**Faculty of Science and Technology**

Department of Engineering and Safety

# Identification of Challenges and Hazards associated with Cruise Traffic and Evacuation in the Arctic

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*Master thesis in Technology and Safety in the High North - June 2016*

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Abstract

Arctic cruise tourism is gaining in popularity. There is a need to better understand hazards that are connected with cruise traffic and evacuation in the Arctic. The Polar Code tries to enhance the safety of persons travelling in polar waters by giving functional requirements to life-saving appliances. However, it is unclear what is needed to achieve the required functionality, and how existing life-saving appliances perform compared to the requirements in the Polar Code.

This thesis looks to present the challenges associated with cruise traffic in the Arctic, the main hazards associated with evacuation in an arctic environment, and what the possible gaps are between the current life-saving appliances and the level of safety the Polar Code tries to ensure.

Based on a literature review, a risk analysis and a practical test, the thesis presents a review of arctic region characteristics, historical accidents, regulations and existing life-saving appliances. It also presents a description of the main hazards associated with evacuation from a cruise ship in an arctic environment, and the corresponding gaps between the performance of existing life-saving appliances and the level of safety the Polar Code tries to ensure.

The challenges, hazards and gaps are discussed through incorporating results from the literature review, the risk analysis and the practical test. The thesis also highlights the contributions the authors provided to the SARex project through a preliminary hazard analysis, leading risk assessments prior to the practical test, actively participating in the test and documenting the workshop that summarized the experiences from the test.

***Keywords:*** *Preliminary Hazard Analysis, Risk Analysis, Polar Code, Life-saving Appliances, Lifeboat Habitability, Arctic Cruise Challenges, Personal Protective Equipment, Personal Survival Kit, Group Survival Kit, SARex, Full-scale Exercise.*

# Preface

The thesis “Identification of Challenges and Hazards associated with Cruise Traffic and Evacuation in the Arctic” concludes our master’s degree in Technology and Safety in the High North at the Faculty of Science and Technology, UiT – The Arctic University of Norway. The research for and writing of this thesis was performed from January to June 2016.

We would like to thank our supervisors, Professors Javad Barabady and Ove Tobias Gudmestad, for assistance and guidance in the preparation and completion of this thesis. Professor Gudmestad also deserves special thanks for inviting us to participate and contribute in the SARex project, which gave valuable first-hand experience and unique opportunities for data collection.

Erik Mostert from Norsafe AS has provided expert knowledge and insight about lifeboats and arrangements, which was invaluable information when performing the risk analysis. We would also like to show our appreciation to all of the SARex participants, for valuable contributions to the risk assessments and interesting technical discussions.

The commanding officer of KV Svalbard Endre Barane and his crew deserves our gratitude, by sharing their experiences they helped us better understand the challenges in the Arctic areas. Jim A. Olsen and Ståle Antonsen at the Department of Engineering and Safety were very helpful and provided us with measuring equipment that allowed us to present data we collected ourselves. We would also like to thank Frigg Jørgensen from AECO for always answering us swiftly and thoroughly on all questions we had regarding arctic cruise tourism.

Tromsø, June 2016

Raymond Dalsand & Tord Nese

# Contribution

The thesis is written as a cooperation between Dalsand and Nese. The following lists describe who were in charge of the sections, although it has to be noted that we have cooperated extensively on all parts. All sections have been discussed thoroughly between us, and both have contributed to the creative process of all sections. All appendices were equally contributed to by the both of us.

Written by Dalsand with feedback and inputs from Nese:

- Abstract
- Introduction
- Wildlife
- Search and rescue
- Historical accidents
- Regulations
- Review of lifeboat habitability
- About SARex
- Planning and preparation
- Research trip timeline
- Main findings regarding hazards and possible gaps
- Discussion

Written by Nese with feedback and inputs from Dalsand:

- Preface
- Research methodology
- Basic concepts of risk analysis
- Arctic region characteristics (except the parts from Dalsands list)
- Life-saving appliances
- Phase one details
- Preliminary hazard analysis
- Graphic presentation of identified hazards
- Conclusion
- Suggestions for further research

# Abbreviations

| | |
|---|---|
| **AECO** | Association of Arctic Expedition Cruise Operators |
| **AIS** | Automatic Identification System |
| **ALARP** | As Low as Reasonably Practicable |
| **CO** | Carbon Monoxide |
| **$CO_2$** | Carbon Dioxide |
| **GPS** | Global Positioning System |
| **GRP** | Glass-reinforced Plastic |
| **GSK** | Group Survival Kit |
| **HF** | High Frequency |
| **HRS** | Hovedredningssentralen (Joint Rescue Coordination Centre) |
| **IAATO** | International Association for Antarctica Tour Operators |
| **IMO** | International Maritime Organization |
| **LSA** | Life-saving Appliances |
| **MF** | Medium Frequency |
| **MOB** | Man Overboard |
| **PEC** | Pilot Exemption Certificate |
| **PHA** | Preliminary Hazard Analysis |
| **PPE** | Personal Protective Equipment |
| **PPM** | Parts Per Million |
| **PSK** | Personal Survival Kit |
| **RH** | Relative Humidity |
| **RRM** | Risk-reducing Measures |
| **SAR** | Search and Rescue |
| **SARiNOR** | Search and Rescue in the High North |
| **SOLAS** | International Convention for the Safety of Life at Sea |
| **TELB** | Totally Enclosed Lifeboat |
| **TPA** | Thermal Protective Aid |
| **VHF** | Very High Frequency |
| **WP** | Work Package |

# Definitions

| | |
|---|---|
| **Automatic Identification System** | Radio or satellite based vessel identification system that is used for collision avoidance, identification and location information. AIS ship tracking is also used for maritime domain awareness, search and rescue, environmental monitoring and maritime intelligence applications (ORBCOMM, n.d.). |
| **Davit** | A small crane on board a ship, especially one of a pair for suspending or lowering a lifeboat (Oxford Dictionaries, n.d.) |
| **Echo sounder** | A piece of equipment, especially on a ship, that uses sound waves to discover water depth or the position of an object in the water (Cambridge Dictionaries Online, n.d.) |
| **Hydrography** | The branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and defense, scientific research, and environmental protection (International Hydrographic Organization, 2015). |
| **Immersion suit** | Suit designed to protect the user’s body from the cooling effects of unintended immersion in water (ISO, 2012). |
| **Iridium** | Satellite system used to provide voice and data coverage to satellite phones, pagers and other equipment with full global coverage (including the poles) (Poole, n.d.). |
| **Polar low** | Small, relatively intense depressions (low pressure area) which forms mainly in winter over some high-latitude seas with polar or arctic air mass (MetLex, n.d.) |

| | |
|---|---|
| **Risk** | Combination of possible future consequences/outcomes and the associated uncertainties. Probabilities can be used to specify uncertainty. If this is done, risk can be expressed as a function of probability and consequence (Aven, et al., 2008). |
| **Salinity** | Term referring to the amount of dissolved salts that are present in water (Encyclopædia Britannica, n.d.) |
| **Snow squall** | A brief, but intense fall of snow that greatly reduces visibility and which is often accompanied by strong winds (National Snow & Ice Data Center, n.d.) |
| **Svalbard Fisheries Protection Zone** | A 200 nautical mile zone of fisheries jurisdiction around the Svalbard archipelago, under Norwegian sovereignty. Effective from 15$^{th}$ of June 1977 (Regjeringen.no, 2014). |
| **Winterization** | To make (something) able to resist the effects of winter weather (Merriam-Webster, n.d.) |

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# 1. Introduction

## 1.1 Background

Cruise traffic in the Arctic is gaining in popularity. The more passengers that travel there on cruise ships, the more challenging it will be to ensure their survival in case of an accident. When it comes to tourism, attractions such as remoteness and extreme conditions are key elements of the experience. These characteristics are central to emergency preparedness as well, creating a bit of a paradox. The challenge is to facilitate for arctic tourism and traffic while at the same time ensuring the safety of all travelers, also in emergency situations. In recent years there have been more focus on increasing the safety of ships operating in these remote, vulnerable and potentially harsh polar waters. This focus has culminated in International Maritime Organization (IMO) adopting The International Code for Ships Operating in Polar Waters, the Polar Code.

The Polar Code requirements, especially the maximum expected time of rescue of five days, will put additional strain on existing life-saving appliances. The life-saving appliances will most likely have to be more suited to the polar environment, withstand a harsher climate and temperatures, and keep people safe for a longer period of time than the existing International Convention for the Safety of Life at Sea (SOLAS) approved life-saving appliances.

In order to identify and explore the possible gaps between existing SOLAS approved safety equipment and the functionality required by the Polar Code, the full scale exercise SARex was planned. The exercise was conducted together with the Norwegian Coast Guard, leading experts from the industry, governmental organizations and academia. The authors were invited to participate on this exercise, and it serves as the backbone of this thesis.


*Figure 1: KV Svalbard in the ice in Woodfjorden. Photo © Trond Spande*

SARex was conducted in late April 2016, with the help of the Coast Guard ship KV Svalbard, depicted in Figure 1. Norsafe provided a lifeboat that was picked up by KV Svalbard in Tromsø prior to the exercise. Viking Life-Saving Equipment provided a life raft, various Personal Protective Equipment (PPE), Personal Survival Kit (PSK) and Group Survival Kit (GSK). The trip lasted for one week, KV Svalbard departed with the participants from Longyearbyen on a Friday and travelled north on the west side of Svalbard. During Sunday, Monday and Tuesday the exercises were conducted in Woodfjorden. KV Svalbard stopped on the return trip in Ny-Ålesund on Thursday and returned to Longyearbyen approximately one week after departure.

## 1.2 Research problem

Arctic cruise tourism is gaining in popularity and more passengers mean more lives are at risk every year. It is increasingly important to ensure the safety of passengers and crew on these cruises. To accomplish this, there is a need to better understand the hazards connected with cruise traffic and evacuation in case of an accident in the Arctic.

The Polar Code tries to enhance the safety of persons travelling in polar waters by giving functional requirements to life-saving appliances. However, it is unclear what is needed to achieve the required functionality. It is also not clear how the current life-saving appliances perform in arctic conditions, and how they perform compared to the requirements of the Polar Code.

## 1.3 Research questions

Based on the research problems described, the following research questions have been defined:

1. What are the main challenges related to cruise traffic in the Arctic?
2. What are the main hazards associated with evacuating from a cruise ship in an arctic environment?
3. What are the gaps between the existing life-saving appliances functionality and the level of safety the Polar Code tries to ensure?

## 1.4 Aim and research objectives

This thesis looks to present the challenges associated with cruise traffic in the Arctic, the main hazards associated with evacuation in an arctic environment, and what the possible gaps are between the current life-saving appliances and the level of safety the Polar Code tries to ensure.

In order to answer research question one, the following research objective has been developed:

- Identify the characteristics of the arctic region, review historical accidents and regulations, and look into existing life-saving appliances to be able to discuss the main challenges related to cruise traffic in the Arctic.

