase 2) in which results from three different model hindcasts performed by three different modelling groups were assessed for a trial period of one year (July 1, 1987 through April, 1988). Prior to Phase 2 the participating models and modelling groups were first selected through a qualification Phase (KARBIAC Phase 1). The results from the various modelling groups were assessed by a third party who compared the model results with measurements at up to 29 sites in the Barents Sea (2008). Furthermore, the results of an intermediate hindcast project, referred to as KARBIAC Phase 2b, was published in 2011.			
Mapping of ice occurrence	PSA	The PSA has initiated a pre-study regarding mapping of ice occurrence in the Norwegian part of the Barents Sea. Through this project information will be gathered regarding icebergs, growlers, bergy bits and snowfall that can impact petroleum activities on the Norwegian continental shelf north of 73°. There is limited knowledge of this today. Ice occurrence in this area that is difficult to detect may represent a risk for drilling operations and may give acute pollution to sea in the case of an undesired event. Obtaining this knowledge is regarded a prerequisite for developing safe petroleum activities in the Norwegian High North. Obtaining this knowledge will be seen in light of research, education and knowledge about the Norwegian High North, in addition to climate changes, environment and natural resources in the area.		Metocean and ice data - Norwegian Barents Sea, north of 73°	Pre-study 2015Project planned 2016
Metocean and ice characterization for the Newfoundland and Labrador regions	C-CORE on behalf of Nalcor Energy	C-CORE recently completed a study for Nalcor Energy on metocean and ice characterization for the Newfoundland and Labrador regions (King et al., 2015). The metocean study looks into metocean conditions, including winds, waves, currents, fog, vessel icing, pack ice, icebergs and ice islands and the influence of environmental changes on such conditions. The study illustrates what is known about the existing metocean conditions for offshore Newfoundland and Labrador, and how the region ranks compared to other ice-prone regions (the North Sea, Barents Sea, Kara Sea, Caspian Sea, offshore Sakhalin Island, Chukchi Sea, Beaufort Sea and East and West Greenland). To facilitate the use of this vast data set, Nalcor has used the Nalcor Exploration Strategy System (NESS), an interactive, map-based system.	King, T. (C-CORE), Wright, R. (Nalcor Energy), Drover, K. (Nalcor Energy), Fleming, G. (Nalcor Energy) and Gillis, E. (Nalcor Energy), 2015. Offshore Newfoundland and Labrador metocean study. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25495. http://nalcorenergy.com/OILGAS/test.asp	Metocean and ice data - Newfoundland & Labrador	Article published in 2015
Nalcor Exploration Strategy System (NESS)	Nalcor Energy	Nalcor Energy has developed a proprietary web-based, interactive database management and geographic information system, called NESS (Nalcor Exploration Strategy System). This map-based system was developed by Nalcor's exploration team in 2013 in partnership with ICI Solutions to help capture data and scientific insights from the work the team is undertaking in the frontier regions of offshore Newfoundland and Labrador. NESS includes metocean data as well as other geographic and geophysical data for Newfoundland and Labrador's offshore, including sedimentary basins, offshore boundaries, well data as well as licenses.	http://www.nalcorenergy.com/OILGAS/ness.asp	Metocean and ice data - Newfoundland and Labrador	Portal
Northeast Greenland ice study JIP	BMP together with 12 oil companies	The region that lies off the northeast coastline of Greenland is a very remote area, well known for the severity of its physical environment. Factors of note include a limited open water season, heavy pack ice conditions, icebergs, low temperatures and poor visibility. The constraints that are imposed by this environment will present significant challenges for various oil industry activities such as seismic data acquisition, exploratory drilling operations, and potential development and export systems. However, good data on the physical environmental conditions in this region are sparse. In order to improve the current state of knowledge, a northeast Greenland ice study group was formed to conduct "directed ice R&D work" of relevance to oil industry needs (Wright et al., 2014). The NE Greenland group supports ice related R&D on a proportionate basis. The objective is to improve the state of knowledge of ice regimes that then inform ice management, logistics and other operational considerations through collaboratory studies.Wright et al. (2014)	Wright, J. (Chevron Arctic Center), Hammeken-Holm, J. (BMP), Renganathan, V. (Chevron Arctic Center) and Robertson, S. (Chevron Arctic Center), 2014. NE Greenland Ice Study Group and Recent Project Work. Arctic Technology Conference, 10-12 February, Houston, Texas, USA. OTC 24596.	Metocean and ice data - Northeast coastline of Greenland	JIP ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		highlight the northeast Greenland study group approach that has been developed, along with the northeast Greenland ice studies conducted by our group to date. They also highlight some of the results of the northeast Greenland ice study group projects carried out so far.			
Norwegian Young sea ICE cruise (N-ICE2015)	Norwegian Polar Institute	The main objectives of the project were to understand the effects of the new thin, first year, sea ice regime in the Arctic on energy flux, ice dynamics and the ice associated ecosystem, and local and global climate. As part of the project, the vessel RV Lance was frozen into the ice during the winter 2015. The vessel froze into the ice at approximately 83° North on 15 January 2015. Then, Lance drifted passively in the ice with researchers located onboard, until it was released by the ice in the beginning of May 2015.	www.npolar.no/nice2015	Metocean and ice data	Project 2014-2016
Ocean and Sea Ice Satellite Application Facility (OSI SAF)	The EUMETSAT Network of Satellite Application Facilities, Meteo-France, Norwegian Meteorological Institute, Danish Meteorological Institute, Ifremer and the Royal Netherlands Meteorological Institute	The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) created Satellite Application Facilities (SAFs) based on co-operation between several institutes and hosted by a National Meteorological Service.The Ocean and Sea Ice Satellite Application Facility (OSI SAF) is an answer to the common requirements of meteorology and oceanography for a comprehensive information on the ocean-atmosphere interface. One of the objectives of the OSI SAF is to produce, control and distribute operationally in near real-time OSI SAF products using available satellite data with the necessary users support activities.The current phase of the EUMETSAT OSI SAF, the CDOP-2 (Continuous Development and Operations Phase number 2), covering the period from 2012 to 2017, has taken into account new requirements expressed at international level in particular by WMO, GCOS, GHRSST, etc., and at European level by MyOcean (precursor of the Copernicus Marine Service), with a strong need for increasing the temporal and geographical resolution of the products and for extending the coverage range from coastal to global. CDOP-2 is also consolidating assets by enhancing the algorithms and products, by increasing the effort on reprocessing, by taking into account new satellites. The OSI SAF is preparing its next phase, the CDOP-3, that will cover from 2017 to 2022. CDOP-3 will take into account new satellites (in particular MTG, GOES-S, EPS-SG).	http://www.osi-saf.org	Metocean and ice data	1997-2002: Development phase 2002-2007: Initial operational phase 2007-2012: Continuous development and operations phase (CDOP) 2012-2017: CDOP-2 2017-2022: CDOP-3
Ocean and Sea Ice Satellite Application Facility (OSI SAF) High Latitude Processing Center	MET Norway, Danish Meteorological Institute, Swedish Meteorological and Hydrological Institute	The Norwegian Meteorological Institute (met.no) is hosting the high latitude part of the Ocean and Sea Ice SAF under a contract with Météo France. The OSI SAF High Latitude Center project team includes members from the Norwegian Meteorological Institute (met.no), Danish Meteorological Institute (DMI) and the Swedish Meteorological and Hydrological Institute (SMHI). The Ocean and Sea Ice Satellite Application Facility (OSI SAF) High Latitude Processing Center website gives information and products from the high latitude part of the EUMETSAT OSI SAF. The High Latitude Center has responsibility for the production and distribution of the OSI SAF Sea Ice products. They also produce the high latitude part of the OSI SAF sea surface temperature and radiative flux products.	http://osisaf.met.no/	Metocean and ice data	1997-2002: Development phase 2002-2007: Initial operational phase 2007-2012: Continuous development and operations phase (CDOP) 2012-2017: CDOP-2 2017-2022: CDOP-3
Ocean current modelling	Simula Research Laboratory / KALKULO	A project that looks into the scientific basis and state-of-the-art for ocean current modelling with the intention of contributing to improved ice modelling.		Weather forecasting	Project
Pan Arctic Metocean Study (PAMOS)	IOGP	The Pan Arctic Metocean Study (PAMOS) will be completed in multiple phases including a large storm population hindcast with derivative statistics (complete), continuous hindcast (complete), and ice edge sensitivity (pending).	IOGP, 2015. Metocean industry projects. http://www.iogp.org/Technical-expertise/Metocean/Industry-projects	Metocean and ice data - Pan Arctic	JIP ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Shell Ice and Weather Advisory Center (SIWAC)	Shell	In the absence of pooled forecasting services and operational-grade forecasting capacity by public weather services, Shell has developed and operates an in-house, Anchorage based, forecasting program designed specifically for the demands and requirements of Shell's Alaska operations. Shell Ice and Weather Advisory Center (SIWAC) is a focused ice and weather forecast operation covering the offshore and coastal areas from the Gulf of Alaska to the Canadian Beaufort Sea. SIWAC consists of a team of fulltime Arctic experienced forecasters working in a 24/7 rotation schedule and are fully integrated into the operations process, directly engaging with field personnel and decision makers. Development of differentiating forecast products and services depends not only on an expert team, but also a robust observation program consisting of contracted and public satellite imagery, a network of metocean buoys, satellite-tracked ice movement beacons, and steady stream of field observations from specially trained personnel abroad marine and aviation assets. The SIWAC forecasters develop numerous daily products including site-specific, wide-area, vessel routing, and weather window forecasts that are delivered to end users through websites and live briefings. To aid in improving forecasting performance and research across the board, Shell entered into a Memorandum of Agreement with the National Oceanic and Atmospheric Administration (NOAA) in 2012. This collaborative agreement makes Shell's Arctic metocean data and ice charts publically available through NOAA and fosters dialog between the SIWAC and NOAA forecasters.	Raye, R. (Shell), 2015. Forecasting ice and weather conditions for field operations in Alaska. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25497. www.siwac.com	Metocean and ice data	R&D centre established in 2007

Ice management

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Advanced acoustic instrumentation for deep sea imaging and sensing in Arctic and harsh environments project	PRNL, Kraken Sonar Systems Inc.	PRNL funded research project undertaken by Kraken Sonar Systems Inc. to develop and demonstrate a high resolution acoustic sensor for 3D seabed survey and underside ice profiling with increased area coverage rate compared to currently available technologies. A high coverage rate will minimize the time required to survey a given area, thereby reducing the cost of the survey and the risk for personnel exposed to harsh environmental conditions. High resolutions imagery and topography are useful for seabed exploration, infrastructure survey, characterization of ice thickness and composition and potentially for detection oil spills either on the seabed or at the ice / seawater interface.	http://pr-ac.ca/index.php?id=172	Ice detection, forecasting and monitoring Oil spill detection	Project 2013-2015
Advanced satellite radar JIP	PRNL, C-CORE	This JIP is part of the PRNL Ice Management Program regarding ice and iceberg detection/discrimination. One of the objectives of the Ice Management Program is to be able to detect ice / icebergs in remote locations, to discriminate between icebergs and other targets, to detect icebergs in high seas and in sea ice and to provide sea ice characterization (e.g. ice thickness). C-CORE led a project to extend the capabilities of satellite radar to distinguish between multi-year ice and other ice variations. The project involves advanced satellite radar-based iceberg detection and sea ice monitoring. Furthermore, the project includes software enhancements and ice island hindcasting.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166 http://www.canada.no/PDFS/ONS2012_Cook.pdf	Ice detection, forecasting and monitoring	JIP 2012-2013
Altimeter Ice Detection (AID)	C-CORE	C-CORE has been working with its LOOKNorth R&D team to develop the tool AID (Altimeter Ice Detection). AID uses freely available satellite altimeter data. The AID offers the ability to surveil large areas quickly, identifying target areas that can be further investigated using Synthetic Aperture Radar (SAR). More recently, C-CORE has enhanced AID capabilities to include analysis of the long-term altimeter data record from the Jason 1 & 2 and Poseidon satellites. In characterizing the ice regime in an area of the South Atlantic Ocean (approximately 51°S latitude, approaching the Antarctic) newly under consideration for hydrocarbon development, AID analysis yielded many detections, from which C-CORE produced an initial 20-year time series of ice populations within the region. Work is ongoing to improve ship / iceberg discrimination in AID and to compare AID detections against C-CORE's extensive in-house historical SAR datasets. The aim is to reliably extrapolate iceberg population within an area of interest from an AID point detection.	https://www.c-core.ca/AID	Ice detection, forecasting and monitoring	Technology development
Analytical estimation of manoeuvrability of moored FPU with internal turret in close ice	Gazprom VNIIGAZ LLC, Ishlinsky Institute for Problems in Mechanics RAS, UNIS	Onishchenko et al. (2015) have performed analytical estimations of the manoeuvrability of a moored floating production unit (FPU) with an internal turret in close ice. The process of the FPU rotating has been analysed within relatively simple engineering models based on consideration of mass, momentum and energy balances. An assessment has been performed of the mechanical work that is required for ice breaking and further ice piling up near the moving FPU hull. Conservative estimates demonstrate that the active turn of an FPU by 90° at reasonable angular velocity in medium first-year level ice would require the total power being well above values now available. Another model considers an FPU turning on the spot in broken compact ice. Comparison of the two cases demonstrates that the overall design of the FPU mooring system can be inadequate when the design ice loads are addressed only for the case of FPU heading against ice drift direction.	Onishchenko, D. (Gazprom VNIIGAZ LLC / A. Yu. Ishlinsky for Problems in Mechanics RAS), Marchenko, A. (University Centre in Svalbard), 2015. Analytical estimation of maneuverability of moored FPU with internal turret in close ice. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-082.	Station keeping in ice	Article published in 2015
API RP 2N Planning, designing and constructing	API	The API RP 2N Recommended Practice for planning, designing and constructing structures and pipelines for Arctic conditions was first published in 1982. API RP 2N served as the basis for ISO 19906 Arctic offshore structures, which was published in 2010. In April 2015, a new edition of API RP 2N was published. The new edition is a modified adoption of the ISO 19906:2010.	API RP 2N:2015. API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions. Third edition.	Disconnection Pipelines and subsea structures Facility design	Recommended practice, published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
structures and pipelines for Arctic conditions		The main observed differences between the ISO 19906:2010 and the API RP 2N standards are: - API RP 2N uses the wording 'loads' and 'loads effects' rather than 'actions' and 'actions effects' used by ISO 19906 - API RP 2N does not mention a reliability target expressed as annual failure probability at 1E-5 for L1 structures as given in Table A.7-1 of ISO 19906			
Arctic Coring Expedition (ACEX)	International Ocean Drilling Program	The Arctic Coring Expedition (ACEX) was a venture by the International Ocean Development Program (IODP) to extract core samples from the Lomonosov Ridge, at a point only 250 km from the North Pole. The offshore operations took place in the late summer of 2004. ACEX was a logistical challenge because the drillship had to hold its position while surrounded by the moving sea ice of the Arctic Ocean. This required two icebreakers, the Oden (Swedish) and Sovetskiy Soyuz (Russian) to crush large ice-floes into small pieces which allowed a third icebreaker, the Vidar Viking (Swedish), specially converted for the task, to maintain position and undertake the coring. This operation demonstrated that station-keeping in thick moving ice could be successfully performed provided that it was possible to go off location during the highest ice load situations.	http://www.ecord.org/pub/ACEX.pdf	Station keeping in ice	Project
Arctic drillship in ice with and without ice management	ACAK Inc., Statoil	Keinonen et al. (2007) evaluate an Arctic drillship developed by Statoil in terms of its achievable operability in moving ice, specifically when ice management by icebreakers is used to support it. The operational experience with stationary vessels in moving ice is described, by which has proven the use of ice management with icebreakers to enhance the operability in ice. Furthermore, it is described how azimuth icebreaker technology radically changed the ice management operations during the last year of oil production in Sakhalin Energy Investment Company offshore project.The operability of vessel shape stationary platforms in moving ice is to a significant degree determined by how the platform can deal with reorientation of itself in ice drift loops, ice drift reversals and ice pressure events. Furthermore, the time required to safely stop an operation and to remove the platform from the operational site, will influence the operational uptime. Keinonen et al. (2007) conclude that the independent operability of the Arctic drillship in ice without any ice management vessel is limited to thin first year ice, low concentration areas, or ice conditions where ice drift loops and reversals are not a reoccurring event. Critical ice events, such as ice drift reversal in the presence of ice pressure, would likely stop operations in less than 0.5 meters thick ice.The operations of the Arctic drillship in ice can be made feasible in up to thick first year pack ice conditions by means of introducing an ice management system of two icebreakers in its support, capable each of breaking more than 1.6 meters thick ice continuously and at least one of them having suitable design azimuth thruster system for ice clearing. Even a single icebreaker, suitably designed, with azimuth thrusters can significantly improve the operational envelope of the Arctic drillship in ice.	Keinonen, A. (AKAC Inc.), Martin, E. (AKAC Inc.), Neville, M. (AKAC Inc.) and Gudmestad, O.T. (Statoil), 2007. Operability of an Arctic drill ship in ice with and without ice management. Proceedings of the DOT 2007 Deep Offshore Technology, 10-12 October 2007, Stavanger, Norway. On CD.	Physical ice management	Article published in 2007
Arctic mooring systems - the past, present and future	Kwan Engineering Services, ABS, Global Maritime	Kwan et al. (2014) describe two JIPs related to Arctic mooring systems: - Arctic mooring system JIP led by Global Maritime and Kwan Engineering Service - Ice loads on floating structures led by ABS HETC Kwan et al. (2014) describe disconnect and reconnect devices for Arctic petroleum activities in terms of ice management (move-off capability), internal disconnectable turret mooring, interocean rig anchor release, subsea ballgrab and a new device specifically designed for Arctic operations called QRS (Quick Disconnect Reconnect).	Kwan, C.T.T. (Kwan Engineering Services), Bond, J. (ABS), Yu, H. (ABS) and Morandi, A. (Global Maritime), 2014. Arctic mooring systems – the past, present and future. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24581.	Disconnection	Article published in 2014
Arctic mooring systems JIP	Global Maritime and Kwan Engineering Services. Broad industry participation including operators, drilling contractors, designers, regulators, installation	The Arctic mooring systems JIP is established to develop design standards and operation practices for Arctic and other cold regions mooring systems. The main objective is to create a guidance document which can be used as a foundation document for industry standards or company specific design and operation guidelines worldwide (Kwan et al., 2014).	Kwan, C.T.T. (Kwan Engineering Services), Bond, J. (ABS), Yu, H. (ABS) and Morandi, A. (Global Maritime), 2014. Arctic mooring systems – the past, present and future. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24581.	Station keeping in ice	JIP 2013-2016

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
	companies, and mooring component manufacturers.				
Arctic operations handbook	Allseas Engineering, Bluewater, Canatec, TU Delft, Gusto MSC, Heerema Marine Contractors [Project Coordinator], Huisman, Imares, INTECSEA, MARIN, Royal Boskalis Westminster, Shell, TNO	The Arctic operations handbook JIP was set up in 2012 with a focus on the operational activities for transport and installation of fixed, floating and subsea units, as well as for dredging, trenching, pipe laying and floating oil and gas production in Arctic and cold weather conditions. The prime purpose of the JIP was to identify gaps in the existing standards and guidelines. Specific recommendations were subsequently proposed with the intention to contribute to the development of internationally accepted standards and guidelines. The project addressed safety and sustainability of offshore operations in the Arctic. This investigation into existing rules, regulations, standards and guidelines was intended to provide a common understanding for the offshore industries. Work groups were formed to execute work packages which were judged to be of prime importance. Three pilot projects were conducted as part of the JIP; IceStream, Marine Icing and Environmental Impact. Taking into account numerous aspects of the impact of the Arctic on various operations it was considered that the overall risk levels for such operations can be reduced by adopting the outline recommendations including, for instance, those related to weather monitoring and forecasting, environmental impacts, logistics, equipment preparation, vessel operations, training and health and safety management. The Arctic marine operations challenges and operations report (2013) documents the output from the JIP, including the results of the gap analysis and of the three pilot projects. The report provides the offshore industry an overview of identified gaps and proposes a large number of recommendations in order to close the gaps. The identified gaps and recommendations could support the further development of ISO TC67 SC8 Arctic operations, ISO 19906 SC7 Offshore structures, ISO 19901-6 Marine operations and future JIPs. Wiersema et al. (2014) describe the Arctic operations handbook JIP. The Arctic operations handbook recommends guidelines for the reliability of the disconnection operations to ensure the integrity of the station-keeping and offloading capability after later re-connection (Wiersema et al., 2014). In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPs. However, only the SALTO JIP was initiated for various reasons.	Arctic operations handbook, 2013. Arctic marine operations challenges & recommendations. Final report of the Arctic operations handbook JIP. http://www.arctic-operations-handbook.info/ Wiersema, E. (Heerema Marine Contractors), Lange, F. (Shell), Cammaert, G. (TU Delft), Sliggers, F. (TU Delft), Jolles, W. (Canatec) and van der Nat, C. (Bluewater), 2014. Arctic operations handbook JIP. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24545.	Ice management Disconnection	JIP 2012-2013
AWAC Ice profiler	Nortek	Nortek's AWAC (acoustic wave and current) ice profiler is a combined current profiler, wave directional system, and ice profiler. For ice measurements, the AWAC can be used to detect the interface between water and ice as an ice profiler. The surface is a strong acoustic reflector, and this is true also when the water surface is covered with ice. When compared with a reference measurements the AWAC can be used to estimate the surface ice thickness. This method was used during the winter 2008/2009 in the Arctic with very good results (Magnell et al., 2010).	Magnell, B. (Woods Hole Group Inc.), Ivanov, L. (Woods Hole Group Inc.) and Siegel, E. (Nortek), 2010. Measurements of ice parameters in the Beaufort Sea using the Nortek AWAC acoustic doppler current profiler. OCEANS 2010, 20-23 September 2010, Seattle, Washington, USA. DOI: 10.1109/OCEANS.2010.5664016. http://www.nortekusa.com/usa/products/wave-systems/awac-wave-measurements-current-ice-profiler	Ice detection, forecasting and monitoring	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Challenges of deep-water Arctic development	ExxonMobil	The oil and gas industry has demonstrated the ability to drill and develop offshore oil and gas resources in first-year sub-Arctic ice and in shallow-water high-Arctic environments. However, development in deep water (water depths exceeding 100 meters) remains a formidable challenge due to small, unpredictable open-water windows and large environmental loads from multi-year ice features. Hamilton (2011) reviews the key technical challenges facing deep-water high-Arctic development along with the current industry efforts aimed at meeting the challenges.According to Hamilton (2011), the foremost challenge is the drilling of development wells. This will require new floating drilling platforms with much higher mooring capacities, most likely coupled with maximum-capability ice management systems. Because some multi-year ice features cannot be managed by the largest conceivable icebreakers, efficient disconnection and reconnection capability will be essential.	Hamilton, J.M. (ExxonMobil), 2011. The challenges of deep-water Arctic development. International Journal of Offshore and Polar Engineering by the International Society of Offshore and Polar Engineers, 21(4), pp. 241-247. ISOPE-11-21-4-241.	Disconnection Facility design	Article published in 2011
Challenges related to ice management in Arctic offshore operations and field developments	NTNU	Eik (2010, in his PhD thesis at NTNU, Trondheim, Norway) identified challenges and solutions for ice management in Arctic offshore operations and field developments.	Eik, K.J. (NTNU), 2010. Ice management in Arctic offshore operations and field developments. PhD thesis at NTNU, Trondheim, Norway.	Ice management	PhD thesis published in 2010
Challenges related to station-keeping in ice	Barlindhaug Consult, NTNU, Statoil	Bonnemaire et al. (2007) describe challenges related to station-keeping in ice. The paper describes structural considerations and presents examples from research projects involving NTNU, Statoil and Barlindhaug Consult. Bonnemaire et al. propose implementing a disconnection possibility of the moored structure in combination with an efficient ice management system to make it possible to design cost-effective solutions with high regularity and uptime for drilling, production and offloading in severe ice conditions.	Bonnemaire, B. (Barlindhaug Consult), Jensen, A. (Barlindhaug Consult), Gudmestad, O.T. (NTNU / Statoil), Lundamo, T. (Barlindhaug Consult) and Løset, S. (NTNU), 2007. Challenges related to station-keeping in ice. 9th annual INTSOK conference, March 2007, Houston, Texas.	Station keeping in ice	Article published in 2007
Common operational picture display	Viking Ice Consultancy	Viking Ice Consultancy has developed a common operational picture display system for offshore operations. The system includes real time tracking of ice objects and vessels, communication and reporting and display of all relevant metocean and ice data. This system will provide for a better basis for decision making. The system was first time used in the Kara Sea in 2014.	http://www.viking-ice.com/whatwedo	Ice detection, forecasting and monitoring	Technology developed
Disconnectable mooring systems for Arctic conditions	SBM Offshore	SBM Offshore is developing a new disconnection and reconnection system for a ship-shaped floating production unit (FPU) in Arctic conditions (Bauduin et al.,2 015). Bauduin et al. (2015) review the requirements to and challenges of disconnection and reconnection systems. Furthermore, the development of SBM Offshore's new disconnection and reconnection system is presented.	Bauduin, C., Boulard, R., Caille, F. and Newport, A. (SBM Offshore), 2015. Disconnectable mooring systems for Arctic conditions. Presented at the Offshore Technology Conference, 4-7 May 2015, Houston, Texas, USA. OTC 25910.	Disconnection	Technology developmentArt icle published in 2015
Disconnection requirements for a moored floater in hard ice conditions	UiS, NTNU	Gudmestad et al. (2009) discuss the design requirements for the mooring of floating offshore production systems for Arctic conditions with drift ice. Scenarios for determining relevant design action effects are discussed and the paper emphasises the inclusion of dynamic effects. Then, the effect of methods to mitigate the actions through ice management (ice vaning and use of propellers to open up leads) is evaluated. Furthermore, the need for disconnecting the floater in extreme conditions is reviewed. The operational procedures and potential downtime in case of disconnection are finally discussed.	Gudmestad, O.T. (UiS / NTNU), Dalane, O. (NTNU) and Aksnes, V. (NTNU), 2009. Design of floating production systems in the Arctic. On the requirement to disconnection for a moored floater in hard ice conditions. Proceedings of the POAC 2009 20th International Conference on Port and Ocean Engineering under Arctic Conditions, 9-12 June 2009, Luleå, Sweden. POAC09-137.	Disconnection	Article published in 2009
Double acting tanker (DAT)	Aker Arctic	Aker Arctic has developed a double acting tanker (DAT) for transport in ice covered seas (Juurmaa et al., 2002). The vessel is designed to follow the double acting principal and the hull form is designed accordingly. The vessel is fitted with bulbous bow, designed to be capable of operating in light ice conditions, whereas the stern shape is of icebreaking type, in order to operate	Juurmaa, K., Mattsson, T., Sasaki, N., Wilkman, G., 2002. The development of the double acting tanker for ice operation. Proceedings of the 17th International Symposium on Okhotsk Sea & Sea Ice, 24-	Physical ice management	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		independently in severe ice conditions. This design allows for the vessel to run efficiently in both ice conditions and open water.	28 February 2002, Mombetsu, Hokkaido, Japan. http://www.cargos-paquebots.net/Reportages_divers/Port_Revel_30-04-2014/Azipods_Histoire.pdf		
DP operations in ice	AKAC Inc.	AKAC Inc. is conducting research related to DP operations in ice. Their R&D is directly linked to their experience and held key positions in two full scale operations in ice: the ACEX and the CSO Constructor. Their focus is on development of model testing procedures for DP vessels, the design of vessels specifically adapted for DP operations, and operational procedures that permit optimal, safe use of these new capabilities.	http://www.akacinc.com/project_type/sred/	Station keeping in ice	R&D ongoing
DP operations in ice offshore Sakhalin	AKAC Inc., Sakhalin Energy Investment Company, Canatec, P.E. Dunderdal and Associates Inc., Coflexip Stena Offshore	Keinonen et al. (2000) describes the DP operations in ice offshore Sakhalin that took place in 1999 when the CSO Constructor installed the subsea infrastructure and pipeline from the Molikpaq facility to the offshore loading buoy system (SALM) position. The operation lasted six weeks in the presence of widely varying ice conditions, including, in several occasions ten tenths of ice cover and ice pressure. The operation was supported by two icebreakers, Smit Sakhalin and Magadan. Furthermore, the ice operation was managed by an ice management team, which for this operation developed specific ice management techniques based on offshore ice operational experience in the Canadian Beaufort Sea. This DP operation was the first of its kind in the world to take place in the presence of a significant amount of moving ice. Imminent presence of severe ice at the CSO Constructor, required stopping of DP operations and allowing the vessel to drift with the ice. This occurred on several occasions in May 1999, leading to a need to drift with the ice. The total ice induced downtime over the whole operation was approximately 22%. The operation was considered successful as it was performed safely, on schedule (Keinonen et al., 2000). The above information has been confirmed by Reed (2014), summarising experience from Sakhalin operations.	Keinonen, A. (AKAC Inc.), Wells, H. (Sakhalin Energy Investment Company), Dunderdale, P. (P.E. Dunderdale and Associates Inc.), Pilkington, R. (Canatec), Miller, G. (Coflexip Stena Offshore) and Brovin, A. (Calgary, Canada), 2000. Dynamic positioning operation in ice, offshore Sakhalin, May-June 1999. Proceedings of the ISOPE 2000 10th International Offshore and Polar Engineering Conference, 28 May-2 June 2000, Seattle, USA. Document ID ISOPE-I-00-102. Reed, I. (Shell), 2014. Oil exploration and production offshore Sakhalin island. Ice management and marine operations. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 6 on maritime logistics, infrastructure and ice management, 17-18 June 2014.	Station keeping in ice	Technology available
Dual polarized marine radar JIP	PRNL, Rutter Inc.	This JIP is part of the PRNL Ice Management Program regarding ice and iceberg detection / discrimination. One of the objectives of the Ice Management Program is to be able to detect ice / icebergs in remote locations, to discriminate between icebergs and other targets, to detect icebergs in high seas and in sea ice and to provide sea ice characterization (e.g. ice thickness). This JIP involves building and testing an advanced radar system that is capable of providing enhanced ice navigation and detection. The integral dual polarized navigation and detection radar is expected to help operators distinguish between the much harder multi-year ice and first-year ice. Research has shown that multi-year ice responds differently to radar signals from first-year ice and the radar enhancement gives the operator the ability to make immediate and informed decisions on navigation. The project involves enhancement of Rutter Inc.'s dual-polarized Sigma 6 marine radar platform for better detection and discrimination of multi-year ice.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166 http://www.canada.no/PDFS/ONS2012_Cook.pdf http://www.canadianmanufacturing.com/technology/rutter-gets-1-4-million-for-radar-rejig-61635/	Ice detection, forecasting and monitoring	JIP 2012
Dynamic positioning in ice (DYPIC)	HSVA, DNV, Kongsberg Maritime, NTNU, SIREHNA, Statoil	The dynamic positioning in ice (DYPIC) project involves development of a tool box which allows the prediction of station keeping capability of different vessel types and offshore structures under various ice conditions. The aim of the project is to advance model testing facilities for DP in ice and to use the results of that testing to produce numerical modelling and further develop an ice optimised DP system.	Kerkeni, S. (DCNS-Research/Sirehna), dal Santo, X. (DCNS-Research/Sirehna), Doucy, O. (DCNS-Research/Sirehna), Jochmann, P. (HSVA), Haase, A. (HSVA), Metrikin, I. (NTNU / Statoil), Løset, S. (NTNU), Jenssen, N.A. (Kongsberg Maritime), Hals, T.	Station keeping in ice	JIP 2010-2012

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		Kerkeni et al. (2014) summarize the work performed within the project and spotlights the technical and scientific findings emerged from it. Special attention is paid to two facets of the project: the design of experimental devices, systems and set-ups for ice tank testing including the development of a DP system for model basin facility, and the development of an ice basin numerical simulator. Finally, Kerkeni et al. (2014) discuss the opened perspectives with a special focus on the operational matters.	(Kongsberg Maritime), Gürtner, A. (Statoil), Moslet, P.O. (DNV) and Støle-Hentschel, S. (DNV), 2014. DYPIC project: technological and scientific progress opening new perspectives. Proceedings of the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24652. http://www.dypic.eu/		
Enhanced DP operations in ice environments	PRNL, Centre for Marine Simulation (Fisheries and Marine Institute of MUN), NRC, Kongsberg Maritime	The JIP is a part of PRNL Ice Management Program regarding station-keeping in ice (PRNL, 2014). The objectives for the station-keeping in ice are: - advance the understanding of the magnitude and nature of pack ice loads on vessels, including mooring and/or station-keeping forces - determine response actions necessary for station keeping - develop technologies for station keeping The objective is to enhance DP control algorithms to respond to ice loads. The scope includes an extensive series of model tests in ice in support of algorithm development, and deployment of the software into a simulation environment to assist in training, operational assessment, risk analyses and equipment design.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166 http://www.km.kongsberg.com/ks/web/nokbg0238.nsf/AllWeb/CE65AD76FF9AA9BDC1257A2B0024B0A0?OpenDocument	Station keeping in ice	JIP initiated 2014
Enhanced iceberg and sea ice drift models and forecasts	PRNL, C-CORE, CARD	The JIP is a part of PRNL Ice Management Program regarding enhanced iceberg and sea ice drift forecasting (PRNL, 2014). The objective of the JIP is to develop technologies for improving ice and iceberg drift forecasting. The scope is to explore novel drift forecasting models and integrate this into operations. This will lead to more time for planning alternative ice management options, reduced downtime and optimized resource utilization. An assessment of gaps and opportunities to improve iceberg and sea ice drift forecasting was completed in 2013 and follow-on activities continue, primarily related to improving the understanding and prediction of environmental driving forces.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166%0c%0c http://www.canada.no/PDFS/ONS2012_Cook.pdf	Ice detection, forecasting and monitoring	JIP initiated 2012
Field data for sea ice and iceberg drift offshore Newfoundland and Labrador	MUN, CARD, Department of Fisheries and Oceans	Offshore operations in ice environments require detailed knowledge of ice conditions. Reliable forecasts of ice drift behaviour for first year sea ice and extreme ice features such as thick multi-year ice and icebergs are essential in supporting ice management activities and in supporting effective operational decision making. Central to the development of improved drift forecasting models is the collection of new field data that can be used to improve understanding of the physical environment and to validate and improve predictive tools. Three ice drift beacons have recently been deployed offshore Newfoundland and Labrador. Taylor et al. (2015) present a description of the beacons used, deployment activities, as well as results from these beacons are reported, along with initial analysis of the data. These new data provide interesting and sometimes unexpected drift behaviour. Results from these beacons are analysed in light of ocean current and wind data and conclusions regarding the correlations between these environmental conditions and observed drift behaviour are discussed for each case.	Taylor, R. (MUN / CARD), Turnbull, I. (CARD), Slaney, A. (Department of Fisheries and Oceans), 2015. Field data for sea ice and iceberg drift offshore Newfoundland and Labrador. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25575.	Ice detection, forecasting and monitoring - Newfoundland & Labrador ice data	Article published in 2015
Ice advisor package	Canatec	Canatec has developed a software and hardware for measuring, communicating and forecasting ice movement. The software package contains all public available imagery for the total Arctic. Tiffin et al. (2014) describe the development of the integrated toolkit.	Tiffin, S. (Canatec), Pilkington, R. (Canatec), Hill, C. (Canatec), Debicki, M. (Canatec), McGonigal (Glacialis Ice Consulting) and Jolles, W. (Canatec), 2014. A decision-support system for ice / iceberg surveillance, advisory and management activities in offshore petroleum operations. Presented at the Arctic Technology	Ice detection, forecasting and monitoring	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24657.		
Ice charting guideline	C-CORE, Polar Imaging, Bear Ice Technology / Shell, IOGP, ESA	This project involves development of guidelines for the use of satellite-based ice information in the oil and gas sector (C-CORE, 2014). The industry has spent significant effort developing standards for operations in the Arctic, however, no industry-wide standard exists for ice charting. The guideline will cover offshore oil and gas industry, from the polar regions to the mid-latitudes, and for current and future developments. The guideline will be limited to sea ice and icebergs, and will not cover other metocean conditions. The project is conducted by C-CORE, Polar Imaging Ltd. and Bear Ice Technology / Shell, and is supported by IOGP and ESA . Phase 1: Requirements and current practices (completed) - Description of the oil and gas lifecycle and corresponding ice assessment and monitoring needs - Ice assessment, monitoring product / service requirements and current remote sensing practices by region; Beaufort Sea, Chukchi Sea, Sea of Okhotsk, Canada East Coast, Greenland, Barents Sea (Shtokman field), North Caspian Sea, Bohai Sea, Southern Atlantic (Falklands) and Kara Sea -Preliminary identification of constraints and opportunities, and corresponding conclusions and recommendations Phase 2: Development of guideline document (in progress).	C-CORE, 2014. Guidelines for the use of satellite-based ice information in the oil and gas sector. A project supported by the ESA and IOGP. Presented at the 15th International Ice Charting Working Group Meeting, 20-25 October 2014, Punta Arenas, Chile. https://nsidc.org/noaa/iicwg/presentations/IICWG-2014/Power_OPG_Guidelines_for_the_Use_of_Satellite_Based_Ice_Information.pdf	Ice detection, forecasting and monitoring	Project phase 1: CompletedProject phase 2: In progress
Ice loads on floating structures	PRNL, ABS HETC	The JIP is a part of PRNL Ice Management Program regarding station-keeping in ice (PRNL, 2014). The objectives for the station-keeping in ice are:- advance the understanding of the magnitude and nature of pack ice loads on vessels, including mooring and/or station-keeping forces- determine response actions necessary for station keeping - develop technologies for station keepingPhase 1 "State-of-the-art review, gap analysis and recommendations" was completed by a consortium led by ABS' Harsh Environment Technology Centre (HETC) in 2014. Phase 2 plans are being reviewed. Potential work includes full scale field data collection of ice loads on, and responses of, moored floating structures in managed and unmanaged pack ice conditions, and related assessment of numerical and physical model tests and load predictions. Kwan et al. (2014) describe phase 1 of the JIP.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166 Kwan, C.T.T. (Kwan Engineering Services), Bond, J. (ABS), Yu, H. (ABS) and Morandi, A. (Global Maritime), 2014. Arctic mooring systems – the past, present and future. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24581. http://ww2.eagle.org/content/dam/eagle/publications/Reprints/2014/EandP%20Magazine_June%202014_Solving%20Arctic%20Challenges.pdf	Station keeping in ice	JIP initiated 2013
Ice management	NPC	NPC topical paper # 6-8 on ice management. The paper refers to examples of ice management systems that have been developed over time to allow safe operations in ice regimes.	NPC, 2015. Arctic Potential - Realizing the Promise of U.S. Arctic Oil and Gas Resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org	Ice management	Report published in 2015
Ice management program - improving ice management capabilities for operations in Arctic and harsh environments	PRNL	PRNL has established a multi-year Ice Management Program. The program aims at the development of improved ice management capabilities for operations in Arctic and harsh environments. The ultimate goal of the program is the development of enhanced ice management technologies and tools for use at various stages of the overall process. The vision, strategy and overall scope of the program was developed with input from industry and a gap analysis conducted by C-CORE in 2010-2011. The focus areas are: 1. Ice and iceberg detection/discrimination2. Enhance iceberg and sea ice drift forecasting3. Towing of large icebergs4. Operations in sea ice5. Station-keeping in sea ice 6. Technology integration and	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166	Ice management	JIP initiated 2013