To be able to answer research questions two and three, the following research objective has been developed:

- Perform a risk analysis that will, together with the tests done with SARex in Woodfjorden, try to identify the main hazards associated with evacuation from a cruise ship in an arctic environment and identify possible gaps between the performance of existing SOLAS approved life-saving appliances and the level of safety the Polar Code tries to ensure.

## 1.5 Limitations

This thesis is governed by some limitations, which are:

- Life-saving appliances that are analyzed in this thesis is limited to lifeboats, PPE used in the test, PSK and GSK.
- The Arctic in this thesis, mainly refers to the Norwegian area of responsibility in the Arctic.
- The SARex test did not include a davit, which is the lifeboat launching arrangements.
- The preliminary hazard analysis (PHA) is based on an evacuation into and survival in a lifeboat, not onto ice.

## 1.6 Structure of thesis

- **Chapter 1 – Introduction**
  - In this chapter the background of the thesis is described. It defines the research problem and presents the research questions that were developed. The chapter also explains the aim for the thesis and the research objectives that were developed to try to answer the research questions. Limitations to the thesis and its structure is also mentioned.
- **Chapter 2 – Research methodology**
  - Chapter 2 includes the overview of the methods used for the research on which the thesis is based. It describes the process of how the literature review was performed, what choices were done regarding the risk analysis and the objective of the practical test the authors participated in.
- **Chapter 3 – Literature review**
  - The literature review presents the basic concepts of risk analysis, the arctic region characteristics, the most relevant regulations and life-saving appliances to this thesis. It also includes historical accidents and a review of previous lifeboat habitability studies.
- **Chapter 4 – SARex research trip**
  - The details surrounding SARex and the trip to Woodfjorden on the north side of Svalbard are presented in this chapter. It includes the planning and preparations done before the trip and an informative timeline of the events on the trip. It also presents the details regarding the lifeboat test that were the main focus for the authors on this trip, and the results from the logging and the equipment used during the test. This chapter also highlights the contributions the authors provided to the SARex project.
- **Chapter 5 – Preliminary hazard analysis**
  - This chapter explains the focus of the PHA, why it was chosen as the preferred method, how it was performed and the results gathered.
- **Chapter 6 – Discussion**
  - Both research objectives are discussed in this chapter, the first mostly based on the literature review and the experiences from the research trip. The second research objective is discussed mostly based on the findings from the PHA and the experiences from the research trip.
- **Chapter 7 – Conclusions**
  - The last chapter includes conclusions and suggestions for further research.

# 2. Research methodology

This chapter aims to provide an overview of the methods used for the research on which this thesis is based.

To be able to fulfil the research objectives, extensive information and data gathering was necessary. The research for this thesis was conducted through literature review, risk analysis and practical testing. Each of these research methods provided essential information in order to accomplish the aim.

## 2.1 Literature review

To obtain information and knowledge within the characteristics of the arctic region, relevant regulations and life-saving appliances, a comprehensive literature review was performed. The review covers online sources, books, reports, presentations, legislation and research papers. In addition, valuable information was gathered from industry contacts via email inquiries and conversations.

## 2.2 Risk analysis

In order to identify hazards associated with cruise ship evacuations in an arctic environment, a PHA was performed. Along with the identified hazards, associated causes, consequences and possible risk-reducing measures were also considered. A qualitative analysis approach was chosen, mainly because it would produce the desired results, but also due to the wide extent of the analysis object. The concept and methodology for the PHA is based on technical literature, and the analysis process is presented in Chapter 4. Because the PHA is a central element of this thesis, it was carried out in collaboration with participants from the SARex project group. This served to ensure a high level of accuracy and quality.

The PHA was drafted before the research trip, then revised during and after the trip. This analysis also provided the basis for risk assessments performed prior to the tests done on the research trip. The purpose of these risk assessments were to aid the overall analysis and to make sure the participants were aware of the risks involved with performing such tests in the cold polar environment.

## 2.3 Practical test

To supplement the analysis, and obtain practical knowledge and experience regarding the research problem, the authors participated in the full-scale SARex exercise. One of the objectives of this exercise was to test a lifeboat in a 24-hour survival scenario. Staying in the lifeboat for the full length of the test gave first-hand knowledge about challenges related to habitability and functionality.

The lifeboat test also presented a unique opportunity to collect quantitative data on lifeboat habitability. Logging equipment for measuring CO, $CO_2$, humidity and temperature was placed in the lifeboat, collecting data throughout the test period. Information about the logging equipment used, and its placement in the lifeboat, is thoroughly documented in Chapter 4.4.3.1. Upon return from the exercise, the data was analyzed and interpreted, as presented in Chapter 4.4.3.2.

# 3. Literature review

## 3.1 Basic concepts of risk analysis

### 3.1.1 Risk

The term "risk" is common and widely used in all types of activities and businesses, with various definitions depending on the context. In everyday speech, risk often relates to hazards and the potential or possibility for unwanted events and losses. In technical terms, risk is commonly described as a combination of the probability and consequence of an unwanted event (Rausand & Utne, 2009). This combination is expressed in the following equation:

$$Risk = Probability * Consequence$$

The parameters in this equation relates to a specific occurrence, often characterized as an unwanted event. An unwanted event is in these circumstances defined as any irreversible, physical event that can lead to damage to humans, the environment or assets (Rausand & Utne, 2009).

The concept of uncertainty is central when investigating risk, and can be included in the definition in the following manner:

> Risk is related to events, and consequences of these, that may occur in the future. It is not known whether these events will occur or not, and if they happen, what the consequences will be. Thus, there are uncertainty linked to both the events and the consequences. The likelihood of an occurrence happening, leading to specific consequences, can be expressed using probabilities based on background knowledge (Aven, et al., 2008, p. 27).

One can therefore say that risk expresses uncertainty regarding the consequences, seen in relation to the seriousness of the consequences. Low uncertainty does not necessarily mean low risk, and high uncertainty does not necessarily mean high risk.

### 3.1.2 Preliminary hazard analysis

The PHA is a risk analysis method for identification of hazards, built on a technique originally developed by the United States Armed Forces. The method provides a systematic approach, seeking to uncover possible sources of hazard, threats and unwanted events (Rausand & Utne, 2009).

A PHA is normally carried out by a work group consisting of 3-10 persons. Systematically, the group identifies and reviews hazards or unwanted events including associated causes, consequences and probabilities. Risk-reducing measures are often identified and assessed as part of the analysis. It is common to perform the PHA by splitting the analysis object into modules, and carrying out the analysis for each of the modules consecutively. The results are usually documented in an analysis form (Aven, et al., 2008). A flow chart showing the analysis methodology is illustrated in Figure 2.

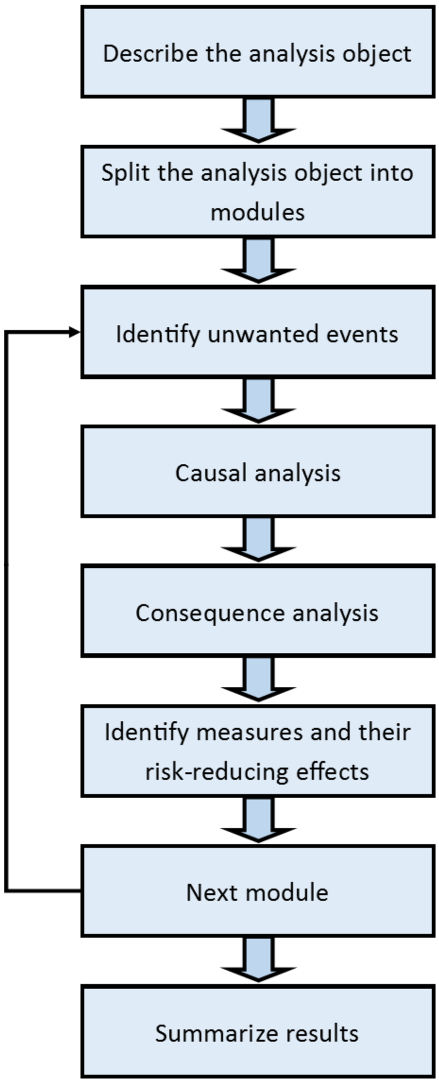


*Figure 2: PHA methodology, adapted from Aven, et al. (2008)*

In this thesis, a qualitative PHA has been performed in order to discover and assess potential sources of hazards related to a lifeboat evacuation from a cruise ship. As a part of the analysis, risk-reducing measures has also been identified and assessed.

### 3.1.3 As low as reasonably practicable

As low as reasonably practicable (ALARP) is a common principle to apply when risk reduction is required. It expresses that the risk should be reduced to a level as low as reasonably practicable. This means that identified measures to reduce the risk shall be implemented unless it can be demonstrated that costs or inconvenience of implementation is grossly disproportionate to the risk-reducing effect of the measure. It must be documented that the risk has been systematically reduced to a level as low as reasonably practicable (Aven, et al., 2008). The ALARP principle is illustrated in Figure 3.

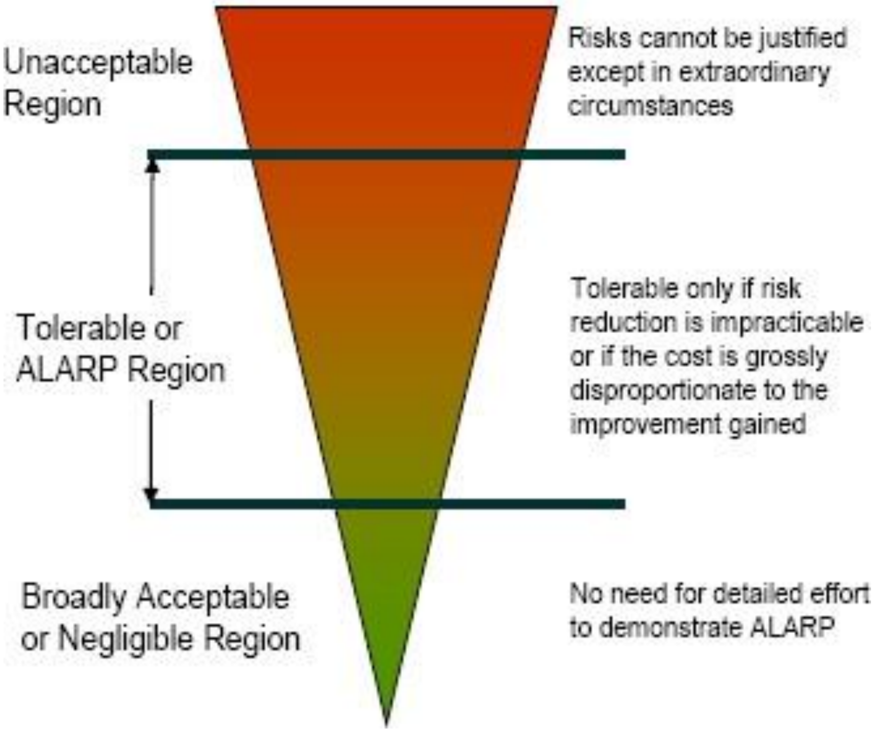


*Figure 3: The ALARP-principle (Global CCS Institute, n.d.)*

Central in the ALARP principle is dividing risks into three regions, which can be explained as follows (Rausand & Utne, 2009):

1. *Unacceptable region.* In this category, the risk is only acceptable under extraordinary circumstances, such as war. Risk-reducing measures must be implemented prior to operation, or to continue operation.
2. *Tolerable region,* also called ALARP region. In this category, the risk can be perceived as tolerable if the benefit of the operation is considerable. The assumption is that risk-reducing measures are implemented unless the associated costs are grossly disproportionate to the risk-reducing effect of the measure.