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		trainingThe program involves several JIPs, including:- Dual polarized marine radar- Advanced satellite radar- Ice thickness radar- Enhanced iceberg and sea ice drift models and forecasts- Towing icebergs in sea ice / managing large icebergs- Ice loads on floating structures- Enhanced dynamic positioning (DP) system- Large scale iceberg impact experimentEach of these JIPs are presented in this overview.			
Ice management videos	AKAC Inc.	AKAC Inc. has issued two videos on ice management for educational purposes.	http://www.akacinc.com/category/video/	Ice management	Operational measure
Ice management with icebreakers	-	The operational experience with stationary vessels in moving ice, and the use of ice management with icebreakers to enhance the operability in ice, is described by Keinonen et al. (2007).	Keinonen, A. (AKAC Inc.), Martin, E. (AKAC Inc.), Neville, M. (AKAC Inc.) and Gudmestad, O.T. (Statoil), 2007. Operability of an Arctic drill ship in ice with and without ice management. Proceedings of the DOT 2007 Deep Offshore Technology, 10-12 October 2007, Stavanger, Norway. On CD.	Physical ice management	Technology developed
Ice Navigator	Rutter Inc.	Operating in ice-threatened regions such as the Arctic is a vital part of marine operations. The Sigma S6 Ice Navigator is an ice navigation solution for ice defence, ice breaking and port access. It is an ice detection and navigation system that enables ships operating in ice to differentiate between open water, ice pans, leads in ice fields, and thicker ice ridges that impact operations in ice zones. The Ice Navigator is developed to detect both large icebergs as well as bergy bits and growlers that can significantly damage a vessel or platform. The situational awareness provided by the Ice Navigator occur across a wide range of sea states, weather, and daylight conditions, providing tactical information essential for real time route planning and decision making.	http://www.rutter.ca/ice-navigator	Ice detection, forecasting and monitoring	Technology developed
Ice profiling sonar	ASL Environmental Sciences	ASL Environmental Services has developed an ice profiler which is an upward-looking sonar device mounted on the sea floor to accurately measure ice draft. In order to estimate ice forces, production rates and mass balances, accurate measurements of ice thickness are essential. The ice profiler makes those measurements easier to obtain. The ice profiler can be used to :- estimate the ice forces for design of offshore platforms and operational planning- determine the extreme thickness of ice for pipeline installations- examine in detail the underside of sea-ice- understand the dynamics and thermodynamics of the sea ice regime for scientific research	http://www.aslenv.com/IPS.html	Ice detection, forecasting and monitoring	Technology developed
Ice thickness radar JIP	PRNL, C-CORE	This JIP is part of the PRNL Ice Management Program regarding ice and iceberg detection/discrimination. One of the objectives of the Ice Management Program is to be able to detect ice / icebergs in remote locations, to discriminate between icebergs and other targets, to detect icebergs in high seas and in sea ice and to provide sea ice characterization (e.g. ice thickness). The scope of this JIP is to develop a radar system for characterizing ice thickness for tactical ice management purposes. Field trials of this are being considered.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166	Ice detection, forecasting and monitoring	JIP 2013-2015
Iceberg profiling project	C-CORE, Fugro, Pro-Dive	C-CORE was responsible for software development, data collection and production of the above-water portion (sail) of the iceberg profile. The iceberg sail model was developed using photogrammetric software through which iceberg photographs taken by a common-trigger three-network camera system were used to render 3D point cloud in Universal Transverse Mercator (UTM) coordinates and Coordinated Universal Time (UTC). The model data quality produced from this expedition is believed to rival any iceberg profile data set collected to date.	https://www.c-core.ca/IcebergProfiling	Physical ice management	Project 2012
Iceberg towing net	C-CORE	C-CORE has developed an iceberg towing net to reduce risk of iceberg roll during towing operations	https://www.c-core.ca/ice	Physical ice management	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Icebergfinder	C-CORE, Canadian Space Agency (ESA), Hospitality Newfoundland and Labrador, Atlantic Canada Opportunities Agency, zedIT, Newfoundland and Labrador Department of Tourism, Culture and Recreation	Icebergfinder.com is a website that reports the locations of icebergs along Newfoundland & Labrador's east coast and is geared toward tourists and the tourism industry. During the iceberg season, satellite surveillance is used to locate the icebergs, which are then mapped using Google Maps. The website cleanly merges advanced satellite image analysis with the familiar Google Maps application for easy navigation by non-technical users. Its iceberg location maps are updated regularly, reflecting the most recent satellite imagery for the area of interest.	www.icebergfinder.com	Ice detection, forecasting and monitoring	Portal launched in 2012
Icebreaker technology with azimuth	AKAC Inc.	AKAC Inc. directly applies azimuth icebreaker technology in both ice trials and ice management operations. Based on this AKAC Inc. is developing numerical tools and icebreaker designs that will maximize the efficiency of azimuth technology.	http://www.akacinc.com/project_type/sred/	Physical ice management	Technology developed
ISO 19906:2010, Arctic offshore structures	ISO	The ISO 19906:2010, Arctic offshore structures standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. Reference to Arctic and cold regions in ISO 19906:2010 is deemed to include both the Arctic and other cold regions that are subject to similar sea ice, iceberg and icing conditions. The objective of ISO 19906:2010 is to ensure that offshore structures in Arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value to the owner, to the industry and to society in general. ISO 19906:2010 describes design considerations for disconnection and subsequently reconnection, in addition to corresponding requirements. ISO 19906:2010 does not contain requirements for the operation, maintenance, service-life inspection or repair of Arctic and cold region offshore structures, except where the design strategy imposes specific requirements. While ISO 19906:2010 does not apply specifically to mobile offshore drilling units, the procedures relating to ice actions and ice management contained herein are applicable to the assessment of such units. ISO 19906:2010 does not apply to mechanical, process and electrical equipment or any specialized process equipment associated with Arctic and cold region offshore operations except in so far as it is necessary for the structure to sustain safely the actions imposed by the installation, housing and operation of such equipment. ISO 19906:2010 has been adopted as a national standard by Canada, Russia and the European Union (Frederking, 2012). Furthermore, API has adopted a modified edition of ISO 19906:2010, published as API RP 2N:2015. Blanchet et al. (2011) provides a brief history of the document preparation as it relates to country and industry involvement, development of technical input, editing and review processes undertaken and acceptance of the document by ISO and its participating members. The standard is currently under revision lead by the convenor, Karen Muggeridge. Draft International Standard (DIS) version is planned for mid-2016.	ISO 19906:2010. Petroleum and natural gas industries – Arctic offshore structures. 1st edition, International Standardisation Organisation, Geneva, Switzerland. http://www.iso.org/iso/catalogue_detail.htm?csnumber=33690 Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia. Blanchet, D. (BPXA Alaska), Spring, W. (Bear Ice Technology Inc.), McKenna, R.F. (McKenna and Associates) and Thomas, G.A.N. (BP), 2011. ISO 19906: An international standard for Arctic offshore structures. Presented at the Offshore Technology Conference, 7-9 February 2011, Houston, Texas. OTC 22068.	Disconnection Pipeline and sub sea structures Facility design	International standard published in 2010, currently under revision. Draft International Standard (DIS) version is planned for mid-2016.

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
ISO 35104 Ice management standard (TC67 SC8 WG4)	ISO	The overall objective of the standard is to ensure that ice management is planned, engineered and implemented within defined and recognized safety / confidence levels, wherever they are performed. The following in-ice activities and infrastructures which require ice management are covered by this standard; floating moored and/or dynamically positioned drilling vessels, coring vessels, production facilities and work-over vessels, construction and installation (incl. trenching, dredging, pipelaying), tanker loading and other offloading operations, protecting subsea installations, seismic operations, oil spill response, bottom founded structures (fixed installations). The development of the standard is led by the convenor, Robin Browne.		Ice management	International standard under development, close to CD
Monitoring Arctic land and sea ice using Russian and European satellites (MAIRES)	Nansen Environmental and Remote Sensing Center, Joanneum Research Forschungsgesellschaft, Scientific foundation NansenInternational Environmentaland Remote Sensing Centre, Moscow State University of Geodesy and Cartography (MIIGAiK), Research Center for Earth Operative Monitoring	The objective of the MAIRES project is to develop methodologies for satellite monitoring of Arctic glaciers, sea ice and icebergs. Methodologies to retrieve quantitative information from the European Space Agency (ESA) and Russian Space Agency data will be developed, and examples of satellite derived products for each of the three thematic areas will be presented. The main satellite data will be Synthetic Aperture Radar (SAR), optical and infrared images, radar altimeter data, passive microwave data and geoid data from GOCE (Gravity field and Ocean Circulation Explorer). The MAIRES project is focussed on the Barents and Kara Sea region. Specific objectives: • to establish cooperation between ongoing GMES projects and Russian actors in the area of Arctic ice observation from space; • to develop a method for precise overall modelling of glacier elevation changes by use of differential interferometry and altimetry data; • to develop sea ice classification methods using new high-resolution SAR images with dual polarization, combined with use of Russian high-resolution optical images; • to develop iceberg detection methods using a combination of high-resolution SAR and optical images; • to document inter-annual and decadel changes in land and sea ice variables based on the EO-products developed in the project; • to disseminate EO-based products for/of monitoring land and sea ice to users and stakeholders.	http://maires.nersc.no/	Ice detection, forecasting and monitoring - Barents Sea and Kara Sea ice data	Project 2011-2014
Monitoring hazardous sea ice features using satellite imagery	C-CORE	The Canadian Arctic is a highly dynamic environment that has the oldest and thickest sea ice in the world. The ice includes various features hazardous for shipping and offshore operations. Zakharov et al. (2015) describe a technology addressing the problem satellite based monitoring of hazardous ice features, which include ice ridges, hummocks and rubble fields. Additional attention was paid to identifying glacier ice (ice islands and icebergs). Zakharov et al. (2015) have demonstrated the technology using images collected over the Canadian Arctic in 2013-2014 and verified the ice features by analysing high resolution satellite optical images that overlap spatially and temporally with the synthetic aperture radar (SAR) data. Various satellite images and data fusion techniques were explored by Zakharov et al. (2015) for identifying ice features and retrieving their characteristics. Ice parameters being studied include height, size and frequency of ice features. The work by Zakharov et al. (2015) addresses the problem of quantitative retrieval of hazardous ice features from a variety of SAR and optical images: - Data fusion and SAR polarimetry provide valuable information for detecting glacier ice and hummocks, especially when these features are embedded in pack ice. - Detecting small features in low resolution data can be challenging, but medium resolution optical and SAR fusion has been successful at distinguishing first-year and multi-year deformed ice features. Using dual polarized SAR data alone, it is possible to highlight glacier ice, but manual interpretation is required to verify results. - Future work for this area will be to assess the utility of SAR and optical fusion products for automatic feature detection.	Zakharov, I., Bobby, P., Power, D., Saunders, K. and Warren S. (C-CORE), 2015. Monitoring hazardous sea ice features using satellite imagery. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25570.	Ice detection, forecasting and monitoring	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Operating experience with Navion Munin FPSO at the Lufeng field	Navion, Advanced Production Systems, Statoil	Tangvald et al. (2000) describe the operational experiences gained from oil production from the Lufeng 22-1 field in the South China Sea with the FPSO unit 'Navion Munin'. Typhoons are frequent in the area and the area is affected by solitons (subsurface waves generated by tidal variations). The FPSO has been designed to disconnect and temporarily abandon the Lufeng field when typhoons approach the field. Wellstream fluid arrives on the FPSO via two flexible production risers. Station-keeping of Navion Munin is provided by the Submerged Turret Production (STP) concept. The FPSO is moored with a conventional catenary mooring system consisting of six symmetrically spread mooring lines all connected together in the upper end to the disconnectable STP buoy. The mooring lines are designed for two operational modes:- Disconnected - with the STP buoy submerged to a depth of approximately 45 meters below the water surface- Connected - with the STP buoy and turret connected to the ship 52 meters from the bowThe extreme condition for FPSO disconnection from the STP buoy is the 25 year return wave which has a significant wave height (Hs) of 7.0 meters. When the FPSO is disconnected, the remaining STP buoy and mooring lines are designed to withstand conditions of 100 year return typhoon, which has a significant wave height (Hs) of 13.7 meters.Preparation for disconnection is initiated when forecasted conditions exceed 7 meter significant wave height. During the two first years of operation, Navion Munin has disconnected 4 times due to extreme weather conditions. The average production downtime associated with temporary field abandonment has been 96 hours. From offloading is stopped, the Navion Munin can disconnect within approximately 17 hours. However, it is noted that the operating disconnection and subsequently reconnection experience with Navion Munin is limited to two risers.	Tangvald, T.B. (Navion), Wiik, E. (Advanced Production Systems) and Boge, H. (Statoil), 2000. Operating experience with Navion Munin FPSO at the Lufeng field. Presented at the Offshore Technology Conference, 1-4 May 2000, Houston, Texas, USA. OTC 12057.	Disconnection	Technology available Article published in 2000
Physical ice management	AKAC Inc.	AKAC Inc. is conducting project and R&D activities related to physical ice management.	http://www.akacinc.com/project_type/sred/	Physical ice management	R&D ongoing
PractICE JIP	MARIN	In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPS. However, only the SALTO JIP was initiated for various reasons. The aim of the PractICE JIP would be to provide a real-time simulation platform enabling practical simulations of offshore operations in ice. It would build on previous conceptual studies, initial model work and would comply with training objectives and requirements set by the industry.	NEN, 2013. Arctic operations and technology. Joint industry research and standardization. http://www.marin.nl/web/file?uuid=6094db87-5a44-4a40-96d1-f3efda866e73&owner=8d68985e-5c67-4085-b2be-90b5c1bbb707&search=icetower	Ice detection, forecasting and monitoring	JIP not initiated
Safe Arctic Logistics, Transport and Operations (SALTO) JIP	MARIN, Danish Meteorological Institute, Canatec, AKAC Inc., IMARES	In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPS. However, only the SALTO JIP was initiated for various reasons.The SALTO JIP will provide a PC simulation tool for risk-based, probabilistic design to help the industry prepare for the environmental conditions (wind, fog, ice, icing) of the Arctic and, henceforth, to optimise operations of ships and offshore constructions. Pre-knowledge of workability, risk and limiting conditions will lead to enhanced safety and reduced environmental impact. Some scientific challenges are: - Modelling of ship performance in ice, progress, limiting conditions - Modelling of human decision making for operations in ice, routing logic - Probabilistic modelling of ice berg collision damage risk, icing risk, initial environmental risk.	NEN, 2013. Arctic operations and technology. Joint industry research and standardization. http://www.marin.nl/web/JIPs-Networks/Public/SALTO.htm	Ice detection, forecasting and monitoring	JIP 2014-2017
Satellite-based monitoring of the polar regions	Polar View	Polar View is a global organization providing leading-edge satellite-based information and data services in the polar regions and the cryosphere. The services include enhanced sea ice information (charts and forecasts) as well as ice-edge and iceberg monitoring data.	http://www.polarview.org/	Ice detection, forecasting and monitoring	Technology developed
Ship and iceberg detection satellite surveillance tool	C-CORE	The semi-automated satellite surveillance tool increase the capability for ship and iceberg detection with up to 95% accuracy. Performance analysis of available sensors and a framework for integrating all available data will provide an up-to-date and accurate wide-area picture.	https://www.c-core.ca/IceManagement	Ice detection, forecasting and monitoring	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Stability and drift of icebergs under tow	C-CORE	Current ice management tactics rely on iceberg towing using offshore supply vessels. Knowledge of an iceberg's stability characteristics is necessary when attempting to perform towing operations. Without this knowledge, improper tow force, speed and angle can all have a detrimental effect on the safe and efficient removal of an iceberg. C-CORE received funding from Petroleum Research Atlantic Canada (PRAC) to research the relationship between iceberg stability and towing parameters such as tow force, point of application, acceleration and tow speed. The project also focused on whether tow strategy can be optimized using a model that integrates the forces from the sail and the keel of the iceberg. The end result is a set of practical guidelines to improve the effectiveness of iceberg towing operations, which may pave the way for the use of physically-based models in iceberg management (C-CORE, 2005).	C-CORE, 2005. Stability and drift of icebergs under tow. C-CORE Report R-04-072-216 v1. Draft report. St. John's, Newfoundland and Labrador, Canada. http://pr-ac.ca/index.php?id=95	Physical ice management	Project 2003-2004
Station keeping of drillships under changing direction of ice movement	NRC, B. Wright and Associates Ltd.	The ability of a drillship to maintain its heading to face oncoming pack ice is crucial under situations involving pack ice drift direction changes. Sayed et al. (2015) have examined the performance of a vessel employing a Thruster-Assisted Mooring (TAM) system under such conditions. Numerical simulations were used to determine the stresses and deformations within the moving pack ice cover, as well as the response of the drillship. The results display clear trends of the dependence of the offsets, ice forces and movements of the initial heading and the limit on thrusters' torque. Plots show near linear increase of peak ice forces and moments with increased angle between the initial heading and the target heading of 180°. The maximum offsets are shown to decrease for increasing thrusters' torque. They also increase with decreasing values of the angle between the initial heading and the target headings. In an operational setting, response actions may be taken to reduce the offsets. The results provide insights in the manner in which drillships can correct their heading given pack ice drift directions changes.	Sayed, M. (NRC), Kubat, I. (NRC), Watson, D. (NRC), Wright, B. (B. Wright and Associates Ltd.), Gash, R. (NRC) and Millan, J. (NRC), 2015. Simulations of the StationKeeping of Drillships under Changing Direction of Ice Movement. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25565.	Station keeping in ice	Article published in 2015
Station-keeping in ice	CARD	The Centre for Arctic Research and Development (CARD) conducts a research program on station-keeping in ice. Detailed understanding of ice conditions, ice mechanics and loading, ice management and the response of floating systems are necessary inputs in the development of station-keeping solutions for ice environments. Key research topics identified for CARD's station-keeping program includes: - Scale-model testing of floating systems: Scale-model testing of ice-induced loads no mooring systems and DP floating systems have been identified ae areas for further research - Model of loads on moored floating platforms: Modelling of ice-induced loads of mooring systems for different loading scenarios, ice features, types of ice, metocean conditions, vessel designs, anchor systems and mooring configuration is needed. Research is needed to improve understanding of issues associated with the disconnection of turrets under high ice loads, reconnection of mooring in ice conditions, or interactions of individual mooring lines with ice features - Modelling of loads on DP platforms: The response of DP systems to loads from managed and unmanaged ice is complex and at present is not well understood. The development of a probabilistic framework for studying and evaluating DP system response has been identified as an area for further research - Concept evaluation and downtime reduction tools: To aid in the evaluation of different floating system concepts for a range of environmental conditions and design configurations, new tools will be developed	https://www.card-arctic.ca/station-keeping-topics	Station keeping in ice	R&D ongoing
Station-keeping in ice	NRC	The National Research Council of Canada (NRC) has for many years focused on improving station keeping capabilities for both moored and DP Arctic vessels.	http://www.nrc-cnrc.gc.ca/eng/	Station keeping in ice	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Submarine upward looking sonar ice draft profile data and statistics	National Snow and Ice Data Center	This data set consists of upward looking sonar draft data collected by submarines in the Arctic Ocean. It includes data from both U.S. Navy and Royal Navy submarines. Maps showing submarine tracks are available. Data is provided as ice draft profiles and as statistics derived from the profile data. Statistics files include information concerning ice draft characteristics, keels, level ice, leads, un-deformed and deformed ice. Data from the U.S. Navy's Digital Ice Profiling System (DIPS) have been interpolated and processed for release as unclassified data at the U.S. Army's Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Data from the analogue draft recording system were digitized and then processed by the Polar Science Center, Applied Physics Laboratory, University of Washington. Data from British submarines were provided by the Department of Applied Mathematics and Theoretical Physics, University of Cambridge. All data sources used similar processing methods in order to ensure a consistent data set.	NSIDC, 2006. Submarine upward looking sonar ice draft profile data and statistics. Boulder, Colorado, USA. DOI: 10.7265/N54Q7RWK. http://nsidc.org/data/g01360	Ice detection, forecasting and monitoring	Technology developed
Tests of DP in ice	Statoil, HSVA, DCNS Research, NTNU	Statoil and HSVA have recently reported from tests of dynamic positioning in ice (Metrikin et al., 2015). The work is continuing.	Metrikin, I. (NTNU / Statoil), Kerkeni, S. (DCNS Research / Sirehna), Jochmann, P (HSVA). and Løset, S. (NTNU), 2015. Experimental and numerical investigation of dynamic positioning in level ice. Journal of Offshore Mechanics and Arctic Engineering, 137(3), 031501. DOI: 10.1115/1.4030042.	Station keeping in ice	Article published in 2015
Towing decision support tool	C-CORE	A computer package to aid towing decisions.	https://www.c-core.ca/IceManagement	Ice detection, forecasting and monitoring	Technology developed
Towing iceberg in sea ice JIP	PRNL, Canatec, C-CORE	This JIP is a part of the PRNL Ice Management Program regarding towing icebergs in sea ice. The objectives for towing icebergs in sea ice are:- develop and test methods for towing icebergs in pack ice- develop training material and/or simulation tools for towing large icebergsA JIP to investigate the practical and technical feasibility for towing icebergs in various levels and types of sea ice coverage was initiated in 2013. Initial work was being executed by Canatec and other partners. The scope for this project consists of defining performance scenarios to assess the practical and technical feasibility of towing icebergs and other objects such as work barges in various levels and types of sea ice coverage. The scenarios will consider both first year and multi-year ice coverage from 1/10 to 10/10 with and without icebreaker support. A major objective is to identify the marine spread - the number and types of vessels required, as well as the costs associated with such an operation and estimate tow loads for selected scenarios. Follow-on work may include field work to collect data for validation of towing feasibility.	PRNL, 2014. Joint Industry Program: Development of Improved Ice Management Capabilities for Operations in Arctic and Harsh Environments. http://petroleumresearch.ca/index.php?id=166	Physical ice management	JIP initiated 2013

Drilling technology, well integrity and well control

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
API RP 17W Subsea capping stacks	API	The document provides subsea capping stack recommended practices for design, manufacture and use. The document applies to the construction of new subsea capping stacks and can be used to improve existing subsea capping stacks. The document does not include recommendations for either procedures or equipment for containment systems that may be connected to a subsea capping stack. All equipment and operations downstream of the subsea capping stack are considered part of a containment system and are not within the scope of this recommended practice. Annex A contains a discussion of possible subsea capping contingency procedures. Annex B contains example procedures for deployment, well shut-in and recovery of a subsea capping stack.	API RP 17W:2014. API RP 17W Subsea capping stacks. First edition.	Well control - not Arctic specific	Recommended practice, published in 2014
API RP 96 Deepwater well design and construction	API	This recommended practice (RP) provides engineers a reference for deepwater (DW) well design as well as drilling and completion operations. This RP can also be useful to support internal reviews, internal approvals, contractor engagements, and regulatory approvals.The scope of this RP is to discuss DW drilling and completion activities performed on wells that are constructed using subsea blowout preventers (BOPs) with a subsea wellhead. This document addresses the following.- Identifies the appropriate barrier and load case considerations to maintain well control during DW well operations (drilling, suspension, completion, production, and abandonment). - Supplements barrier documentation in API 65-2 with a more detailed description of barriers and discussion of the philosophy, number, type, testing, and management required to maintain well control. This document also supplements the barrier documentation in API 90 in regard to annular pressure buildup (APB). Abandonment barrier requirements are described for use when designing the well.- Discusses load assumptions, resistance assumptions, and methodologies commonly used to achieve well designs with high reliability. The load case discussion includes less obvious events that can arise when unexpected circumstances are combined.- Describes the risk assessment and mitigation practices commonly implemented during DW casing and equipment installation operations.	API RP 96:2013. API RP 96 - Deepwater well design and construction. First edition.	Well design - not Arctic specific	Recommended practice, published in 2013
API Specification 4F Specification for drilling and well servicing structures	API	This specification states requirements and gives recommendations for suitable steel structures for drilling and well servicing operations in the petroleum industry, provides a uniform method of rating the structures, and provides two Product Specification Levels. This specification that addresses the fabrication of such structures used in cold climate.	API Specification 4F:2013. API Specification 4F Specification for drilling and well servicing structures. Fourth edition.	Drilling technology	Specification, published in 2013
Arctic plugging and abandonment	SINTEF	SINTEF has research targeting permanent well plugging and abandonment, which aims to ensure that the wells can be safely sealed after production has ended.	http://www.sintef.no/en/oil-and-gas/#/	Drilling technology	R&D ongoing
Alternative Well Kill System (AWKS)	Chevron	Chevron, in a technology agreement with Cameron, is developing an enhanced BOP system – the Alternative Well Kill System (AWKS). The AWKS provides greater well control flexibility, redundancy, safety and environmental protection for the Arctic offshore and other harsh environment applications relative to existing BOP systems. An emergency disconnect for late season floating Arctic drilling operations in pack ice cover may require shearing the pipe and leaving the BOP on the seafloor. A combination of more severe ice conditions and the need to demobilize the rig may require the BOP to be left on the seafloor till the following year. In such situations, it would be a desirable feature to add a second physical sealing barrier throughout the winter months. In most modern BOP stacks, a shear and seal operation requires the coordinated use of two rams with a single sealing barrier when shearing a heavy wall or large diameter casing is involved. On most floating drilling rigs this is an automated, three stage process: 1. The super shear ram (SSR) cuts the drilling, casing or production tubular pipe body allowing the lower section of the pipe to drop	Chevron Canada Limited, 2010. Submission to National Energy Board policy hearing for same season relief well capability for drilling in the Beaufort Sea. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll/fetch/2000/90463/589151/594086/594088/601008/609585/C-03-4B_-_Chevron_SSRW_Capability_Policy_Review_Submission_-_A1S2U2_.pdf?_gc_lang=en&nodeid=609506&vernum=0 NEB, 2015. ARCHIVED - Chevron Canada Limited - Exploration License EL 481 - Same Season Relief Well Technical Proceeding. https://www.neb-one.gc.ca/pplctnflng/mjrpp/archive/chvrnssrw/index-eng.html#s2	Well control	Technology development

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		2. Drill string tension lifts the upper section of cut pipe above the shear blind ram (SBR) 3. The SBR is then closed and a single barrier seal is achieved The AWKS design philosophy involves: - shear and seal simultaneously in a single step using a single ram - cut and seal on the range of grade and weight of drilling and production tubular bodies (including casing) planned for well program As with conventional shear rams, the AWKS can not guarantee a shear and seal on a tubular connection. To avoid this issue on a subsea BOP stack, two AWKS units would be utilized, thus allowing one of the AWKS to always be cutting on the tubular body and ensuring a shear and seal. The AWKS safety package for existing drill systems includes a twin AWKS system with completely independent back-up system.			
Arctic capping stack	Trendsetter Engineering / Shell	Trendsetter Engineering developed an Arctic Capping Stack for Shell in 2012. It is built in such a way that it can be used as an emergency pressure containing device that acts as a barrier in case of BOP failure (Trendsetter Engineering, 2012). The capping stack is designed to be operated in shallow water depths (200 fsw). Furthermore, built with ROV interfaces, the Arctic capping stack is ROV operable and capable of capturing / processing 100,000 barrels of fluid per day, with onboard accumulation for rapid well control. In June 2015 BSEE personnel witnessed the deployment and manoeuvring of the capping stack off the rear deck of the M/V Fennica to 150 feet of water, which is deeper than Shell's current well sites in the Chukchi Sea. The capping stack functioned properly under pressures exceeding the maximum expected pressures Shell may encounter in the Arctic.	http://www.trendsetterengineering.com/media/files/files/f2d8d560/Clean_Gulf_Trendsetter_Subsea_Well_Control_Equipment_Capping_Stack_MCD_Kill_Manifold_.pdf http://www.trendsetterengineering.com/news/trendsetter-completes-arctic-capping-stack/ http://www.bsee.gov/BSEE-Newsroom/BSEE-News-Briefs/2015/BSEE-Oversees-Testing-of-Shell-Arctic-Drilling-Well-Containment-Equipment/	Well control	Technology developed
Arctic containment system	Shell	Shell has developed an Arctic containment system which includes a capping stack, a containment dome, high pressure hoses and a production processing system on board the Arctic Challenger. The Arctic Challenger is a ship-shaped barge that houses the containment dome and the offshore support vessels that are necessary in order for the containment system to be deployed effectively. The 20-feet-tall steel containment dome would be used in the event that a capping stack could not completely staunch an uncontrolled subsea flow event. Rather than attaching to the top of the blowout preventer as the capping stack did at the Macondo well in Gulf of Mexico, the containment dome is lowered to the seafloor over the well site by use of buoyancy tanks. The hydrocarbons flowing from the wellhead are collected at the top of the dome and pumped back to the Arctic Challenger for processing. The capabilities of the capping stack and containment dome must meet the requirements that are specific to the characteristics of the proposed well. Shell and contractors deployed and tested the containment dome in March 2015. It was demonstrated that the dome can be deployed and operated as designed, and that it is capable of pumping at a rate greater than a discharge of 25,000 barrels of fluid per day.	http://www.bsee.gov/BSEE-Newsroom/BSEE-News-Briefs/2015/BSEE-Observes-Demonstration-of-Containment-Dome-Deployment/http://www.bsee.gov/uploadedFiles/BSEE/BSEE_Newsroom/Publications_Library/OSRPs/Arctic/ACStest.pdf	Well control	Technology developed
Arctic Mudline Closure Device (MCD)	Trendsetter Engineering	Trendsetter Engineering has developed an Arctic Class, 18 ¾"– 15,000 psi mudline closure device (MCD) system that is installed in addition to the traditional BOP assembly to enhance safety during drilling in harsh environments. The MCD is designed to be installed between the BOP and subsea wellhead during drilling operations and can be used to shear and isolate the well should loss of well control occur. The MCD could also be installed on the seabed when connected via a rigid riser to a surface BOP when used with jack-up rigs. The MCD may also be considered for drilling from a TLP, a SPAR and in situations where there is a tightly spaced array of wells on the seabed.The MCD serves as an additional safety shut-in device during drilling operations, with dedicated hydraulic controls independent of the BOP and BOP control system. The MCD provides a clean re-entry capability and is capable of monitoring, logging, and transmitting pressure and temperature readings up to 9 months should the rig need to abandon the well due to an unforeseen event.Along with the MCD, the system includes a dedicated subsea control system that includes subsea	Lochte, G. (Trendsetter Engineering), Lingo, D. (Trendsetter Engineering), Matson, A. (Trendsetter Engineering), 2015. Case study – a mudline closure device as a pre-installed well control system. Presented at the AOGP 2015 Arctic Oil & Gas North America, 14-15 April 2015, St. John's, Canada. http://www.trendsetterengineering.com/media/files/files/0dfa1aac/Case_Study_A_mudline_closure_device_as_a_pre-installed_well_control_system_AOGNA_2015.pdf	Well control	Technology developed and deployed into the Russian Arctic in 2014 (ExxonMobil / Rosneft)

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		accumulator modules (SAMs), acoustic electro-hydraulic control systems and hydraulic flying leads. In addition, the system includes a test stand, an 18 ¾" – 15,000 psi secondary pressure cap and other supporting equipment. The Arctic MCD facilitates immediate disconnect / drive off / drift off capability and is designed to be left as an in-place well cap. The MODU with its drilling riser and BOP can be used elsewhere during the winter ice season. A metal sealed cap is installed on the standard mandrel at the top of the MCD for long term multi-month capping. The MCD system is designed to perform the following basic functions: •Connects and seals to an 18 ¾" 10,000 psi or 15,000 psi wellhead housing¨ •Provides an 18 ¾" 10,000 psi or 15,000 psi upper mandrel connection to the subsea BOP •Provides two individual BOP rams capable of shearing and sealing off wellbore with 15,000 psi wellbore pressure when actuated with acoustics or with the ROV back-up system •Provides two subsea mateable connections for contingency bore access, well kill operations and cap and flow scenarios	http://www.trendsetterengineering.com/projects/arctic-mudline-closure-device/		
Arctic oil spill prevention and response: working collaboratively to improve and extend safe practice	Shell, Statoil	This paper describes advancement initiatives and efforts under the auspices of the International Association of Oil and Gas Producers (IOGP) regarding prevention and mitigation of a loss of well control incident and places them into the Arctic context. These initiatives include development of new technology, equipment, guidelines, standards as well as knowledge sharing. The initiatives are aimed at both improving incident prevention and the robustness of response measures.	Winkler, M. (Shell), Jahre-Nilsen, C. (Statoil), Blaauw, R. (Shell) and Dyve-Jones, R. (Statoil), 2015. Arctic oil spill prevention and response: working collaboratively to improve and extend safe practice. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25485.	Drilling technology, well integrity and well control	Article published in 2015
Arctic well integrity	SINTEF	Study of leakages occurring as a result of downhole temperature variations in Arctic wells (injection of cold fluids or production of hot fluids through a cold well).Background: Due to limited access to the drilling site / well, and as a result of harsh weather conditions, operations will be following an on/off pattern in the Arctic. If a well is shut in when the seafloor temperatures are below zero, there is a risk for freezing of water-based fluids in the top of the well and in choke and flowlines connected to the wellhead. This can damage the well itself or associated equipment. Furthermore, whether hot hydrocarbons are produced on/off through a colder subsurface, or colder fluids are injected on/off into the well, the downhole temperature variations will be large. Cement, which seals the annulus between the casing pipe and the rock formation, is a brittle material that can crack or de-bond upon such thermal cycling. In the laboratory, SINTEF has demonstrated that thermal cycling is a potential cause of well integrity loss on the Norwegian continental shelf, and this will probably be aggravated in the Arctic.	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing
Arctic well integrity and spill prevention methods and technology	NPC	NPC topical paper # 8-10 on Arctic well integrity and spill prevention methods and technology . The paper describes the state-of-the-art for well integrity and spill prevention. It refers to general methods of prevention of hydrocarbon spill and prudent well designs, not methods specifically developed for the Arctic. However, it describes the experiences with Arctic wells from the Norman wells in Canadian Northwest Territories in 1920 until wells today.	NPC, 2015. Arctic Potential - Realizing the Promise of U.S. Arctic Oil and Gas Resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org	Drilling technology, well integrity and well control	Report published in 2015
Automated drilling	SINTEF	In the Arctic it might be necessary to automize drilling, especially in harsh and varying weather conditions with relatively short time windows. SINTEF has an ongoing knowledge-building project for the industry with Huisman where they do research on automated drilling to ensure consistency and improve efficiency of drilling operations.	http://www.sintef.no/en/oil-and-gas/#/	Drilling technology	R&D ongoing
Auxiliary Safety Isolation Device (ASID)	ConocoPhillips	The auxiliary safety isolation device (ASID) is a source control device, stopping the blowout by controlling the source. The ASID is designed to have a minimum of two blind shear rams that could be controlled from either the drilling unit or remotely from a location off the drilling unit. If loss of well control occurs, the ASID can be activated immediately and is intended to regain well control in minutes. The ASID can be deployed with all types of drilling units. Although it is considered a type of BOP, it does not replace the drilling unit's BOPs. For a jack-up drilling rig with a surface BOP, an ASID on the seafloor can keep the well isolated with pressure	NEB, 2011. Public review of Arctic safety and environmental offshore drilling requirements. NEB file OF-EP-Gen-AODR 01. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll/fetch/2000/90463/621169/649241/679746/A1Y4U5_-_ConocoPhillips_-_Response_to_Call_for_Information.pdf?_gc_lang=en&nodeid=679806&vernum=0	Well control	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		containment, even if the rig is moved off location. In water depths where a subsea BOP is required, the ASID could also be used for source control. The BOP stack will be deployed with the ASID below it. The ASID and the BOP will each have their own stored power supply (accumulators) and controls. Consequently, the ASID can be controlled even if control of the BOP stack is lost.			
Cement formulations for permafrost	-	Special cement formulations may be necessary for drilling operations in areas with permafrost (Winkler et al., 2015).	Winkler, M. (Shell), Jahre-Nilsen, C. (Statoil), Blaauw, R. (Shell) and Dyve-Jones, R. (Statoil), 2015. Arctic oil spill prevention and response: working collaboratively to improve and extend safe practice. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25485.	Well integrity	R&D ongoing
Decision support during drilling	SINTEF	SINTEF studies monitoring and decision support based on advanced mathematical models to ensure consistency and reduce the number of unwanted events. The work is developed with eDrillingSolutions, ConocoPhillips Norway and China National Offshore Oil Corporation (CNOOC).	http://www.sintef.no/en/oil-and-gas/#/	Drilling technology	R&D ongoing
Degassing of fluids	SINTEF	Measurements of the dynamics / kinetics of gas loading is ongoing, and may easily be extended to degassing. This issue is especially important when the mud is at low temperature with high liquid viscosity.	http://www.sintef.no/en/oil-and-gas/#/	Drilling technology	R&D ongoing
Divert / Flow Control (DFC) System	Trendsetter Engineering	The Divert / Flow Control (DFC) system is a pre-installed flow diversion system in the event well shut-in can not be achieved. This can be related to breach of well bore integrity of release of gas on the drilling rig. The DFC system can enable the following operations: - subsea flow diversion - surface flaring - surface containment The DFC provides divert / flow capability which can enable re-boarding the rig, re-entering the well to perform a well kill operation and preparing for centralised oil collection for oil spill response operations.	Lochte, G. (Trendsetter Engineering), Lingo, D. (Trendsetter Engineering), Matson, A. (Trendsetter Engineering), 2015. Case study – a mudline closure device as a pre-installed well control system. Presented at the AOGP 2015 Arctic Oil & Gas North America, 14-15 April 2015, St. John's, Canada. http://www.trendsetterengineering.com/media/files/files/0dfa1aac/Case_Study_A_mudline_closure_device_as_a_pre-installed_well_control_system_AOGNA_2015.pdf	Well control	Technology developed
Drill cutting and waste injection assurance in the Barents Sea	UiT	Pour et al. (2015) discusses the various factors that need to be considered for a reliable drill cutting and waste injection operation, including the surface and subsurface risks.	Pour, F.S. (University of Tromsø), Naseri, M. (University of Tromsø) and Barabadi, J. (University of Tromsø), 2015. Drill cutting and waste injection assurance in the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-180.	Well integrity	Article published in 2015
Drilling and well challenges in the Arctic	SINTEF	Torsæter and Vrålstad (2014) discuss the subsurface challenges related to drilling, well construction and petroleum production in the High North and the importance of these challenges being thoroughly explored in order to ensure safe and cost-efficient Arctic wells.	Torsæter, M. and Vrålstad, T. (SINTEF Petroleum Research), 2014. Drilling and well challenges in the Arctic. Marine Technology Society Journal, 48(5), pp. 76-80.	Drilling technology, well integrity and well control	R&D ongoing
Drilling packages and cranes suitable for Arctic operation	National Oilwell Varco	National Oilwell Varco has developed and quoted several concepts / layouts for drilling packages and cranes suitable for Arctic operations. National Oilwell Varco applies a contained system approach, thus, minimising the consequences of a leak, in addition to using electrical drive systems over electro-electrical systems which reduce the probability of leaks.		Drilling technology	Technology developed
Drilling through gas hydrate	SINTEF	Study of how to ensure borehole stability when drilling through gas hydrate bearing sediments.	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
bearing sediments		Background: There are geohazards in the Arctic subsurface like gas hydrate bearing formations. These are a threat towards safe drilling and production since they can lead to gasification of mud during drilling and thawing / subsidence of the near-well region during production. These shallow gas zones are also impermeable, and can have high overpressured sands residing under them. Such zones are difficult to predict upfront drilling.			
DrillWell - Drilling and Well Centre for Improved Recovery	IRIS, UiS, SINTEF, NTNU	The vision of the Drilling and Well Centre for Improved Recovery is to unlock petroleum resources through better drilling and well technology. The Drilling and Well Centre for Improved Recovery was established in 2010 and received status as a Centre for Research Based Innovation (SFI) from the Research Council of Norway in 2011. DrillWell's objective is to improve drilling and well technology, providing improved safety for people and the environment, and value creation through better resource development, improved operational efficiency and reduced costs.This will be achieved by targeted research and development, focusing on: 1.Safe and efficient drilling process2.Drilling solutions for improved recovery3.Well solutions for improved recoverySome research and development activities are Arctic specific. The developed technology and solutions will be commercially available in the market through cooperation with the service industry.	http://drillwell.no/home	Drilling / wells	R&D centre established in 2010
Environmental Safe Guard System (ESG)	Cameron	Cameron's Environmental Safe Guard (ESG) System implies a single BOP on the wellhead that can shear and seal the well if required, allowing the rig to disconnect and move away. The ESG system utilises a floating vessel equipped with a combination of subsea and surface modules. The subsea portion is used to shear, seal and disconnect from the seabed while the traditional surface BOP stack handles all the well control functions. The subsea stack consists of upper and lower wellhead connectors, a ram-type BOP with shearing blind rams and a mini (acoustic, electric, ROV-actuated or hydraulic) control system. The subsea portion is tied back to a traditional surface BOP stack via a high-pressure riser system. In the event of an emergency, the control system is used to signal the subsea BOP to shear the pipe. Once the shearing blind rams shear and seal off the bore, the control system is used to signal the upper connector to disconnect, allowing the rig to be moved safely off location with minimal loss of drilling or well fluids.	http://www3.c-a-m.com/forms/Product.aspx?prodID=5e505612-7a79-4bb7-ad1a-3762981d64dd	Well control	Technology developed
Global and local geomagnetic reference model for improving wellbore surveying accuracy	Teknova, sponsored by the Norwegian Research Council, ConocoPhillips, Lundin and DTU	The aim of the project is to improve drilling accuracy by modelling all sources of the geomagnetic field that affect the wellbore C29. Aeromagnetic surveys will be integrated with data from ground observatories and satellites, including observation of auroras. The project is part of ConocoPhillips' and Lundin's Northern area programme.	ConocoPhillips and Lundin, 2013. Arctic approach. http://www.conocophillips.no/Documents/English/Arctic_Approach.pdf http://teknova.sitegen.no/customers/teknova/index.php?a=118&e=7&t=1&l=1	Drilling technology and well integrity	Project 2013-2017

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Joint industry task forces	API and industry	In response to the Gulf of Mexico Macondo incident, the offshore oil and gas industry, with the assistance of the American Petroleum Institute (API), International Association of Drilling Contractors (IADC), Independent Petroleum Association of America (IPAA), National Ocean IndustriesAssociation (NOIA), and the United States Oil and Gas Association (USOGA), assembled four Joint Industry Task Forces (JITFs) on;1. Offshore Operating Procedures 2. Offshore Equipment3. Subsea Well Control and Containment4. Oil Spill Preparedness and ResponseThe JITFs were not involved in the review of the Macondo incident; rather, they brought together industry experts to identify best practices in offshore drilling operations and oil spill response; with the definitive aim of enhancing safety and environmental protection. The ultimate goal for these JITFs is to improve well containment and intervention capability, spill response capability, and Industry drilling standards to form comprehensive safe drilling operations.A common executive summary report for all four JITFs was delivered in March 2012. 1. Offshore Operating Procedures The Procedures JITF reviewed critical processes associated with drilling and completing deepwater wells to identify gaps between existing practices and regulations and Industry best practices. Their recommendations were intended to move Industry standards to a higher level of safety and operational performance. Their recommendations resulted in either revision or new development of API guidelines, which are considered Industry best practices for US oil and gas operations. 2. Offshore EquipmentThe Equipment JITF reviewed current BOP equipment designs, testing protocols and documentation. Their recommendations were designed to close any gaps or capture improvements in these areas. After submitting its recommendations, the Equipment JITF formed three subgroups to evaluate information regarding BOP shearing capabilities, BOP acoustics systems, and BOP/ROV interface. These subgroups each produced white papers regarding their topics in January of 2011. Based on the Equipment task force's recommendations, an API work team began development on the fourth edition of API RP 53 Recommended Practices for Blowout Prevention Equipment Systems for Drilling Wells. This edition was updated to a Standard and was published in 2012. 3. Subsea Well Control and ContainmentThe Subsea JITF reviewed technologies and practices for controlling the release of oil from its source, including equipment designs, testing protocols, R&D, regulations and documentation to determine if enhancements were needed. The JITF developed 29 recommendations on specific steps to enhance the industry's subsea control and containment capability, including 15 immediate action items. One of the first recommendations implemented was to provide near-term response capability for well containment. This was achieved through the establishment of collaborative containment companies (such as Marine Well Containment Company (MWCC) and Helix Well Containment Group (HWCG)). In addition, over the summer of 2011 the JITF began work on a Recommended Practice (RP) for containment certification for wells with subsea BOP and BOPs on floating structures and a RP for capping stacks. Both RPs will incorporate the recommendations as appropriate. 4. Oil Spill Preparedness and Response (OSPR)Following the September 3, 2010, OSPR JITF preliminary recommendations report the API Oil Spill Preparedness and Response Subcommittee (OSPRS) convened to address the recommendations made by the JITF. The OSPRS spent several months developing and prioritizing project plans to address each preliminary recommendation, and subsequently received approval and Industry funding commitment for a multi-year work program. The OSPRS divided the recommendations into seven categories, or work streams, as outlined in the original report. Within each category there are a number of projects being worked by individual project teams.	http://www.api.org/oil-and-natural-gas-overview/exploration-and-production/offshore/api-joint-industry-task-force-reports	Drilling technology, well integrity and well control - transferability of findings to Arctic operations	JITF 2010-2012
Mechanical testing of Arctic core samples	SINTEF	Arctic rocks / sediments have been exposed to different pressure and temperature histories compared to more southern ones. SINTEF has mechanically tested various Arctic shales from Havis and Bay du Nord. Knowing the behaviour of Arctic rocks is important to ensure efficient and safe drilling.	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Mudline cellar	-	A mudline cellar is an excavation into the seafloor that may house the wellhead equipment and the BOP. The purpose of the mudline cellar is to protect the equipment against exposure to deep keeled ice features.	Winkler, M. (Shell), Jahre-Nilsen, C. (Statoil), Blaauw, R. (Shell) and Dyve-Jones, R. (Statoil), 2015. Arctic oil spill prevention and response: working collaboratively to improve and extend safe practice. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25485. https://s03.static-shell.com/content/dam/shell-new/local/country/usa/downloads/alaska/alaska-tophole-factsheetfinal2.pdf	Well integrity	Technology developed
Mud-weight control during Arctic drilling operations	SINTEF	In Arctic regions, permafrost and gas hydrate bearing sediments below the seabed present a technical problem for drilling operations. The first and most important challenge is to be able to control the well if pressured gas is encountered in or below such formations, and the second problem is the stability of the borehole if these sediments begin thawing during drilling. Both these issues are strongly dependent on the choice of mud and mud weight. Torsæter et al. (2015) presents a method that can aid mud and mud-weight choices during Arctic drilling. It involves using a numerical borehole stability code, which calculates safe mud-weight windows by applying time-dependent physico-chemo-thermo rock mechanical models. As a part of the process of adapting the numerical borehole stability code to Arctic environments, several simulations were done using Arctic well parameters from literature as input. It is concluded that with more detailed input on the Arctic subsurface, the presented method has the potential to predict safe mud-weight windows for drilling through permafrost and gas hydrate bearing sediments. Thereby it can contribute to safer and more cost-efficient exploitation of Arctic petroleum resources. By using Arctic well data as input for a borehole stability code adapted for North Sea wells, it is observed that gas hydrate bearing formations seem to be difficult to drill, even when thawing and mud rheology changes are not taken into account. For permafrost, the properties of the sediments do not cause the same collapse of the mud-weight window. It is also observed that lower well temperatures decrease the borehole stability.	Torsæter, M. and Cerasi, P. (SINTEF Petroleum Research), 2015. Mud weight control during Arctic Drilling Operations. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25481.	Well integrity	Article published in 2015
Multi-seasons well	-	Drilling of a well extends over multiple seasons. After having established the mudline cellar and the top hole section, the well can be drilled to total or partial depth, and re-entered later if desired.	https://s03.static-shell.com/content/dam/shell-new/local/country/usa/downloads/alaska/alaska-tophole-factsheetfinal2.pdf	Beaufort and Chukchi Sea drilling operations	Operational measure
NORSOK D-010 Well integrity in drilling and well operations	Standards Norway	The NORSOK D-010 Well integrity in drilling and well operations standard defines the minimum functional and performance oriented requirements and guidelines for well design, planning and execution of safe well operations. The focus of the standard is well integrity.	NORSOK D-010, 2013. Well integrity and drilling and well operations. Edition 4. Standards Norway, Oslo, Norway.	Well design - not Arctic specific	National standard, published in 2013
Portfolio of capping stacks	-	Today, specialized service companies have built a portfolio of capping stacks for every offshore scenario, including systems uniquely designed for shallow water Arctic drilling operations, for which glory holes (well cellars / mudline cellars) are excavated below the seafloor to protect well equipment such as BOPs for ice ridge scouring (Madrid and Matson, 2014).		Well control	Technology developed
Relief well	-	A relief well is a directional well drilled to communicate with a nearby uncontrolled (blowout) wellbore and control or stop the flow of reservoir fluids (NPC, 2015). If it is assumed that the original rig is disabled, a second rig would need to be mobilised and brought into proximity of the flowing well. The second rig will need to be equipped with casing, cement, drilling fluids and wellhead equipment to construct the relief well. The distance between the blowout well and the relief well typically ranges between 500 feet and 3,500 feet.		Well control	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Same Season Relief Well (SSRW) Policy	NEB	In the Canadian Arctic offshore, the National Energy Board (NEB) has a policy that says the applicant must demonstrate, in its contingency plan, the capability to drill a relief well to kill an out-of-control well during the same drilling season (NEB, 2014). This is the Same Season Relief Well (SSRW) Policy. An applicant wishing to depart from the SSRW Policy would have to demonstrate how they would meet or exceed the intended outcome of the Policy. Assuming that the relief well is drilled by a second rig, this means that the relief well must be completed, and both wells secured, in the same operating season before ice conditions exceed the safe operating capability of the selected drilling system, marine support and emergency response equipment (Scott and Denstedt, 2015). Scott and Denstedt (2015) discuss the regulatory flexibility required to utilise the potential value offered by the adoption of emerging technologies. Three cases are discussed; 1) using a relief well (current situation), 2) using well capping and relief well, and 3) using well capping.	NEB, 2014. National Energy Board Filing Requirements for Offshore Drilling In the Canadian Arctic. https://www.neb-one.gc.ca/bts/ctrg/gnthr/rctcrvwflngrqrmnt/index-eng.html#s4c Scott, B. (Chevron) and Denstedt, S. (Osler, Hoskin & Harcourt LLP), 2015. Equivalency: regulatory flexibility in a changing world. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25486.	Canadian Arctic offshore drilling operations	Technology developed
Secondary BOP controls and intervention	Trendsetter Engineering	Trendsetter Engineering has developed independent back-up controls / subsea accumulator modules (SAMs) with acoustic and ROV control for mudline cellar applications.	http://www.trendsetterengineering.com/controls-distribution-equipment/http://www.trendsetterengineering.com/bop-subsea-accumulator-modules/	Well control	Technology developed
Single season well	-	Drilling of a well is completed within a single season.		Drilling operations	Operational measure
Source control	Trendsetter Engineering	Trendsetter Engineering has formed a service line for source control. This has been developed to provide the industry with the solution to bridge the existing gap from compliance (i.e. equipment) to preparedness (i.e. comprehensive response plan and personnel). Trendsetter Engineering's solution is a comprehensive package ranging from strategic to tactical response services. This strategic response group provides services such as source control training, emergency response and logistics planning, as well as subject matter experts for drill, exercise and actual response support. The tactical response group provides the "boots on the ground" team to conduct field engineering, equipment build, test, installation and operation, as well as ancillary engineering work on location, such as sea fastening planning and operational procedure modifications.	http://www.trendsetterengineering.com/source-control/	Well control	Operational measure developed
Testing of drilling fluids	SINTEF	SINTEF takes detailed measurements of fluid properties over a large range of temperatures, from very low to high. Functionality of fluids and materials are required down to lower than -20 degree Celsius. In the DrillWell project they typically characterize rheology, density and stability of drilling fluids.	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing
Training simulator for Arctic drilling	SINTEF	SINTEF has developed an advanced training simulator for drilling with very realistic responses to normal drilling and unwanted events with the actual upcoming well as a case. This gives the drilling team good preparation for handling possible challenges. The simulator can be extended also to include typical Arctic drilling problems (short time windows / seasons - faster drilling operations necessary, drilling through gas hydrate bearing sediments, large temperature variations between bottom and top of well, sensitive environment).	http://www.sintef.no/en/oil-and-gas/#/	Drilling technology	R&D ongoing
Weak Link Bails	ScanTech	Weak Link Bails is a device that prevent damage to the well barriers in case of accidental loads in the riser system. At the set load the Weak Link Bail will shear, allowing the stroke of the Weak Link Bails to increase, offering overload protection to all components in the riser, wellhead and derrick. The Weak Link Bail protects the rig in instances for surge, mechanical failure or human error causing overloading of the riser or other expensive equipment. It reduces the risk of uncontrolled spillage into the environment. The increased stroke allows the rig operator to regain control without having to disconnect the riser and riser leakage into the environment. The equipment serves as its weakest link, and is controlled fracture when conditions warrant before fixed gear gives way.	http://www.scan-tech.no/index.cfm?tmpl=butikk&a=product_inline&b_kid=192195&b_id=1426910	Drilling technology	Technology developed
Well integrity	Chevron	Continuous improvement in well integrity through proprietary technology research and development. Participation in specific well secure initiatives, through JIPs, either specifically with Arctic application or with transferability of findings to Arctic operations.		Well integrity	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Well kill manifold	Trendsetter Engineering	The well kill manifold concept can be used for wells when determined adequate kill rates cannot be achieved from a single vessel. The well kill manifold allows for sufficient pump rates to be achieved through a single relief well by manifolding multiple kill vessels into the well near the wellhead and providing a flow path through the annulus. Well kill can be achieved by injecting through the well kill manifold, down the relief well, through the formation into the flowing well at a high flow rate that forms a homogeneous slug with enough fluid head to stop flow.	http://www.trendsetterengineering.com/media/files/files/f2d8d560/Clean_Gulf_Trendsetter_Subsea_Well_Control_Equipment_Capping_Stack_MCD_Kill_Manifold_.pdf	Well control	Technology developed
Well materials for the Arctic	SINTEF	SINTEF is studying several types of annular sealants for wells, and several types of plugging materials. These have the potential to ensure more robust wells, which will be a requirement in the Arctic.	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing
Wellbore positioning	SINTEF	Research on how to avoid collisions as a result of poor wellbore positioning accuracy (azimuth) in the Arctic. Background: The positioning accuracy (azimuth) during drilling becomes poor when moving towards the geographic / magnetic North Pole both for gyroscopic and magnetic instruments. When fields are developed with many wells this means that the risk for wellbore collisions increases, and that larger safety margins to geological faults will be necessary. It also means that the draining of the reservoir will not be ideal, and most importantly, that it will be difficult to drill a relief well to stop an ongoing Arctic blowout (in this case wells need to hit a very precise target).	http://www.sintef.no/en/oil-and-gas/#/	Well integrity	R&D ongoing
WellSafe Explorer	Well Partner	The WellSafe Bail system is currently under development. The system is developed for semisubmersible drilling rigs and shall function as a riser safeguard and weaklink system during subsea well testing, subsea completions, well cleanup and riser based intervention operations. The system will be a significant contribution to safety in "locked to bottom" type operations from floating rigs.	http://www.wellpartner.no/products	Drilling technology	Technology developed

Pipelines and subsea structures

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Analysis methods for pipelines in ice gouge environments	INTECSEA	INTECSEA is developing advanced analysis methods for pipelines in ice gouge environments. Conventional methods to evaluate the ice gouge loading on a buried pipeline rely on decoupled analysis of the ice-soil and soil-pipe responses, which is believed to be a conservative approach and not adequately representative. El-Gebaly et al. (2012) investigate ice gouging using advanced numerical modelling techniques to reduce the conventional conservatism and better quantify the loads experienced by the pipeline due to ice gouges.	El-Gebaly, S., Paulin, M., Lanan, G. and Cooper, P. (INTECSEA), 2012. Ice gouge interaction with buried pipelines assessment using advanced coupled Eulerian Lagrangian. Presented at the Arctic Technology Conference, 3-5 December 2012, Houston, Texas, USA. OTC 23764.	Pipeline integrity	Technology development
API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions	API	The API RP 2N Recommended Practice for planning, designing and constructing structures and pipelines for Arctic conditions was first published in 1982. API RP 2N served as the basis for ISO 19906 Arctic offshore structures, which was published in 2010. In April 2015, a new edition of API RP 2N was published. The new edition is a modified adoption of the ISO 19906:2010. The main observed differences between the ISO 19906:2010 and the API RP 2N standards are: - API RP 2N uses the wording 'loads' and 'loads effects' rather than 'actions' and 'actions effects' used by ISO 19906 - API RP 2N does not mention a reliability target expressed as annual failure probability at 1E-5 for L1 structures as given in Table A.7-1 of ISO 19906	API RP 2N:2015. API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions. Third edition.	Disconnection Pipelines and subsea structures Facility design	Recommended practice, published in 2015
Arctic offshore pipeline design and installation challenges	-	Paulin et al. (2014b) discuss the design and installation challenges for Arctic offshore pipelines. The major design loads that are considered for Arctic projects include ice gouging, strudel scour, upheaval buckling as well as thaw settlement. These issues can have a significant influence on the pipeline engineering considerations such as strain based design, target burial depth requirements, cost, and safety. While important to the design of the pipeline, these issues account for just a few of the many criteria that must be considered when routing a pipeline; criteria which can be categorized as either engineering, environmental, social, administrative, or infrastructural. Pushing the limits to developments further offshore in deeper water will require that additional consideration be given to aspects related to pipeline design, in particular with respect to burial for protection against ice gouging.	Paulin, M., DeGeer, D., Cocker, J. and Flynn, M. (INTECSEA), 2014b. Arctic offshore pipeline design and installation challenges. ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, California, USA. Paper no. OMAE2014-23117.	Pipeline integrity	Article published in 2014
Arctic pipeline leak detection JIP	PRNL, INTECSEA	Testing of fibre optic cable distributed sensing leak detection systems for Arctic and cold region applications. The overall aim of the JIP is to test detectability, determine minimum thresholds of detection (i.e. minimum leak rate and response time), enhance technology readiness level, simulate cold-region, deepwater environmental testing, and identify false alarm rate. Phase 1: Designing, costing, scheduling and execution planning to establish the basis and boundary of the testing program. Phase 2: Large scale field testing in a simulated environment in St. John's, Newfoundland & Labrador, Canada.	http://aogexpo.com.au/wp-content/uploads/2015/03/Real-time-Subsea-Pipeline-Leak-Monitoring-using-Fiber-Optic-Sensing-Technology.pdf	Pipeline leak detection	Phase 1: 2014 (completed) Phase 2: 2015-2016 (proposed)
Bundle technology for Arctic pipelines	INTECSEA	Burial under the seabed is the common practice of protecting offshore pipelines and these pipelines are often installed as bundles for many reasons, including economic considerations, short installation windows, and technical issues (Georghiou et al., 2015). Bundles have been used in all of the developments utilising subsea pipelines offshore the North Slope of Alaska. INTECSEA extends the state of practice of analysing buried pipelines using pipe-soil-interaction elements on individual pipelines to account for the effects of the different pipelines in the bundle (Georghiou et al., 2015). The behaviour of a bundle cannot be accurately modelled as a sum of individual parts or as an equivalent bundle. Georghiou et al. (2015) present an example for permafrost thaw settlement of a bundle, where the	Georghiou, A.E., Davis, A., Eskandari, F. and Paulin, M. (INTECSEA), 2015. Extending conventional pipe-soil interaction models to include bundle effects for Arctic subsea pipeline design. Presented at the Arctic Technology Conference, 23-25 March 2015,	Pipeline integrity	Technology development

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		individual models would result in over conservatism in determining the maximum axial strains. According to Georghiou et al. (2015) a more complete model of the given scenario should be sought in future designs to reduce unnecessary conservatism.	Copenhagen, Denmark. OTC 25524.		
Bundle technology for Arctic pipelines	Subsea 7	Subsea 7 is developing bundle technology for Arctic pipelines. The technology includes, but is not limited to, fibre optics for real time detection of pressure, temperature, strain and leaks.		Pipeline integrity, monitoring and leak detection	Technology development
Detection of leaks in offshore pipelines JIP	SwRI, funded by ExxonMobil, Shell, BP, and Chevron	The JIP focuses on distributed sensors for offshore leak detection. The overall scope was to study the leak behaviour (thermal, acoustic) for various leaks and perform testing of fibre-based systems. The overall objective was to determine, in a controlled environment, if the two candidate technologies, distributed temperature sensing (DTS) and distributed acoustic sensing (DAS), can detect small (<0.25") leaks. Siebenaler et al. (2015) describe the JIP and the physical characteristics of potential underwater leaks using lab-scale experimental analysis. Large-scale test results are planned for publishing in 2015.	Siebenaler, S. (SwRI), Iyer, M. (Shell), Kulkarni, M. (ExxonMobil), Salmatanis, N. (Chevron), 2015. Thermal characterization of potential leaks in offshore pipelines. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25515. https://www.mtsociety.org/pdf/conferences/2014%20Subsea%20Leak%20Detection%20Symposium/14SLDS_Siebenaler_Shane.pdf	Pipeline leak detection	JIP 2013-2015
Development of Ice Ridge Keel Strengths (DIRKS)	CARD, NRC OCRE	The DIRKS project was a four-year collaborative venture between C-CORE's Centre for Arctic Resource Development (CARD) and the National Research Council's – Ocean, Coastal & River Engineering (NRC OCRE). The DIRKS project investigated the failure mechanisms associated with gouging ice ridge keels and the conditions under which these keels will continue to gouge without breaking up. This is important for the design of subsea structures in shallow waters where ice keels have been observed to scour the sea floor, posing a threat to pipelines and subsea infrastructure.The main focus of the project was a series of near full-scale keel-gouge tests to investigate the strength characteristics of a first-year ice keel and its eventual failure as it is pushed into an artificial seabed. The project builds on knowledge from the PIRAM JIP. The testing component of the project was successfully completed February-April 2013, and the project was completed in March 2015. Findings from DIRKS will ultimately assist oil and gas companies to establish physical limits of an ice keel gouge and influence the design criteria for subsea pipelines and infrastructure in areas prone to ice gouging, such as the Beaufort, Barents and Caspian seas.	https://www.card-arctic.ca/DIRKSProject	Pipeline integrity	JIP 2011-2015
DNV-OS-F101:2013 Submarine pipeline systems	DNV GL	The standard gives criteria and recommendations on concept development, design, construction, operation and abandonment of submarine pipeline systems. The objectives of the standard are to ensure that the concept development, design, construction, operation and abandonment of pipeline systems are safe and conducted with due regard to public safety and the protection of the environment, provide an internationally acceptable standard of safety for submarine pipeline systems by defining minimum requirements for concept development, design, construction, operation and abandonment, serve as a technical reference document in contractual matters between purchaser and contractor and serve as a guideline for designers, purchaser and contractors. The standard includes a section on the design of pipelines subjected to potential ice interaction.	DNV, 2013a. Offshore standard DNV-OS-F101 Submarine pipeline systems. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Pipeline integrity	Offshore standard, published in 2013
DNV-RP-F107:2010 Risk assessment of pipeline protection	DNV GL	The recommended practice presents a risk-based approach for assessing pipeline protection against accidental external loads.	DNV, 2010a. Recommended practice DNV-RP-F107 Risk assessment of pipeline protection. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Pipeline integrity	Recommended practice, published in 2010

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Full scale gouging JIP	PRNL, MMI Engineering, Golder Associates, INTECSEA	The overall objective is to reduce the technical uncertainty associated with design of buried pipelines for ice-prone regions, including assessment of the feasibility of establishing a full scale gouging test facility. Phase 1 is administered by MMI Engineering in partnership with Golder Associates and INTECSEA, and is funded by PRNL. INTECSEA is involved in studying the magnitude and parameters that affect subgouge displacements for the design of buried submarine pipelines in cold regions. The objective is to advance the design of buried submarine pipelines in cold regions subject to ice gouge conditions through the development of a large scale 1g physical test facility and to use the data collected through the test program for calibration and verification of numerical models.	http://www.canada.no/PDFS/ONS2012_Cook.pdfhttp://www.intecsea.com/news/ice-gouge-interaction-with-buried-pipelines-assessment-using-advanced-coupl/	Pipeline integrity	JIP Phase 1: 2012
Ice features action on seabed	-	Vershinin et al. (2007) prepare a comprehensive summary of the effects of ice ridges on pipelines and subsea structures.	Vershinin, S.A., Truskov, P.A., Liferov, P.A., 2007. Ice features action on seabed. IPK "Russkaya kniga", Moscow, Russia, 196 p. (in Russian).	Pipeline integrity	Article published in 2007
ICE PIPE JIP	DNV, with the following partners: ENI Saipem, ExxonMobil, ConocoPhillips, CTC Marine, JP Kenny, KBR, Reinertsen, StatoilHydro and Technip	The objective of the ICE PIPE JIP was to establish a DNV Recommended Practice (RP) for Arctic Offshore Pipelines. The RP will be a consensus industry code that will present a common and documented approach to achieve an acceptable safety level for offshore pipeline projects in cold climate regions. The RP is intended to supplement the requirements of DNV-OS-F101 Submarine Pipeline Systems, and should therefore comply with the intentions of ISO 13623 Petroleum and natural gas industries - Pipeline transportation systems and relevant functional requirements of ISO/CD 19906 - Petrochemical and natural gas industries - Arctic Offshore Structures. The RP will be subsequently updated and maintained to reflect ongoing R&D, future JIPs and project experience.	DNV, 2008. State of the Art Review, Arctic Specific Hazards to the Design of Arctic Offshore Pipelines, Energy Report ICE PIPE JIP, Report no./DNV reg. no.: 2008-1267/121CU6F-54, Rev. 02, Høvik, Norway.	Pipeline integrity	JIP 2008-2009
IceGouge JIP	Wood Group, MUN	The IceGouge JIP will validate engineering models and develop best practice guidelines for the design of offshore pipelines in ice gouge environments. The JIP will leverage the current Wood Group and Memorial University of Newfoundland (MUN) research program, which has complementary work scope and objectives.	http://www.woodgroupkenny.com/newspoint/WGK-Technology-Newspoint-2-2013.pdf	Pipeline integrity	JIP 2013-2016
ISO 19906:2010, Arctic offshore structures	ISO	The ISO 19906:2010, Arctic offshore structures standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. Reference to Arctic and cold regions in ISO 19906:2010 is deemed to include both the Arctic and other cold regions that are subject to similar sea ice, iceberg and icing conditions. The objective of ISO 19906:2010 is to ensure that offshore structures in Arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value to the owner, to the industry and to society in general. ISO 19906:2010 describes design considerations for disconnection and subsequently reconnection, in addition to corresponding requirements. ISO 19906:2010 does not contain requirements for the operation, maintenance, service-life inspection or repair of Arctic and cold region offshore structures, except where the design strategy imposes specific requirements. While ISO 19906:2010 does not apply specifically to mobile offshore drilling units, the procedures relating to ice actions and ice management contained herein are applicable to the assessment of such units. ISO 19906:2010 does not apply to mechanical, process and electrical equipment or any specialized process equipment associated with Arctic and cold region offshore operations except in so far as it is	ISO 19906:2010. Petroleum and natural gas industries – Arctic offshore structures. 1st edition, International Standardisation Organisation, Geneva, Switzerland. http://www.iso.org/iso/catalogue_detail.htm?csnumber=33690 Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia. Blanchet, D. (BPXA Alaska), Spring, W. (Bear Ice Technology Inc.), McKenna, R.F. (McKenna and Associates) and Thomas, G.A.N. (BP), 2011. ISO 19906: An	Disconnection Pipelines and subsea structures Facility design	International standard published in 2010, currently under revision. Draft International Standard (DIS) version is planned for mid-2016.