3. *Broadly acceptable region.* In this category, the risk is low and generally acceptable, making it unnecessary to identify and analyze risk-reducing measures. It is however important to monitor and manage the risk to prevent it from moving into the ALARP area.

The division between the unacceptable region and the tolerable region is called the upper tolerance, while the division between the tolerable region and the broadly acceptable region is called the lower tolerance. The tolerances are often quantitative, set by the government or the company itself (Rausand & Utne, 2009).

The upper and lower tolerances in the ALARP principle are entirely dependent on what is vulnerable to risks. When considering people, for instance, the level where costs are grossly disproportionate to safety improvements are naturally set very low. For other exposed factors such as temporary shutdowns and environmental damage, various analyses can be used in order to estimate the tolerances of the ALARP region. Tolerances for assets can be based on the net present value (Kristiansen, 2001). The ALARP principle forms the basis of the risk acceptance criteria for the PHA presented in this thesis.

### 3.1.4 Risk matrix

A risk matrix is a tool that can be used for risk visualization. It consists of two axes, where one describes probability and the other describes consequence. When hazards or unwanted events have been assessed in terms of risk, they can be placed in the matrix based on the probability and consequence grades. An example of a 5x5 risk matrix is illustrated in Figure 4. There are a variety of risk matrices, depending on area of use and the desired resolution.

When constructed as in Figure 4, hazards located in the top right corner are the ones with highest risk (very high probability and very high consequence), while hazards located in the bottom left corner are the ones with lowest risk (minimal probability and minimal consequence). The risk matrix shows clearly which hazards that are most severe, and can therefore be of use when prioritizing risk-reducing measures (Rausand & Utne, 2009).

| Consequence → Probability↓ | A Minimal | B Low | C Medium | D High | E Very high |
|---|---|---|---|---|---|
| **5 - Very high** | | | | | |
| **4 - High** | | | | | |
| **3 - Medium** | | | | | |
| **2 - Low** | | | | | |
| **1 - Minimal** | | | | | |

*Figure 4: Example of 5x5 risk matrix*

The risk matrix is usually divided into three areas, shown in red, yellow and green color. These areas are often interpreted using the ALARP principle:

*Red area:* Unacceptable, risk-reducing measures are required.
*Yellow area:* Tolerable, apply the ALARP principle and consider further analyses.
*Green area:* Acceptable, risk-reducing measures not necessary.

In this thesis, a risk matrix is applied to visualize the results from the preliminary hazard analysis. By plotting the results before and after the implementation of risk-reducing measures, it is possible to illustrate the effect of the measures on the risk level.

## 3.2 Arctic region characteristics

This chapter presents some aspects of the Arctic related to the topic of this thesis. The focus of this chapter is on the Norwegian area of responsibility in the Arctic, although some facts and examples from other parts of the Arctic and Antarctica are included for the sake of providing an adequate informational basis. This chapter will also cover the historical accidents the authors have considered the most relevant to the thesis.

### 3.2.1 Geography

The boundaries for the Arctic varies depending on which definition that is used. When it comes to climatic and weather-related conditions, it is most suitable to use the "10°-isotherm". This isotherm is developed by drawing a dividing line through locations on the map where the mean temperature in July is 10°C. The area north of this line cover approximately 26 million square kilometers, of which around 18 is oceanic (Store norske leksikon, 2015). Figure 5 illustrates the 10°-isotherm on a map centered on the North Pole (Wikimedia Commons, 2009).


*Figure 5: Arctic region (Wikimedia Commons, 2009)*

The map confirms that the arctic area mainly consists of ocean areas, although it is important to consider that sea ice covers central parts of these, to a varying extent, throughout the year.

IMO defines the arctic boundaries somewhat different from the 10°-isotherm-area. The main difference is that the Polar Code boundary is adjusted due to warmer waters in the North Atlantic. As Figure 6 shows, the boundary is located at 60 degrees north in the Bering Sea. To include all of Greenland it shifts slightly to the south, following the east coast of Greenland, via the island of Bjørnøya, to an intersection point with the Russian arctic coast in the Barents Sea. Areas that are ice-free throughout the entire year is not included, which means that neither Iceland, Norway nor the Kola Peninsula is considered within the Polar Code area (ACCESS, 2015).


*Figure 6: Polar Code Arctic boundary (IMO - Polar Code, 2014)*

The Norwegian rescue service's area of responsibility in the Arctic is extensive, covering parts of the Norwegian Sea, Barents Sea, Greenland Sea, Svalbard and stretches all the way to the North Pole (BarentsWatch, 2013). The Norwegian area of responsibility is presented in Figure 7. Combined with the Polar Code arctic boundary, as illustrated with a yellow dotted line, this forms an arrowhead-shaped zone centered on the Svalbard archipelago.

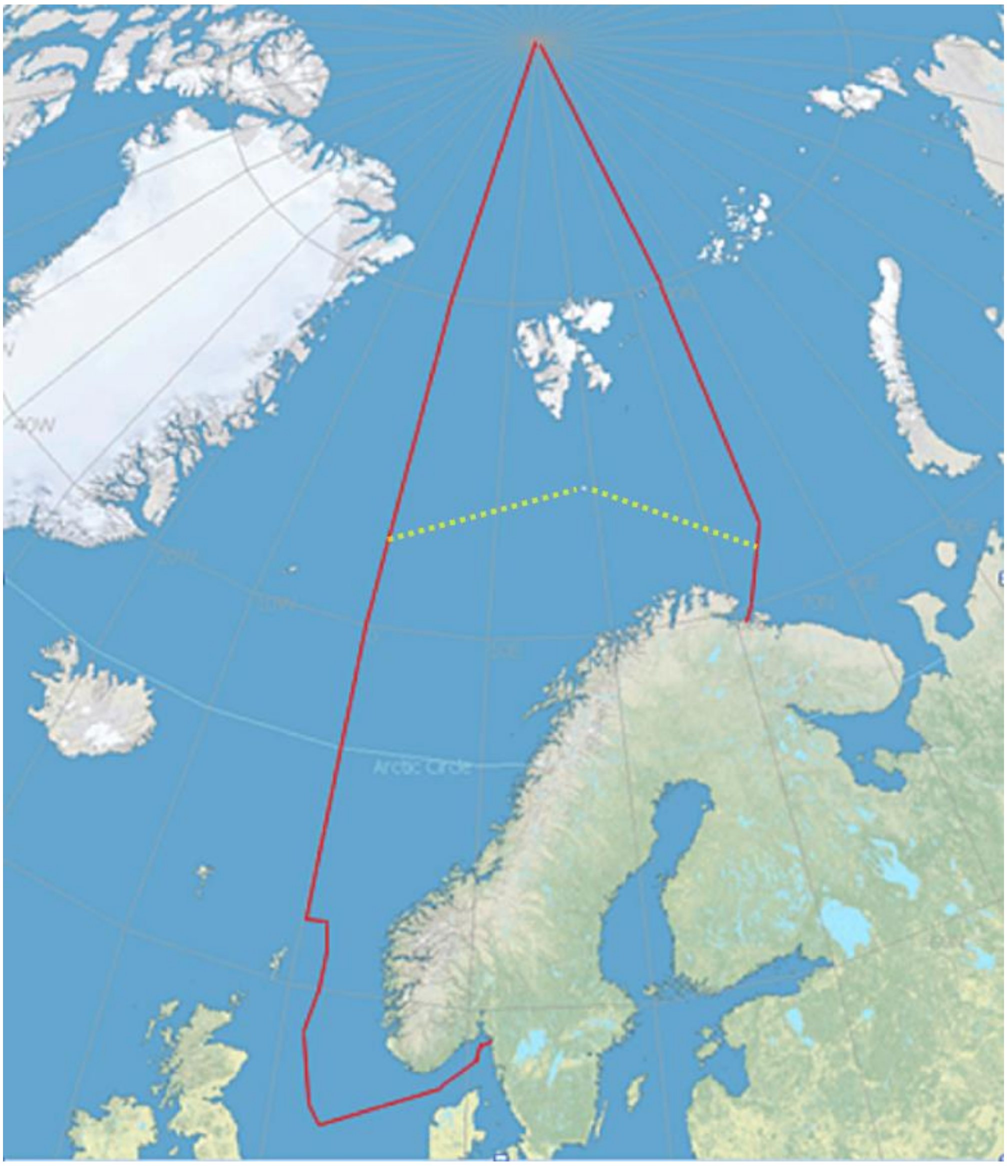


*Figure 7: The Norwegian rescue service's area of responsibility (red line) combined with Polar Code boundary (yellow dotted line) – Adapted from BarentsWatch (2013)*

### 3.2.2 Oceanography

In order to understand mechanisms related to weather like water temperature and sea ice in the arctic region, it is necessary to look into some oceanographic details regarding this area. The generic term for arctic waters is the "Arctic Ocean", which has multiple definitions regarding extent. One of the more extensive definitions includes the Baffin Bay, Barents Sea, Beauford Sea, Chukchi Sea, East Siberian Sea, Greenland Sea, Hudson Bay, Kara Sea, Laptev Sea, White Sea and other smaller waterbodies.

The Arctic Ocean is approximately centered on the North Pole, and is the smallest and shallowest of the five oceans on earth. When defined as above, it covers an area of approximately 14 056 000 square kilometers, has an estimated coastline of 45 390 kilometers, and the average depth is around 987 meters. The northern coastal lines of North America, Greenland, Eurasia, and many islands surround the Arctic Ocean, making it almost entirely bordered by land (Worldatlas, 2015).

The part of the Gulf Stream called the Norwegian Atlantic Current provides almost 60% of the water flowing into the Arctic Ocean. This current transports warm water north along the Norwegian coast into the Barents Sea. There, it splits into two main branches and continues north with one branch on each side of Svalbard. Once in the Arctic Ocean, the Atlantic water masses are cooled down and sinks. After a circulation in the Arctic Basin, the cooled water flows out of the Arctic Ocean, mainly though the Fram Strait between Svalbard and Greenland (Norsk Polarinstitutt, n.d.).

Other contributions to the water masses in the Arctic Ocean comes from the Bering Strait, as well as fresh water from the large rivers in Russia and Canada. This fresh water inflow is the reason why the uppermost 45 meters of the Arctic Ocean water column has a lower salinity than the lower-lying water. The surface ocean currents in the Arctic is illustrated in Figure 8.