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		necessary for the structure to sustain safely the actions imposed by the installation, housing and operation of such equipment. ISO 19906:2010 has been adopted as a national standard by Canada, Russia and the European Union (Frederking, 2012). Furthermore, API has adopted a modified edition of ISO 19906:2010, published as API RP 2N:2015. Blanchet et al. (2011) provides a brief history of the document preparation as it relates to country and industry involvement, development of technical input, editing and review processes undertaken and acceptance of the document by ISO and its participating members. The standard is currently under revision lead by the convenor, Karen Muggeridge. Draft International Standard (DIS) version is planned for mid-2016.	international standard for Arctic offshore structures. Presented at the Offshore Technology Conference, 7-9 February 2011, Houston, Texas. OTC 22068.		
Labrador iceberg scour risk	C-CORE	Seabed surveys conducted to define the Labrador iceberg scour regime have captured over 7,300 km2 of high-resolution multibeam on or near the Makkovik Bank on the Labrador Shelf and a data set of over 27,000 scour features. Scour data have been extracted from less than half of the area shown on the mosaic. Repetitive mapping of the seabed to estimate iceberg scour formation rates has been performed by comparing modern multibeam against sidescan mosaics collected in the 1970s and 80s, as well as comparing two multibeam surveys collected in 2003 and 2008. Additional repetitive surveys covering larger areas are planned for the future. Data collected to date (along with additional modelling to evaluate variations in scour formation rates) show another order of magnitude reduction in pipeline contact risk is possible, and that with foreseeable advances in pipeline trenching technology a 1000-year reliability target is reasonable.	https://www.c-core.ca/Labrador%20Iceberg%20Scour%20Risk	Pipeline integrity - Labrador	R&D ongoing
Mechanics of Ice Rubble (MIR)	CARD	The Mechanics of Ice Rubble (MIR) project examines the physical and mechanical properties of ice rubble and its behaviour when it interacts with a structure or with the sea floor. Ice rubble is an accumulation of ice fragments formed when an intact ice sheet comes into contact with another ice sheet or an obstacle. Building upon the previous CARD project, Development of Ice Ridge Keel Strength (DIRKS); the main focus of the MIR project is to gain a greater understanding of the fundamental mechanics and key physical parameters that contribute to the strength of the ice keel as it interacts with structures. CARD researchers will conduct a series of tests and numerical simulations to study the thermo-mechanical behaviour of the ice rubble.	https://www.card-arctic.ca/MIR	Pipeline integrity	JIP 2014-2016
Pipeline Ice Risk Assessment and Mitigation (PIRAM)	C-CORE, seven oil and gas companies and the Atlantic Innovation Fund of Atlantic Canada Opportunities Agency	PIRAM developed methodologies to determine contact frequency and loads from gouging ice keels, established pipeline mechanical behaviour in response to ice keel load events, and developed engineering models and procedures that could be implemented into industry best practices for mitigation of risk and protection of pipeline infrastructure from ice keel loading.	https://www.c-core.ca/piram	Pipeline integrity	JIP 2007-2009

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Real-time Arctic pipeline integrity and leak monitoring using fibre optics	INTECSEA	INTECSEA is developing a real-time integrity monitoring system which is a sensor-based monitoring system aiming at enhancing the productivity of Arctic pipelines. The intent is to assess operating conditions and performance, improve performance and pipeline throughput, extend life, inform the operator if pipeline integrity is compromised, and provide the necessary information to perform optimal inspection and maintenance activities. Real-time monitoring provides warning when something is starting to go wrong, and provides instantaneous information when things have gone wrong. Arctic pipeline integrity monitoring solutions consist of different technologies, ranging from flow, pressure and temperature gauges, sand and CO2 monitors, usage of in-line inspection tools and ROV, external continuous fibre optic cable temperature and strain sensors, satellite surveillance and overflight by helicopters. While not all are continuous monitoring solutions, developing an intelligent integrity monitoring solution with any of the presented technologies is believed to provide the operator with necessary information on a potential deteriorating pipeline, as well as aid in the development an optimal inspection and maintenance program. Thodi et al. (2015) present the detectability and operating principles of fibre optic cable systems in the Arctic including the experience gained from using them in past projects. The paper focuses on detecting integrity threats arising from the unique Arctic design and operational challenges. Furthermore, the paper covers the operating principles and technology status of leak monitoring systems for Arctic pipelines. The paper concludes that fibre optic cable distributed sensing systems, such as distributed temperature sensing and distributed acoustic sensing, have a high potential to be used for Arctic pipelines to detect and locate leakages.	Thodi, P., Paulin, M., DeGeer, D. and Squires, M. (INTECSEA), 2015. Real-time Arctic pipeline integrity and leak monitoring. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25604.	Pipeline integrity monitoring	Technology development
Subsea Ice Risk Assessment and Mitigation (SIRAM)	C-CORE, seven oil and gas companies and the Atlantic Innovation Fund of Atlantic Canada Opportunities Agency	The SIRAM program aimed at quantifying site-specific risk and developing broadly applicable solutions, including mitigation techniques and structures, for protecting subsea infrastructure from interaction with ice and iceberg keels. In pursuit of these objectives, SIRAM developed improved models for estimating iceberg keel contact frequency and loads, as well as identified and evaluated novel protection concepts as alternatives to conventional Excavated Drill Centres (EDCs).	https://www.c-core.ca/siram	Subsea structure integrity - East Coast of Canada, specifically the Grand Banks and the Labrador Shelf	JIP 2007-2009
Subsea pipelines and subsea production facilities	NPC	NPC topical paper # 6-6 on subsea pipelines and subsea production facilities. The paper refers to offshore pipelines that are already installed in the USA, Canada and Russia. It describes that pipelines must be designed to prevent damage due to interaction with deep ice keels, and that burial is the most common method for pipeline protection.	NPC, 2015. Arctic Potential - Realizing the Promise of U.S. Arctic Oil and Gas Resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org	Pipeline integrity	Report published in 2015
Subsea processing and ultralong multiphase transport	SINTEF	Current challenges in long-distance multiphase transport are related to effects of water such as water accumulation, corrosion and generally incomplete understanding of three phase flow. In the Arctic there may be long distances and long (cold) multiphase pipelines will be necessary for optimal field exploration.	www.sintef.no/en	Pipeline integrity	R&D ongoing
Trenching JIP	PRNL, INTECSEA	The objective of the JIP is to develop proven trenching system for protection of subsea systems against ice scouring of seafloor so future field developments can be planned based upon reliable, predictable execution of trenching effort. The scope is to:- Understand trenching requirements in specific conditions- Evaluate improved trenching technologies- Evaluate marine infrastructure needs- Extend trenching technology capabilities to meet requirements- Conduct field trials to evaluate and prove capabilitiesThe JIP is planned to be a research and technology development project with four phases. The overall objective is to prove a trenching system that is capable of meeting the following requirements (Paulin et al., 2014a):- Trenching to depths greater than current industry norms (burial depths greater than 3 meters with potential trench depths as much as 7 meters)- Trenching in highly variable soil conditions that may include sand, gravel, clay, glacial till and bedrock, including the possible presence of boulders-	Paulin, M., Cocker, J., Humby, D., Lanan, G. (INTECSEA), 2014a. Trenching considerations for Arctic pipelines. ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, California, USA. Paper no. OMAE2014-23116.	Pipeline integrity	JIP, Phase 1: 2011

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		Trenching in water depths beyond the majority of trenching requirements (water depths from 5 meters up to 300 meters)- Operating in harsh marine conditions (e.g. the Western North Atlantic)INTECSEA has been awarded a contract by PRNL for phase 1 of the JIP. The goal of phase 1 is to conduct studies including participation from potential trenching contractors and technology solution providers to determine a shortlist of technologies to be further developed and evaluated in phase 2 (Paulin et al., 2014a).	http://www.canada.no/PDFS/ONS2012_Cook.pdf		
Trenching technology for pipelines	INTECSEA	INTECSEA is conducting R&D activities related to trenching technology. Paulin et al. (2014a) discuss trenching considerations for Arctic pipelines. Offshore pipelines installed in the Arctic and other cold regions are often buried to reduce the risk of damage from ice gouging, upheaval buckling, and other loading challenges specific to the region. Pipeline burial is normally achieved through trench excavation and backfill. As developments are proposed for areas that experience relatively deep ice gouging (up to 5 meters), burial depth requirements will exceed the capabilities of current technologies. New technologies capable of working in deeper water, achieving greater burial depths, achieving reasonable trenching advance rates, operating in harsh environments, and trenching through variable and difficult seabed soils will be required.	Paulin, M., Cocker, J., Humby, D., Lanan, G. (INTECSEA), 2014a. Trenching considerations for Arctic pipelines. ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, California, USA. Paper no. OMAE2014-23116.	Pipeline integrity	Technology development

Facility design

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Anti-icing coatings using nanotechnology	SINTEF, sponsored by ConocoPhillips and Lundin	The project involves development of anti-icing coatings using nanotechnology for use on vessels and offshore structures and is part of ConocoPhillips' and Lundin's Northern area program (ConocoPhillips and Lundin, 2013). The project will focus on the modification of commercial coating systems to obtain durable icephobicity. Through the use of micro and nanotechnology, ice-repellent surface coatings will be developed and characterized. The ice adhesion properties will be evaluated and compared to existing commercial coatings through laboratory testing and field tests.	ConocoPhillips and Lundin, 2013. Arctic approach. http://www.conocophillips.no/Documents/English/Arctic_Approach.pdf	Material selection	JIP
API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions	API	The API RP 2N Recommended Practice for planning, designing and constructing structures and pipelines for Arctic conditions was first published in 1982. API RP 2N served as the basis for ISO 19906 Arctic offshore structures, which was published in 2010. In April 2015, a new edition of API RP 2N was published. The new edition is a modified adoption of the ISO 19906:2010. The main observed differences between the ISO 19906:2010 and the API RP 2N standards are: - API RP 2N uses the wording 'loads' and 'loads effects' rather than 'actions' and 'actions effects' used by ISO 19906 - API RP 2N does not mention a reliability target expressed as annual failure probability at 1E-5 for L1 structures as given in Table A.7-1 of ISO 19906	API RP 2N:2015. API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions. Third edition.	Disconnection Pipeline and subsea structures Facility design	Recommended practice, published in 2015
Arctic Blankets	Stamas Engineering	Insulated Arctic blankets can be used to cover flanges, valves, expansion joints, heat exchangers, pumps, turbines, tanks, and other irregular surfaces. The blankets are flexible and vibration resistant and can be used with equipment that is horizontally or vertically mounted or that is difficult to access. Any high temperature piping or equipment should be insulated to reduce heat loss, emissions and improve safety. The insulated blankets can be easily removed for periodic inspections or maintenance, and replaced as required.	http://engineering.stamas.no/content/documents/STAMAS_Arctic_Blankets.pdf	Winterization	Technology developed
Arctic jack-up design	KOMtech	Keppel Offshore and Marine Technology Centre is conducting R&D activities on mobile offshore self-elevating drilling units (MODU) for open water exploration drilling and for extended season development drilling over a wellhead. Wang et al. (2012) review studies carried out to determine the feasibility of using a modern high capacity jack-up MODU for exploratory drilling in areas with water depths less than 50 meters and where sea ice can move in with high concentrations. The studies, including structural analysis, ice management approaches and well control considerations are reviewed, in addition to the further potential of jack-ups in the Arctic (Wang et al., 2012). Shafer et al. (2013) describe the basis of design and specifications for a self-elevating Arctic MODU for use in water depths from 10 to 50 meters, capable of drilling a wide range of wells.	Wang, C. (Keppel Offshore & Marine Technology Centre), Quah, M. (Keppel Offshore & Marine Technology Centre), Noble, P.G. (ConocoPhillips), Shafer, R. (ConocoPhillips), Soofi, K.A. (ConocoPhillips), Alvord, C. (ConocoPhillips) and Brassfield, T. (ConocoPhillips), 2012. Use of jack-up drilling units in Arctic seas with potential ice incursions during open water season. Presented at the Arctic Technology Conference, 3-5 December 2012, Houston, Texas. OTC 23745. Shafer, R.S. (ConocoPhillips), Noble, P.G. (ConocoPhillips), Cheung, T.O. (Keppel Offshore and Marine), Chow, Y.Y. (Keppel Offshore and Marine), Quah, M. (Keppel Offshore and Marine), Foo, K.S. (Keppel Offshore and Marine), Wang, C.D. (Keppel Offshore and Marine) and Perry, M.J. (Keppel Offshore and Marine), 2013. Basis of design and specifications for shallow water Arctic MODU for year-round	Facility design	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			operation, development and exploration. Presented at the SPE/IADC Drilling Conference and Exhibition, 5-7 March 2013, Amsterdam, The Netherlands. SPE/IADC 163429.		
Arctic materials	Research Council of Norway, Statoil, Total, ENI, JFE Steel, Nippon Steel Corporation, Scana Steel Stavanger, Trelleborg, Bredero Shaw, Aker Solutions, GE Oil and Gas, Miras, NTNU, SINTEF, Technip, DNV, Brück Pipeconnections	The overall objective of the project is to establish criteria and solutions for safe and cost-effective application of materials for hydrocarbon exploration and production in Arctic regions. The main research tasks are aimed at developing understanding and models to describe the performance of materials under conditions of specific interest for Arctic applications; low temperatures, large temperature variations and large imposed deformations. An overall research task is to develop guidelines for qualification of materials for use under Arctic conditions. The project will address steel materials and weldments, polymer materials, and composite and hybrid solutions. Four main work packages have been defined within the project: - Steel fabrication and mechanical characterisation - Strength and toughness criteria for safe materials utilisation - Polymer coatings - New concepts and materials solutions - Project guidelines	https://www.sintef.no/projectweb/arctic-materials/	Material selection	Project phase I: 2008-2012 Project phase II: 2013-2018
Arctic offshore and maritime heating solutions	Thermon Solutions	Thermon Solutions has developed anti-icing and de-icing solutions for offshore support and supply vessels, icebreakers, semi-submersible drill ships and platforms. The trace heating systems are designed to ensure that all pipes, vessels, instruments and equipment are adequately for operations in low temperatures with cold sea water and high wind. Four design philosophies apply:- Anti-icing: Ice and freeze prevention where surfaces will be maintained above freezing under the 'worst case' ambient design conditions- De-icing: Removal of accreted ice in a reasonable and defined period of time- Winterization: Anti-freeze for piping, valves, instruments and equipment containing fluids- Process temperature maintenance: temperature maintenance of piping, valves, instruments and equipment.	http://www.thermon.com/catalog/uk_pdf_files/tmp0039u.pdf	Winterization	Technology developed
Arctic Pads	Stamas Engineering	Arctic pads are heated rubber mats providing a durable, non-slip surface for Arctic and harsh environments that can be used on stairways, platforms, landings, escape ways, muster stations, marine and topside decks, rig floors etc. Embedded within the core is a self-regulating heat trace, which is commonly used throughout many industry sectors for freeze protection.	http://engineering.stamas.no/content/documents/STAMAS_ARCTIC_PAD.pdf	Winterization	Technology developed
Challenges of deep-water Arctic development	ExxonMobil	The oil and gas industry has demonstrated the ability to drill and develop offshore oil and gas resources in first-year sub-Arctic ice and in shallow-water high-Arctic environments. However, development in deep water (water depths exceeding 100 meters) remains a formidable challenge due to small, unpredictable open-water windows and large environmental loads from multi-year ice features. Hamilton (2011) reviews the key technical challenges facing deep-water high-Arctic development along with the current industry efforts aimed at meeting the challenges.According to Hamilton (2011), the foremost challenge is the drilling of development wells. This will require new floating drilling platforms with much higher mooring capacities, most likely coupled with maximum-capability ice management systems. Because some multi-year ice features cannot be managed by the largest conceivable icebreakers, efficient disconnection and reconnection capability will be essential.	Hamilton, J.M. (ExxonMobil), 2011. The challenges of deep-water Arctic development. International Journal of Offshore and Polar Engineering by the International Society of Offshore and Polar Engineers, 21(4), pp. 241-247. ISOPE-11-21-4-241.	Disconnection Facility design	Article published in 2011
Challenges with bringing collision risk models used in the North Sea and Norwegian	NTNU	Hassel et al. (2015) discuss the challenges with bringing the industry standard risk model for ship-installation impacts (COLLIDE) used in the North Sea and Norwegian Sea to the Barents Sea. The COLLIDE collision risk model relies heavily on operational elements and risk reducing measures commonly found throughout the North Sea and Norwegian Sea. These are presently not available in the Barents Sea. The main operational barriers and risk reducing measures against ship-installation impacts in Southern Norway are two control centres that operate an integrated network of radars, VHF stations and AIS base stations. The same level of emergency resources, surveillance and communication coverage is not	Hassel, M. (NTNU), Utne, I.B. (NTNU) and Vinnem, J.E. (NTNU), 2015. Challenges with bringing collision risk models used in the North Sea and Norwegian Sea to the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions,	Ship collision detection	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Sea to the Barents Sea		available in the Barents Sea. The lack of infrastructure and available resources affect core assumptions in collision risk assessment models and may cause otherwise minor incidents to have a more serious outcome in a remote area. Hassel et al. (2015) discuss these challenges and propose alternatives to overcome these issues.	14-18 June 2015, Trondheim, Norway. POAC15-017.		
Concrete ice abrasion	TU Delft, MUN	Concrete structures in marine environments subject to sea ice interaction are at risk of erosion and damage. Industry is interested in characterising the ice abrasion phenomenon so that abrasion risk can be managed. Tijsen et al. (2015) present results of experiments which have an exploratory character in order to identify the abrasion phenomenon and qualitatively observe the corresponding processes. Concrete of varying mixtures has been examined and the effects on the concrete surfaces from repeated static ice-bonding and bond-breakage is analysed by Tijsen et al. (2015).	Tijsen, J. (TU Delft), Bruneau, S. (MUN) and Colbourne, B. (MUN), 2015. Laboratory examination of ice loads and effects on concrete surfaces from bi-axial collision and adhesion events. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-36.	Ice loads	Article published in 2015
Consolidation of first-year sea ice ridges	UNIS	Sea ice ridges are formed by compression or shear in the ice cover. The ice cover is broken and a pile of broken ice, water, snow and air is created. Ridges are important ice features from an engineering as well as from a geophysical point of view (Høyland, 2002). The ridging process changes the drag from winds and currents which makes ridging and ridges important to large-scale constitutive models for sea ice. Furthermore, ridges are zones of material inhomogeneity in the ice cover, and they represent zones of strength or weakness in the ice cover depending on their degree of consolidation (Høyland, 2002). Thus, in many Arctic and sub-Arctic areas, ridges may represent the design load for offshore structures. However, it is not clear what load a first-year ridge can exert on a given structure or how the ridge deforms. It depends on the age and composition of the ridge as well as the structure. Høyland (2002) describes the measurements that have been performed of temperature development, geometry morphology and physical properties in three first-year sea ice ridges at Spitsbergen and in the Gulf of Bothnia. The corresponding thickness and the physical properties of the surrounding level ice were also measured. The thickness of the consolidated layer was examined through drilling and temperature measurements. The thickness of the consolidated layer depended on the method of investigation (Høyland, 2002). However, the measured growth of the consolidated layer did not depend on the method of investigation. The scatter of the physical properties in the consolidated layer was higher than that of the level ice. The consistency of the unconsolidated rubble differed markedly at the two sites. Three possible explanations for these differences are discussed by Høyland (2002); surrounding currents, different keel shapes and difference in salinity.	Høyland, K.V. (University Courses on Svalbard), 2002. Consolidation of first-year sea ice ridges. Journal of Geophysical Research 107(C6), pp. 15.1-15.16. DOI: 10.1029/2000JC000526.	Ice loads	Article published in 2002
Development of icebreaking ships with ice model tests	Wilkman Arctic Advisor	Wilkman (2015) discusses the role of ice model tests in development of ships, different aspects of icebreaking and steps taken to develop vessels using ice model tests.	Wilkman, G. (Wilkman Arctic Advisor), 2015. Development of icebreaking ships with ice model tests. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25532.	Ice model testing	Article published in 2015
DNVGL-OS-A201:2015 Winterization for cold climate operations	DNV GL	The standard provides general principles for preparation of mobile units and offshore installations for intended operations in cold-climate conditions. The standard has been developed for general world-wide application. Governmental legislation in excess of the provisions of this standard may apply depending on type, location and intended service of the unit or installation. The objective of winterization is ensuring that a vessel is capable of and suitably prepared for operations in cold climates. This is provided for by setting functional requirements to systems and equipment which are intended to be in operation in cold-climate conditions.	DNV GL, 2015a. Offshore standard DNVGL-OS-A201 Winterization for cold climate operations. https://rules.dnvgl.com/servicedocuments/dnvgl	Winterization	Offshore standard, published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
DNV-RP-C209 Arctic environmental conditions, ice loads and load effects	DNV GL	This recommended practice is under development and expected for hearing in 2015. The development of this recommended practice is based on experiences from the IceStruct JIP. The RP will provide practical and consistent design recommendations for fixed and floating structures in ice. It will provide guidance where existing codes are incomplete, silent or merely provide functional requirements.	-	Facility design	Recommended practice under development. Expected for hearing draft 2015.
Drilling rig Polar Pioneer	Transocean	The drilling rig Polar Pioneer was the first semi-submersible drilling rig built and winterized for cold climate conditions. The rig has been operating successfully in cold climate areas since 1985.		Winterization	Technology developed
Drilling units for cold climate regions	PSA	The PSA has initiated a pre-study for evaluating drilling units for the Norwegian part of the Barents Sea. In this project the risk of using semi-submersible drilling units will be compared with using drillships in areas where growlers and bergy bits can affect the integrity of drilling and well control equipment at sea level. The project will map protection methods and evaluate the need for other types of drilling units than what is currently used in the Norwegian part of the Barents Sea. Knowledge will be gathered, in particular how this is handled at other countries' continental shelves where attention is towards simplified relocation of units between the shelves.	-	Drilling units - Norwegian Barents Sea	Pre-study 2015 Project planned 2016
Durable Advanced Concrete Solutions (DACS)	Kværner Concrete, together with Multiconsult, Statens vegvesen, Concrete Structures, Norcem, Norbetong, Skanska, AF Gruppen, Unicon, Veidekke, Mapei and St. Gobain Weber, NTNU and SINTEF Byggforsk	The purpose of the project is to develop knowledge, methods and tools to create concrete constructions that will withstand environmental effects in an Arctic environment. The project is divided into the following work packages: • Early age cracking and crack calculation in design • Production and documentation of frost durable concrete • Concrete ice abrasion • Ductile lightweight aggregate concrete (LWAC)	http://www.sintef.no/prosjekter/byggforsk/dacs--durable-advanced-concrete-structures/	Facility design	Project 2015-2019
Experimental study of ice failure processes for design load estimation	PRNL, MUN OERC, NRC IOT and industry partners	The project involved technical and practical considerations of petroleum exploration, examining how to minimize the risk of damage caused by icebergs. By studying the composition of ice, structural design and creating models of iceberg impacts, the team noted that engineers are able to build ice-resistant structures to withstand certain loads. Another valuable aspect of the research was the incorporation of risk analysis and probability into the larger challenge of operating offshore structures in iceberg-busy waters. Research to date has helped provide a necessary first step towards defining the fundamental role played by such mechanical processes as ice crushing, spalling, fracture and damage on global load reduction, which is crucial to achieving the ultimate goal of a reduction in the amount of conservatism used in the design of offshore structures and vessels. The next phase of research involves a series of medium scale ice tank tests to further knowledge of how ice loads are transferred to structures and any scale-effect biases contained in the experimental data. In particular, the goal of understanding the scale effect is crucial to making improvements in the economical design of offshore structures.	http://pr-ac.ca/index.php?id=93	Ice loads	Project 2005-2010

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Explosion safety drivers for Arctic platform design	Lloyd's Register	Lloyd’s Register is conducting research on explosion safety drivers for Arctic platform design, specifically for enclose mechanically ventilated modules (Dalheim et al., 2012).	Dalheim, J. Nodland, S. and Pappas, J. (Scandpower), 2012. Explosion safety drivers in Arctic platform design. Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering, 10-15 June 2012, Rio de Janeiro, Brazil. OMAE2012-83026.	Winterization	Article published in 2012
Floating ice induced ship casualties	UNIS	In September 2013, the tanker Nordvik was holed by an ice floe and suffered ingress of water in the Matisen Strait in the Kara Sea (Marchenko, 2014). New regulations have been inacted in the Russian Arctic since 2013. All vessels need to have permission issued by the Northern Sea Route Administration (NSRA), to navigate in the waters controlled by the administration. The tanker Nordvik had been given permission by the NSRA to sail in the Kara and Laptev Seas under light ice conditions and only escorted by an icebreaker. The Federal Agency for Sea and River Transport stated that the tanker acted in violation of the permit by entering waters with medium ice conditions without an icebreaker escort. Experienced captains submitted that it was quite possible that the ice conditions had changed rapidly and that the tanker had unintentionally ended up in an area with heavy ice conditions. The Commission has not yet decided the case proceedings. Nevertheless, on September 4 the tanker was struck and holed by ice. The tanker quickly began taking in water through one of the ballast tank. The hole, which measured 100 cm x 10 cm, was plugged with a cement box to stem the water ingress on September 10. There were not any oil leakage. The accident showed that ice conditions in the Arctic remain harsh and unpredictable.	Marchenko, N. (University Centre in Svalbard), 2014. Floating ice induced ship casualties. Proceedings of the 22nd IAHR International Symposium on Ice, 11-15 August 2014, Singapore.	Ice model testing	Article published in 2014
GPU-based event mechanics (GEM) simulation technology	MUN	Daley et al. (2014) describe a GPU-based event mechanics (GEM) model of the action of managed pack ice on a floating offshore structure. The work represents a further exploration of the possibilities of GEM technology, which was previously used to explore both resistance and local structural loads for ships transiting pack ice. The work is part of a research project at Memorial University of Newfoundland (MUN) called STePS2 (Sustainable Technology for Polar Ships and Structures). The STePS2 project was a five year project from 2009 to 2014 investigating into ice loads and structural responses. The aim was to increase the understanding of impact forces between ice and steel structures and to improve the tools that are used to design ships and structures for year-round Arctic operations.	Daley, C., Alawneh, S., Peters, D., Blades, G. and Colbourne, B. (MUN), 2014. Simulation of managed sea ice loads on a floating offshore platform using GPU-event mechanics. ICETECH 2014, 28-31 July 2014, Banff, Alberta, Canada.	Ice loads	R&D ongoing
Heating panels	GMC Electro	The electric power needed for winterization of a rig or other facilities may become very large. The Norwegian company GMC Electro is developing lightweight heating panels designed for maximum effect with minimum of energy use.	http://www.gmc.no/?lang=en_GB	Winterization	Technology developed
Ice engineering	C-CORE	Since 1975, C-CORE has provided research-based advisory services to help clients mitigate operational risk in harsh environments. C-CORE conducts applied engineering research and development focusing on ice loads and risk evaluation, finite element and numerical analyses, as well as field studies in support of client research and development activities.	https://www.c-core.ca/ice	Ice loads	R&D ongoing
Ice loads	NRC	The National Research Council of Canada (NRC) has for many years focused on investigating ice loads on offshore structure.	http://www.nrc-cnrc.gc.ca/eng/	Ice loads	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Ice model test of an Arctic SPAR	Aker Engineering & Technology, Total, HSVA	Bruun et al. (2009) presents results from an ice model test of a SPAR platform in level ice and ice ridges. The ice model tests were performed at HSVA on behalf of Aker Solutions as a part of a study performed in 2008. The platform was tested in fixed configuration with a low and high ice drift velocity in 100 year return conditions with level ice and ice ridges. The ice model test shows that the concept is feasible to operate in the tested ice conditions.	Bruun, P.K. (Aker Engineering & Technology), Husvik, J. (Aker Engineering & Technology), Le-Guennec, S. (Total) and Hellmann, J.H. (HSVA), 2009. Ice model test of an Arctic SPAR. POAC 2009, Proceedings of the 20th International conference on Port and Ocean Engineering under Arctic Conditions, 9-12 June 2009, Luleå, Sweden. POAC09-136.	Ice model testing	Article published in 2009
Ice model testing	Aker Arctic	In 2009 it was 40 years since Aker Arctic's ice model test start-up in Finland. Aker Arctic offers a wide range of ice model testing services: - performance and power predictions of ships - ship manoeuvring tests in ice - ice load and impact tests of floating and fixed offshore structures - mooring tests of floating vessels - loading and offloading operations – multi-model testing - tests of ice encroachment on artificial islands and ice protection units - ice formation tests Aker Arctic models following ice conditions: - one- and multi-year level ice - brash ice channels - ice rubble - floe ice - one- and multi-year ridges	http://akerarctic.fi/en/services/ice-model-testing	Ice model testing	R&D ongoing
Ice model testing	HSVA	Ice model testing in HSVA's large ice tank is the main expertise of the HSVA Arctic Technology department in Hamburg, Germany. Several kinds of ships and structures can be tested in all kinds of sea ice features. Frequently tested vessel types are ice going merchant ships (tanker, gas tanker, bulk carrier, heavy lift carrier, general cargo vessel, etc.), icebreakers, ice breaking research vessels, ice breaking service ships (offshore supply, anchor handler, emergency response) and ice breaking inland waterway vessels. Frequently tested fixed structures are loading tower and terminal, jacket structures, wind generator foundations, berthing structures, multi-legged GBS, artificial islands and mitigation and protection structures. Frequently tested floating structures are ship-shaped floaters like drill ships, FPSOs, FPUs etc., semi-submersibles, buoy-shaped floaters and spar buoys.	http://www.hsva.de/our-services/model-testing/tests-in-the-ice-tank.html	Ice model testing	R&D ongoing
Ice model testing	Krylov Shipbuilding Research Institute, St. Petersburg	Krylov Shipbuilding Research Institute has an ice model basin in which physical simulation and study of various scenarios of the object / ice interaction can be performed. The purpose of the tests is to estimate the ice loads acting on offshore structures using the model test results, and to develop and calibrate theoretical models describing the object / ice interaction process.	http://shipbuilding.ru/eng/technologies/dynamics/7/	Ice model testing	R&D ongoing
Ice model testing	NRC OCRE	NRC OCRE assists industry and other government departments to develop solutions to engineering challenges within ocean, coastal and river environments with a particular focus on harsh and extreme conditions. Their approach include physical and numerical modelling, engineering analysis, technology development as well as full scale experiments and field work conducted with the support of a comprehensive suite of world-class model test basins and tanks capable of reproducing a wide range of	http://www.nrc-cnrc.gc.ca/eng/rd/ocre/index.html	Ice model testing	R&D ongoing

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		ice, wave, current and wind conditions. Its facilities include a 90-metre ice tank, 200-metre towing tank, cavitation tunnel and offshore engineering basin complete with wind, wave and current generators.			
Ice model testing of structures with a downward breaking cone at the waterline	Aker Solutions, NTNU, Statoil, Shell, ExxonMobil, Chevron	Two large ice model test campaigns were performed in the period 2007-2010 as a part of a JIP. The objectives of the project were to investigate different floater geometries and ice model test set-ups (model fixed to a carriage and pushed through the ice vs. ice pushed towards a floating model moored to the basin bottom) and their influence on the ice failure mode and structure responses in the various tested ice conditions. Bruun et al. (2011) present the objectives and motivations for the project, the models tested, the target test set-up for the various tested configurations and the test matrix. Initial results from a fixed model tested in three first-year ice ridges with similar target ice properties are also presented and compared.	Bruun, P.K. (Aker Solutions), Løset, S. (NTNU), Gürtner, A. (Statoil), Kuiper, G. (Shell), Kokkinis, T. (ExxonMobil), Sigurdsen, A. (Chevron) and Hannus, H. (Aker Solutions), 2011. Ice model testing of structures with a downward breaking cone at the waterline JIP; presentation, set-up & objectives. Proceedings of the ASME 2011 30th international conference on Ocean, Offshore and Arctic Engineering, 19-24 June 2011, Rotterdam, the Netherlands. OMAE 2011-49380.	Ice model testing	Article published in 2011
Ice rubble generation for offshore production structures : Current practices overview	NRC CHC	Barker and Timco (2005) research the state-of-the art use of ice rubble generators and ice protection structures. Analysis of ice load data have shown that rubble fields can be very beneficial for attenuating ice loads. The ice rubble, which is large accumulations of broken ice pieces that ground around offshore structures, reduce the ice load by transmitting some of the ice load to the seabed and preventing ice crushing on the face of the structure. A hybrid design of an ice rubble generator and an ice protection structure, has the potential to reduce ice loads by stabilising the ice rubble surrounding offshore structures during the winter, and by providing a depth-limiting mechanism for summer ice floes (Timco and Barker, 2005). Furthermore, the use of year-round passive load-reduction technology would significantly reduce the ice loads, which would result in lower-cost structure and increased environmental integrity (Timco and Barker, 2005). Their research assembles available information on protective structures that have generated rubble. The majority of structures investigated were designed for use in shallow (approximately 4 meters) of water. However, a number of concepts show the potential to be adapted for deeper water use. Structures specifically designed to generate rubble have focused on rubblemound berm or barge-based structures, which, although costly for deep water, appear to hold the most promise for a number of locations in the Canadian Beaufort Sea (Barker and Timco, 2005). Additionally, an arrangement of piles designed to hold back rubble or to encourage the formation of a stable ice sheet, comprised of highly loaded torsion piles, could be suitable for the Canadian Arctic.	Barker, A. (NRC CHC) and Timco, G. (NRC CHC), 2005. Ice rubble generation for offshore production structures: Current practices overview. NRC technical report CHC-TR-030. DOI: http://doi.org/10.4224/12340901	Ice loads	Report published in 2005
Ice simulation tool for Arctic platform design	Bureau Veritas, Cervval, Technip	A new type of ice simulation tool for offshore platform design is being developed by Cervval and Bureau Veritas on behalf of Technip (Dudal et al., 2015). The aim for the simulator is to predict the flow of ice around both fixed and floating offshore structures of different shapes using a multi-model approach. The simulator is not envisaged to replace the verification stage of testing in an ice basin, but to enable an optimization of the design on a standard PC which is then confirmed in an ice tank.The simulator program based on a multi-model approach has been developed to predict ice behaviour and loads exerted on offshore engineering structures accounting for water currents and the mutual reciprocal actions between an offshore structure, ice sheet / ice floes, ice blocks due to ice sheet or ice floes failure, water, current and the seabed. Dudal et al. (2015) illustrate the complexity of the simulator and how it treats each ice fragment individually, and the effect of current and the seabed. The validation of the simulator builds on results of ice model tests and shows a good agreement with ice basin tests. Even though the simulator is not yet considering the local ice edge crushing and snow effects, the software is already able to simulate ice interaction with any type of structure shape considering ice failure due to bending, crushing or a combination of both and may be used for structures optimization, minimizing the ice loading and ice rubble build-up, prior to final verification in a test basin (Dudal et al., 2015).	Dudal, A. (Bureau Veritas), Septseault, C. (Cervval), Beal. P.A. (Cervval), Yaouanq, S.L. (Cervval) and Roberts, B. (Technip), 2015. A new Arctic platform design tool for simulating ice-structure interaction. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-066.	Ice loads	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Ice-induced vibrations	SAMCoT	Kuiper et al. (2015) discuss the phenomenon of ice-induced vibrations, the topics related to the phenomenon that are not yet solved, and SAMCoT's contribution to research on this phenomenon.	Kuiper, G. (Shell) and Løset, S. (SAMCoT, NTNU) 2015. SAMCoT: Leveraging Cross Sector Collaboration to Drive Sustainable Energy Developments in the Arctic. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25494.	Ice loads	Article published in 2015
IceStream JIP	MARIN	In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPS. However, only the SALTO JIP was initiated for various reasons. The IceStream JIP would be a follow-up of the pilot IceStream project. A floating structure would be modelled, along with a generated set of ice particles. Additionally, model tests would be carried out in the NRC ice tank, as well as with artificial ice at MARIN.	NEN, 2013. Arctic operations and technology. Joint industry research and standardization. http://www.marin.nl/web/file?uuid=6094db87-5a44-4a40-96d1-f3efda866e73&owner=8d68985e-5c67-4085-b2be-90b5c1bbb707&search=icetower	Ice loads	JIP not initiated
IceStruct JIP	DNV, sponsored by 23 members	The aim of this project was to provide design guidelines in compliance with ISO 19906:2010, Arctic offshore structures. Deliverables:- The IceStruct JIP commentary on ISO 19906, which is a document identifying gaps in the ISO 19906 standard and commenting on possible solutions aimed at filling these gaps- The IceStruct JIP guideline, which is a step-by-step 'recipe' guidance document, targeted at the offshore designer, for obtaining appropriate characteristic ice loads and ice load effects, which are required for design checks according to standard offshore design practice- The IceStruct JIP background report, documenting the basis for the work done towards producing the first two deliverablesThe IceStruct JIP guideline is currently under development into a DNV Recommended Practice; DNV-RP-C209.	http://issuu.com/dnv.com/docs/dnv_research_review_2012_lr__2_	Facility design	JIP 2009-2012
Internal best practices for installation winterization	Aker	Aker has established internal best practices to be consulted regarding possible winterization solutions for different areas.		Winterization	Practice established
ISO 19906:2010, Arctic offshore structures	ISO	The ISO 19906:2010, Arctic offshore structures standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. Reference to Arctic and cold regions in ISO 19906:2010 is deemed to include both the Arctic and other cold regions that are subject to similar sea ice, iceberg and icing conditions. The objective of ISO 19906:2010 is to ensure that offshore structures in Arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value to the owner, to the industry and to society in general. ISO 19906:2010 describes design considerations for disconnection and subsequently reconnection, in addition to corresponding requirements. ISO 19906:2010 does not contain requirements for the operation, maintenance, service-life inspection or repair of Arctic and cold region offshore structures, except where the design strategy imposes specific requirements. While ISO 19906:2010 does not apply specifically to mobile offshore drilling units, the procedures relating to ice actions and ice management contained herein are applicable to the assessment of such units. ISO 19906:2010 does not apply to mechanical, process and electrical equipment or any specialized process equipment associated with Arctic and cold region offshore operations except in so far as it is	ISO 19906:2010. Petroleum and natural gas industries – Arctic offshore structures. 1st edition, International Standardisation Organisation, Geneva, Switzerland. http://www.iso.org/iso/catalogue_detail.htm?csnumber=33690 Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia. Blanchet, D. (BPXA Alaska), Spring, W. (Bear Ice Technology Inc.), McKenna, R.F. (McKenna and Associates) and Thomas, G.A.N. (BP), 2011. ISO 19906: An international standard for Arctic offshore structures. Presented at the Offshore Technology Conference, 7-9 February 2011, Houston, Texas. OTC 22068.	Disconnection Pipeline and subsea structures Facility design	International standard published in 2010, currently under revision. Draft International Standard (DIS) version is planned for mid-2016.

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		necessary for the structure to sustain safely the actions imposed by the installation, housing and operation of such equipment. ISO 19906:2010 has been adopted as a national standard by Canada, Russia and the European Union (Frederking, 2012). Furthermore, API has adopted a modified edition of ISO 19906:2010, published as API RP 2N:2015. Blanchet et al. (2011) provides a brief history of the document preparation as it relates to country and industry involvement, development of technical input, editing and review processes undertaken and acceptance of the document by ISO and its participating members. The standard is currently under revision lead by the convenor, Karen Muggeridge. Draft International Standard (DIS) version is planned for mid-2016.			
Maintenance and inspection activities	-	Oil and gas facilities require regular inspection and maintenance to function safely and without need for emergency interruptions. In cold climate, the challenges related to frozen equipment, ice and snow as well as freezing temperatures represent a challenge. Experience from running land-based operations under similar conditions exist and are taken into account. Furthermore, the experience of the maritime and fishing industries is of great value to ensure safe operations. For an overview, see Markeset et al. (2015).	Markeset, T., Sæland, A., Gudmestad, O. and Barabady, J., 2015. Petroleum production facilities in Arctic operational environments. In: Bourmistrov, B., Mellemvik, F., Bambulyak, A. Gudmestad, O., Overland, I. and Zolotukhin, A. (editors), 2015: International Arctic Petroleum Cooperation, Barents Sea Scenarios. ISBN 978-1-13-878326-3, Routledge Series in Environmental Policy.	Maintenance and inspection	Article published in 2015
MARICE	DNV, with the following partners: SINTEF, Jeppesen Marine, Re-turn, Statoil and NTNU	The MARICE; Marine Icing JIP studied the process of sea spray icing, or marine icing. When wind and waves whip sea spray onto a ship or rig, the resulting accumulation of ice can pose a risk to the safety of the vessel and its crew and jeopardize their ability to operate effectively. The purposes of the project were to study ice accretion in Arctic weather conditions by scientific experiments, to model this process using physically realistic understanding of marine icing and translating that knowledge into guidelines and recommendations for vessel design and operation, including emergency response. The main outcomes of the MARICE project were: 1. A series of small-scale field studies of icing resulted in:- A new experimental equipment for measuring ice accumulation on a cylinder with respect to known weather and water spray conditions- Data for validation of time-dependent numerical icing model developed during the project- Testing of ice-resistant coatings 2. Large-scale vessel-based study of icing and sea spray resulted in- A new experimental equipment based on video cameras to register occurrence, duration and period of the sea spray- Extensive video material useful in studying sea spray characteristics with respect to vessel design and voyage parameters 3. Fully 3D CFD-based model for ice accreation on vessel superstructure	DNV, 2014. MARICE project summary. DNV report 2014-0096, Rev. 01, Høvik, Norway.	Ice loads Material selection	JIP 2009-2013
Marine icing observed on KV Nordkapp during a cold air outbreak with a developing polar low in the Barents Sea	UiT, MET Norway, SAMCoT / NTNU, UNIS	Marine icing is a phenomenon that may occur for temperatures below subfreezing where sea spray either is lofted from the sea surface or being generated by waves interacting with a ship or a structure. On a voyage from Tromsø to the waters east of Bjørnøya in late February 1987, the Norwegian Coast Guard vessel KV Nordkapp experienced heavy icing due to a polar low that raged over these waters during the voyage (Samuelsen et al., 2015). This polar low developed in an unstable air mass due to a cold-air outbreak over relatively warm waters. KV Nordkapp experienced air temperatures in the range of minus 10°C to minus 20°C, and was moving	Samuelsen, E.M. (University of Tromsø / Norwegian Meteorological Institute), Løset, S. (SAMCoT, NTNU / University Centre in Svalbard) and Edvardsen, K. (University of Tromsø), 2015. Marine icing observed on KV Nordkapp during a cold air outbreak with a developing polar low in the Barents Sea. Proceedings of the POAC 2015 23rd international conference on Port and	Ice loads	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		against 20-30 m/s winds producing waves up to 7.5 meters high. During the icing event KV Nordkapp accumulated 110 tons of ice. The icing was encountered all the way from the hull just above the water level to the top of the wheelhouse. Samuelsen et al. (2015) have analysed the icing event and made calculations for comparison between observations and modelling results.	Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-087.		
Maximum ice force on the Molikpaq during the April 12, 1986 event	NRC CHC	On April 12, 1986, the Molikpaq, a caisson-type offshore drilling structure, experienced a series of loading events when second-year and multi-year ice moved against the structure. The highest loads that the Molikpaq experienced during the 1985-86 season were during this day. Extensive ice thickness measurement had been taken in the ice around the Molikpaq prior to April 12. Thickness of up to 6 m were measured and 8 to 12 m estimated for a multi-year hummock. Medof panels on the outer face of the caisson and strain gauges on inner bulkheads of the structure were the primary instrumentation used to calculate forces on the faces. Detailed analysis of strain gauge and extensionmeter data indicated that the maximum global force on the Molikpaq was no more than 420 MN and most likely was 380 MN. This is in contrast to higher and lower values quoted in the literature for the April 12 event. Other loading events during the day when multiple strain gauges and Medof panels were being recorded produced global loads of 250 MN.	Frederking, R. and Sudom, D., 2006. Maximum ice force on the Molikpaq during the April 12, 1986 event. Cold Regions Science and Technology 46(3), pp. 147-166. DOI: 10.1016/j.coldregions.2006.08.019	Ice loads	Article published in 2006
NORSOK N-003 Actions and action effects	Standards Norway	The NORSOK N-003 Actions and action effects standard specifies general principles and guidelines for determination of characteristic actions and action effects for the structural design and assessment and for the design verification of structures. The standard is applicable: - To all types of offshore structures used in the petroleum activities, including bottom-founded structures as well as floating structures - To the design and assessment of complete structures including substructures, topside structures, vessel hulls, foundations, mooring systems, risers and subsea installations - To the different stages of construction (namely fabrication, transportation and installation), to the use of the structure during its intended life, and to its abandonment. Aspects related to verification and quality control are also addressed. NORSOK N-003 is primarily written for the facilities on the Norwegian continental shelf (including the continental shelf of Svalbard) as defined by the Norwegian Petroleum Directorate 16 June 2014, but the principles may also be applicable for other areas.	NORSOK N-003, 2015. Actions and action effects. Edition 3 (draft version). Standards Norway, Oslo, Norway.	Facility design - Norwegian continental shelf (including the condinental shelf of Svalbard), but may be applicable also for other areas	National standard, edition 3 is under development, planned to be published in 2015.
Performance characteristics of surface protection coating systems for offshore structures under Arctic conditions	Fraunhofer AGP, Muehlan AG	Eight organic coating systems have been investigated according to their performance under Arctic offshore conditions (Irmer et al., 2013). Three performance groups were considered; corrosion protection performance, performance under mechanical loads, and de-icing performance. The investigations involved the following tests; accelerated corrosion protection / ageing testing, anti-icing tests, tests for coating and ice adhesion, impact resistance tests, hardness measurements, and wettability tests. The test conditions were adapted to Arctic offshore conditions, which mainly covered low temperatures down to -60°C, dry-wet cycles, and UV radiation. Testing facilities for icing / de-icing performance tests have been developed. Standard offshore tests for corrosion protection assessment were partly modified. The coating systems investigated were organic coating systems which differed in generic coating material, number of layers, dry film thickness and application method. Irmer et al. (2013) present the experimental design, the test methodologies, and test facilities used, in addition to discussing the results of the investigations. Based on an assessment scheme, a ranking of coating systems is recommended regarding their protection performance under Arctic offshore conditions (Irmer et al., 2013).	Irmer, M. (Fraunhofer), Glück, N. (Fraunhofer) and Momber, A. (Muehlan), 2013. Performance characteristics of surface protection coating systems for offshore structures under Arctic conditions. Presented at the Offshore Technology Conference, 6-9 May 2013, Houston, Texas, USA. OTC 23936.	Material selection	Article published in 2013
Preliminary results of 3D	Aalto University, SAMCoT	Heinicke et al. (2015) have studied the failure of an initially intact ice sheet against an inclined structure, where the most prevailing forces on the ice sheet are vertical. When an initially intact ice cover moves against an inclined structure, it fails by fragmenting into discrete ice blocks which then accumulate in	Heinicke, C. (Aalto University), Polojärvi, A. (Aalto University / SAMCoT, NTNU) and Tuhkuri, J. (Aalto University / SAMCoT,	Ice loads	Article published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
simulations of a failing ice sheet		front of the structure and form an increasingly large rubble pile. Understanding this fragmentation process and predicting the subsequent ice load on the structure are important for the design and operation of marine structures in ice-covered waters. Heinicke et al. (2015) describe the theory and results of the simulations performed. The simulated fracture process is then validated with analytical models and field experiments described in the literature. Focus is laid on cantilever beam tests and vertical breakthrough tests. The conclusion is that simulations agree with the literature data (Heinicke et al., 2015).	NTNU), 2015. Preliminary results of 3D simulations of a failing ice sheet. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-119.		
Re-evaluation of Molikpaq multi-year ice loads	CHC NRC, PERD, ConocoPhillips, Shell, ABS, Statoil, Keppel, ExxonMobil	This JIP was carried out to revisit the original data of the 1985-86 Amauligak I-65 deployment of the Molikpaq in the Beaufort Sea. The ice interactions with the Molikpaq over the 1985-86 winter season represent the only data set on direct measurements of multi-year ice loading on an offshore structure (Jordaan et al., 2011). Several JIPs were initiated on dynamic ice structure interaction of the Molikpaq that produced confidential reports in 1987, 1989 and 1991. Through limited access to the reports and data, a number of papers were published. The estimated loads differed, which left an uncertainty on multi-year ice loads. Through this JIP, a comprehensive review of the original data was performed, focusing on loads from multi-year ice and re-evaluating the instrumentation, ice conditions load analysis methods.The load estimates based on the original calibration of the Medof panels have strongly influenced estimates of multi-year ice loads on the Molikpaq in past publications. The conclusion from this JIP is that the 'best estimate case' loads determined through the JIP, which are about half the previous estimates, are an improved representation of multi-year ice loads on the Molikpaq over the 1985-86 season.	Jordaan, I. (Ian Jordaan & Associates Inc. / C-CORE), Bruce, J. (C-CORE), Hewitt, K. (K.J. Hewitt & Associates Ltd.) and Frederking, R. (Canadian Hydraulics Centre), 2011. Re-evaluation of ice loads and pressures measured in 1986 on the Molikpaq structure. Proceedings of the POAC 2011 21st International Conference on Port and Ocean Engineering under Arctic Conditions, 10-14 June 2011, Montréal, Canada. POAC11-130. NRC-CHC controlled technical report CHC-CTR-068, Ottawa, ON, Canada. ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/PCSmith/OEF-MTS%20Workshop_29-30Nov11_PDFs/2-AM-1-2_GTimco_Design%20and%20op%20criteria%20for%20structures%20in%20ice-covered%20waters.pdf	Ice loads	JIP 2007-2010
Rig spray	DNV GL	DNV GL has initiated a JIP to improve sea spray icing models. Sea spray icing poses a threat on multiple levels, from blocking the operation of essential components to jeopardising stability and integrity and thus leading to an increased risk of capsizing. The standards available today give requirements to safety functions and to some extent describe mitigation solutions, but do not give a specific answer to how and where they should be implemented. The JIP aims at developing a simulation tool that bridges functional winterisation requirements and real physical conditions for drilling rigs, production platforms and vessels to ensure that the design of icing-mitigation measures delivers both safety and cost benefits.	https://www.dnvgl.com/news/arctic-design-sea-spray-icing-models-to-be-improved-5980	Ice loads	JIP initiated in 2014
Risk-based winterization for vessels	MUN, ABS HETC	Because the oil and gas industry has an increasing interest in the hydrocarbon exploration and development in the Arctic regions, it becomes important to design exploration and production facilities that suit the cold and harsh operating conditions. Winterization should be considered as a priority measure early in the design spiral for vessels operating in the Arctic environments. The development of winterization strategies is a challenging task, which requires a robust decision support approach. Yang et al. (2013) proposes a risk-based approach for the selection of winterization technologies and determination of winterization levels or requirements on a case-by-case basis. Temperature data are collected from climatology stations located in the Arctic regions. Loading scenarios are defined by statistical analysis of the temperature data to obtain probabilistic distributions for the loadings. Risk values are calculated under different loading scenarios. Based on the risk values, appropriate winterization strategies can be determined. A case study is used to demonstrate how the proposed approach can be applied to the identification of heating requirements for gangways.	Yang, M. (MUN), Khan, F.I. (MUN), Lye, L. (MUN), Sulistiyono, H. (MUN), Dolny, J. (HETC) and Oldford, D. (HETC), 2013. Risk-based winterization for vessels operations in Arctic environments. Journal of Ship Production and Design 29(4), pp. 199-210.	Winterization	Article published in 2013
SAFEARC - Safe Arctic Marine Operation	DNV GL & Rolls Royce Marine Propulsion,	The project objectives were first to learn and investigate operations aspects, demands and challenges of ice-going ships, and second to study the forces of ice on podded propulsion through full-scale measurements. The main purpose of these measurements was to calibrate the DNV GL class rules and	DNV GL, 2015b. SAFEARC – Safe Arctic Marine Operation. http://www.dnvgl-	Ice loads	Project 2011-2014

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
	funded by Norwegian Research Council	assess the IMO Polar Code requirements for ship hull and machinery design, as well as to investigate efficient operational patterns and efficient propulsions system design.	source.com/assets/documents/src/safearc_twopager_2015_05_l0x.pdf		
Sea Ice Loads Software (SILS)	C-CORE	The Sea Ice Loads Software (SILS) tool was developed as a JIP to estimate extreme first-year and multi-year sea ice loads on offshore structures, both in probabilistic and deterministic modes. It assists users in the selection of design loads for concept evaluation and for feasibility and scoping studies. Compliant with ISO 19906 standards, it is a flexible tool, accepting inputs of differing structure types and designs, ice and environmental conditions, seasonality and interaction models. SILS provides a simple graphical interface which enables the following: - Ability to create new, or modifying existing scenarios - Visualization of input data through tables and figures - Access to various SILS help documents - Visualization, analysis and export of simulation results	https://www.c-core.ca/SILS	Ice loads	Technology developed
Simulation of multi-modal vibrations due to ice actions	NTNU, Technical University of Denmark, Luleå University of Technology	Kärnä et al. (2010) have addressed the condition where a vertical offshore structure is subjected to actions of level ice. The simulations show that the dynamic response to ice action is a complicated phenomenon in cases where the structure has several eigenmodes in the frequency range below 10 Hz. The results show that: - The real action speed of an ice floe can be significantly lower than the free-field ice speed, which is not affected by the presence of offshore structure(s) - Ice crushing on a vertical structure may create multimodal response where frequency lock-in at an eigenmode is associated with nearly harmonic vibrations at one or several other modes	Kärnä, T. (NTNU), Gravesen, H. (Technical University of Denmark), Fransson, L. (Luleå University of Technology) and Løset, S. (NTNU), 2010. Simulation of multi-modal vibrations due to ice actions. IAHR 20th International Symposium on Ice, 14-18 June 2010, Lahti, Finland.	Ice loads	Article published in 2010
STePS2 (Sustainable Technology for Polar Ships and Structures)	Host institution: MUN. Other partners: Husky Energy Inc., ABS, Samsung Heavy Industries Co. Ltd., Rolls-Royce Marine, BMT Fleet Technology, Atlantic Canada Opportunities Agency, Natural Sciences and Engineering Research Council of Canada.	One of the key aims of the STePS2 (Sustainable Technology for Polar Ships and Structures) JIP was to better understand the impact forces between ice and steel structures and to improve the tools that are used to design ships and structures for year-round Arctic operations.	http://www.sea-technology.com/features/2013/0413/5_arctic_operations.php	Ice loads	JIP 2009-2014
Structural integrity in cold climate regions	PSA	The PSA has initiated a pre-study for evaluating challenges for structural integrity such as movement of semi-submersible units and ships in ice-covered waters, including anchor loads, loads on structural members due to lumps of ice (growlers) in waves. Furthermore, the development of models for icing (atmospheric and sea spray) will be evaluating and knowledge regarding cracking and material fracture in temperatures below -20°C will be gathered. The work will be seen in light of research, education and knowledge about the Norwegian High North.		Ice loads - Norwegian Barents Sea	Pre-study 2015Project planned 2016
Studies of materials behaviour for future cold climate applications (SMACC)	SINTEF, NTNU, Statoil, ENI, Total, Lundin, Aker Solutions, Kværner Verdal, Nexans, FMC Kongsberg Subsea, Marine Aluminium, Hydro, Sapa, Bredero Shaw, Trelleborg, Borealis, Posco, JFE	The overall objective of the SMACC-project (studies of materials behaviour for future cold climate applications) is to develop robust and cost effective materials and solutions for use in Arctic areas. The project comprises: • Development of a material database for material properties at low temperatures with an integrated toolbox for post-processing of data and modelling • Characterization of materials at low temperatures and actual loads, including structural steels / pipelines, polymers / polymer coatings and light weight solutions (e.g. aluminium) • Develop relevant models for materials behaviour and degradation under relevant conditions	https://www.sintef.no/en/projects/smacc--studies-of-materials-behaviour-for-future-cold-climate-applications/	Material selection	JIP 2013-2018

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
	Steel, Kobe Steel, SSAB (former Ruukki Metals) and Scana Steel Stavanger				
Thermo responsive elastomer composites (TREC) JIP	SINTEF, NTNU, Statoil, FMC Technologies	Thermo-responsive elastomer composites (TREC) by material formulations including negative thermal expansion filter (FMC Technologies, 2015): - Cater for seal contraction and may provide additional energizing effect at low temperatures - Especially useful for low pressure sealing situations and in particular with gas	FMC Technologies, 2015. FMC Technologies' solutions to harsh environment. Presented at INTSOK's 13th Annual Russian-Norwegian Oil & Gas Conference, 28 January 2015. http://www.intsok.com/content/download/23164/161727/version/1/file/017+FMC+E.pdf	Material selection	JIP 2014-2017
Toward a holistic load model for structures in broken ice	SAMCoT, AMOS	Kim et al. (2015) present several semi-analytical solutions that are useful to model interaction between floe ice and structures. The ambition is to support the development of multi-body numerical simulators that incorporate rigid-body dynamics, hydrodynamics and ice mechanics in a 3D space. Furthermore, the Kim et al. delineate a new map of competing failure modes of ice floes that includes ice crushing depth distribution for the dominant ice failure modes.	Kim, E. (SAMCoT / AMOS, NTNU), Lu, W. (SAMCoT, NTNU), Lubbad, R. (SAMCoT, NTNU), Løset, S. (SAMCoT, NTNU) and Amdahl, J. (SAMCoT / AMOS, NTNU), 2015. Toward a holistic load model for structures in broken ice. Proceedings at the POAC 2015 23rd International Conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-255.	Ice loads	Article published in 2015

Loading and offloading

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Challenges related to loading / offloading in ice	Gubkin University of Oil and Gas in Moscow, Russia / UiS	Subbotin (2015, in his master thesis to the Gubkin University of Oil and Gas in Moscow, Russia, and the University of Stavanger, Norway) has reviewed oil-offloading solutions for the Pechora Sea exemplified by the Prirazlomnoye field. Challenges related to ice movements limit the weather windows for the offloading operations.	Subbotin, E., 2015. Oil offloading solutions for the Pechora Sea exemplified by the Prirazlomnoye field. MSc thesis Gubkin University of Oil and Gas in Moscow, Russia / University of Stavanger, Norway.	Offloading in ice	MsC published in 2015
Challenges related to loading / offloading in ice	NTNU	Jensen (2002, in his PhD thesis at NTNU, Trondheim, Norway) studied concepts for loading of hydrocarbons in ice-infested waters.	Jensen, A. (NTNU), 2002. Evaluation of Concepts for Loading of Hydrocarbons in Ice-infested Waters. PhD thesis at NTNU, Trondheim, Norway.	Offloading in ice	PhD thesis published in 2002
Challenges related to loading / offloading in ice	NTNU	Bonnemaire (2005, in his PhD thesis at NTNU, Trondheim, Norway) continued Jensen's studies by studying different loading concepts and documented that offshore loading in ice should be feasible in principle.	Bonnemaire, B. (NTNU), 2005. Arctic Offshore Loading: Submerged Turret Loading and Loading Downtime in Drifting Ice. PhD thesis NTNU, Trondheim, Norway.	Offloading in ice	PhD thesis published in 2005
Experience related to loading / offloading in ice	Lukoil	Lukoil has installed a tower offshore Varandey from which offshore loading is taking place.	-	Offloading in ice	Operational experience
Experience related to loading / offloading in ice	Sakhalin	Offshore loading in ice has been implemented at offshore Sakhalin using a buoy which was submerged during the heavy ice seasons.	-	Offloading in ice	Operational experience
IceTower JIP	MARIN	In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPS. However, only the SALTO JIP was initiated for various reasons. The IceTower JIP initiative involved the instrumentation of an offloading tower encountering severe ice floes. During three winter seasons, the loads on the tower and the ice conditions would be monitored.	http://www.marin.nl/web/file?uuid=82342ab0-67df-40f7-9ae5-f30eeb184cd7&owner=a7f82238-c028-4d39-97e6-316ffcc032a2&search=icetower	Offloading in ice	JIP not initiated
Offtake and tankering	NPC	NPC topical paper # 6-7 on offtake and tankering. The paper describes some of the recent experience with tanker offtake and transport in Arctic and Sub-Arctic waters, which illustrates the advanced state of the art of design, construction and operation of the physical plant required.	NPC, 2015. Arctic Potential - Realizing the Promise of U.S. Arctic Oil and Gas Resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org	Offloading and loading	Report published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Winterization of loading systems	UiS, UiT, Teekay	Lack of experience when it comes to offloading operations in cold climates requires additional safety barriers related to the bow loading system. In order to ensure the availability of all components related to the bow loading system during the loading operation the system has to be winterized according to the physical environmental conditions in the operational area. Nikolaisen et al. (2015) have looked into the critical winterization aspects related to bow loading systems on shuttle tankers, and how to control such risks. The study showed that one of the most effective safety barriers is to carry out work during suitable weather windows in order to control the risks. This calls for further studies regarding proper weather limitations related to Arctic offloading operations. Selection of design temperatures for all materials is also of immediate concern when deciding on the winterization design.	Nikolaisen, Ø. (UiT), Sunde, J. (Teekay Shipping Norway) and Gudmestad, O.T. (UiS), 2015. Winterization of bow loading systems on shuttle tankers. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25568.	Offloading winterization	Article published in 2015

Communication solutions

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Advanced Research in Telecommunications Systems (ARTES)	ESA	The Advanced Research in Telecommunications Systems (ARTES) programme is a long-running, large-scale programme that enables European and Canadian industry to explore, through R&D activities, innovative concepts to produce leading-edge satcom products and services. The elements are as follows: - ARTES 1 Preparatory is dedicated to strategic analysis, market analysis, technology and system feasibility studies and to the support of satellite communication standards. - ARTES 3-4 Products is dedicated to the development, qualification, and demonstration of products. Telecommunication applications can be undertaken under the terms of this element. - ARTES 5 Technology is dedicated to long term technological development, either based on ESA's initiative, or on the initiative of the satcom industry. - ARTES 7 EDRS is a specific element dedicated to the development and implementation of an European Data Relay Satellite (EDRS) system. - ARTES 8 Alphabus/Alphasat is a specific element dedicated to the development and deployment of Alphasat. - ARTES 10 Iris is a satellite-based communication system that will complement the future generation of an air traffic management system currently being developed under the SESAR programme of the EU, by Eurocontrol and the European Aeronautical community. - ARTES 11 Small GEO is a specific element dedicated to the development and implementation of the Small GEO System. - ARTES 14 Neosat is a specific element dedicated to developing the "Next Generation Platform", in partnership with industry. - ARTES 20 IAP is dedicated to the development, implementation and pilot operations of Integrated Applications. These are applications of space systems that combine different types of satellites, such as telecommunications, earth observation and navigation. - ARTES 21 SAT-AIS The Automatic Identification System (AIS) is a short range coastal tracking system currently used on ships. - ARTES 33 Partner is a new programme element to provide the satcom industry with an efficient framework to bring innovative products and systems into the marketplace through industry-generated public–private partnerships.	https://artes.esa.int/	Communication	R&D programme
Arctic communication challenges	MARINTEK	Bekkadal (2014) outlines the Arctic communication challenges and the current situation, in addition to identifying future systems capable of mitigating the lack of adequate electronic communications infrastructure in the High North.	Bekkadal, F., 2014. Arctic communications challenges. Marine Technology Society Journal 48(2), pp. 8-16. DOI: 10.4031/MTSJ.48.2.9.	Communication	Article published in 2014
Arctic satellite communication (ASK)	Telenor Satellite Broadcasting, the Norwegian Space Centre, Space Norway	A Norwegian satellite project could provide broadband coverage in the Arctic (Lunde, 2014). Phase 1: Identify future needs for data communication in the Arctic, and possible technical solutions. MARINTEK performed a study to analyse potential user groups and their needs in the Arctic satellite communication project.Phase 2: Follow-up of output / conclusion from phase 1. Continue working with the most important user groups that may have interests in Arctic broadband to further map their needs and requirements to such a system, timeframe and willingness to pay.Based on this a conclusion will be made regarding investing in a HEO satellite system for the Arctic.	Telenor Satellite Broadcasting, 2014. Satellite communication in the High North - challenges and solutions. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 4 on risk management and design, 20-21 May 2014. (In Norwegian).	Communication	Project 2013-2015
Communication solutions	NPC	NPC topical paper # 7-10 on communication solutions. The paper describes the telecommunications transport methods being utilized in northern Alaska; satellite, point to point radio (microwave) and fibre optic connectivity. The paper points out that the current communications infrastructure does not integrate well into the modern broadband world, as the infrastructure to support them is limited, and the opportunities for further development of telecommunication facilities (fibre optic connectivity, long	NPC, 2015. Arctic Potential - Realizing the Promise of U.S. Arctic Oil and Gas Resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org	Communication	Report published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		hall microwave networks) are economically challenging and require significant infrastructure to support. Furthermore, the paper points out that enhanced telecommunications capabilities in northern Alaska would benefit from the availability of broadband services, as the development of this will link communities and bring necessary broadband bandwidth to enable them to participate in capabilities similar to the rest of the USA. The development of a suitable telecommunications infrastructure will require a coordinated (industry, federal, state and local) investment decision.			
Communications in the Arctic	MARINTEK	Since 2007 MARINTEK has run several projects investigating the status of communication at sea in the Arctic. From interviews, theoretical analyses and practical field tests they have learned that the current communication infrastructure is inadequate for the operational requirements of expected future maritime activities in the Arctic.	http://www.sintef.no/home/marintek/projects/maritime/what-is-the-problem-with-communication-in-the-arctic/	Communication	R&D 2007-present
Communications in the High North and other remote areas (COINOR)	MARINTEK, sponsored by ConocoPhillips and Lundin	The primary objective of the COINOR project is to minimize the knowledge gap on telecommunications in the High North, in order to provide sound recommendations on how to alleviate the current lack of infrastructure and technological solutions. This applies both to the Arctic user community, the oil and gas sector, and the associated suppliers of communication products and services as well as the public authorities. The main objective is achieved by addressing specific operational needs and requirements as regards data and information exchange, and the associated technical demands on telecom systems. The operations to be investigated will cover both the planning, exploration and production phases in different geographical areas.As essential accomplishments in its endeavours to close the knowledge gaps:- COINOR will develop a methodology and show examples that combine the operational requirements as regards telecom needs – i.e. how factors like bandwidth, availability, robustness, latency (delay) etc. affect operational constraints. - COINOR will investigate how new (near future) telecom solutions (including Hybrid Satellite Earthbound (HSE) and Hybrid Fibre Earthbound (HFE) access networks) may be used to meet the operational needs for telecom support in the High North. - The Arctic environmental impacts on communication signals will be investigated to its full extent. COINOR will address these issues prior to the implementation of new communication systems, in order for the real Quality-of-Service (QoS) requirements from demanding operations and high end users in the Arctic can be met. - Understanding the procedural requirements in the High North, where the Integrated Operations (IO) concept is to be assessed, and where use of telecom is a crucial tool in the operations. COINOR will address possibilities for collaboration in remote areas, such as the High North, where limited bandwidth is often the case.	Bekkadal, F. and Fjørtoft, K.E., 2014. COINOR - Communications in the High North and other remote areas. Presented at Arctic Frontiers, 19-24 January 2014, Tromsø, Norway. Publication ID: CRIStin 1182304. http://www.arcticfrontiers.com/downloads/arctic-frontiers-2014/conference-presentations-3/thursday-23-january-2014/part-iii-shipping-a-offshore-in-the-arctic-1/544-15-fritz-bekkadal/file ConocoPhillips and Lundin, 2013. Arctic approach. http://www.conocophillips.no/Documents/English/Arctic_Approach.pdf	Communication	Project 2012-2016
Fibre optic telecommunication in the Arctic	Arctic Fibre	Arctic Fibre is a fibre optic telecommunications project developing one of the largest subsea cable networks in the world. The cable will connect Asia to Western Europe via the southern portion of the North West Passage through the Canadian and Alaskan Arctic. In addition to providing transoceanic connectivity directly between the two continents, Arctic Fibre will be bringing affordable high speed Internet access to the Arctic for the first time where bandwidth is currently limited. The introduction of high speed Internet will enable Arctic governments to deliver improved health and education services more cost effectively, spur economic development and empower local businesses, and allow consumers to access video and high speed applications. The backbone cable will be over 15,000 km long, provide ultra low latency service between Tokyo and London, and will utilize 100 gigabit wavelengths. The construction of the system is beginning in the summer of 2015 with the first segment of the network scheduled to be in service by the end of 2016.	http://arcticfibre.com/	Communication	Project 2015-2016
Galileo	-	Galileo, the European navigation system, is under development, planned to be in service from 2016. The complete Galileo constellation will comprise satellites spread evenly around three orbital planes inclined at an angle of 56° to the equator. From most locations, six to eight satellites will always be visible, allowing positions and timing to be determined very accurately to within a few centimetres. Interoperability with the U.S. system of GPS satellites will increase the reliability of Galileo services.	http://www.gsa.europa.eu/galileo/why-galileo#	Communication -Europe	Technology developed
Geostationary (GEO) satellites	-	The most common technology used for maritime communications are satellite systems. Most of these are based on geostationary (GEO) satellites that orbit the earth above the equatorial line. They have little or no cover at all in the Arctic. Their low angles of elevation make them more vulnerable to	SINTEF, 2015b. What is the problem with communication in the Arctic? http://www.sintef.no/home/marintek/p	Communication	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		external influences. The theoretical limit for GEO systems is 81.3° North, but instability and signal dropout can occur at latitudes as low as 70° North under certain conditions (SINTEF, 2015b).	rojects/maritime/what-is-the-problem-with-communication-in-the-arctic/		
GLObal NAvigation Satellite System (GLONASS)	-	GLObal NAvigation Satellite System (GLONASS) is the Russian navigation system, presently with 24 operative satellites in three orbits with 64.8° inclination to equator. The system is well suited for positioning at high latitudes (Statoil, 2014).	Statoil, 2014. Rig positioning in the High North. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 1 on climatic conditions and communication, 24-25 March 2014. (In Norwegian) https://www.glonass-iac.ru/en/	Communication - Russia	Technology developed
Global Positioning System (GPS)	-	Global Positioning System (GPS), the U.S. navigation system, provides location and time information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites. GPS satellites cross the equatorial plane with 55° angle, 24-32 satellites are in operation (Statoil, 2014).	Statoil, 2014. Rig positioning in the High North. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 1 on climatic conditions and communication, 24-25 March 2014. (In Norwegian) http://www.gps.gov/	Communication - USA	Technology developed
Highly elliptical orbit (HEO) satellites	-	Highly Elliptical Orbit (HEO) satellites are under feasibility evaluation. Such satellites are expected to provide good communication also in polar regions.		Communication	Technology development
Iridium NEXT	Iridium Communications Inc.	A next generation Iridium satellite constellation is under deployment, which will provide L-band data speeds of up to 1.5 Mbps and high-speed Ka-Band service of up to 8 Mbps. Iridium NEXT is scheduled to begin launching in 2015, and planned to be fully deployed within 2017.	https://www.iridium.com/About/IridiumNEXT.aspx	Communication	Technology developmentBegin launching in 2015, fully deployed within 2017
Iridium satellite constellation	Iridium Communications Inc.	Iridium satellite constellation provides radio band communication at high latitudes with limited band width. 66 satellites are presently in operation in 6 orbital planes with 86.4 degree inclination.	https://www.iridium.com//About/IridiumGlobalNetwork/SatelliteConstellation.aspx	Communication	Technology developed
Maritime radio system performance in the High North (MARENOR)	EMGS, Remøy havfiske, Telenor, Kongsberg Seatex, SINTEF ICT, Polar Science Guiding, UNIS and Wroclaw University of Technology	Navigation and communication systems are exposed to special performance degrading factors in the High North. For navigation systems the ionospheric disturbances, icing on antennas and relatively limited access to differential corrections and integrity information on global navigation satellite systems (GNSS) are the most important factors. For communication system the combination of low elevation angles, longer transit distances through atmosphere (rain and snow) and poor ground infrastructure is a challenge. As is also icing of antennas; the consequence could be signal attenuation, information loss and delays. The main objective of MARENOR is to quantify the performance of the most common navigation and communication systems being used in the High North, through data acquisition and data analysis. The MARENOR result will be a tool for prediction of navigation and communication system performance in the High North. The MARENOR activities are divided into five phases: 1. Technical studies on signal propagation in L-, C-, Ku- and Ka-band including studies on signal degrading factors like ionosphere and atmosphere activity, icing and vessels movements 2. Specification of test installations, including navigation and communication equipment, measurement systems, data management, test vessels and fixed locations 3. Installation of test equipment and crew training 4. Analysis of measurement data	http://www.sintef.no/home/marintek/projects/maritime/marenor-maritime-radio-system-performance-in-the-high-north/	Communication	JIP 2012-2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		5. Development of business plan for further implementation of project results, in addition to dissemination and communication of results			
Operational experience from rig positioning in the High North	Statoil	Statoil's operational experience from rig positioning in the High North, is that several measures must be implemented to secure positioning in the High North, i.e. use of both GPS and GLONASS navigation system onboard a rig with high quality cables and short length to reduce loss of signals, special antennas designed for satellites with low elevation, optimal placement of antennas to secure free sight to satellites as well as Precise Point Positioning and Iridium satellites to receive clock and orbital corrections. Wrong positioning of rig have HSE consequences, e.g. danger of encountering shallow gas and damage to marine infrastructure (Statoil, 2014).	Statoil, 2014. Rig positioning in the High North. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 1 on climatic conditions and communication, 24-25 March 2014. (In Norwegian)	Communication - Norwegian High North	Operational experience
Polaris	Polar View, C-CORE, VTT, Airbus and VISTA, funded by ESA	The project shall study the user needs and high-level requirements for the next generation of observing systems for the polar regions. The main objectives of this project include: • Review, identify and consolidate user community environmental information requirements for the polar regions • Establish consensus and endorsement for these requirements via close dialogue with key user representative bodies across the user categories in scope • Identify information gaps considering existing and planned EO and integrated (EO/nav/telecom) systems, space and non-space based (such as GNSS, AIS, telecommunications and in-situ measurements) • Consolidate and prioritise information gaps together with key user representatives bodies • Establish a set of endorsed, high-level mission requirements reflecting the gaps in connection and dialog with stakeholders, • Identify potential new integrated information services possibly provided by synergetic use of space assets (EO, navigation and telecommunications etc.) • Perform a preliminary assessment of the high-level operations requirements for supplying these integrated services In the long-term the project aims at stimulating the development of novel space mission concepts for the polar regions that may exploit new and existing European operational capacity in order to address, in a cost-effective manner, new scientific and operational information needs.	http://due.esrin.esa.int/stse/projects/stse_project.php?id=193	Communication	Project 2015-2016