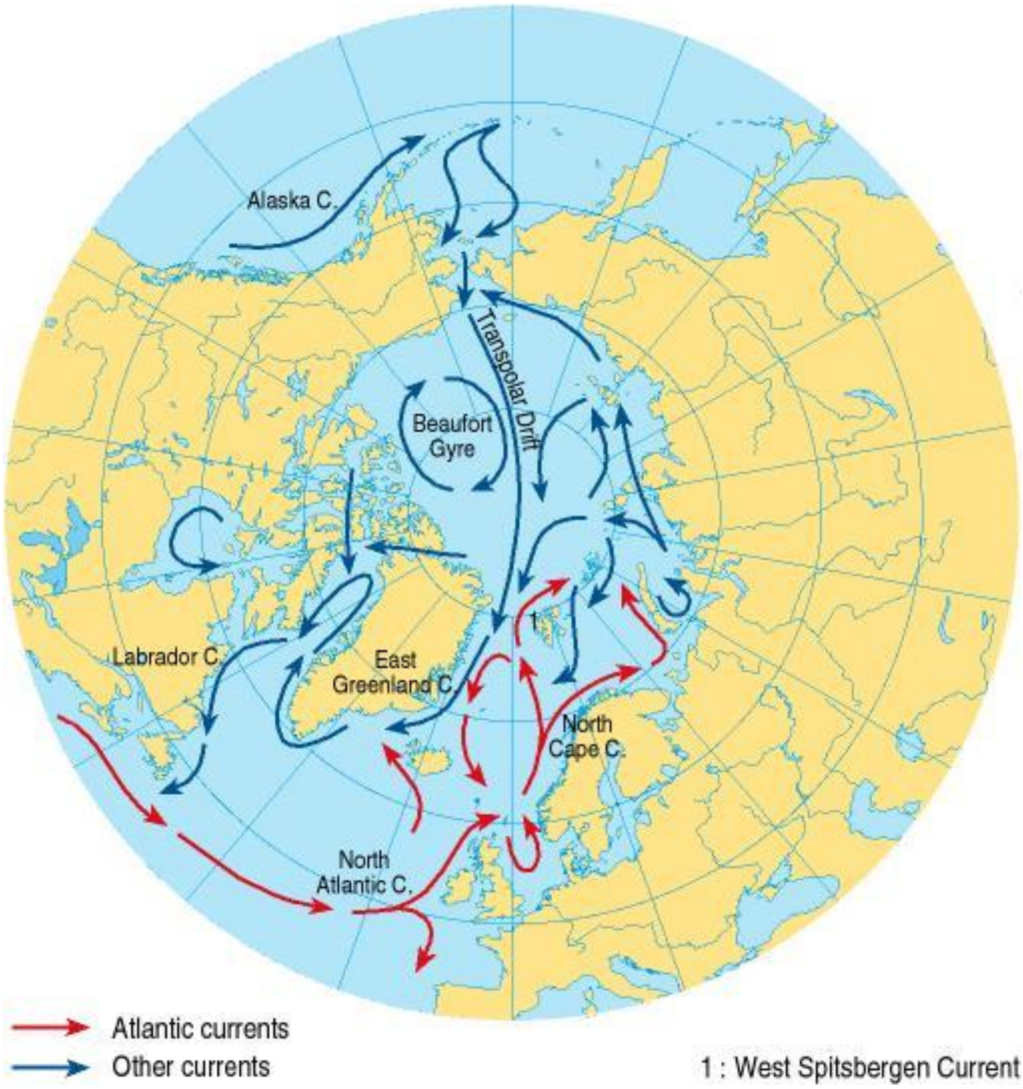


*Figure 8: Surface ocean currents in the Arctic (UNEP/GRID-Arendal, 1997)*

The oceanography and weather conditions of the waters surrounding Svalbard is strongly related to the Norwegian Atlantic Current, which transports relatively warm water north along the Norwegian coast, into the Barents Sea Basin and along the west coast of Svalbard into the Arctic Basin. The water masses in the Barents Sea mainly consist of a mixture of the warm water from the Norwegian Atlantic Current along with cold, arctic water from the Bear Island Current and some warm coastal water (Store norske leksikon, 2014). The eastern and northern parts of the Barents Sea is receiving less warm water from the Norwegian Atlantic Current, which makes these regions colder (Petroleum Safety Authority Norway, 2014a).

There are obvious correlations between the sea ice extent and the warm-water currents originating from the Norwegian Atlantic Current. The relatively high water temperature prevents the formation of sea ice in the southern parts of the Barents Sea, and the West Svalbard Current keeps the western coast of Svalbard ice free large parts of the year. The ice edge normally stretch south towards the island of Bjørnøya during late winter and springtime when the ice extent is at its maximum. This is much due to the cold arctic water transported by the Bjørnøya Current, which lowers the temperature of the water mixture.

According to the National Aeronautics and Space Administration (Viñas & Garner, 2015), the maximum Arctic sea ice extent in 2015 was reached in the end of February. The corresponding ice-map from the Norwegian Meteorological Institute for 25th of February 2015 is presented in Figure 9.

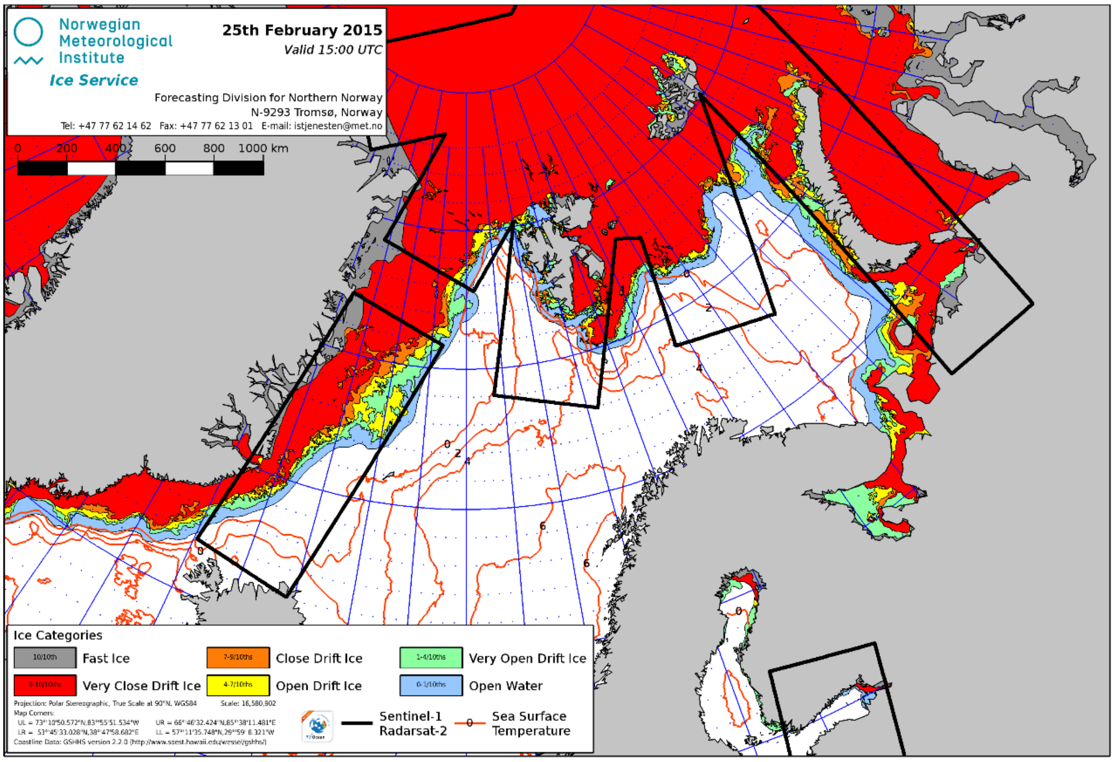


*Figure 9: Ice-map for 25th of February 2015 (Norwegian Meteorological Institute, 2015a)*

The minimum Arctic sea ice extent in 2015 was reached in the beginning of September (National Snow & Ice Data Center, 2015). The corresponding ice-map from the Norwegian Meteorological Institute for 11th of September 2015 is shown in Figure 10.

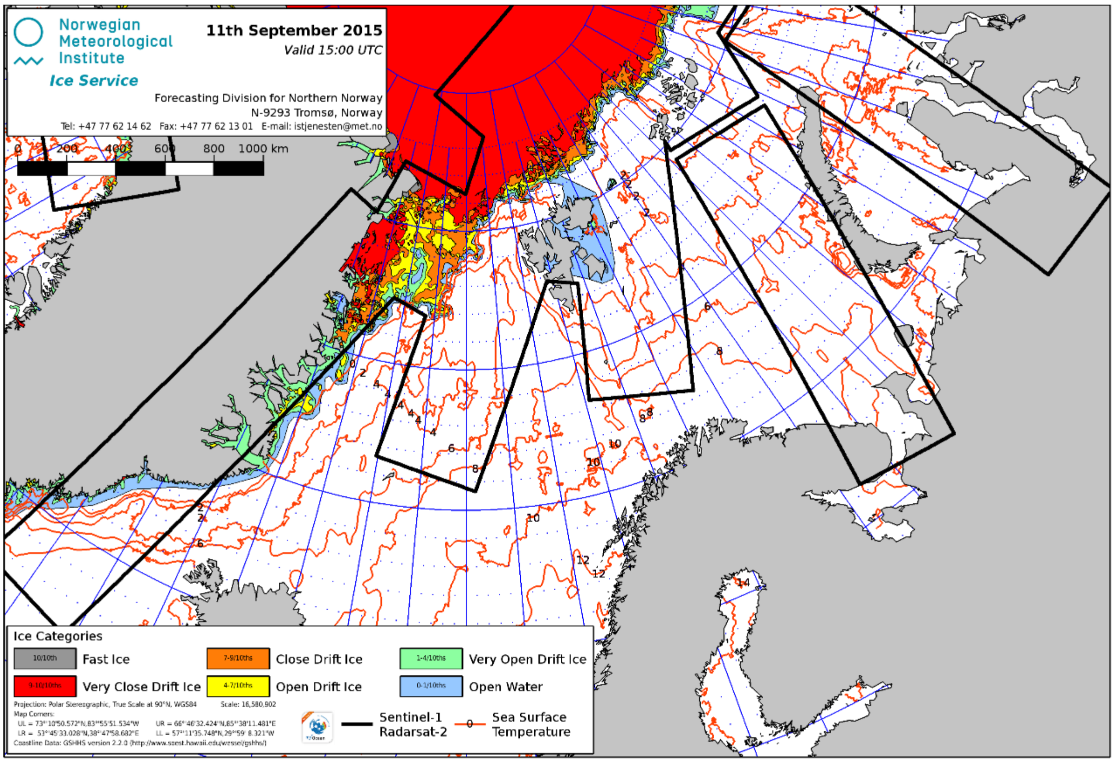


*Figure 10: Ice-map for 11th of September 2015 (Norwegian Meteorological Institute, 2015b)*

It is important to note that the sea ice extent varies greatly from year to year, so the conditions in the coming years will most likely be different from what is presented in the figures.

The waters surrounding Svalbard have for large parts of the year, a possibility for sea ice and drift ice that can propose a challenge to vessels without proper ice class. Depending on the location, this may be a relevant challenge all year. Even though some of the water masses in this area are warmer than in other areas of the Arctic Ocean, it is still cold in terms of e.g. immersion during a vessel evacuation. As seen on the ice-maps, the sea surface temperature around Bjørnøya ranges from sub-zero when the sea ice is at its maximum extent, to +4°C at the minimum extent. In the waters north of Svalbard, the temperatures at minimum sea ice extent vary from sub-zero near the ice edge to around +3°C in the coastal areas. During the period of maximum sea ice extent, these waters usually experience sea ice in various forms; hence, the water surface temperature is below zero degrees Celsius.

### 3.2.3 Weather

The weather conditions in the arctic seas are in some cases very similar to conditions in more accessible and meteorologically studied areas, such as the North Sea, but can also be quite different. Low temperatures, fog, snow squalls, icing and very sudden weather changes are all characteristics of the arctic conditions. When it comes to safety, factors like wind, waves and icing are of utmost importance. Local meteorological phenomena such as polar lows and arctic fronts occurs frequently, and are difficult to forecast (Grønås, 2004).

Polar lows are short-lived weather systems characterized by rapidly increasing wind speeds, dense snow squalls and low visibility. The winds can develop from breeze to storm in a matter of minutes, and wave heights can rise with five meters in less than an hour. Polar lows disappear suddenly, and has an average duration of 18 hours. Troughs are another special weather phenomenon that occur in the arctic seas. These are dense snow squalls leading to significantly reduced visibility, and brings along high wind speeds and thunderstorms. Polar lows are mostly winter-related phenomena, whereas fog is a summertime problem. Fog leads to poor visibility, as an example the areas around Bear Island experience a yearly average of 76 days with visibility of less than one kilometer (Petroleum Safety Authority Norway, 2014c).

Low temperatures combined with strong winds can lead to freezing of sea spray, freezing rain and wet snow freezing. Accumulation of icing on a vessel can make it unstable, which is highly unwanted in rough sea conditions. Icing can also affect the safety equipment on board a vessel or installation, and impair the function of personal protective equipment (Petroleum Safety Authority Norway, 2014a).

### 3.2.4 Light

Areas north of the Arctic Circle are affected by polar darkness during the winter months and midnight sun during the summer months. At the North Pole, the dark period lasts six months of the year. The periods of polar darkness and midnight sun gradually decrease towards the Arctic Circle (Petroleum Safety Authority Norway, 2014b). At the latitude of Longyearbyen, the midnight sun lasts from the end of April to the end of August.

### 3.2.5 Wildlife

The Arctic has a flourishing wildlife. The species that can pose a significant threat to humans are to some degree walruses, but especially polar bears.

Most of the time humans are safe from walruses. There are no known reports of a walrus attacking for no reason or making a meal out of a human. However, the walrus is a formidable fighter and will do all it can to protect itself and the offspring. There have been reports of hunters that have lost their lives or been seriously injured due to not being prepared for the strength and aggression of the walrus that they were attacking (Walrus-world, 2013).

Polar bears are the largest Arctic predator that lives on land. Contrary to animals that normally have contact with humans, most polar bears are not used to human beings. Most polar bears approaches humans out of curiosity, but will continue wandering after examining this unknown phenomenon. If the polar bear is scared off at once, it usually learns to stay away from humans and settlements. Young and inexperienced polar bears or polar bears that are too sick or old to hunt efficiently can still become a problem. These animals can act aggressively due to long periods without food (Naturhistorisk museum, 2015). Figure 11 shows a polar bear at the ice edge.

*Figure 11: Polar bear (Balto, 2016)*

### 3.2.6 Navigation

When navigating in polar waters, there are several hazards that must be considered. In addition to the already mentioned oceanographic and weather-related challenges, there are also challenges related to navigation. These issues arise from insufficient navigational charts in areas such as the Northeast Passage and around Svalbard, which are characterized by many reefs and drift ice. As icebergs move in shallow waters, they can scour against the seabed and thereby change the bottom topography. This causes deviations between the actual water depths and the navigational charts (Gemini, 2012). Many charts are based on few and widely spaced depth measurements, which fails to identify potentially large variations in water depth (Amble, 2011).

The Norwegian authorities has been aware of the problem regarding insufficient navigational charts for some time. As early as 1999, it was stated in White Paper no. 9 (Justis- og beredskapsdepartementet) that the extent of uncharted waters around Svalbard was a safety hazard for the increasing traffic. More recently, the Governor of Svalbard (2013) stated that the waters around Svalbard are insufficiently charted or uncharted, which combined with the tough climatic conditions increases the risk of accidents. Large areas, in particular along the east coast of Svalbard, are only mapped using old measurements or without the use of systematic measurement methods. This information confirms that insufficient navigational charts is still a problem for ships sailing in the waters around the Svalbard archipelago.

The obvious solution to this problem is to create new, detailed maps for the entire area of focus. However, there are several challenges related to mapping these waters, which makes the process expensive and time-consuming. The sea must be ice-free to perform the necessary measurements, and the task must be approached systematically using multi-beam echo sounder equipment. This means that the research vessel needs to make multiple parallel passes in each area to achieve valid data collection. These limitations make mapping a question of cost-benefit, and the number of ships frequenting each area must be included in the calculations (Gemini, 2012).

Because of the slow development of official navigational charts for Svalbard, the cruise ship industry has recently introduced a system for sharing hydrographic data recorded by cruise ships. This development is a collaboration between the Association of Arctic Expedition Cruise Operators (AECO), the International Association for Antarctica Tour Operators (IAATO) and Lindblad Expeditions, and relies on the chart data that each cruise ship record for its own purposes. Such records have been ongoing for decades, and the amount of historical data is therefore substantial. This information is collected in a database, readily available to members of AECO and IAATO as a supplement to the official charts. As a ship collects new hydrographic data, it is added to the database and thereby updates and strengthens the existing data. Waters covered by this initiative include the Antarctic Peninsula, Svalbard, Greenland and other areas in the Arctic (Flaaten, 2015).

From 1 January 2015, a full compulsory pilotage for Svalbard internal waters entered into force. Vessels with a length of 70 meters or more, and passenger vessels with a length of 50 meters or more, are subject to this compulsory pilotage. This means that ships covered by these rules must either use a pilot or hold a pilot exemption certificate (PEC). The PEC is a certificate that are issued to navigators with sailing experience in the area of validity, after passing a theoretical and practical exam (Kystverket, 2015). The requirements serve to ensure that experienced personnel pilot any ship sailing in the hazardous waters around Svalbard.

### 3.2.7 Communication

Communication is a key element for safety at sea, especially if an emergency should occur. A recent gap analysis performed as a part of the SARiNOR project revealed that the available radio links and satellite communication in the Arctic lacks in reliability, and therefore presents a safety hazard in major accident scenarios (DNV GL, 2014).

Very High Frequency (VHF) radio is a well-established and much used means of communication at sea, but is limited to short distances such as ship to ship contact. High Frequency (HF) and Medium Frequency (MF) radio communication is mostly used under special circumstances such as emergencies and for distribution of navigational information and met ocean-reports in areas where the satellite coverage is insufficient. The capacity of the HF and MF radio systems is limited, and the development of new ship technology introduce more systems that rely on data communication to operate. Other systems have sufficient capacity for data transfer, such as digital VHF, mobile networks and other wireless technology, but to utilize these one must be within the coverage area of a base station. The number of such base stations is very limited in the Arctic, and the existing ones are placed in central locations such as ports. It is also possible to use the Automatic Identification System (AIS) to transfer small amounts of data, but there are only a limited number of AIS base stations available in the arctic waters. The satellite-based AIS system is primarily designed for reception of data from ships (MARINTEK, n.d.).

The most common marine communication systems are based on geostationary satellites, such as Inmarsat and Very Small Aperture Terminal (VSAT). However, the drawback with geostationary systems is that the satellites have poor coverage in the Arctic. The low elevation angle, determined by the satellite orbit in relation to the location of the Arctic, leads to unstable or absent connections. The coverage quality is also vulnerable to factors such as precipitation, atmospheric- and sea spray icing, large vessel motions, signal reflection from the sea surface and blockage from surrounding topography.

Iridium is the only satellite communication system to provide a complete theoretical coverage in the Arctic. This system provides telephony as well as data communication, although the bandwidth is limited and is shared between the users in an area. Although the Iridium system is said to have complete coverage in the Arctic, there have been several reports of interrupted connections from users (MARINTEK, n.d.). This problem is also mentioned by the Norwegian Coastal Administration, which states that some areas around Svalbard lack coverage (Kystverket, 2014).

The safety of ships travelling in the Arctic was improved in May 2015, as the new satellite center in Vardø opened. This is an initiative lead by the Norwegian Coastal Administration, incorporating two AIS-satellites covering the northernmost sea areas. The satellites receive and forward information about position, speed and direction from the AIS equipment on board every vessel. This enables the satellite center in Vardø to maintain better control of the ship traffic status in the Norwegian Arctic. The old system consisted of land-based stations only, which did not cover the northern sea areas. A third and fourth satellite is due to launch later in 2015 and 2016, which will improve the coverage further (Stensvold, 2015).

### 3.2.8 Tourism

There is significant cruise traffic activity to, from and around Svalbard. This area is extreme and exotic, drawing adventurous tourists from all over the world. The cruise ships travel around the archipelago, showing passengers the uninhabited areas such as the Magdalene fjord to the far north of Svalbard (Transportøkonomisk institutt, 2003).

There are two main types of cruise ships frequenting the waters around Svalbard. The largest ones are the overseas cruise ships, which arrives in Svalbard as a part of a longer cruise during the summer months. These ships carry from 200 to 3 500 passengers, and usually spend one to two days in the area. The short stopping period limits the number of disembarkations, which traditionally are done in the Magdalene fjord, Ny-Ålesund and Longyearbyen (Sysselmannen, 2015). Statistics of cruise ship arrivals at Svalbard is presented in Figure 12. The statistical results from 1997 to 2001 is not accurate, as some ships in that period neglected to report the necessary information. It is also important to note that prior to 2001, expedition cruises were included in the overseas cruise statistics. This means that the statistical results before and after 2001 are incomparable.