Human resources, competence and management

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Health aspects of work in extreme climates	IPIECA & OGP	The health aspects of work in extreme climates are discussed in the IPIECA & OGP report (2009).	IPIECA & OGP, 2009. The health aspects of work in extreme climates. A guide for oil and gas industry managers and supervisors. Report no. 398. London, UK. http://www.ogp.org.uk/pubs/398.pdf	Human resources and competence	Report published in 2009
Human factors and special reactions in cold, dark and remote areas	UNIS	Hansen (2014) presents human factors and special reactions to be aware of in incidents in cold, dark and remote areas.	Hansen, F.S. (UNIS), 2014. Menneskelige faktorer og beredskap. Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 5 on emergency preparedness, 2-3 June 2014 (in Norwegian).	Human resources and competence	Presentation from 2014
Human performance working in cold climate	PSA	The PSA has initiated a pre-study for evaluating the human performance when working in cold climate. Through this project knowledge will be gathered regarding working environment risk for employees working on units in the Norwegian High North. This knowledge will form the basis for the PSA's priorities and strategy for following-up working environment and will contribute to identifying and clarifying R&D needs. The work will illustrate challenges that need to be addressed, such as actual coldness exposure in petroleum activities, evaluating exposure compared with standards / guidelines (e.g. ISO 15743, SINTEF 2013), coldness exposure and shift work, in addition to technical, operational and organisational measures. The work will be seen in light of research, education and knowledge about the Norwegian High North.		Human resources and competence - Norwegian Barents Sea	Pre-study 2015 Project planned 2016

Oil spill detection

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Advanced acoustic instrumentation for deep sea imaging and sensing in Arctic and harsh environments project	PRNL, Kraken Sonar Systems Inc.	PRNL funded research project undertaken by Kraken Sonar Systems Inc. to develop and demonstrate a high resolution acoustic sensor for 3D seabed survey and underside ice profiling with increased area coverage rate compared to currently available technologies. A high coverage rate will minimize the time required to survey a given area, thereby reducing the cost of the survey and the risk for personnel exposed to harsh environmental conditions. High resolutions imagery and topography are useful for seabed exploration, infrastructure survey, characterization of ice thickness and composition and potentially for detection oil spills either on the seabed or at the ice / seawater interface.	http://pr-ac.ca/index.php?id=172	Ice detection, forecasting and monitoring Oil spill detection	Project 2013-2015
Arctic earth observation and surveillance technologies	NORUT	NORUT, the Northern Research Institute, located in Narvik, Norway has ongoing research related to Arctic Earth Observation and Surveillance Technologies (2009-2017).	www.norut.no/nb/prosjekter/arctic-earth-observation-and-surveillance-technologies	Surveillance technology	Project 2009-2017
Arctic pipeline leak detection JIP	PRNL, INTECSEA	Testing of fibre optic cable distributed sensing leak detection systems for Arctic and cold region applications. The overall aim of the JIP is to test detectability, determine minimum thresholds of detection (i.e. minimum leak rate and response time), enhance technology readiness level, simulate cold-region, deepwater environmental testing, and identify false alarm rate. Phase 1: Designing, costing, scheduling and execution planning to establish the basis and boundary of the testing program. Phase 2: Large scale field testing in a simulated environment in St. John's, Newfoundland & Labrador, Canada.	http://aogexpo.com.au/wp-content/uploads/2015/03/Real-time-Subsea-Pipeline-Leak-Monitoring-using-Fiber-Optic-Sensing-Technology.pdf	Pipeline leak detection	Phase 1: 2014 (completed) Phase 2: 2015-2016 (proposed)
Arctic Response Technology (ART) JIP - Oil Spill Detection and Mapping in Low Visibility and Ice	Managed by IOGP, sponsored by BP, Chevron, ConocoPhillips, Eni, ExxonMobil, NCOC, Shell, Statoil, Total	In January 2012, members of the international oil and gas industry launched a collaborative effort to enhance Arctic oil spill capabilities under the auspices of the International Association of Oil and Gas Producers (IOGP). This collaboration, called the Arctic Oil Spill Response Technology JIP will expand industry knowledge of, and proficiencies in Arctic oil spill response. Over the course of the programme, the JIP will carry out a series of advanced research projects in laboratory conditions on six key areas of research: dispersants, environmental effects, trajectory modelling, remote sensing, mechanical recovery and in situ burning. The goal is to advance Arctic oil spill response strategies and equipment, as well as to increase the understanding of potential impacts of oil on the Arctic marine environment. One of the research projects within this JIP is the Oil Spill Detection and Mapping in Low Visibility and Ice. During freeze-up and through much of the winter, long periods of darkness and numerous variables involving oil type and ice coverage all add to the challenges of detecting, mapping and tracking oil in ice. A phase one assessment and evaluation of existing and emerging technologies has been performed that includes an evaluation of further research and development needs, logistical support requirements, and operational considerations including testing opportunities. Two reports have been published: 1. Oil spill detection and mapping in low visibility and ice: surface remote sensing (Puestow et al., 2013) 2. Capabilities for detection of oil spills under sea ice from autonomous underwater vehicles (Wilkinson et al., 2013) Based on this assessment, a test program was developed to identify and qualify the most promising sensors and platforms capable of determining the presence of oil on, in, and under ice and mapping its extent. Phase two experiments were initiated in November 2014. Specifically, the experiments aim to: •Acquire spectral, hydro-acoustic, thermal and electromagnetic signatures of oil on, within, and	http://www.arcticresponsetechnology.org/research-projects/oil-spill-detection-and-mapping-in-low-visibility-and-ice	Oil spill detection	JIP 2012-2016

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		underneath a solid ice sheet. •Determine the capabilities of various sensors to detect oil in a specific ice environment created in the test tank. •Specify design parameters for improved Arctic sensors in the future. •Recommend the most effective sensor suite for detecting oil in the ice environment, based on modelling the expected sensor performance in a wider range of real life scenarios.			
Detection of leaks in offshore pipelines JIP	SwRI, funded by ExxonMobil, Shell, BP, and Chevron	The JIP focuses on distributed sensors for offshore leak detection. The overall scope was to study the leak behaviour (thermal, acoustic) for various leaks and perform testing of fibre-based systems. The overall objective was to determine, in a controlled environment, if the two candidate technologies, distributed temperature sensing (DTS) and distributed acoustic sensing (DAS), can detect small (<0.25") leaks. Siebenaler et al. (2015) describe the JIP and the physical characteristics of potential underwater leaks using lab-scale experimental analysis. Large-scale test results are planned for publishing in 2015.	Siebenaler, S. (SwRI), Iyer, M. (Shell), Kulkarni, M. (ExxonMobil), Salmatanis, N. (Chevron), 2015. Thermal characterization of potential leaks in offshore pipelines. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25515. https://www.mtsociety.org/pdf/conferences/2014%20Subsea%20Leak%20Detection%20Symposium/14SLDS_Siebenaler_Shane.pdf	Pipeline leak detection	JIP 2013-2015
DNV-RP-F302:2010 Selection and use of subsea leak detection systems	DNV GL	The objective of this recommended practice is to summarize industry experiences and knowledge with relevance to selection and use of detectors for a subsea leak detection system. The document is a result of a JIP on leak detection ongoing from 2005 to 2010.	DNV, 2010b. Recommended practice DNV-RP-F302 Selection and use of subsea leak detection systems. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Subsea leak detection	Recommended practice, published in 2010
Kongsberg Satellite Services	KSAT	KSAT provides maritime monitoring and surveillance services using data from several radar and optical sources. KSAT is offering near-realtime services providing accurate information to oil and gas and government customers based on satellite imagery within less than 20 minutes.	http://www.ksat.no/	Surveillance	Technology developed
Leak detection project	IRIS, sponsored by ConocoPhillips and Lundin	The overall objective of this project is to adapt environmental sampling processor (ESP) modules to the autonomous detection of oil-degrading microbial targets as a means to detect subsurface oil leaks from oil and gas installations (ConocoPhillips and Lundin, 2013). The long-term vision is to accommodate the ESP onto an autonomous underwater vehicle. The project is part of ConocoPhillips' and Lundin's Northern area programme.	ConocoPhillips and Lundin, 2013. Arctic approach. http://www.conocophillips.no/Documents/English/Arctic_Approach.pdf	Leak detection	Project
Microscale interaction of oil with sea ice for detection and environmental risk management in sustainable operations (MOSIDEO)	NORUT	The primary objective of the research project MOSIDEO is to advance the 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 ice-covered seas.	http://norut.no/en/prosjekter/microscale-interaction-oil-sea-ice-detection-and-environmental-risk-management	Leak detection	Project 2015-2018
Offshore leak detection JIP	DNV GL	DNV GL has taken the initiative to establish a JIP for developing a guideline for offshore leak detection. The JIP aims at shaping the future of offshore leak detection and gaining state of the art knowledge in this emerging field.Over the last few years, following several oil releases, there has been an increasing focus by both operators and authorities on the environmental impact related to offshore oil and gas activities. This is especially an issue that needs to be addressed now since society's tolerance for leaks is dropping and especially as we are moving into the Arctic and other environmentally sensitive areas. Hydrocarbon leak detection systems are a requirement on the Norwegian Continental Shelf, but authorities around the world are also increasingly demanding such systems for new field developments. The overall aim of the JIP is to ensure safe and environmentally sound operations by limiting hydrocarbon spills through detecting acute discharges, with a high level of certainty, at the earliest possible stage. The planned outcome of the will be a DNV GL Recommended Practice that will	https://www.dnvgl.com/oilgas/innovation-development/joint-industry-projects/offshore-leak-detection-jip.html	Oil spill detection	JIP 2014-2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		address the leak detection system through all the lifecycle phases of offshore development projects. The project will define relevant functional requirements and general specifications for a leak detection system as well as developing a methodology for designing an integrated system, including surface and subsea technologies.			
Oil spill detection and management JIP	Aptomar, the Norwegian Coastal Administration, Engie, Eni Norway, OMV Norway and Statoil	The objective of the JIP is to improve oil spill management via communication infrastructure and management systems. Firstly, Aptomar will develop the functionality to provide remote control of the SECurus system – a technology that is used to detect and combat oil spills. The objective is to enable onshore personnel to assist offshore crews performing oil spill monitoring and detection, both during production and in the event of oil spill combating. Secondly, the JIP will develop a system that facilitates integration of all types of existing camera sources – from ROVs and PSVs to platforms and fishing vessels – including geographical information, into Aptomar's tactical collaboration and management system. To ensure a common operating picture on-site during an oil spill, the JIP also aims to develop a local offshore communication network that enables data sharing of this information between all assets involved in combating the spill, including vessels, installations and airborne support without using base stations or satellites.	http://tto.ntnu.no/oil-companies-join-oil-spill-project	Oil spill detection	JIP initiated in 2014
Oil spill detection and modelling in Hudson and Davis Straits	LOOKNorth on behalf of Nunavut Planning Commission	LOOKNorth completed a study in 2014 to assess the current state of oil spill monitoring and response capability in the Hudson Strait and Davis Strait areas, and to recommend improvements; it provides a snapshot of the state of the art in oil spill detection and impact prediction, reviewing existing research on the use of remote sensing technologies for oil spill monitoring in Arctic waters, the modelling of oil fate and trajectories in the presence of ice, and experience to date in Arctic transportation operations. It also includes an assessment of local capabilities in Nunavut (and gaps therein) to respond to oil spills, as well as recommendations to increase local capacity of effective oil spill response.	LOOKNorth, 2014. Oil spill detection and modelling in the Hudson and Davis Straits. LOOKNorth Report R-13-087-1096. Rev. 2.0. St. John's, Newfoundland and Labrador, Canada. http://www.nunavut.ca/files/2014-05-29%20Oil%20Spill%20Detection%20and%20Modelling%20Report.pdf	Oil spill detection - Hudson Strait & Davis Strait	Study published in 2014
Oil spill detection radar	ISPAS	In 2012 ISPAS signed a contract with Statoil for the research and development of a new oil spill detection radar for detecting oil spills at sea. The objective of the project was to develop a high frequency radar for the detection and quantification of oil spills on the sea under all weather conditions. This will significantly improve the oil spill detection capabilities and reduce the number of false alarms and allowing for targeted and efficient oil spill environmental monitoring and management. The radar shall be able to detect oil spills on both calm sea and with waves. The radar will be tested at the Edvard Grieg field at the Norwegian Continental Shelf during 2015. ISPAS has recently signed a contract with Statoil for the delivery of a new advanced Oil Spill Detection radar system for the Johan Sverdrup oil field at the Norwegian Continental Shelf.	http://www.ispas.no/	Oil spill detection	Technology development Will be tested at the Edvard Grieg field during 2015.
Oil Spill Response (OSR) JIP	Managed by IPIECA on behalf of IOGP, sponsored by Shell, BG Group, BP, Chevron, ConocoPhillips, ExxonMobil, Petrobras, Statoil, Total, Marathon Oil, Nexen, Eni, GDF SUEZ, Wintershall,	In response to the April 2010 Gulf of Mexico (Macondo) oil spill incident, IOGP formed the Global Industry Response Group (GIRG) tasked with identifying learning opportunities both on causation and in respect to the response to the incident. Nineteen recommendations were identified, and these are being addressed by the three-year JIP Oil Spill Response started in 2011. The JIP is being managed by IPIECA (the global oil and gas industry association for environmental and social issues on behalf of IOGP. The project is taking proactive steps to develop modern tools and technology to ensure effective solutions are available to handle a potential spill. The JIP has initiated discrete projects and provided support to projects initiated by other trade associations. As part of the OSR JIP, there are four JIPs related to surveillance, monitoring and tracking: •JIP 08 – Surface surveillance & tracking •JIP 10 – Subsea surveillance and tracking •JIP 11 – Common Operating Picture •JIP 16 – Devices for subsea monitoring	Oil spill response project (http://oilspillresponseproject.org/) Batelle, 2014 (http://oilspillresponseproject.org/sites/default/files/uploads/report_ogp-ipieca_osr_jip_wp1___in_water_surveillance_13nov2014_v1.0.pdf) Oceaneering, 2014 (http://oilspillresponseproject.org/sites/default/files/uploads/report_ogp-	Oil spill detection	JIP 2011-2014

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
	Inpex, Hess, Cairn, RWE, Repsol	This work will be broken down into seven Work Packages (WP) covering the recommendations as follows: •WP1 - In-Water Surveillance •WP2 - Surface Surveillance •WP3 - Modelling & Prediction •WP4 - Metocean Databases •WP5 - GIS / Mapping and Common Operating Picture •WP6 - Regulatory Issues •WP7 - Write up and publishing of results & recommendations Several reports have been published regarding detection of oil spill: 1. Capabilities and Uses of Sensor-Equipped Ocean Vehicles for Subsea and Surface Detection & Tracking of Oil Spills (Battelle, 2014) 2. Capabilities and Uses of Sensor and Video-Equipped Waterborne Surveillance-ROVs for Subsea Detection and Tracking of Oil Spills (Oceaneering, 2014) 3. An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Satellite Remote Sensing (Polar Imaging Ltd., 2014) 4. An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Airborne Remote Sensing (Polar Imaging Ltd., 2015a) 5. Surface Surveillance Capabilities for Oil Spill Response using Remote Sensing (Polar Imaging Ltd., 2015b)	ipieca_osr_jip_wp1___in_water_surveillance_13nov2014_v1.0.pdf) Polar Imaging Ltd., 2014 (http://oilspillresponseproject.org/sites/default/files/uploads/OGP%20WP2%20satellite%20report%20version%201%202%20docx.pdf) Polar Imaging Ltd., 2015 a (http://oilspillresponseproject.org/sites/default/files/uploads/OGP%20WP2%20airborne%20report%20version%201.1_0.pdf) Polar Imaging Ltd., 2015 b (http://oilspillresponseproject.org/sites/default/files/uploads/20150331-OGP%20WP2%20final%20report%20v1%202.pdf)		
Real-time Arctic pipeline integrity and leak monitoring using fibre optics	INTECSEA	INTECSEA is developing a real-time integrity monitoring system which is a sensor-based monitoring system aiming at enhancing the productivity of Arctic pipelines. The intent is to assess operating conditions and performance, improve performance and pipeline throughput, extend life, inform the operator if pipeline integrity is compromised, and provide the necessary information to perform optimal inspection and maintenance activities. Real-time monitoring provides warning when something is starting to go wrong, and provides instantaneous information when things have gone wrong. Arctic pipeline integrity monitoring solutions consist of different technologies, ranging from flow, pressure and temperature gauges, sand and CO2 monitors, usage of in-line inspection tools and ROV, external continuous fibre optic cable temperature and strain sensors, satellite surveillance and overflight by helicopters. While not all are continuous monitoring solutions, developing an intelligent integrity monitoring solution with any of the presented technologies is believed to provide the operator with necessary information on a potential deteriorating pipeline, as well as aid in the development an optimal inspection and maintenance program. Thodi et al. (2015) present the detectability and operating principles of fibre optic cable systems in the Arctic including the experience gained from using them in past projects. The paper focuses on detecting integrity threats arising from the unique Arctic design and operational challenges. Furthermore, the paper covers the operating principles and technology status of leak monitoring systems for Arctic pipelines. The paper concludes that fibre optic cable distributed sensing systems, such as distributed temperature sensing and distributed acoustic sensing, have a high potential to be used for Arctic pipelines to detect and locate leakages.	Thodi, P., Paulin, M., DeGeer, D. and Squires, M. (INTECSEA), 2015. Real-time Arctic pipeline integrity and leak monitoring. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25604.	Pipeline integrity monitoring	Technology development
Remote sensing technology	C-CORE	C-CORE's capability in remote sensing centres on expertise in satellite based Earth Observation (EO) and terrestrial radar systems for: - Ship, ice and iceberg detection, classification tracking and historical analysis for: -operational support - environmental characterization, risk assessment and planning - Monitoring of oil slicks and water quality - Onshore monitoring for (in)stability and encroachment of: - slopes and permafrost areas - pipeline	https://www.c-core.ca/	Remote sensing	Technology development

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		- critical infrastructure facilities The remote sensing systems involve a wide variety of functions that help ensure the safety and security of people and infrastructure. Remote sensing systems provide information that helps improve operational performance and mitigate risks. From algorithm development for advanced signal and image processing to instrumentation development and transponder design. C-CORE has advanced machine and vision systems for use on and under the ocean, on and beneath the Earth, and in the skies and space above.			
Sigma S6 oil spill detection and monitoring system	Rutter Inc.	Rutter Inc.'s Sigma S6 Oil Spill Detection (OSD) and monitoring system combines proven strength in early detection with tools that generate essential information about oil spill volume, thickness, deformation and drift. Rutter's systems have been extensively tested and proven effective in independent trials conducted by the Norwegian Clean Seas Association for Operating Companies (NOFO). The systems have been integrated with Sigma S6 Ice Navigator to provide simultaneous oil and ice detection and tracking capabilities on one display.	http://www.rutter.ca/oil-spill-detection	Leak detection	Technology developed
Subsea leak detection	SINTEF	SINTEF conducts R&D activities regarding subsea leak detection.	www.sintef.no/en	Subsea leak detection	R&D ongoing
Subsea leak detection	Biota Guard	Biota Guard's leak detection service is a highly sensitive early warning system comprising hardware, data management tools, analytical framework and visualization tools. The service uses three complementary detection principles – biosensor, acoustic and optical to provide leak detection service.	http://biotaguard.no/services/subsea-leak-detection/	Subsea leak detection	Technology development

Development of new concepts

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
A multi-purpose submarine concept for Arctic offshore operations	ThyssenKrupp Marine System GmbH	Brandt et al. (2015) document the results of a feasibility study for the development of a multi-purpose submarine which could be applied to a variety of offshore operations sub-ice and in harsh weather areas. The versatile vessel is designed for several key missions. Installation, inspection, maintenance and repair tasks for subsea facilities can be performed in water depths up to 1500 meters by use of an onboard gantry crane, an automatic storage system and two work class ROVs. The submarine can also be used to perform seabed seismic surveys at the same water depth. Furthermore, the submarine offers abilities to respond to sub-ice oil and gas spills (Brandt et al., 2015). Submarines operating submerged are not affected by harsh weather conditions. The subsea environment can be regarded as rather static compared to the surface. Therefore, submarines can operate year-round without the need for weather windows (Brandt et al., 2015). The study by Brandt et al. (2015) indicates that the multi-purpose submarine is technically feasible. Future work will focus on a sound evaluation of the economic performance and detailed technical studies.	Brandt, H., Frühling, C., Hollung, A., Schiemann, M, Voß, T. (ThyssenKrupp Marine Systems GmbH), 2015. A multi-purpose submarine concept for Arctic offshore operations. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25501.	Production system The technology is intended in water depths up to 1500 m.	Technology development, feasibility study published in 2015
Air cushion vehicles (ACV) in the Arctic	Shell, Griffon Hoverwork Ltd.	An air cushion vehicle (ACV) is a craft capable of travelling over land, water, mud or ice and other surfaces. Andrews et al. (2015) set out the current advances in ACV technology and planned future developments including the results of recent trials. ACVs use blowers to produce a large volume of air below the hull that is slightly above atmospheric pressure. The pressure difference between the higher pressure air below the hull and lower pressure ambient air above it produces lift, which causes the hull to float above the running surface. For stability reasons, the air is typically blown through slots or holes around the outside of a disk or oval shaped platform, giving most ACVs a characteristic rounded-rectangle shape.	Andrews, D. (Shell) and Coveney, M. (Griffon Hoverwork), 2015. ACVs in the Arctic. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25503.	Support vessel	Technology development
Arctic and sub-Arctic subsea technology JIP	PRNL, INTECSEA, three oil companies participating in Arctic development offshore Eastern Canada	The Arctic and sub-Arctic subsea technology JIP aimed at offering the industry a mechanism for optimising design schemes and field development architecture for the efficient delivery of hydrocarbons in Arctic and sub-Arctic waters. The JIP investigated the conventional, enhanced, and active subsea production technologies including subsea separation, boosting, compression and direct electric heating systems, suitable for stranded and existing field developments. The objective of the JIP was to encourage the use of proven and evolving technologies from deepwater Gulf of Mexico, offshore Brazil and northern North Sea to enhance production in Arctic and sub-Arctic waters.	http://www.newtechmagazine.com/index.php/daily-news/archived-news/9090-intecsea-launches-jip-focused-on-arctic-offshore-eastern-canada http://issuu.com/frontierenergy/docs/fe_7_spring14_lr_si/12	Production system	JIP 2010-2011
Arctic Construction and Intervention Vessel (CIVARCTIC) project	MARINTEK, STX OSV, Statoil, Aker Arctic, VTT	The Arctic Construction and Intervention Vessel (CIVARCTIC) project investigates a dedicated design basis for a vessel operating in the Northern Norwegian waters with seasonal ice.The primary objective of the project is to extend the operational season for installations and maintenance of subsea oil and gas installations in waters with seasonal ice. As a business case the vessel was scheduled to operate on fields off the coast of Northern Norway and east of Svalbard.The project is divided into the following work packages:- Intervention philosophies and tasks- Design guide for metocean and ice- Systematic parameter variation- Environmental footprint	http://www.sintef.no/en/marintek/initiatives/arctic-and-the-high-north/civ-arctic/	Support vessel	Project
Arctic drillship	Inocean	Inocean has developed an Arctic drillship. The new unit has been named IN-ICE (Inocean, 2015). The ship is completely enclosed and winterized, is environmentally friendly, and has enhanced logistics / storage facilities. The ice class is for a substantially extended drilling season for a large part of the Arctic – with a PC-4 ice class. The drillship is designed with a conventional bow for operations in rough open water wave conditions, as well as to implement a moderate stern for aft-way operations in managed ice.	Inocean, 2015. Arctic drillship. http://www.inocean.no/inocean-goes-in-ice	Drilling unit	Technology development

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		Inocean envisages the stern more optimized for avoiding ice into the moon pool than for ice breaking, but also because drilling operations in Arctic areas are expected to be conducted primarily in "managed ice". Positioning will be done through thruster assisted turret mooring in the shallow parts of the operational area, and by DP in the deeper parts.			
Arctic drillship design for severe ice conditions	Aker Solutions, Aker Arctic	Aker Solutions and Aker Arctic have developed an Arctic drillship concept design for a MODU with capabilities to perform extended season drilling in waters with sea ice (Bruun et al., 2015). The objective of the drillship design is to propose a concept that may extend the drilling season in areas with limited open water season by having capability to perform drilling operations during interaction with sea ice. Focus has been on the elements that enables these operations such as design of the drilling topside for low air temperature, capability of performing drilling operations through a forward located turret moonpool, performing internal handling when having a forward located turret moonpool position and design optimisation of hull lines and turret position for sea ice interaction. The design was developed starting in 2012 and ice model tests were performed in 2013. Design work has been performed through sizing of the hull, drilling, turret and station-keeping system. General arrangement drawings have been developed for each deck level and the technical work has been documented through development of an outline specification.	Bruun, P.K. (Aker Solutions), Ågedal, B. (Aker Solutions) and Matala, R. (Aker Arctic), 2015. Arctic drillship design for severe ice conditions. Proceedings of the POAC 2015 23rd international conference on Port and Ocean Engineering under Arctic Conditions, 14-18 June 2015, Trondheim, Norway. POAC15-187.	Drilling unit	Technology development
Arctic MODU	ConocoPhillips and KOMtech	ConocoPhillips and Keppel Offshore and Marine Technology Centre, have jointly developed a basis of design and specifications for a self-elevating Arctic mobile offshore drilling unit (MODU) for use in water depths from 10 to 50 meters for drilling a wide range of wells (Shafer et al., 2013). The intention is to achieve year-round operation, development and exploration. Shafer et al. (2013) detail major items that impact the size, weight and configuration of an Arctic MODU. This will result in a conceptual unit design that will be used to determine ice loads, layout and structural design of the Arctic MODU. The MODU will not be designed for the highest possible ice load. In the event an ice feature is forecasted to result in loads that exceed the MODU's capabilities, the MODU will be moved. Furthermore, an ice management system will be in place for all Arctic MODU operations.	Shafer, R.S. (ConocoPhillips), Noble, P.G. (ConocoPhillips), Cheung, T.O. (Keppel Offshore and Marine), Chow, Y.Y. (Keppel Offshore and Marine), Quah, M. (Keppel Offshore and Marine), Foo, K.S. (Keppel Offshore and Marine), Wang, C.D. (Keppel Offshore and Marine) and Perry, M.J. (Keppel Offshore and Marine), 2013. Basis of design and specifications for shallow water Arctic MODU for year-round operation, development and exploration. Presented at the SPE/IADC Drilling Conference and Exhibition, 5-7 March 2013, Amsterdam, The Netherlands. SPE/IADC 163429.	Drilling unit	Technology development
AIV for subsea inspection in Arctic regions	Subsea 7	In Arctic regions it is difficult to conduct 'Life of Field' inspection operations (inspections and maintenance) from a support vessel due to restricted freedom of operation caused by polar low or winter storms and/or the formation and movement of sea ice. Seabed hosted vehicles have the potential to eliminate these challenges. The AIV developed by Subsea 7 enables complete autonomous inspection of a subsea asset (Jamieson and Hopkins, 205). The system is deployed using a launch and recovery basket, which can be configured to remain on the seabed for significant periods of time. Jamieson and Hopkins (2015) describe the advanced features of the autonomous inspection vehicle (AIV) technology and discuss how it can be effective in the Arctic regions, under ice operations.The advanced navigation and control technology in the AIV enables it to operate from a basket deployed to the seabed from a surface facility, vessel or FPSO. The AIV leaves the basket to carry out prepared missions before returning and docking back into the basket without operator input. Mission data is downloaded from the AIV when recovered in its basket to the surface facility. Mission planning and data processing can be carried out locally on the offshore facility or onshore in cases where high speed data links exist between offshore and shore base. The AIV would be recharged, data uploaded and missions downloaded without coming to surface. In Arctic areas, servicing would be coordinated with seasonal access to the site by field support vessels.	Jamieson, J. and Hopkins, D. (Subsea 7), 2015. The potential benefits autonomous underwater vehicles bring to subsea inspection in Arctic regions. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25540.	Support vessel	Technology development

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
AUV for environmental monitoring and asset integrity	Eni Norge, Tecnomare	Eni, in cooperation with Tecnomare, have launched the CLEAN SEA project (Continuous Long-term Environmental and Asset iNtegrity monitoring in SEA) with the objective to use a commercially available AUV, properly upgraded with key enabling technologies, for the execution of environmental monitoring and asset integrity in offshore fields where Eni operates. Buffagni et al. (2014) describe how to reach this goal. A custom designed mission payload, arranged as modular and interchangeable pods, has been installed at the AUV. These modules, characterised by a set of sensors, are built to perform different offshore monitoring activities according to specific needs; automatic water samples collection, visual inspection (asset, seabed) and hydrocarbon leakage detection through automatic chemical analyses of trace pollutants and acoustic survey of seabed and pipelines / flowlines.	Buffagni, M., Gasparoni, F., Bergseth, N.H., Bjørnbom, E. and Broccia, P. (Eni), 2014. Development and test of an AUV for environmental monitoring and asset integrity in offshore O&G scenarios: CLEAN SEA project. Presented at the SPE International Conference on Health, Safety and Environment, 17-19 March 2014, Long Beach, California, USA.	Support vessel	Technology developed
Badger Explorer	Badger Explorer	The Badger Explorer is a formation and reservoir evaluation tool which drills into the subsurface and buries itself (Badger Explorer, 2015). It features a slim electrically powered drilling system and carries sensors, which continuously record data, producing logs while drilling, and providing continuous, long-term data in surveillance mode. The Badger Explorer consists of the following main functions: - drill bit driven by an electro-motor and gear - cutting transport, deposition and compression - spooled cable, through which power is supplied to the tool and data transferred to surface. It is a non-reusable exploration tool that remains permanently underground. The ambition of the concept is to contribute to the following improvements:- Reduce the requirement for large drilling rigs and related logistics, which will reduce the impact and disturbances to the wild life, fisheries and the surrounding environment- No emission to air or sea, either of polluted drill cuttings or CO2 emission from power generation, since the Badger Explorer produces no cuttings or fluids to surface- A self-contained operation, which will reduce the safety exposure for personnel during operations- With no communication path to surface for hydrocarbons, the risk of blow-out is minimized. The Badger Demonstrator Program, commenced in January 2012, is a three-year program that aims to design, build, test and qualify the Badger Explorer tool. Current sponsors include ExxonMobil, Statoil, Chevron and Wintershall. On 5 February 2015, the Steering Committee of the Badger Demonstrator Program concluded the Demonstrator Program by approving Milestones 5 and 6. The Field Pilot Project is designed to deploy the Badger Explorer developed in the Demonstrator Program in its first commercial applications. A series of field deployments is planned, each of which represents an increased degree of challenge in technology, application or operational capability.	Badger Explorer, 2015. Badger Explorer. www.bxpl.com	Exploration drilling technologyIts development is based on the use of proven technology, combined with proprietary solutions.Uncerta in whether the risk of blowout is limited completely.	Technology development
Centre for Autonomous Marine Operations and Systems (AMOS)	NTNU, SINTEF, MARINTEK, Statoil, DNV GL	The centre for Autonomous Marine Operations and Systems (AMOS) works to create a world-leading centre for autonomous marine operations and control systems. AMOS will contribute with fundamental and interdisciplinary knowledge in marine hydrodynamics, ocean constructions and control theory. The research results will be used to develop intelligent ships and ocean structures, autonomous unmanned vehicles (under water, on the surface and in air) and robots for high-precision and safety-critical operations in extreme environments. This is necessary in order to meet challenges related to environmental and climate, safe maritime transport, mapping and surveillance of large ocean and coastal regions, offshore renewable energy, fisheries and aquaculture as well as deep-sea and Arctic oil and gas exploration. AMOS projects are: 1. Renewable offshore energy 2. Intelligent aquaculture structures 3. Autonomous unmanned vehicles 4. Autonomous underwater robotics	https://www.ntnu.edu/amos/	Support vessel	R&D centre 2012-2022

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		5. Autonomous unmanned aerial vehicles 6. Energy and green operations 7. Autonomous marine operations 8. Accidents and abnormal events 9. Subsea intervention			
Cylindrical floating drilling unit	Sevan Marine	Sevan Marine is developing a cylindrical floating drilling unit for Arctic environments. The cylindrically shaped hull is particularly suitable in drifting ice as it will face the ice with the same shape in all directions. The unit is designed for obtaining good performance both in harsh open water wave conditions as well as in drifting ice. Year round operation requires design with sloped sides for breaking heavy ice.	http://www.sevanmarine.com/solutions/sevan-arctic	Drilling unit	Technology developed
Deepwater Arctic subsea separation & storage systems	Kvaerner Concrete Solutions	Eie (2015) describes solutions on how deepwater subsea separation of hydrocarbons and storage of oil can be achieved in hostile environments enabling close to continuous production also when surface production facilities have to abandon location. The description is based on ongoing development of a subsea separation and storage system for application in deepwater Arctic. Furthermore, Eie (2015) presents overall Arctic field development suggestions based on the solutions. Eie (2015) discusses a possible way to develop large reservoirs located in the Arctic by use of a subsea separation and storage unit. The solution depends on further development and qualification of several technologies additional to the actual subsea separation and storage unit, as outlined by Eie (2015).	Eie, R. (Kværner Concrete Solutions), 2015. Deepwater Arctic subsea separation & storage systems. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25526.	Production system	Technology development
Drilling of exploration and production wells from land	Rosneft/ExxonMobil and BP have experience from Sakhalin and southern England, respectively	Extended reach drilling (ERD), designed to drill wells at offshore targets from land-based locations or artificial islands, enables drilling in areas with level ice and/or icebergs without other precautions. Wells are drilled with a horizontal reach of more than 10,000 meters. Rosneft and ExxonMobil performed drilling operations from Sakhalin, with a horizontal reach of 12,033 meters and a measured depth of 13,500 meters (Rosneft, 2015). This technology can be applied whenever close to shore, however, there are some challenges related to permafrost and erosion of the shoreline.	Rosneft, 2015. Sakhalin-1 Sets Another Extended Reach Drilling Record. Rosneft press release 14 April 2015.	Drilling technology	Technology developed
Floating production unit (FPU)	Shtokman Development, Technip, Aker Solutions, SBM Offshore	Technip, in a consortium with Aker Solutions and SBM Offshore, was awarded, by Shtokman Development AG, an engineering contract for the floating production unit (FPU) for the offshore portion of the first phase of the integrated development of the Shtokman gas condensate field in Russia. The concept included winterization and disconnection options.	http://www.technip.com/en/press/technip-consortium-awarded-engineering-contract-shtokman-gas-project	Production system	Technology development
Goliat FPSO	Eni, Sevan Marine	The Goliat FPSO is developed with the circular Sevan FPSO 1000 concept. The circular shape implies that the FPSO does not need to be turned up towards the ice drift direction. As of October 2015, the FPSO is being installed at the field, and is preparing for production.	http://www.eninorge.com/en/Field-development/Goliat/Development-solution/The-platform---FPSO/	Production system	Technology developed
JBF Arctic drilling unit	Huisman	Huismann has designed the JBF Arctic drilling unit to drill wells in Arctic conditions, moored in ice infested waters with ice thickness up to approximately 2.0 meters (Huisman, 2015). Depending on ice conditions, ice breaker support can be required. The unit consists of a round floater, eight columns and a round deckbox. When operating in ice the unit will ballast to ice draft (partly submerged deckbox) to protect the riser against level ice, rubble and ice ridges. The round conical shaped deckbox has a heavily strengthened structure at waterline level to deflect and break the ice. The round floater is also strengthened for transit through broken ice (icebreaker assisted). When no ice is present the unit operates at its operating draft as a conventional semi-submersible unit. Station keeping in ice infested waters is achieved by a heavy 12-point mooring system. The unit can operate in water-depths between 50 and 1,500 meters. If required the design can be customised for setting the unit on the sea bed in shallow water.	Huisman, 2015. JBF Arctic. http://www.huismanequipment.com/en/products/drilling/jbf_14000/jbf_arctic	Drilling unit	Technology developed