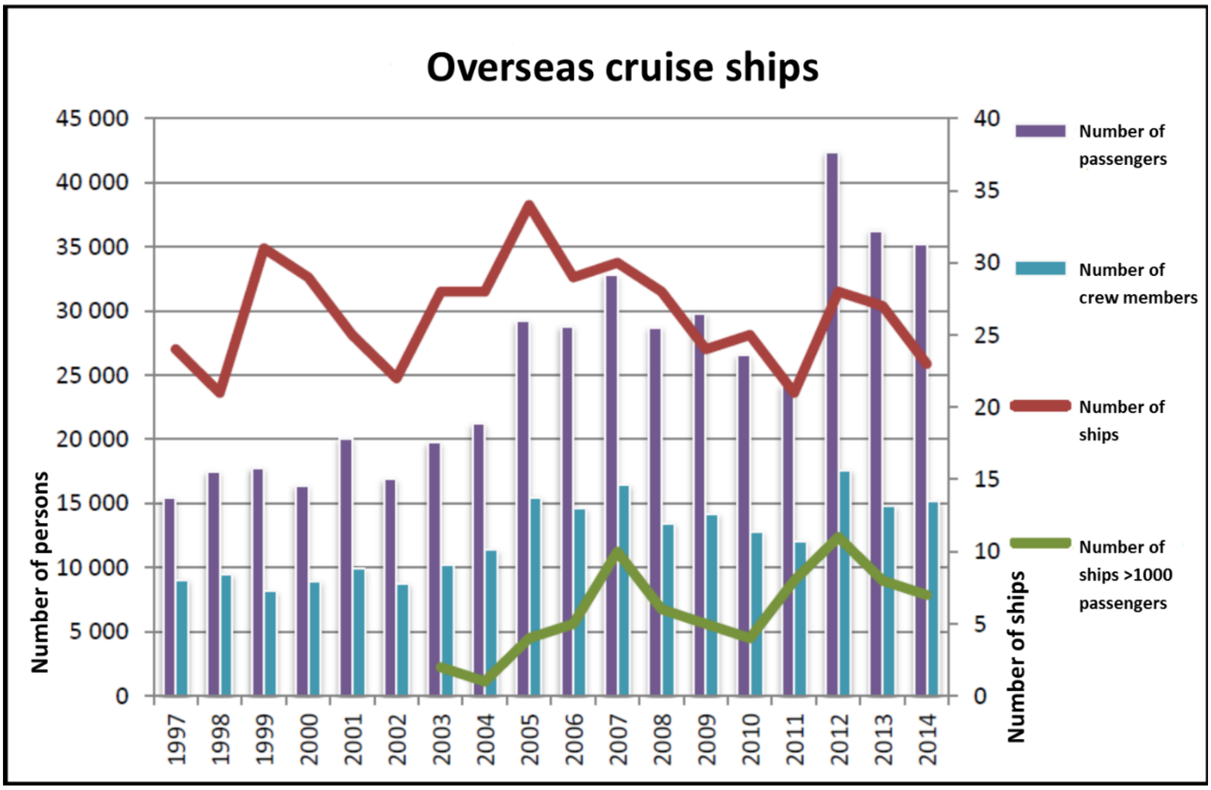


*Figure 12: Overseas cruise ships at Svalbard – Statistics from 1997 to 2014 (Sysselmannen, 2015). Translated.*

The statistics shows a variation in the number of ships visiting Svalbard, although no significant increase or decrease is apparent. The number of passengers, however, has almost tripled in the recorded period. The apparent cause for this is an increase in each ship's passenger capacity, and that the biggest ships often have multiple cruises with Svalbard as destination each summer.

The largest cruise ship so far to dock in Longyearbyen, the MSC Splendida of MSC Cruises, visited in June 2015. This ship is capable of carrying 4 300 passengers and 1 300 crewmembers, however the passenger count on this particular journey was around 3 500. Due to its large dimensions, measuring 333 meters of length and 67 meters of height, the docking of the MSC Splendida at the small quay in Longyearbyen required ideal wind conditions. Despite the challenges, the docking procedure went smoothly (Barstein, 2015). According to cruise booking site Seascanner.com (2015), MSC Splendida is scheduled for three cruises with planned stops in Longyearbyen during the summer of 2016.

The second main type of cruise ships frequenting the waters of Svalbard is the expedition cruise ships. These vessels normally carry from 4 to 300 passengers, sailing to destinations all around the Svalbard archipelago. Because they are smaller than the overseas cruise ships, the expedition cruise ships are able to navigate in narrower and shallower waters, such as straits and fjords. Longyearbyen is commonly used as point of embarkation and disembarkation, although some cruises are based on sailing to and from harbors on the Norwegian coast, or other countries in northern Europe. Because of the sea ice extent during large parts of the year, these cruises are normally limited to a season ranging from the beginning of June to the middle of September. Most of the expedition cruise ships operating around Svalbard have navigated the waters for several seasons, although there are some newcomers every year (Sysselmannen, 2015). Statistics for expedition cruise ship traffic in the Svalbard area is presented in Figure 13.

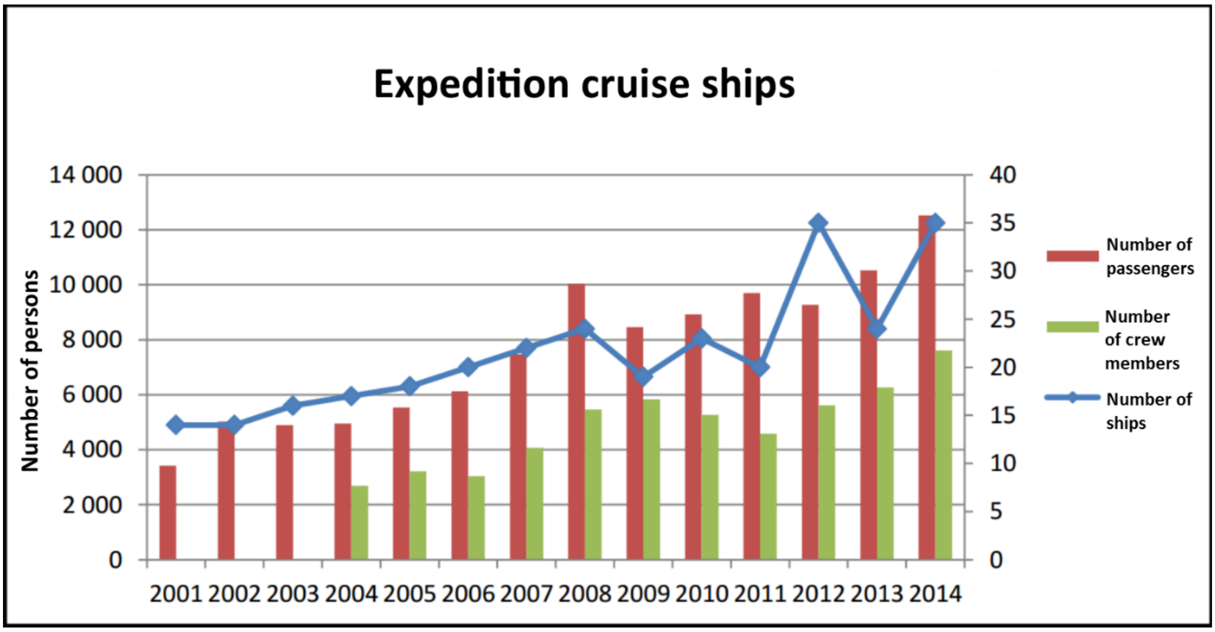


*Figure 13: Expedition cruise ships at Svalbard - Statistics from 2001 to 2014 (Sysselmannen, 2015). Translated.*

The statistics show an increase in the number of expedition cruise ships, with peaks in 2012 and 2014. There has been an increase in the number of passengers as well, but this is more of a steady growth except a small peak in 2008. The tendency for 2014 shows high numbers for both ships and passengers, compared to the historical results (Sysselmannen, 2015).

### 3.2.9 Search and rescue

Rescue services at sea and in the air are mostly international cooperation regulated by conventions and agreements. All rescue services at sea and in the air follows the same regulations worldwide through the IMO and International Civil Aviation Organization (ICAO) conventions. Each individual country is responsible for rescue services on land. In Norway a Royal Decree, decided 4 July 1980 called "Organizational Plan for Rescue Services", describes the rescue service on land. Norway has in addition to its national plan, many agreements with its neighboring countries regarding search and rescue. One of these agreements governs cooperation on search and rescue in conjunction with air and sea traffic in the Arctic (BarentsWatch, 2013).

The Norwegian rescue service is a national effort in which all resources that are available and suitable for saving lives will be used, both private, public and voluntary. The rescue service has access to almost all the resources society has to offer, but only have a few dedicated resources. The 330 squadrons' rescue helicopters are the only dedicated resources available to the rescue service. These are on standby at six bases around Norway. The base that is closest to polar waters is Banak, in Finnmark. New helicopters that have a longer range, are better equipped and is faster will replace the 330 squadrons' Sea-King rescue helicopters in the coming years. The Governor of Svalbard has two rescue helicopters that the Joint Rescue Coordination Centre (HRS) uses in search and rescue missions. These helicopters are the only resource that is permanently stationed in this part of the Arctic. The range of helicopters are increased with fuel depots at e.g. Bjørnøya and Hopen. For the arctic areas, the oil and gas industry has one "All weather search and rescue" helicopter that is stationed in Hammerfest, which the Norwegian rescue service uses if needed (BarentsWatch, 2013).

The Coast Guard ships are an important part of the rescue at sea resources. They are in the process of being equipped with brand new NH90 helicopters. These are larger, with better range and equipment compared to the old Lynx helicopters that are on the way out. The Coast Guard ships have doctors and divers stationed on the boats periodically (Ingerø, 2013). The Norwegian Society for Sea Rescue (NSSR) rescue boats are stationed along the coast of Norway and is another important resource (BarentsWatch, 2013).

It is normal that the boats who are passing by or are in the vicinity of accidents are often the ones who save lives and property at sea. All vessels are obliged to participate in search and rescue operations, but everyone does it voluntarily because it is so ingrained in the culture and tradition of Norwegian boat owners. For polar expedition cruise ships, there are few boats nearby at the north side of Svalbard should they need assistance. Regardless of preparedness, it can be dangerous to be far away from civilization. Time, distance, climate and fog makes search and rescue operations with the rescue services resources exceedingly difficult and in some cases impossible. It is therefore imperative that the cruise operators take every precaution to prevent accidents from happening (BarentsWatch, 2013).

## 3.2.10 Historical accidents

### *3.2.10.1 TS Maxim Gorkiy (Hovden, 2012)*

The cruise ship TS Maxim Gorkiy was traveling from Iceland to the Magdalene fjord on the Svalbard archipelago when it collided, with high speed, into drift ice around midnight of June 19th, 1989. The ship was severely damaged and had several leaks in the hull. As water started to flow into the ship through the punctured hull, approximately 575 passengers and one third of the 379 crew members were ordered to abandon ship. Svalbard Radio were the first to receive the distress signal. The telegraphist started the procedures to alert the Joint Rescue Coordination Centre in Northern Norway (HRS-NN), and alerting the Coast Guard ship KV Senja and the ship MS Polarsyssel which is owned by the Governor of Svalbard. HRS-NN deployed four Sea-King rescue helicopters in total to assist in the rescue operation and a P3B Orion surveillance plane. KV Senja would use 4 hours to the rescue site and MS Polarsyssel had an estimated time of arrival of 10 hours. KV Senja was the first to arrive at the scene approximately 04:00 on June 20th, 1989.