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
MODUs and FPSOs for operation in Arctic	Moss Maritime	Moss Maritime is designing floaters with ice-breaking and survival capabilities to withstand the impact of the Arctic extremes such as drilling platforms for Arctic environment, icebreaking FPSOs, icebreakers, icebreaking LNG carriers, gravity base barges (Moss Maritime, 2015).	Moss Maritime, 2015. Arctic environment units. http://www.mossww.com/technologies/arctic.php	Drilling unit Production system	Technology development
Next generation subsea inspection, maintenance and repair (NextGenIMR)	NTNU, SINTEF, Norwegian Research Council, FMC Technologies, Statoil	The project "Next Generation subsea inspection, maintenance and repair operations" will develop novel integrated sensor platforms with robust perception methods and collision-free motion planning algorithms for subsea inspection and light intervention operations (NTNU, 2015). The project will also focus on subsea factory design, and will especially address autonomous platforms. It combines novel concepts for sensor platforms, advanced localisation and perception methods based on vision and acoustic sensors and collision free path planning and high-level task planning for autonomous services. NextGenIMR results will be tested, verified and demonstrated in full scale test beds available to the project.	NTNU, 2015. NTNU Oceans - into the deep ocean. https://www.ntnu.edu/oceans/into-the-deep-ocean	Support vessel	Project 2014-2017
Portfolio of drilling designs (jack-ups / drillships)	Gusto MSC	GustoMSC has developed a portfolio of solutions for Arctic offshore drilling comprising both jack-up type and drillship type solutions (Wassink and List, 2013). The designs are developed to address the specific challenges of exploratory and development drilling in the Arctic, and are developed to cover the full extent of the Arctic, from very shallow to deep water. The SEA ICE series of jack-ups has been developed with four circular legs and hydraulic jacking systems. The series is fully winterized and features a sloped hull to reduce ice loads in floating mode. These jack-ups could operate in water depths of 20 to 50 meters and in managed ice conditions of up to 2.0 meters first-year ice. The NanuQ drillship series has been developed based on the same design philosophies as all GustoMSC drillships. The NanuQ 5,000 TM is the most capable Arctic drillship, capable of extended season to year-round operations in up to 4 meters of multi-year ice. This unit is turret moored, with DP capability for station-keeping during mooring system hook-up. It is self-propelled and offers ice class up to PC2, allowing year-round access to all Arctic areas. The NanuQ drillship series does also consist of DP units.	Wassink, A., and List, R. van der (GustoMSC), 2015. Development of solutions for Arctic offshore drilling. Presented at the SPE Arctic and Extreme Environments Conference & Exhibition, 15-17 October 2013, Moscow, Russia. SPE 166848.	Drilling unit	Technology developed
Seabed rig	Robotic Drilling Systems	Robotic Drilling Systems is developing a drilling rig to be located submerged at the seabed for cost-effective drilling in deep waters and Arctic areas (Robotic Drilling Systems, 2015). The seabed submerged rig is connected to a surface support vessel through an umbilical with power, control and mud flow. All functions on the rig are remotely controlled from a control room on the surface vessel or from land. The rig is made up of modules that can be lowered via a surface vessel and guided in place by means of guide wires. The rig is filled with water, pressure compensated and encapsulated in order to avoid contamination of the surrounding environment.	Robotic Drilling Systems, 2015. Seabed rig. http://www.rds.no/seabed-rig/about-seabed-rig	Drilling unit	Technology development
Subsea compression	Statoil	The Åsgard subsea compression is one step closer to realizing the vision of a full offshore processing plant subsea. Subsea processing and especially gas compression is a vital technology to develop fields in deep waters and harsh environments (Statoil, 2015a).	Statoil, 2015. Åsgard subsea compression project. http://www.statoil.com/no/technologyinnovation/fielddevelopment/aboutsubsea/Pages/The%C3%85sgardComplex.aspx	Production system	Technology developed
Subsea production system	FMC Technologies	FMC Technologies are working on developing subsea production systems for Arctic conditions. Furthermore, they are working on developing lubricants and sealing technology for Arctic conditions.	http://www.fmctechnologies.com/	Production system	Technology development
Unmanned aerial vehicle (UAV)	-	Unmanned aerial vehicles (UAVs) can assist in ice management and ice transiting for offshore operations.		Support vessel	Technology developed

Standards and guidelines

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions	API	The API RP 2N Recommended Practice for planning, designing and constructing structures and pipelines for Arctic conditions was first published in 1982. API RP 2N served as the basis for ISO 19906 Arctic offshore structures, which was published in 2010. In April 2015, a new edition of API RP 2N was published. The new edition is a modified adoption of the ISO 19906:2010. The main observed differences between the ISO 19906:2010 and the API RP 2N standards are: - API RP 2N uses the wording 'loads' and 'loads effects' rather than 'actions' and 'actions effects' used by ISO 19906 - API RP 2N does not mention a reliability target expressed as annual failure probability at 1E-5 for L1 structures as given in Table A.7-1 of ISO 19906	API RP 2N:2015. API RP 2N Planning, designing and constructing structures and pipelines for Arctic conditions. Third edition.	Disconnection Pipelines and subsea structures Facility design	Recommended practice, published in 2015
API RP 17W Subsea capping stacks	API	The document provides subsea capping stack recommended practices for design, manufacture and use. The document applies to the construction of new subsea capping stacks and can be used to improve existing subsea capping stacks. The document does not include recommendations for either procedures or equipment for containment systems that may be connected to a subsea capping stack. All equipment and operations downstream of the subsea capping stack are considered part of a containment system and are not within the scope of this recommended practice. Annex A contains a discussion of possible subsea capping contingency procedures. Annex B contains example procedures for deployment, well shut-in and recovery of a subsea capping stack.	API RP 17W:2014. API RP 17W Subsea capping stacks. First edition.	Well control - not Arctic specific	Recommended practice, published in 2014
API RP 96 Deepwater well design and construction	API	This recommended practice (RP) provides engineers a reference for deepwater (DW) well design as well as drilling and completion operations. This RP can also be useful to support internal reviews, internal approvals, contractor engagements, and regulatory approvals.The scope of this RP is to discuss DW drilling and completion activities performed on wells that are constructed using subsea blowout preventers (BOPs) with a subsea wellhead. This document addresses the following.- Identifies the appropriate barrier and load case considerations to maintain well control during DW well operations (drilling, suspension, completion, production, and abandonment). - Supplements barrier documentation in API 65-2 with a more detailed description of barriers and discussion of the philosophy, number, type, testing, and management required to maintain well control. This document also supplements the barrier documentation in API 90 in regard to annular pressure buildup (APB). Abandonment barrier requirements are described for use when designing the well.- Discusses load assumptions, resistance assumptions, and methodologies commonly used to achieve well designs with high reliability. The load case discussion includes less obvious events that can arise when unexpected circumstances are combined.- Describes the risk assessment and mitigation practices commonly implemented during DW casing and equipment installation operations.	API RP 96:2013. API RP 96 - Deepwater well design and construction. First edition	Well design - not Arctic specific	Recommended practice, published in 2013
API Specification 4F Specification for drilling and well servicing structures	API	This specification states requirements and gives recommendations for suitable steel structures for drilling and well servicing operations in the petroleum industry, provides a uniform method of rating the structures, and provides two Product Specification Levels. This specification that addresses the fabrication of such structures used in cold climate.	API Specification 4F:2013. API Specification 4F Specification for drilling and well servicing structures. Fourth edition.	Drilling technology	Specification, published in 2013
Arctic offshore oil and gas guidelines	Arctic Council - Protection of the Arctic Marine Environment (PAME)	The Arctic offshore oil and gas guidelines, issued by the Arctic Council – Protection of the Arctic Marine Environment (PAME) are intended to be of use to the Arctic nations in offshore oil and gas activities during planning, exploration, development, production and decommissioning, with the exception of transportation of oil and gas. The goal is to assist regulators in developing standards that can be applied and enforced consistently for all offshore Arctic oil and gas operators. The intention of the guidelines is to encourage the highest standards currently available by defining a set of recommended practices and outline strategic actions for consideration by those responsible for regulation of offshore oil and gas activities in the Arctic. The guidelines may be of help to the industry when planning for oil and gas activities and to the public in understanding Arctic environmental concerns and practices during offshore oil and gas activities.	Arctic Council, 2009. Arctic offshore oil and gas guidelines. http://www.pame.is/index.php/projects/offshore-oil-and-gas	General	Guideline, pubslihed in 2009
Arctic operations handbook	Allseas Engineering, Bluewater, Canatec, TU Delft, Gusto	The Arctic operations handbook JIP was set up in 2012 with a focus on the operational activities for transport and installation of fixed, floating and subsea units, as well as for dredging, trenching, pipe laying and floating oil and gas production in Arctic and cold weather conditions. The prime purpose of the JIP was to identify gaps in the existing standards and guidelines. Specific recommendations were subsequently proposed with the intention to contribute to the development of internationally accepted standards and guidelines.	Arctic Operations Handbook, 2013. Arctic marine operations challenges & recommendations. Final report of the Arctic operations handbook JIP.	Ice management Disconnection	JIP 2012-2013

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
	MSC, Heerema Marine Contractors [Project Coordinator], Huisman, Imares, INTECSEA, MARIN, Royal Boskalis Westminster, Shell, TNO	The project addressed safety and sustainability of offshore operations in the Arctic. This investigation into existing rules, regulations, standards and guidelines was intended to provide a common understanding for the offshore industries. Work groups were formed to execute work packages which were judged to be of prime importance. Three pilot projects were conducted as part of the JIP; IceStream, Marine Icing and Environmental Impact. Taking into account numerous aspects of the impact of the Arctic on various operations it was considered that the overall risk levels for such operations can be reduced by adopting the outline recommendations including, for instance, those related to weather monitoring and forecasting, environmental impacts, logistics, equipment preparation, vessel operations, training and health and safety management. The Arctic marine operations challenges and operations report (2013) documents the output from the JIP, including the results of the gap analysis and of the three pilot projects. The report provides the offshore industry an overview of identified gaps and proposes a large number of recommendations in order to close the gaps. The identified gaps and recommendations could support the further development of ISO TC67 SC8 Arctic operations, ISO 19906 SC7 Offshore structures, ISO 19901-6 Marine operations and future JIPs. Wiersema et al. (2014) describe the Arctic operations handbook JIP. The Arctic operations handbook recommends guidelines for the reliability of the disconnection operations to ensure the integrity of the station-keeping and offloading capability after later re-connection (Wiersema et al., 2014). In the follow-up from the Arctic operations handbook JIP, several JIPs were suggested; the IceStream, IceTower, PractICE and SALTO JIPs. However, only the SALTO JIP was initiated for various reasons.	http://www.arctic-operations-handbook.info/ Wiersema, E. (Heerema Marine Contractors), Lange, F. (Shell), Cammaert, G. (TU Delft), Sliggers, F. (TU Delft), Jolles, W. (Canatec) and van der Nat, C. (Bluewater), 2014. Arctic operations handbook JIP. Presented at the Arctic Technology Conference, 10-12 February 2014, Houston, Texas, USA. OTC 24545.		
CAN/CSA-ISO 19906:11 Petroleum and natural gas industries - Arctic offshore structures (Adopted ISO 19906:2010, first edition, 2010-12-15)	Canadian Standards Association	This is the first edition of CAN/CSA-ISO 19906, Petroleum and natural gas industries - Arctic offshore structures, which is an adoption without modification of the identically titled ISO (International Organization for Standardization) Standard 19906 (first edition, 2010-12-15).	CAN/CSA-ISO 19906:11. Petroleum and natural gas industries - Arctic offshore structures (Adopted ISO 19906:2010, first edition, 2010-12-15). http://shop.csa.ca/en/canada/structures/cancsa-iso-1990611/invt/27032802011	Facility design	National standard, published in 2011
COLD notation for winterization	Bureau Veritas	Bureau Veritas COLD notation to deal with low ambient temperatures, frozen spray (icing of ships) and reduced effectiveness of components: - Material class and grade selection for low air temperatures - Decks and superstructures - Stability - Propulsion and other essential services (e.g. firefighting, lifesaving, mooring equipment) - Electricity production - Navigation - Crew protection and elimination of ice where necessary for safe access - Lifting appliances		Winterization	Class guideline
DNVGL-OS-A201:2015 Winterization for cold climate operations	DNV GL	The standard provides general principles for preparation of mobile units and offshore installations for intended operations in cold-climate conditions. The standard has been developed for general world-wide application. Governmental legislation in excess of the provisions of this standard may apply depending on type, location and intended service of the unit or installation.	DNV GL, 2015a. Offshore standard DNVGL-OS-A201 Winterization for cold climate operations. https://rules.dnvgl.com/servicedocuments/dnvgl	Winterization	Offshore standard, published in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		The objective of winterization is ensuring that a vessel is capable of and suitably prepared for operations in cold climates. This is provided for by setting functional requirements to systems and equipment which are intended to be in operation in cold-climate conditions.			
DNV-OS-F101:2013 Submarine pipeline systems	DNV GL	The standard gives criteria and recommendations on concept development, design, construction, operation and abandonment of submarine pipeline systems. The objectives of the standard are to ensure that the concept development, design, construction, operation and abandonment of pipeline systems are safe and conducted with due regard to public safety and the protection of the environment, provide an internationally acceptable standard of safety for submarine pipeline systems by defining minimum requirements for concept development, design, construction, operation and abandonment, serve as a technical reference document in contractual matters between purchaser and contractor and serve as a guideline for designers, purchaser and contractors. The standard includes a section on the design of pipelines subjected to potential ice interaction.	DNV, 2013a. Offshore standard DNV-OS-F101 Submarine pipeline systems. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Pipeline integrity	Offshore standard, published in 2013
DNV-RP-A203:2013 Technology qualification	DNV GL	The objective of this recommended practice is to provide the industry with a systematic approach to technology qualification, ensuring that the technology functions reliably within specified limits. The approach is applicable for components, equipment and systems, which are not already covered by a validated set of requirements (such as an applicable standard). The recommended practice describes the philosophy and principles of technology qualification in addition to the basic technology qualification process.	DNV, 2013b. Recommended practice DNV-RP-A203 Technology qualification. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	General	Recommended practice, published in 2013
DNV-RP-C209 Arctic environmental conditions, ice loads and load effects	DNV GL	This recommended practice is under development and expected for hearing in 2015. The development of this recommended practice is based on experiences from the IceStruct JIP. The RP will provide practical and consistent design recommendations for fixed and floating structures in ice. It will provide guidance where existing codes are incomplete, silent or merely provide functional requirements.	-	Facility design	Recommended practice under development. Expected for hearing draft 2015.
DNV-RP-F107:2010 Risk assessment of pipeline protection	DNV GL	The recommended practice presents a risk-based approach for assessing pipeline protection against accidental external loads.	DNV, 2010a. Recommended practice DNV-RP-F107 Risk assessment of pipeline protection. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Pipeline integrity	Recommended practice, published in 2010
DNV-RP-F302:2010 Selection and use of subsea leak detection systems	DNV GL	The objective of this recommended practice is to summarize industry experiences and knowledge with relevance to selection and use of detectors for a subsea leak detection system. The document is a result of a JIP on leak detection ongoing from 2005 to 2010.	DNV, 2010b. Recommended practice DNV-RP-F302 Selection and use of subsea leak detection systems. Høvik, Norway. https://www.dnvgl.com/rules-standards/index.html	Subsea leak detection	Recommended practice, published in 2010
Guidance note NI 543 Ice reinforcement selection in different world navigation areas	Bureau Veritas	This guidance note aims to provide advice on the Ice Class or Polar Class notation to be adopted for the navigation in areas such as the Canadian Arctic, the Greenland waters, the Russian Arctic, the Baltic Sea, the Antarctic and some other locations in Central and Eastern Europe. Based on the climatic conditions in a given area at a specific time of the year and the local legislation where applicable, this note allows identifying the most appropriate additional class notation for navigation in ice.	Bureau Veritas, 2013. Ice Reinforcement Selection in Different World Navigation Areas. Guidance note NI 543 DT R01 E. http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites%20content/live/veristarinfo/web%20contents/bv-content/generalinfo/giRulesRegulations/bvRules/rulenotes/documents/5494.34.543NI_2013-09.pdf	Vessels operating in cold climates	Class guideline, published in 2013

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Guidance note NI 565 Ice characteristics and ice / structure interactions	Bureau Veritas	The purpose of the guidance note is to collect and provide data on the ice (physical and mechanical characteristics) as well as giving some guidance on the calculations of the forces generated by the ice on ships and offshore structures. The note includes information on different types of ice and on the mechanical properties of these different types of ice, it includes analytical formulae and methods to estimate forces applied on the structures due to ice, with respect to the different modes of failure of the ice. These pressures and loads may be used to assess the strength of the structure.	Bureau Veritas, 2010. Ice Characteristics and Ice/Structure Interactions. Guidance note NI 565 DT R00 E. http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites%20content/live/veristarinfo/web%20contents/bv-content/generalinfo/giRulesRegulations/bvRules/rulenotes/documents/4706.24.565NI_2010_09.pdf	Vessels operating in cold climates	Class guideline, published in 2010
Guidance notes on ice class	ABS	The purpose of the guidance notes is to provide ship designers with a clear guidance on alternative design procedures for hull side structures, on alternative methods for determination of power requirements and on procedures for propeller strength assessment based on the finite element method for Baltic ice class vessels.	ABS, 2014a. Guidance notes on ice class. Houston, Texas, USA. http://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/special_service/136_iceclass/ice_class_gn_e-feb14.pdf	Baltic ice class vessels	Class guideline, published in 2014
Guide for ice loads monitoring systems	ABS	The guide provides requirements for the installation of, and the information to be provided by, ice loads monitoring systems fitted on ice classed ABS vessels. The systems are intended as an aid when a vessel is operating in ice infested waters so that appropriate action can be taken to minimize the likelihood of the vessel sustaining structural damage from interaction with the ice.	ABS, 2011. Guide for ice loads monitoring system. Houston, Texas, USA. http://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/conventional_ocean_service/178_iceloadsmon/ice_load_monitoring_guide_e.pdf	Ice load	Class guideline, published in 2011
Guide for vessels operating in low temperature environments (LTE guide)	ABS	ABS issued this guide to assist the marine industry in the operation of merchant vessels in low temperature environments. The operation presents challenges for designers, builders, owners and operators that are related directly to construction, outfitting and operation of vessels and issues pertaining to the ability of the crew to function in a difficult environment. Included in the guide are the ABS criteria that are intended to assist in the design, operation and maintenance of vessels continuously operating in ice, occasionally operating in ice and which are operating in low temperatures in the absence of ice.	ABS, 2014b. Guide for vessels operating in low temperature environments. Houston, Texas, USA. http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/Rules&Guides/Current/151_VesselsOperatinginLowTemperatureEnvironments/LTE_Guide	Vessels operating in cold climates where design service temperatures of -10°C or less are anticipated	Class guideline, published in 2014
Guidelines for ships operating in polar waters	IMO	The guidelines aim at mitigating the additional risk imposed on shipping due to the harsh environmental and climatic conditions existing in polar waters. The polar environment imposes additional demands on ship systems, including navigation, communications, life-saving appliances, main and auxiliary machinery, environmental protection and damage control, and emphasizes the need to ensure that all ship systems both are capable of functioning effectively under anticipated operating conditions and provide adequate levels of safety in accident and emergency situations. In addition, the guideline recognizes that safe operation in such conditions requires specific attention to human factors, including training and operational procedures.	IMO, 2010. Guidelines for ships operating in polar waters. Sales number E190E. 2010 edition. London, UK. http://www.imo.org/en/Publications/Documents/Attachments/Pages%20from%20E190E.pdf	Vessels operating in cold climate	Guideline, published in 2010
Guidelines for transfer of refined oil and oil products in Arctic waters	Arctic Council - Protection of the Arctic Marine Environment (PAME)	The guidelines were developed for vessels operating in the Arctic. The use of the guidelines is encouraged in all ice-infested waters. The aim is to prevent spillage during cargo/fuel oil transfer. According to the guidelines, cargo / oil fuel spillage can be prevented by: securing that reasonable precautions have been taken; that adequate resources can be deployed if unforeseen problems develop; and making sure that transfer supervisors and their crew are able to work safely and carefully.	Arctic Council, 2004. Guidelines for transfer of refined oil and oil products in Arctic waters. http://www.pame.is/index.php/projects/offshore-oil-and-gas	Cargo / fuel transfer	Guideline, published in 2004

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
IMO MODU Code	IMO	The code for the construction and equipment of mobile offshore drilling units (MODU Code) was adopted by IMO in 2009. The MODU Code is not Arctic specific, but it does recommend design criteria, construction standards and other safety measures for mobile offshore drilling units so as to minimize the risk to such units, to the personnel on board and to the environment.	http://www.safety4sea.com/images/media/pdf/A.1023(26)%20MODU%20Code.pdf	Facility design - not Arctic specific	Code adopted by IMO in 2009.
IMO Polar Code	IMO	IMO has adopted the international code for ships operating in polar waters (Polar Code) and related amendments to make it mandatory under both the international convention for the Safety of Life at Sea (SOLAS) and the international convention for the Prevention of Pollution from Ships (MARPOL). The Polar Code is expected to enter into force on 1 January 2017.The Polar Code and SOLAS amendments were adopted during the 94th session of IMO's Maritime Safety Committee (MSC), in November 2014; the environmental provisions and MARPOL amendments were adopted during the 68th session of the Marine Environment Protection Committee (MEPC) in May 2015. The expected date of entry into force of the SOLAS amendments is 1 January 2017, under the tacit acceptance procedure. It will apply to new ships constructed after that date. Ships constructed before 1 January 2017 will be required to meet the relevant requirements of the Polar Code by the first intermediate or renewal survey, whichever occurs first, after 1 January 2018. Because it contains both safety and environment related provisions, the Polar Code will be mandatory under both SOLAS and the International Convention for the Prevention of Pollution from Ships (MARPOL). The Polar Code is intended to cover the full range of shipping-related matters relevant to navigation in water surrounding the two poles. Ship-design, construction and equipment, operational and training concerns, search and rescue will be covered by the code, and in addition protection of the environment and eco-systems of the polar regions will be covered. The code will include mandatory measures regarding both safety and pollution prevention. The code will require ships intending to operate in the defined waters of the Antarctic and Arctic to apply for a Polar Ship Certificate	http://www.imo.org/MediaCentre/HotTopics/polar/Pages/default.aspx	Vessels operating in cold climate	Code adoped by IMO in 2015 and is expected to enter into force early 2017.
ISO 19906:2010, Arctic offshore structures	ISO	The ISO 19906:2010, Arctic offshore structures standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in Arctic and cold regions. Reference to Arctic and cold regions in ISO 19906:2010 is deemed to include both the Arctic and other cold regions that are subject to similar sea ice, iceberg and icing conditions. The objective of ISO 19906:2010 is to ensure that offshore structures in Arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value to the owner, to the industry and to society in general. ISO 19906:2010 describes design considerations for disconnection and subsequently reconnection, in addition to corresponding requirements. ISO 19906:2010 does not contain requirements for the operation, maintenance, service-life inspection or repair of Arctic and cold region offshore structures, except where the design strategy imposes specific requirements. While ISO 19906:2010 does not apply specifically to mobile offshore drilling units, the procedures relating to ice actions and ice management contained herein are applicable to the assessment of such units.ISO 19906:2010 does not apply to mechanical, process and electrical equipment or any specialized process equipment associated with Arctic and cold region offshore operations except in so far as it is necessary for the structure to sustain safely the actions imposed by the installation, housing and operation of such equipment.ISO 19906:2010 has been adopted as a national standard by Canada, Russia and the European Union (Frederking, 2012).Blanchet et al. (2011) provides a brief history of the document preparation as it relates to country and industry involvement, development of technical input, editing and review processes undertaken and acceptance of the document by ISO and its participating members.The standard is currently under revision lead by the convenor, Karen Muggeridge. Draft International Standard (DIS) version is planned for mid-2016.	ISO 19906:2010. Petroleum and natural gas industries – Arctic offshore structures. 1st edition, International Standardisation Organisation, Geneva, Switzerland. http://www.iso.org/iso/catalogue_detail.htm?csnumber=33690 Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia. Blanchet, D. (BPXA Alaska), Spring, W. (Bear Ice Technology Inc.), McKenna, R.F. (McKenna and Associates) and Thomas, G.A.N. (BP), 2011. ISO 19906: An international standard for Arctic offshore structures. Presented at the Offshore Technology	Disconnection Pipelines and subsea structures Facility design	International standard published in 2010, currently under revision. Draft International Standard (DIS) version is planned for mid-2016.

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			Conference, 7-9 February 2011, Houston, Texas. OTC 22068.		
ISO 35104 Ice management standard (TC67 SC8 WG4)	ISO	The overall objective of the standard is to ensure that ice management is planned, engineered and implemented within defined and recognized safety / confidence levels, wherever they are performed. The following in-ice activities and infrastructures which require ice management are covered by this standard; floating moored and/or dynamically positioned drilling vessels, coring vessels, production facilities and work-over vessels, construction and installation (incl. trenching, dredging, pipelaying), tanker loading and other offloading operations, protecting subsea installations, seismic operations, oil spill response, bottom founded structures (fixed installations). The development of the standard is led by the convenor, Robin Browne.	-	Ice management	International standard under development, close to CD
ISO 35106 Arctic metocean, ice and seabed data (TC67 SC8 WG6)	ISO	The standard specifies requirements and provides recommendations and guidance for the collection, analysis and presentation of relevant physical environmental data for Arctic activities of the petroleum and natural gas industries in the Arctic and cold regions.This standard has a separate section regarding physical environment data for Arctic operations and will require collection of ice and metocean data for operations and Arctic and cold climate areas.The development of the standard is led by the convenor, Pavel Liferov.	-	Metocean and ice data	International standard under development, committee draft, CD, submitted for comments in 2015
ISO TC67 SC8 Arctic operations standards	ISO	Based on recommendations from the Barents 2020 project, a new international standardisation Arctic operations subcommitte (SC 8) was established in 2012. The scope of the SC8 is standardisation of operations associated with exploration, production and processing of hydrocarbons in onshore and offshore Arctic regions, and other locations characterised by low ambient temperatures and the presence of ice, snow and/or permafrost. Requirements for offshore pipelines and offshore structures are excluded from SC 8 as they are included under SC 2 and SC 7, respectively. A total of 6 work groups have been established under SC 8 developing a new set of standards for Arctic operations including: - Working environment - Escape, evacuation and rescue - Environmental monitoring - Ice management (close to committee draft, CD) - Arctic materials - Physical environment data for Arctic operations (committee draft, CD, submitted for comments 2015)	Johansen, O.H. (Statoil), 2014. International standardisation Arctic operations (ISO TC67 SC8). Presented at the Norwegian Oil and Gas Association HSE challenges in the High North seminar 6 on maritime logistics, infrastructure and ice management, 17-18 June 2014. https://www.norskoljeoggass.no/Global/HMS-utfordringer%20i%20nordomr%C3%A5dene/Seminar%206%20-%20Maritim%20logistikk,%20infrastruktur%20og%20iskontroll/1545%20Johansen%20ISO%20TC67%20SC8%20-%20NOROG.pdf	Arctic operations	International standard, under development
NORSOK D-010 Well integrity in drilling and well operations	Standards Norway	The NORSOK D-010 Well integrity in drilling and well operations standard defines the minimum functional and performance oriented requirements and guidelines for well design, planning and execution of safe well operations. The focus of the standard is well integrity.	NORSOK D-010, 2013. Well integrity and drilling and well operations. Edition 4. Standards Norway, Oslo, Norway.	Well design - not Arctic specific	National standard, published in 2013
NORSOK N-003 Actions and action effects	Standards Norway	The NORSOK N-003 Actions and action effects standard specifies general principles and guidelines for determination of characteristic actions and action effects for the structural design and assessment and for the design verification of structures.The standard is applicable:- To all types of offshore structures used in the petroleum activities, including bottom-founded structures as well as floating structures- To the design and assessment of complete structures including substructures, topside structures, vessel hulls, foundations, mooring systems, risers and subsea installations- To the different stages of construction (namely fabrication, transportation and installation), to the use of the structure during its intended life, and to its abandonment. Aspects related to verification and quality control are also addressed.NORSOK N-003 is primarily written for the facilities on the Norwegian continental shelf (including the continental shelf of Svalbard) as defined by the Norwegian Petroleum Directorate 16 June 2014, but the principles may also be applicable for other areas.	NORSOK N-003, 2015. Actions and action effects. Edition 3 (draft version). Standards Norway, Oslo, Norway.	Facility design - Norwegian continental shelf (including the continental shelf of Svalbard), but may be applicable also for other areas	National standard, edition 3 is under development, planned to be published in 2015.

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Offshore vessel operations in Ice and/or severe sub-zero temperatures - in Arctic and sub-Arctic regions	OCIMF	The Oil Companies International Marine Forum (OCIMF) has prepared a report with the purpose of providing guidance to operators and charterers of offshore support vessels employed for use in areas impacted by ice or severe sub-zero temperatures with the aim of encouraging high standards of safety and environmental protection for those operating in Arctic and sub-Arctic regions.	OCIMF, 2014. Offshore vessel operations in ice and /or severe sub-zero temperatures. First edition. London, England. http://www.ocimf.org/media/53160/Offshore_Vessel_Operations_in_Ice_and_or_Severe_Sub-Zero_Temperatures_in_Arctic_and_Sub-Arctic_Regions.pdf	Vessels operating in cold climate	Guideline, published in 2014
Overview of regulators' use of standards	IOGP	The IOGP report no. 426 reflects the current situation of selected national regulators' reference and use of national, regional, international and industry standards in their regulatory documents, with a particular focus on standards for materials, equipment, systems and structures for the offshore petroleum industry. The report attempts to analyse the documents prepared by national and provincial lawmakers and the regulators themselves.	IOGP, 2010. Regulators' use of standards. IOGP Report no. 426. http://www.ogp.org.uk/pubs/426.pdf	International standards overview	Standard overview, published in 2010
Overview of standards for petroleum and maritime activities in the Arctic	Arctic Council - Emergency Prevention, Preparedness and Response (EPPR), led by the Norwegian Coastal Administration	The Arctic Council - Emergency, Prevention, Preparedness and Response (EPPR) has initiated a project with the objective of establishing an overview of standards for petroleum and maritime activities in the Arctic. Through the work, it shall be evaluated how the need for standards is identified, how standards are developed, established and maintained, and who participates in the different phases of the work. The work includes standards related to offshore petroleum and maritime activities in the Arctic.	-	International Arctic standards overview	Project initiated 2015. Draft report presenting overview of standards planned Summer 2016.
Requirements concerning polar class	IACS (International Association of Classification Societies)	The IACS unified requirements for polar ships apply to ships constructed of steel and intended for navigation in ice-infested polar waters, except ice breakers. The document presents: - polar class descriptions and application - structural requirements for polar class ships - machinery requirements for polar class ships	IACS, 2011. Unified requirements I. Requirements concerning polar class. http://www.iacs.org.uk/document/public/Publications/Unified_requirements/PDF/UR_I_pdf410.pdf	Polar ships constructed of steel, navigating in ice-infested polar waters	Class requirement, published in 2011
Rule note NR 527 Rules for the classification of Polar Class and Icebreaker ships	Bureau Veritas	The rule note applies to ships constructed of steel and intended for navigation in ice-infested polar waters, including icebreakers. The requirements apply in addition to the applicable requirements of NR 467 Rules for the classification of steel ships. The rule note includes rules regarding material and welding, design ice loads, requirements to machinery and propulsions, auxiliary systems, cooling water, ballast and ventilation system.	Bureau Veritas, 2013. Rules for the Classification of Polar Class and Icebreaker Ships. Rule note NR 527 DT R02 E. http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites%20content/live/veristarinfo/web%20contents/bv-content/generalinfo/giRulesRegulations/bvRules/rulenotes/documents/527-NR_2013-04.pdf	Vessels operating in cold climates	Class requirement, published in 2013
Rule note NR 584 Propulsors in ice	Bureau Veritas	The rule note applies in addition to NR 467 Rules for the classification of steel ships and NR 527 Rules for the classification of Polar Class and Icebreaker ships to the following types of propulsors intended for navigation in ice infested waters; - Podded propulsor, with or without nozzle - Geared propulsor, with or without nozzle The rule includes sections for materials, ice interaction, machinery design and electrical installation.	Bureau Veritas, 2012. Propulsors in ice. Rule note NR 584 DT R00 E. http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites%20content/live/veristarinfo/web%20contents/bv-content/generalinfo/giRulesRegulations/bvRules/rulenotes/docum	Vessels operating in cold climates	Class requirement, published in 2012

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			ents/4980.36.584NR_2012-07.pdf		
Rule note NR 616 Ice load monitoring system	Bureau Veritas	The rule note applies to ships which are fitted with equipment continuously monitoring ice loads exerted on ship's hull by ice formations. The rule includes separate sections for design, installation, testing and surveys.	Bureau Veritas, 2015. Ice Load Monitoring System. Rule note NR 616. http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites%20content/live/veristarinfo/web%20contents/bv-content/generalinfo/giRulesRegulations/bvRules/rulenotes/documents/616-NR_2015-01.pdf	Vessels operating in cold climates	Class requirement, published in 2015
Rules for ice and cold operations	Lloyd's Register	The rules state the requirements for ships intended for operations in ice and cold conditions. It is included in Lloyd's Register rules and regulations for the classification of ships part 8 which is divided into two parts:1. Application - which aims at giving assistance on the selection of a suitable ice class notation for the operation of ships in ice covered regions.2. Ice operations - Ice class - which is separated into 12 different parts dealing with strengthening requirements for navigation in ice, hull requirements (general for navigation in ice, navigation in light ice conditions, navigation in first-year ice, strengthening requirements for navigation in multi-year ice), machinery requirements (general for navigation in ice, navigation in light ice conditions, navigation in first-year ice and strengthening requirements for navigation in multi-year ice) and requirements for icebreakers.	Lloyd's Register, 2015. Rules and regulations for the classification of ships. Part 8: Rules for ice and cold operations. http://www.lr.org/en/RulesandRegulations/ships.aspx	Vessels operating in cold climate	Class requirement, published in 2015
Rules for winterisation of ships	Lloyd's Register	The winterization rules are provisional rules for winterization, and compliance with these are additional to those applicable in the classification rules and regulations. The rules apply to ships intended to navigate in cold climates and that may be exposed to low temperatures that may cause equipment to freeze due to ice accretion from atmospheric icing or sea spray, or due to freezing of liquid within a system. Protection measures are to be provided and operational procedures are to be specified to ensure that equipment is suitably protected to enable operation in low temperatures. The winterisation rules are subdivided into following areas: - Materials for hull construction - Materials for equipment and systems - Enhanced materials for equipment and systems (through risk assessments) - Equipment and systems - Systems redundancy (through risk assessment) - Stability - Ice removal arrangements - Direct design	http://www.lr.org/en/RulesandRegulations/Provisional-Rules-for-the-Winterisation-of-Ships.aspx	Vessels operating in cold climate	Class requirement, published in 2015 (provisional)
Russian standards	-	Frederking (2012) compares standards for predicting ice forces on Arctic offshore structures, amongst others the ISO 19906:2010 standard and the Russian Federation's SNiP 2.06.04-82* Loads and effects on hydrotechnical structures (from waves, ice and vessels) , published in 1995 (Note, the * indicates this is the later 1995 edition). ISO 19906:2010 incorporates guidance on ice strength from the Russian standard. Russia has adopted ISO 19906:2010 Arctic offshore structures as a national standard (Frederking, 2012). However, reference should still be made to the Russian standard VSN 41.88 Design of ice-resistant fixed platforms and SNiP 2.06.04-82 Loads and effects on hydrotechnical structures (from waves, ice and vessels) for design of fixed offshore structures (Barents 2020, 2009).	Frederking, R. (NRC), 2012. Comparison of standards for predicting ice forces on Arctic offshore structures. Proceedings of the 10th ISOPE Pacific / Asia Offshore Mechanics Symposium, 3-5 October 2012, Vladivostok, Russia. Barents 2020, 2009. Barents 2020. Assessment of international standards for safe exploration, production and transportation of oil and gas in the Barents Sea. Final Report	Standards	Standards