*Figure 14: Passengers on the ice waiting to be rescued*

They could see passengers in lifeboats, life rafts and some of them even standing directly on the ice when they arrived as seen in Figure 14. The bow of the cruise ship "Maxim Gorkiy" was at this time already dangerously low in the water. They started to collect passengers from lifeboats and from the ice while informing the Captain of TS Maxim Gorkiy that they would focus on the passengers already evacuated first, and told the Captain to keep evacuating people on board into lifeboats. The first Sea-King helicopter arrived at the scene around 05:40 and immediately started to pick up passengers and bringing them on board KV Senja. Simultaneously the Captain and some of the crew on board the TS

Maxim Gorkiy were trying to save the ship by asking for pumps and other aids to keep the ship afloat. After all of the evacuated passengers had been either picked up by KV Senja or transported to Longyearbyen by helicopter, the crew of KV Senja shifted priorities to help keep TS Maxim Gorkiy from sinking. Divers from KV Senja helped the crew from TS Maxim Gorkiy put a tarp around the ship to help prevent water from leaking into the ship. They also lent them pumps to keep the ship stable in the water. The ship can be seen listing in Figure 15. Two Russian helicopters came from Barentsburg with additional pumps to help stabilize the ship. After this KV Senja went back to Longyearbyen with over 500 passengers and around 200 of the crew from TS Maxim Gorkiy. There were no people severely injured or killed during this accident. The cruise ship TS Maxim Gorkiy was able to get back to Longyearbyen for temporary repairs. The ship was fully repaired in a shipyard in Germany and back in cruise duty in August that same year.


*Figure 15: TS Maxim Gorkiy taking in water.*

This accident ended up on the front page of Norwegian and international newspapers for several days, but was quickly forgotten due to the fact no large mistakes were made during the rescue and no lives were lost. However, this was described by the rescue crews as a very dramatic and dangerous event. The weather during this accident was extremely good compared to the weather only one week before. If it had happened one week before there would have been 45 knot winds and a lot bigger waves. This change alone could have made the outcome far worse.

The Captain of TS Maxim Gorkiy refused to let the last of his crew abandon ship to focus on keeping the ship from sinking. Technical calculations done after the fact show that the ship had taken in 9000 tons of seawater, which reached all the way up to Deck 6 in the bow of the ship. If the pumps were installed only 30 minutes later than they were, the seawater level in the ship would have reached its critical level, at around 9500 tons, and the ship would most likely have sunk.

### *3.2.10.2 MS Explorer (Ford, 2009)*

On November 23rd 2007 the expedition cruise vessel MS Explorer sank after hitting, what is thought to be, hard multi-year ice while moving through an ice field 25 miles southeast of King George Island near Antarctica.

The Master of the ship had many years of experience from the Baltic Sea but this was his first mission as Master in Antarctic waters. Fellow crewmembers and passengers expressed concern about the speed in which the vessel was moving through the ice field. The Master was under the impression that he was moving through thinner first-year ice, and that the speed was unproblematic for these conditions. As the ship approached what crew and passengers have described as “a massive wall of ice”, the Master was confident the ship could ram through it. When the ship collided with the wall of ice, it came to a complete stop. As the Master was explaining to a fellow crewmember that they had to ram the ice repeatedly to go through it, the alarm sounded. Several cabins were flooding and the crew worked for a number of hours trying to stop the leak and to stabilize the ship using pumps. When the ship lost power, the Master ordered the ship to be abandoned. Figure 16 shows the ship sinking.


*Figure 16: MS Explorer sinking with MS Nordnorge in the background (Gonzalez, 2007).*

There was a lot of confusion regarding which passengers were going into which lifeboat, they had been preassigned lifeboats before leaving the dock but most passengers could not remember which lifeboat they were assigned to. Only one of four lifeboats could get their motor running, which made it hard for the lifeboats to get away from the ship after lowering them into the water. After a while of trying to get the motors running, the Safety Officer said the crew was too cold to manage to get the motors running. The crew had to use the Zodiacs (Rigid Inflatable-boat) to tow the lifeboats away from the ship. The lifeboats were not enclosed and the passengers complained about becoming wet and cold from sea spray. The crew and passengers were in the lifeboats and Zodiacs for five hours before the ship MS Nordnorge came to their aid. Figure 17 shows the passengers being rescued by MS Nordnorge.


*Figure 17: Passengers being rescued by MS Nordnorge (Gonzalez, 2007).*

The passengers said that the most dangerous part of the whole operation was getting from the lifeboats and on board MS Nordnorge. Many passengers were too cold to climb up the ladder to get inside MS Nordnorge, and thus had to be transported into a lifeboat hoisted down by MS Nordnorge and then hoisted back up inside the lifeboat. The weather in this area is usually stormy, but at the time of this accident, the weather was calm. When the passengers were being rescued by MS Nordnorge the wind and seas were increasing. Two hours after all passengers were on board MS Nordnorge, the weather and seas deteriorated to gale force winds. There were no lives lost and no major injuries reported from this accident.

## 3.3 Regulations

This chapter will present the most relevant regulations for this thesis regarding ships and life-saving appliances for passenger ships on voyages in polar waters.

### 3.3.1 SOLAS

The International Convention for the Safety of Life at Sea (SOLAS), 1974, currently in force, was adopted on November 1st 1974 by the International Conference on Safety of Life at Sea, which was convened by the International Maritime Organization (IMO), and entered into force on May 25th 1980. It has since been amended several times (IMO - SOLAS, 2014).

On the subject of life-saving appliances for passenger ships engaged on international voyages, SOLAS states that all passenger ships shall carry partially or totally enclosed lifeboats that should accommodate not less than 50% of the total number of persons on board on each side. The Administration may permit the substitution of lifeboats by life rafts of equivalent total capacity provided that there shall never be less than sufficient lifeboats on each side of the ship to accommodate 37.5% of the total number of persons on board. In addition, they shall carry inflatable or rigid life rafts of such aggregate capacity as will accommodate at least 25% of the total number of persons on board (IMO - SOLAS, 2014).

Furthermore, SOLAS states that all passenger ships shall carry for each lifeboat on the ship at least three immersion suits and, in addition, a thermal protective aid for every person to be accommodated in the lifeboat and not provided with an immersion suit. However, these immersion suits and thermal protective aids need not be carried for persons to be accommodated in totally or partially enclosed lifeboats (IMO - SOLAS, 2014).

### 3.3.2 Polar Code

The International Code for Ships Operating in Polar Waters (Polar Code) has been developed to increase the safety of ships operation and mitigate the impact on the people and environment in the remote, vulnerable and potentially harsh polar waters (IMO - Polar Code, 2014). The Polar Code is expected to enter into force of the SOLAS amendments on January 1st 2017 and will apply to ships constructed after that date. Older ships constructed before January 1st 2017 will be required to meet the relevant requirements of the Polar Code by the first intermediate or renewal survey, whichever happens first, after January 1st 2018 (IMO - web, 2015). Figure 18 shows a Polar Code infographic.

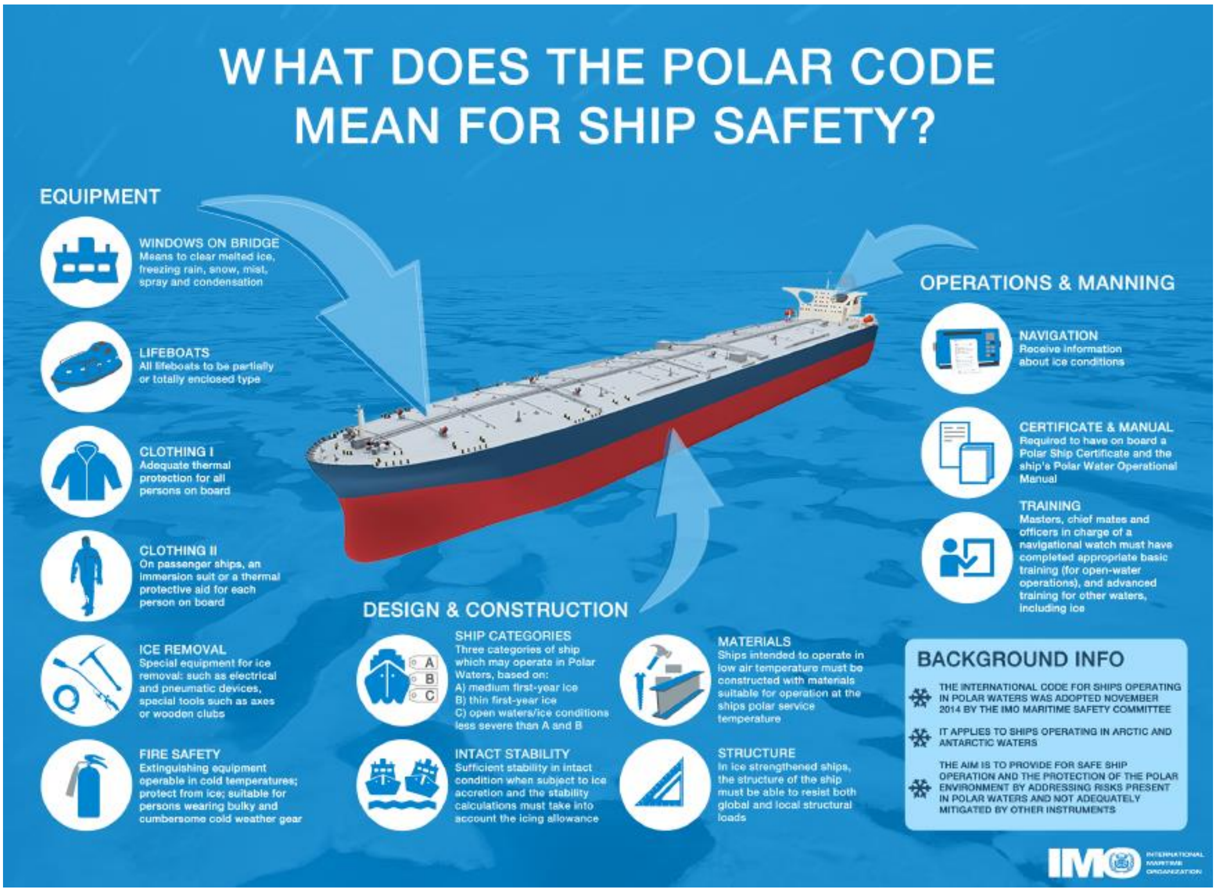


*Figure 18: Polar Code infographic (IMO - web, 2015)*

The Polar Code is intended to apply as a whole to both Arctic and Antarctic, however the legal and geographical differences between the two areas have been taken into account. The Polar Code uses a risk-based approach when determining scope and when adopting a holistic approach in reducing identified risks. The goal of the Polar Code is to "*provide for safe ship operation and the protection of the polar environment by addressing risks present in polar waters and not adequately mitigated by other instruments of the IMO* (IMO - Polar Code, 2014)."

### *3.3.2.1 Polar Code review*

The parts of the Polar Code that are most relevant to this project report is presented and commented on in this section. All text presented in italic in this chapter is extracted from the Polar Code (IMO - Polar Code, 2014).