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			Phase 3. DNV Report 2009-1626, Høvik, Norway.		
Winterization guidelines for LNG/CNG carriers in Arctic environments	ABS	ABS has prepared a paper discussing ship designs for transportation of oil and gas in the Arctic region and Baltic Sea and operation challenges for this trade from an ABS class perspective. Year round carriage by sea in Arctic environments will place extreme challenges on the ships and their crew. The paper focuses on two related perspectives: - Winterization of vessels operating in the Arctic environment - Implications for design, winterization and operations due to the needs of humans operating under Arctic conditions	ABS, 2006. Winterization guidelines for LNG / CNG carriers in Arctic environments. ABS technical paper, USA. https://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/References/Technical%20Papers/2006/WinterizationGuidelinesLNGCNG	LNG / CNG carriers	Class guideline published in 2006

R&D centres, forums, portals, projects and programmes, in addition to general issues

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
ABS Harsh Environment Technology Center (HETC)	ABS, MUN	In 2009, ABS expanded its polar and harsh environment program located within ABS' Technology Department by creating the ABS Harsh Environment Technology Center (HETC) located on the campus of Memorial University of Newfoundland (MUN) in St. John's Canada. The centre supports the development of technologies for ships and offshore structures operating in harsh environments, particularly the Arctic. Applied research is conducted to study vessels and units operating in ice covered waters, low temperature environments and severe wave and wind climates.	http://ww2.eagle.org/en/what-we-offer/offshore-energy/harsh-environment.html	Ships and offshore structures	R&D centre established in 2009
Advanced Research in Telecommunications Systems (ARTES)	ESA	The Advanced Research in Telecommunications Systems (ARTES) programme is a long-running, large-scale programme that enables European and Canadian industry to explore, through R&D activities, innovative concepts to produce leading-edge satcom products and services. The elements are as follows: - ARTES 1 Preparatory is dedicated to strategic analysis, market analysis, technology and system feasibility studies and to the support of satellite communication standards. - ARTES 3-4 Products is dedicated to the development, qualification, and demonstration of products. Telecommunication applications can be undertaken under the terms of this element. - ARTES 5 Technology is dedicated to long term technological development, either based on ESA's initiative, or on the initiative of the satcom industry. - ARTES 7 EDRS is a specific element dedicated to the development and implementation of an European Data Relay Satellite (EDRS) system. - ARTES 8 Alphabus/Alphasat is a specific element dedicated to the development and deployment of Alphasat. - ARTES 10 Iris is a satellite-based communication system that will complement the future generation of an air traffic management system currently being developed under the SESAR programme of the EU, by Eurocontrol and the European Aeronautical community. - ARTES 11 Small GEO is a specific element dedicated to the development and implementation of the Small GEO System. - ARTES 14 Neosat is a specific element dedicated to developing the "Next Generation Platform", in partnership with industry. - ARTES 20 IAP is dedicated to the development, implementation and pilot operations of Integrated Applications. These are applications of space systems that combine different types of satellites, such as telecommunications, earth observation and navigation. - ARTES 21 SAT-AIS The Automatic Identification System (AIS) is a short range coastal tracking system currently used on ships. - ARTES 33 Partner is a new programme element to provide the satcom industry with an efficient framework to bring innovative products and systems into the marketplace through industry-generated public–private partnerships.	https://artes.esa.int/	Communication	R&D programme
Arctic and cold climate solutions	INTSOK	INTSOK has initiated a new project that is a spin-off from the RU-NO Barents project. A catalogue of Norwegian Arctic and cold climate technology and experience was published in February 2015. This project will further develop this catalogue, mapping industry capabilities, and publishing the Norwegian capabilities on the web and in printed catalogues. Both offshore maritime and petroleum industry will be covered.	http://www.intsok.com/content/download/23144/161537/version/2/file/021+INTSOK+ENG.pdf	Arctic technology	Project 2015-2018
Arctic Centre for Unmanned Aircraft (ASUF)	NORUT, UiT, Lufttransport	The Arctic Centre for Unmanned Aircraft (ASUF) is a national and international focal point in the use of unmanned aircraft for emergency preparedness, environmental monitoring and technology development in the Arctic. The centre will also contribute to increased safety in	http://www.asuf.no/english/	Metocean data collection technology	R&D centre established in 2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		connection with commercial flights and ambulance, rescue and police operations. ASUF offers education, training, research and operational services. The centre spans the entire value chain from education and basic research to innovation and commercial activities. ASUF develops communication systems, sensors and instruments, algorithmic and analytical tools and navigation and control systems, as well as testing new materials and adapting these for use in cold and extreme climates. Particularly in the Arctic, unmanned aircraft are extremely well suited given the long distances and the unique weather, light and environmental conditions, as well as the increasing level of international commercial activity.			
Arctic Development Roadmap: Prioritization of R&D	CARD	At the initial stage of the CARD program, an Arctic Development Roadmap (ADR) was generated from data and information collected from numerous surveys with industry proponents. The objective of the ADR was to identify research and development needs for oil and gas development in Arctic and sub-Arctic regions. Environmental protection and environmental characterisation, together with ice management, ice loads / mechanics, station-keeping in ice, were considered to be the highest priority R&D issues.	Taylor, R.S. (CARD), Murrin, D.C. (CARD), Kennedy, A.M. (C-CORE) and Randell, C.J. (C-CORE), 2012. Arctic Development Roadmap: Prioritization of R&D. Presented at the Offshore Technology Conference, 30 April-3 May 2012, Houston, Texas, USA. OTC 23121.	Arctic R&D needs	Article published in 2012
Arctic Petroleum Exploration (ARCEx)	UiT (the Department of Geology) is the host institution for the research centre. The research is carried out at 6 universities (UiT, NTNU, UiO, UiB, UNIS and UiS) and 4 research institutions (Akvaplan-niva, IRIS, NGU and NORUT). ARCEx is funded by the Research Council of Norway, 9 industry partners (Statoil, ENI, Det norske oljeselskap, ConocoPhillips, Lundin, Tullow Oil, Engie, DONG Energy, and Shell), and by in-kind contributions.	The research centre for ARCtic Petroleum Exploration (ARCEx) is a national centre, with several national and international partners, hosted at the Department of Geology at the University in Tromsø, the Arctic University of Norway. The project was initiated in 2014 and has a duration of eight years.The overarching goal of ARCEx is to create new knowledge about the petroleum resources in the Arctic and to provide essential knowledge and methodology for eco-safe exploration. Five work packages have been established:- Basin analysis- Petroleum systems and play concepts- Environment risk management- Technology for eco-safe exploration in the Arctic- Education	http://www.arcex.no/	Barents Sea	R&D centre 2014-2022
Arctic Portal	AOOS	This portal focuses on the northern Bering, Chukchi and Beaufort Seas. It integrates several hundred layers ranging from habitat type, climatic regimes, tagged animal locations, current weather conditions, political and ecological boundaries, and research instruments. A data layer catalogue enables users to browse data and metadata by category or keyword. The development of this portal was supported by the STAMP project.	http://www.aoos.org/aoos-data-resources/	Metocean and ice data - Bering, Chukchi and Beaufort Seas	Portal
Arctic Potential Report	NPC	The National Petroleum Council (NPC) has conducted a comprehensive study considering the research and technology opportunities to enable prudent development of U.S. Arctic oil and gas resources. In March 2015, the report NPC Arctic Potential – Realizing the Promise of U.S. Arctic Oil and Gas Resources was published (NPC, 2015). The report is a result of significant collaboration by Arctic experts from government, the industry, non-government organizations and Native Alaskans. The study plan was organised around two key themes: 1) Prudent development in the Arctic, and 2) Arctic research and technology Part one provides context on Arctic development experience, resource potential, regulatory practices, and the ice and sea environment in general. Part two of provides an overview of	NPC, 2015. Arctic Potential – Realizing the promise of U.S. Arctic oil and gas resources. Washington, D.C., USA. http://www.npcarcticpotentialreport.org/	Arctic technology	Project 2013-2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		emerging research opportunities, technology development, and collaborative approaches applicable to prudent development in the Arctic. The research and technology overview is grouped in six areas: • Ice characterisation • Oil and gas exploration and development • Logistics and infrastructure • Oil spill prevention, control and response • The ecological environment • The human environment The report concludes that the technology exists today to safely and responsibly develop the U.S. Arctic and is supported by nearly a century of experience in the region. The Arctic environment poses some different challenges relative to other oil and natural gas production areas, but these are generally well understood. However, the Council recommends additional research to both validate recently developed technology for use in the U.S. offshore, and to pursue technology extensions that could lead to improved safety, environmental or cost performance. Key findings: 1. Arctic oil and gas resources are large and can contribute significantly to meeting future U.S. and global energy needs 2. The Arctic environment poses some different challenges relative to other oil and gas production areas, but is generally well understood 3. The oil and gas industry has a long history of successful operations in Arctic conditions enabled by continuing technology and operational advances 4. Most of the U.S. Arctic offshore conventional oil and gas potential can be developed using existing field-proven technology 5. The economic viability of U.S. Arctic development is challenged by operating conditions and the need for updated regulations that reflect Arctic conditions 6. Realizing the promise of Arctic oil and gas requires securing public confidence 7. There have been substantial recent technology and regulatory advancements to reduce the potential for and consequences of a spill The report lists existing oil and gas projects that are in operation in Arctic environments, relevant standards for Arctic designs, and research and joint industry programs relating to Arctic technology. The report has several study topic papers attached, which looks into the details of for example ice management and development drilling. These papers are working documents that were part of the analyses that led to development of the summary results presented in the report's executive summary and chapters. The papers represent the views and conclusions of the authors. NPC has not approved or endorsed the statements and conclusions contained in the documents, but has approved the publication of this material as part of the Arctic Potential report study process.			
ArcticWeb	Aker Solutions	Obtaining information about offshore Arctic areas is a challenge. The problem in many cases is not the lack of information, but an inability to easily access information and determine its reliability and quality. Seven operators on the Norwegian continental shelf initiated a JIP to tackle this challenge, and together with KADME and Acona developed the ArcticWeb to simplify access to public data sources in the Arctic region. ArcticWeb is currently owned and	http://www.arcticweb.com	Metocean and ice data - Norwegian Continental Shelf	Portal

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		administrated by Aker Solutions. The technological platform, Where oil, is supplied and hosted by the Norwegian data solutions firm KADME. The information is used by oil and service companies for the purpose of exploration, early field development, environmental risk analysis, emergency preparedness, safety assessments and more. Information is presented to the users via search and map interfaces, for exploration and analysis. Information can also be exported to Excel and Shapefile format for use in corporate data systems. ArcticWeb covers the entire Norwegian continental shelf with data from a wide-range of Norwegian key data owners. These are amongst others Institute of Marine Research, Geological Survey of Norway, Norwegian Meteorological Institute, Norwegian Directorate of Fisheries, Norwegian Coastal Administration and Norwegian Petroleum Directorate.			
Barents 2020	Funded by the Norwegian government, in addition to Russian and Norwegian industry	The Barents 2020 project was initially aimed at creating a dialog between relevant Norwegian and Russian parties regarding safety of petroleum related activities in the Barents Sea. The aim was to arrive at common acceptable standards for safeguarding people, environment and asset values in the oil and gas industry in the Barents Sea, including transportation of oil and gas at sea. The project was funded by Russian and international companies with support from the Norwegian Government's Barents 2020 program. The project was conducted in four phases: Phase 1 (October 2007-October 2008) produced five 'position papers' and established the Norwegian – Russian partnership model for the project (Barents 2020, 2012). Phase 2 (November 2008-March 2009) prioritised and selected from a range of topics, seven key areas for further work in seven specialist working groups; 1. Co-ordination of deliverables 2. Design of floating structures in ice 3. Risk management of major hazards 4. Escape, evacuation and rescue of people 5. Working environment 6. Ice management – state of the art 7. Operational discharges to air and water Phase 3 (May 2009-March 2010) identified 130 standards recommended for common use of which 64 can be applied "as is" and the remaining 66 can be applied provided special considerations are made for low temperatures and/or ice loading. The recommendations provided by five of the seven working groups (2, 4, 5, 6 and 7) were submitted to the relevant standardisation body, primarily ISO technical committee (TC) 67's 19906 standard, and to the new TC 67 subcommittee (SC) 08 on Arctic operations. Working group 1 was tasked with recommending and guiding the process to format and channel the deliverables and results to the correct standardisation addresses, while working group 3 risk management, did not recommend any new standards, though was tasked with running seminars. The phase 3 final report was published in 2009 (Barents 2020, 2009). Phase 4 (May 2010-May 2012) brought forward from phase 3 those issues and topics in greatest need of completion, revision and detailed guidance. The phase 4 final report was published in 2012 (Barents 2020, 2012).	Barents 2020, 2009. Barents 2020. Assessment of international standards for safe exploration, production and transportation of oil and gas in the Barents Sea. Final Report Phase 3. DNV Report 2009-1626, Høvik, Norway. Barents 2020, 2012. Barents 2020. Assessment of international standards for safe exploration, production and transportation of oil and gas in the Barents Sea. Final Report Phase 4. DNV Report 2012-0690, Høvik, Norway.	Standardisation between Russian and Norwegian parties regarding safety of petroleum related activities in the Barents Sea	Project 2007-2012
Barents Sea Exploration and Cooperation (BaSEC)	Statoil, Eni Norge, Lundin Norway, OMV, Engie	The BaSEC project is a joint initiative project between the active operators in the Northern Barents Sea imitated in 2015. The program aims to meet the expectations as stated by governing authorities through strengthening HSE and operational preparedness for	http://www.statoil.com/en/NewsAndMedia/News/2015/Pages/21Apr_Barents_conf.aspx	Exploration activities – Barents Sea	JIP 2015-2018

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		exploration activity in the Norwegian Barents Sea, with special focus upon new areas opened for oil and gas activity in the 23rd concession round areas. The following work groups are established: •Metocean and ice •Environment and oil spill response •Logistics and emergency response •Mobile drilling units •Health and working environment			
BarentsObserver	BarentsObserver	BarentsObserver.com is an open internet news service, which offers daily updated news from and about the Barents Region and the Arctic. The site was founded in 2002 and has since 2005 been run by the Norwegian Barents Secretariat. Staff-writers are employees of the secretariat. The news-desk is located in Kirkenes, northern Norway. The site presents news stories from the northern parts of all the four countries in the region: Russia, Norway, Sweden and Finland. All news stories are published in English and Russian. All news material is categorized in: Energy, Security, Nature, Business, Arctic, Culture, Borders, Politics and Society. An archive search function gives you full access to the news archive, which presently contains more than 15.000 news reports. BarentsObserver also provides background cross-border information about the Barents cooperation and bilateral contacts between the member regions.	http://barentsobserver.com	The site presents news stories from the northern parts of all the four countries in the region: Russia, Norway, Sweden and Finland. All news stories are published in English and Russian.	News service founded in 2002
BarentsWatch	A cooperation between ministries, state agencies and research institutes	BarentsWatch is a comprehensive monitoring and information system for large parts of the world's northern seas.By coordinating information and developing new services based on the combination of data, BarentsWatch will disseminate a better factual basis and more comprehensive picture of the activities in, and condition of, our seas and coastal areas.The system will make relevant information and services more easily accessible for authorities, decision-makers and general users. This will simplify access to and ensure the exchange of public information.An open part of BarentsWatch shall be an information portal available to everyone. This was launched in 2012, and is being developed incrementally. The portal has information about topics such as the climate and environment, marine resources, oil and gas, maritime transport and maritime law, among other things. There are also map services, an overview of ports, and news from about 25 partners.	https://www.barentswatch.no/en/	Metocean and ice data	Portal launched in 2012. Incrementally developed
Centre for Arctic Resource Development (CARD)	C-CORE, Hibernia, R&D Corporation of Newfoundland and Labrador, Terra-Nova, MUN	CARD is a medium to long term R&D initiative dedicated to responsible, cost-effective hydrocarbon development in Arctic regions that was established in 2011. Arctic environments present formidable barriers to hydrocarbon development. CARD serves as focal point for planning, coordinating and conducting research to fill gaps in the knowledge, technology, methodology and training needed to remove these barriers. CARD research programs are organized into core areas of: - Ice mechanics - Ice management and station-keeping in ice, - Floating system modelling CARD is located within C-CORE complex of facilities on Memorial University Campus in St. Johns, Canada. It forms part of a well-established and continually evolving Newfoundland research and development community and technology cluster.	https://www.card-arctic.ca/	General	R&D centre established in 2011
Centre for Autonomous Marine	NTNU, SINTEF, MARINTEK, Statoil, DNV GL	The centre for Autonomous Marine Operations and Systems (AMOS) works to create a world-leading centre for autonomous marine operations and control systems. AMOS will contribute with fundamental and interdisciplinary knowledge in marine hydrodynamics, ocean	https://www.ntnu.edu/amos/	Support vessel	R&D centre 2012-2022

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
Operations and Systems (AMOS)		constructions and control theory. The research results will be used to develop intelligent ships and ocean structures, autonomous unmanned vehicles (under water, on the surface and in air) and robots for high-precision and safety-critical operations in extreme environments. This is necessary in order to meet challenges related to environmental and climate, safe maritime transport, mapping and surveillance of large ocean and coastal regions, offshore renewable energy, fisheries and aquaculture as well as deep-sea and Arctic oil and gas exploration. AMOS projects are:1. Renewable offshore energy2. Intelligent aquaculture structures3. Autonomous unmanned vehicles4. Autonomous underwater robotics5. Autonomous unmanned aerial vehicles6. Energy and green operations7. Autonomous marine operations8. Accidents and abnormal events9. Subsea intervention			
Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA)	UiT Research partners: NORUT (MET Norway) Norwegian Polar Institute NTNU Nansen Environmental and Remote Sensing Centre Researchers from different international research institutions	The centre for integrated remote sensing and forecasting for Arctic operations (CIRFA) project was started in 2015 and will have a duration of up to eight years. The main objective of the centre is to develop knowledge and technology for the monitoring of maritime conditions and forecasting of weather, emissions and sea and ice conditions in Arctic waters. These factors are essential for the petroleum, shipping and fishing industries to be able to conduct safe and sustainable operations in the northern waters. Seven work packages have been established: - Ocean remote sensing - Sea ice, iceberg and growler remote sensing - Oil spill remote sensing - Remotely piloted aircraft systems (RPAS) technologies - Drift modelling and prediction - Data collection and field work - Pilot service demonstration	http://cirfa.uit.no/	Metocean and ice data	R&D centre 2015-2023
Chevron's Arctic Center	Chevron	Chevron's Arctic Center is a centralized, multidisciplinary group of Arctic subject matter experts from a wide range of engineering disciplines and operational backgrounds, including; drilling, Arctic oil spill response, facilities and geotechnical engineering, naval architecture, logistics, environmental, regulatory affairs, indigenous and stakeholder consultation, ice regimes/ice management and Master Mariners. Chevron Arctic Center supports all stages of Chevron projects in Arctic and ice-prone regions globally. Chevron Arctic Center specialists play a key role in identifying, and aiding in providing solutions to, a range of specific Arctic issues, including technological research and development.	http://www.chevron.ca/our-businesses/chevron-arctic-center	General	R&D centre
ColdTech - Sustainable Arctic Technology	Led by NORUT. The forum consists of Høgskolen i Narvik, Energi Campus Nord, NORUT, Luleå Tekniske Universitet, DNV.	The ColdTech project is a research initiative of the NORDSATSING program of the Research Council of Norway to promote sustainable development in northern Norway. Arctic technology covers most aspects of construction, operations and living in the Arctic region. Cold climate technology is technology developed to address challenges and to utilize advantages of cold climate. ColdTech is a platform to support sustainable development of education in the north, networking between research and industry, competence development amongst ColdTech partners (including industry and R&D institutes and universities), and state-of-the-art research activities. It aims to strengthen both research and industry northern Norway. ColdTech is divided into four work packages, and one implementing package: 1. Weather protection design and performance 2. Ice mechanics and ice forces 3. Atmospheric icing on structures 4. Applied Arctic technology	http://www.arctic-technology.com	Arctic technology	Project 2010-2017

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		5. Implementation of technological research			
DrillWell - Drilling and Well Centre for Improved Recovery	IRIS, UiS, SINTEF, NTNU	The vision of the Drilling and Well Centre for Improved Recovery is to unlock petroleum resources through better drilling and well technology. The Drilling and Well Centre for Improved Recovery was established in 2010 and received status as a Centre for Research Based Innovation (SFI) from the Research Council of Norway in 2011. DrillWell's objective is to improve drilling and well technology, providing improved safety for people and the environment, and value creation through better resource development, improved operational efficiency and reduced costs.This will be achieved by targeted research and development, focusing on: 1.Safe and efficient drilling process2.Drilling solutions for improved recovery3.Well solutions for improved recoverySome research and development activities are Arctic specific. The developed technology and solutions will be commercially available in the market through cooperation with the service industry.	http://drillwell.no/home	Drilling / wells	R&D centre established in 2010
European Arctic initiatives compendium	Arctic Info	One of the main activities of the Arctic Info EU Arctic information centre feasibility study was to develop an Arctic initiatives compendium. The European Arctic initiatives compendium compiles flagship initiatives undertaken in the Arctic regions by member states and actors operating within states belonging to the European Union (EU) or the European Economic Area. It aims to assist in an Arctic Information Centre feasibility study; to provide a window into Arctic initiatives that may inform the European Arctic impact assessment which forms part of the preparatory action; and to inform the European Commission on European Arctic initiatives. The compendium provides an overview of existing inventories and reports before proceeding to detail European infrastructural and institutional initiatives in the Arctic. The compendium documents major strategic processes initiated by European bodies in the Arctic. It also outlines initiatives related to monitoring and assessment as well as commercial development.	Dählbäck, B., van der Watt, L.M., Jagodzinski, K., Kankaanpää, P., 2014. European Arctic Initiatives Compendium. Preparatory Action, Strategic Environmental Impact Assessment of development of the Arctic. Arctic Centre, University of Lapland, Finland. http://www.arcticinfo.eu/en/compendium	European Union	Project
High North HSE Challenges Project	Norwegian Oil and Gas Association	The initiative "HSE challenges in the High North" was launched by the Norwegian Oil and Gas Association in 2010 as a three part cooperation between the industries organisations, labour unions and authorities. The purpose of the work was to increase the knowledge and establish a common understanding in the industry on the challenges one may experience with petroleum operations in the High North. A large volume of literature and other information was gathered, systemized and assessed. These formed the basis for six thematic working seminars with invited delegates and expert keynote speakers. At the seminars a large number of issues were raised and discussed and afterwards systemized by the secretariat. The themes of the seminars were: • Climatic conditions and communication • Health and working environment • Helicopter logistics and helicopter emergency preparedness • Risk management and design • Emergency preparedness (other than helicopter) • Logistics and ice control Following the seminars, necessary actions to solve the unsolved issues were identified. The work was finalized with an open summary conference in November 2014 and a summary report with recommendations for further work under the following headlines: • Improved weather forecasts • Emergency preparedness, clarification on industry and public responsibilities • Implementation of remote medical support (telemedical communication) • Satellite communication • Helicopter safety	Norwegian Oil and Gas Association, 2015. HSE challenges in the High North summary report (n Norwegian). https://www.norskoljeoggass.no/no/HMS-utfordringer-i-nordomradene/	Norwegian High North	Project 2010-2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		• Operational guidelines • Clothing and work protection equipment • Contributions to the work on the ISO TC67 SC8 Arctic operation standards • Recommendations for R&D programmes			
INTSOK	INTSOK	INTSOK – Norwegian oil and gas partners – was established in 1997 as an independent non-profit foundation to strengthen the long-term basis for value-creating and employment in the Norwegian oil and gas industry through expanding the industry's international business activities (INTSOK, 2015). The objective is to promote the Norwegian oil and gas industry's leading expertise, technology and experience to key clients in international markets and to provide market information to partners.	http://www.intsok.com/	Russian / Norwegian cooperation	Foundation established in 1997
Lloyd's Register Applied Technology Group - Polar Technologies	Lloyd's Register	Lloyd's Register has an applied technology group. The group provides multidisciplinary consulting services, engineering analysis software and contract research services to clients in industry and government worldwide. The group has capabilities within the following areas: - Public Safety - Survivability - Life-cycle management - Polar technologies - Advances tools - Emerging technologies Within polar technologies, the group work to progress regulatory development hand-in-hand with commercial and government asset development. The specialist areas of expertise are: - Polar code development - Ice and cold operations - Ice damage assessment - Structural analysis - Strength assessment - Risk assessment - Vessel reliability studies	http://www.lr.org/en/marine/technology-and-innovation/AppliedTechnologyGroup/polartechnologies.aspx	General	R&D centre
LOOKNorth	C-CORE, Government of Newfoundland and Labrador (Canada), Network of Centres of Excellence (Canada), R&D Corporation of Newfoundland and Labrador, MUN	LOOKNorth (Leading Operational Observations and Knowledge for the North) is a national (Canadian) centre of excellence for commercialization and research hosted by C-CORE. In collaboration with a broad network of industry, northern, business and research partners, LOOKNorth validates and drives commercialization of monitoring technologies to support safe and sustainable development of Canada's northern natural resources. It promotes the use of remote sensing (RS) technologies in environmental monitoring for northern stakeholder groups.LOOKNorth is mandated to:- Conduct information and technology gap analysis for northern resource development- Facilitate information sharing among stakeholders in northern development- Guide research and development towards commercialization of technologies that can address information gaps- Support technology validation	https://www.looknorth.org/	General	R&D centre
Maritime Surveillance in the Northern Sea Basins (MARSUNO)	24 authorities from 10 countries	The Maritime Surveillance in the Northern Sea Basins (MARSUNO) project was a pilot project initiated by the European Commission. 24 authorities from 10 countries are partners in the project, which aims to achieve a higher degree of interoperability among existing monitoring and tracking systems in order to improve maritime surveillance in the Baltic Sea and the North Sea area. The main purpose of the pilot project is to create a common information sharing environment for the EU maritime domain in order to optimize the efficiency and the cost of maritime surveillance throughout the EU. The work was divided into six work groups: • Integrated border management – law enforcement	http://ec.europa.eu/newsroom/mare/itemdetail.cfm?subweb=342&lang=en&item_id=8669	The project covers Baltic Sea and North Sea. It is suggested that this project is extended to include other cold region areas such as the Barents Sea.	Project 2011-2012

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		• Vessel traffic monitoring information system • Maritime pollution response • Search and rescue • Fisheries control • Maritime situational awareness			
NRC's Arctic Program	NRC	By partnering with the northern shipping and mining industries, as well as with government regulators and operators, the program develops technologies that will result in safer and more efficient shipping operations in ice-covered waters. The Arctic program also works to improve petroleum development by optimising ice management, investigating ice loads on offshore structure, developing oil spill solutions and improving the performance of life-saving appliances (LSA) in extreme and remote environments.	http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/arctic.html	General	R&D programme
Oil and gas in the 21 century (OG21)	OG21, DNV GL	Oil and gas in the 21 century (OG21), the office for the Norwegian national petroleum technology strategy, is currently developing an overview of technology challenges for year-round oil and gas production at 74°North in the Norwegian part of the Barents Sea (DNVGL, 2015).	DNV GL, 2015c. Technology challenges for year-round oil and gas production at 74°N in the Barents Sea. DNV GL report no. 2015-0925, draft edition, Høvik, Norway. www.og21.no	Arctic R&D needs	Project, draft report published in 2015
Petro Arctic	Main partners: Statoil and Eni Norway Partners: OMV, Lundin, Total, Dong, Det Norske, Engie	Petro Arctic is an interest organization for companies wishing to position themselves as suppliers to the development and operation of petroleum projects on the northern Norwegian shelf. The main objective of Petro Arctic is to get as large deliveries of goods and services as possible from the member companies to producing fields or fields under development in the Norwegian Sea North and Barents Sea. This is achieved by marketing the member companies to operators and builders, as well as through motivating and preparing members through participation in networking and skills development program. Petro Arctic is organized as an association with the annual meeting as the highest organ. The Association Board is elected from among the member companies. Petro Arctic was established in 1997.	www.petroarctic.no	Norwegian High North	Portal
Petroleum Research Newfoundland & Labrador (PRNL)	Members are: - Chevron Canada Resources - Exxon Mobil Canada - Husky Energy - Statoil Canada - Suncor Energy	PRNL is a federally-incorporated, member based, non-for-profit organization that facilitates research and technology development and delivers value to members by identifying opportunities, developing proposals, and funding and managing the execution of projects on behalf of the Newfoundland and Labrador offshore oil and gas industry. PRNL seeks proposals for research and technology development projects that address the operational, technical and business of its members.	http://pr-ac.ca/	Arctic R&D - Newfoundland & Labrador	Organisation
Polar View	Service providers, government agencies, research institutions, system developers, universities from 9 countries across Europe and Canada	Polar View is a global organization providing satellite-based information and data services in the polar regions and the cryosphere. Their services include enhanced sea ice information (charts and forecasts) as well as ice-edge and iceberg monitoring data. They also provide monitoring services for lake and river ice, snow cover maps and glacier monitoring and assessment. The Polar View team is comprised of a dynamic group of service providers, government agencies, research institutes, system developers and universities from over 9 countries across Europe and Canada. Each organization brings diverse and complementary skills and world-renowned expertise in polar earth observation technologies, applications and research. The team delivers data and information services for addressing polar issues that meet the ongoing needs of its user sectors, including marine transportation, oil and gas, emergency management and fishing.	www.polarview.org	Ice detection, forecasting and monitoring	Organisation
RU-NO Barents Project (Russian-Norwegian Oil & Gas	Project led by INTSOK, participants are public and	The RU-NO Project is a Russian-Norwegian oil & gas industry cooperation project that will assess the gap between the technology currently available and the technology needed for	http://www.intsok.com/Market-info/Markets/Russia/RU-NO-	Arctic technology – Barents,	Project 2012-2015

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
industry cooperation in the High North)	private actors from Russia and Norway	extracting oil and gas resources in the Barents, Pechora and Kara Seas in an environmentally sound and safe way. The project's tasks are to: - Assess common technology challenges Russia and Norway face in the development of the High North - Analyse existing technologies, methods and best practice Russian and Norwegian Industry can offer for the High North today - Based on the above: Visualize the need for innovation and technology development the industry in our two countries need to overcome - Promote stronger industrial links Focus areas are: 1. Logistics & 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/http://www.intsok.com/Market-info/Markets/Russia/RU-NO-Project/	Pechora and Kara Seas	
Shell Ice and Weather Advisory Center (SIWAC)	Shell	In the absence of pooled forecasting services and operational-grade forecasting capacity by public weather services, Shell has developed and operates an in-house, Anchorage based, forecasting program designed specifically for the demands and requirements of Shell's Alaska operations. Shell Ice and Weather Advisory Center (SIWAC) is a focused ice and weather forecast operation covering the offshore and coastal areas from the Gulf of Alaska to the Canadian Beaufort Sea. SIWAC consists of a team of fulltime Arctic experienced forecasters working in a 24/7 rotation schedule and are fully integrated into the operations process, directly engaging with field personnel and decision makers. Development of differentiating forecast products and services depends not only on an expert team, but also a robust observation program consisting of contracted and public satellite imagery, a network of metocean buoys, satellite-tracked ice movement beacons, and steady stream of field observations from specially trained personnel abroad marine and aviation assets. The SIWAC forecasters develop numerous daily products including site-specific, wide-area, vessel routing, and weather window forecasts that are delivered to end users through websites and live briefings. To aid in improving forecasting performance and research across the board, Shell entered into a Memorandum of Agreement with the National Oceanic and Atmospheric Administration (NOAA) in 2012. This collaborative agreement makes Shell's Arctic metocean data and ice charts publically available through NOAA and fosters dialog between the SIWAC and NOAA forecasters.	Raye, R. (Shell), 2015. Forecasting ice and weather conditions for field operations in Alaska. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25497. http://www.siwac.com/Login.aspx?ReturnUrl=%2f	Metocean and ice data	R&D centre established in 2007
Strategic environmental impact assessment of development of the Arctic	Arctic Info	The strategic environmental impact assessment of development of the Arctic strengthens communication and outreach within the EU and between the EU and the Arctic community about the contribution the EU is making to address environmental and other issues raised by the rapid development of the Arctic region as a result of economic and climate change. The primary objective is to compile stakeholders' knowledge and perspectives on the scientific information about the development of the Arctic as well as increase awareness about the Arctic and its changing political, economic and environmental landscape, and the impact of EU policies. The objective enhances the use of impact assessment and its importance as a tool and a channel to put together information for the use of decision- and policy-makers and the related legal processes.	http://www.arcticinfo.eu/	European Union	Project

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
		The secondary objective is to test the effectiveness and sustainability of the network of leading communication and research centres as the basis of a possible future European Arctic information centre aiming at facilitating information exchange between the EU institutions, Arctic stakeholders and the general public. The project is comprised of four work packages: - EU Arctic information centre feasibility study - Impact assessment - Outreach and communication - Project management			
Sustainable Arctic Marine and Coastal Technology (SAMCoT)	NTNU host institutionIn total 22 partners are members of the centre, of which 13 partners are industry participating partners, including oil and gas companies, offshore contractors, design institutes and regulatory bodies.	SAMCoT (Sustainable Arctic Marine and Coastal Technology) is a centre for research based innovation with long-term funding by the Research Council of Norway and the Energy Industry. The vision of SAMCoT is to be a leading national and international centre for the development of robust technology needed by the industry operating in the Arctic region. SAMCoT started in 2011, and is tasked to meet the engineering challenges due to ice, permafrost and changing climate for the benefit of the energy sector and society. Research is divided in six different work packages: - Data collection and process modelling - Material modelling - Fixed structures in ice - Floating structures in ice - Ice management and design philosophy - Coastal technology Kuiper et al. (2015) describes how SAMCoT is preparing and contributing to the sustainable industry development in the Arctic region. Research and development of new Arctic technology, the implementation of innovative methods in the oil and gas industry, collaborative way of working, and education of the next generation engineers are highlighted in the paper.Reliable designs of Arctic offshore and coastal structures require a proper quantification of the physical environment as well as good prediction models for the response of these structures in interaction with ice features. The researchers at SAMCoT address these challenges with a combined approach that utilizes experimental, theoretical and numerical techniques. Many researchers in SAMCoT are working on understanding the ice physics and developing the underlying theory. The research is as much as possible focused on gathering and analysing full-scale data in the Arctic field. So far, the close cooperation between the academia and industry in SAMCoT has developed into a fruitful two-way bridge to drive sustainable developments in the Arctic. Steer, full-scale data and expert resources are flowing from the industry to the researchers, whereas knowledge, insight and a new generation of Arctic engineers is becoming available.	Kuiper, G. (Shell) and Løset, S. (SAMCoT, NTNU) 2015. SAMCoT: Leveraging Cross Sector Collaboration to Drive Sustainable Energy Developments in the Arctic. Presented at the Arctic Technology Conference, 23-25 March 2015, Copenhagen, Denmark. OTC 25494. https://www.ntnu.edu/samcot	General	R&D centre 2011-2019
Technology challenges and knowledge status	PSA, UiS, IRIS	The PSA has published a report discussing the technology challenges and knowledge status for reducing the risk for undesirable events resulting in acute pollution to sea with regard to offshore petroleum activities in the Norwegian part of the Barents Sea (PSA, UiS and IRIS, 2010). The report summarizes status as of 2010, and it is evident that several new research and development activities have been initiated since then.	PSA, UiS & IRIS, 2010. Teknologi- og kunnskapsstatus av betydning for å redusere risiko for uønskede hendelser som kan føre til akutte utslipp til sjø i forbindelse med petroleumsvirksomhet i Nordområdene. Stavanger, Norway (in Norwegian). http://www.ptil.no/getfile.php/PDF/Underlagsrapporter%20-%20forvaltningsplan%20Barentshavet%20-%20Lofoten%202010/Underlagsrapport	Arctic R&D needs	Report published in 2010

Initiative	Developed by / participants	Description	Reference	Relevance	Type and time perspective
			_4_Teknologi-%20og%20kunnskapsstatus.pdf		