***Introduction***

***3 Sources of hazards***

*3.1 The Polar Code considers hazards which may lead to elevated levels of risk due to increased probability of occurrence, more severe consequences, or both:*

- *.1 Ice, as it may affect hull structure, stability characteristics, machinery systems, navigation, the outdoor working environment, maintenance and emergency preparedness tasks and malfunction of safety equipment and systems;*
- *.2 experiencing topside icing, with potential reduction of stability and equipment functionality;*
- *.3 low temperature, as it affects the working environment and human performance, maintenance and emergency preparedness tasks, material properties and equipment efficiency, survival time and performance of safety equipment and systems;*
- *.4 extended periods of darkness or daylight as it may affect navigation and human performance;*
- *.5 high latitude, as it affects navigation systems, communication systems and the quality of ice imagery information;*
- *.6 remoteness and possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compounded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the potential to affect incident response;*
- *.7 potential lack of ship crew experience in polar operations, with potential for human error;*
- *.8 potential lack of suitable emergency response equipment, with the potential for limiting the effectiveness of mitigation measures;*
- *.9 rapidly changing and severe weather conditions, with the potential for escalation of incidents; and*
- *.10 the environment with respect to sensitivity to harmful substances and other environmental impacts and its need for longer restoration.*

*3.2 The risk level within polar waters may differ depending on the geographical location, time of the year with respect to daylight, ice-coverage, etc. Thus, the mitigating measures required to address the above specific hazards may vary within polar waters and may be different in Arctic and Antarctic waters.*

All of these hazards listed in the Polar Code are important factors for cruise ship operators in the Arctic. Most of these hazards are location specific factors and are described in previous subchapters of this thesis. Executive director Frigg Jørgensen from AECO states that they are always trying to better the cooperation between the cruise ship industry and the different SAR entities to better the safety in the Arctic. They are currently working on a joint industry project with the Icelandic Coast Guard called SAR Entities Arctic SAR TTX, and are planning on meeting in April 2016 with representatives from the cruise ship operators and the SAR units from the arctic countries.

***Safety Measures***

***Chapter 1 – General***

***1.2 Definitions***

*1.2.7 Maximum expected time of rescue means the time adopted for the design of equipment and system that provide survival support. It shall never be less than five days.*

***1.5 Operational Assessment***

*In order to establish procedures or operational limitations, an assessment of the ship and its equipment shall be carried out, taking into consideration the following:*

- *.1 the anticipated range of operating and environmental conditions, such as:*
    - *.1 operation in low air temperature;*
    - *.2 operation in ice;*
    - *.3 operation in high latitude; and*
    - *.4 potential for abandonment onto ice or land;*
- *.2 hazards, as listed in section 3 of the Introduction, as applicable; and*
- *.3 additional hazards, if identified.*

All of the anticipated range of operating and environmental conditions mentioned here will apply to cruise ships operating in the Arctic. If every person on board were strong, healthy and fit, these hazards would still be associated with high risk. It is likely that a cruise ship will have elderly people with significant health problems amongst their passengers. This must be taken into account when doing the assessment.

***Chapter 8 – Life-saving appliances and arrangements***

***8.2 Functional requirements***

***8.2.1 Escape***

*8.2.1.1 Exposed escape routes shall remain accessible and safe, taking into consideration the potential for icing of structures and snow accumulation.*

Escape routes will need to be ice and snow free. This will require them to be either heated, treated with non-icing chemicals or manually cleaned of snow and ice if needed. The danger of falling ice must also be considered, and the escape routes must be protected against these hazards.

*8.2.1.2 Survival craft and muster and embarkation arrangements shall provide safe abandonment of ship, taking into consideration the possible adverse environmental conditions during an emergency.*

These arrangements often have many handles, wires and unlocking mechanisms that are vulnerable to icing making them unable to perform their required function if frozen. All of this equipment has to be winterized or normally enclosed. It is also important that all of the equipment can be handled easily while using warm gloves.

***8.2.2 Evacuation***

*All life-saving appliances and associated equipment shall provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue.*

The maximum expected time of rescue shall be no less than five days according to the Polar Code. The presence of ice, large waves, strong winds and low temperatures must be taken into consideration when designing the life-saving appliances and associated equipment.

***8.2.3 Survival***

*8.2.3.1 Adequate thermal protection shall be provided for all persons on board, taking into account the intended voyage, the anticipated weather conditions (cold and wind), and the potential for immersion in polar water, where applicable.*

The low polar water temperature will require immersion suits to be of high quality for any extended periods of immersion. Having high quality immersion suits for all people on board is a challenge for cruise ships that holds thousands of people. Training all passengers to be comfortable with handling immersion suits and how to act in the water is also challenging.

*8.2.3.2 Life-saving appliances and associated equipment shall take account of the potential of operation in long periods of darkness, taking into consideration the intended voyage.*

Being visible to rescue crews is very important, and can be challenging in polar waters during periods of darkness. Immersion suits should have lights and other arrangements for making them visible. It is important to have searchlights in lifeboats that are operating in ice-infested waters to be able to spot floating ice.

*8.2.3.3 Taking into account the presence of any hazards, as identified in the assessment in chapter 1, resources shall be provided to support survival following abandoning ship, whether to the water, to ice or to land, for the maximum expected time of rescue. These resources shall provide:*

- *.1 a habitable environment;*
- *.2 protection of persons from the effects of cold, wind and sun;*
- *.3 space to accommodate persons equipped with thermal protection adequate for the environment;*
- *.4 means to provide sustenance;*
- *.5 safe access and exit points; and*
- *.6 means to communicate with rescue assets.*

There are many challenges related to these six points. Lifeboats and life rafts will need to be enclosed, sanitation will be challenging considering lifeboats and life rafts do not have toilets. The capacity of the lifeboats and life rafts will need to be reduced to accommodate adequate space when wearing thermal protection and to hold the necessary toilet paper, the required food and water to keep people sufficiently fed and hydrated for five days. Lifeboats should have communication devices built-in that can communicate with rescue assets. People boarding life rafts will need to have communication equipment easily accessible close to the access point.

***8.3 Regulations***

***8.3.1 Escape***

*In order to comply with the functional requirements of paragraphs 8.2.1.1 and 8.2.1.2 above, the following apply:*

- *.1 for ships exposed to ice accretion, means shall be provided to remove or prevent ice and snow accretion from escape routes, muster stations, embarkation areas, survival craft, its launching appliances and access to survival craft;*
- *.2 in addition, for ships constructed on or after 1 January 2017, exposed escape routes shall be arranged so as not to hinder passage by persons wearing suitable polar clothing; and*
- *.3 in addition, for ships intended to operate in low air temperatures, adequacy of embarkation arrangements shall be assessed, having full regard to any effect of persons wearing additional polar clothing.*

Preventing ice and snow accretion can be done with low friction surfaces where suitable, chemicals and enclosing. Removing ice and snow can be handled with heat tracing, external heating sources and of course manual removal with various equipment. Persons wearing polar clothing will need more space to be able to move around, the clothing is normally larger and the persons' movement will be somewhat restricted.

***8.3.2 Evacuation***

*In order to comply with the functional requirements of paragraph 8.2.2 above, the following apply:*

- *.1 ships shall have means to ensure safe evacuation of persons, including safe deployment of survival equipment, when operating in ice-covered waters, or directly onto the ice, as applicable; and*
- *.2 where the regulations of this chapter are achieved by means of adding devices requiring a source of power, this source shall be able to operate independently of the ship's main source of power.*

Safe deployment of survival equipment can be challenging if the equipment is covered by ice. Since deployment of survival equipment like lifeboats can be impossible without a power source, one option is that the deployment system is gravity based.

***8.3.3 Survival***

*8.3.3.1 In order to comply with the functional requirement of paragraph 8.2.3.1 above, the following apply:*

- *.1 for passenger ships, a proper sized immersion suit or a thermal protective aid shall be provided for each person on board; and*
- *.2 where immersion suits are required, they shall be of the insulated type.*

Keeping people dry will always be the most challenging and most crucial part of evacuating people at sea. In polar waters, it is also crucial to keep the body temperature at a normal level to keep people from developing hypothermia. This means designing the immersion suits for the polar environment, with insulation and other technologies to help keep people warm.

*8.3.3.2 In addition, for ships intended to operate in extended periods of darkness, in order to comply with the functional requirements of paragraph 8.2.3.2 above, searchlights suitable for continuous use to facilitate identification of ice shall be provided for each lifeboat.*

During the winter months around Svalbard, there will be periods of darkness. Searchlights will help the lifeboats navigate safely through ice-infested waters. They can also be helpful for the rescue crew to find the lifeboat quickly and to locate people drifting in the sea.

*8.3.3.3 In order to comply with the functional requirement of paragraph 8.2.3.3 above, the following apply:*

- *.1 no lifeboat shall be of any type other than partially or totally enclosed type;*
- *.2 taking into account the assessment referred to in chapter 1, appropriate survival resources, which address both individual (personal survival equipment) and shared (group survival equipment) needs, shall be provided, as follows:*
  - *.1 life-saving appliances and group survival equipment that provide effective protection against direct wind chill for all persons on board;*
  - *.2 personal survival equipment in combination with life-saving appliances or group survival equipment that provide sufficient thermal insulation to maintain the core temperature of persons; and*
  - *.3 personal survival equipment that provide sufficient protection to prevent frostbite of all extremities; and*
- *.3 in addition, whenever the assessment required under paragraph 1.5 identifies a potential of abandonment onto ice or land, the following apply:*

- *.1 group survival equipment shall be carried, unless an equivalent level of functionality for survival is provided by the ship's normal life-saving appliances;*
- *.2 when required, personal and group survival equipment sufficient for 110% of the persons on board shall be stowed in easily accessible locations, as close as practical to the muster or embarkation stations;*
- *.3 containers for group survival equipment shall be designed to be easily movable over the ice and be floatable;*
- *.4 whenever the assessment identifies the need to carry personal and group survival equipment, means shall be identified of ensuring that this equipment is accessible following abandonment;*
- *.5 if carried in addition to persons, in the survival craft, the survival craft and launching appliances shall have sufficient capacity to accommodate the additional equipment;*
- *.6 passengers shall be instructed in the use of the personal survival equipment and the action to take in an emergency; and*
- *.7 the crew shall be trained in the use of the personal survival equipment and group survival equipment.*

In order to keep dry and warm in rough seas with high wind speeds, it can be difficult to achieve this with a partially enclosed lifeboat. A totally enclosed lifeboat will probably be much more effective in the harsh polar conditions. Having sufficient survival equipment, for both individuals and groups, is important to protect against wind chill, frostbite and to maintain the core temperature of persons. The survival craft needs to be designed to have room for all the survival equipment in addition to all the people. This will further reduce their capacity compared to when they are used in warmer areas where maximum time of rescue is significantly lower. Training passengers and crew in the use of the survival equipment on polar journeys is not something to be taken lightly. The risks are significantly higher and more complex on a cruise in polar waters than in e.g. the Mediterranean.

> *8.3.3.4 In order to comply with the functional requirement of paragraph 8.2.3.3.4 above, adequate emergency rations shall be provided, for the maximum expected time of rescue.*

Adequate emergency rations are in the International Life-Saving Appliances Code (LSA Code) described as 1.5 liters of water for life rafts and 3 liters of water for lifeboats per person and 10,000 kJ (2,400 kcal) of food per person (IMO - LSA, 2010). However, this does not refer to a maximum expected time of rescue of five days.

***Part 1B***

### *9 Additional guidance to chapter 8 (Life-saving appliances and arrangements)*

### *9.1 Sample personal survival equipment*

*When considering resources to be included with the personal survival equipment, the following should be taken into account:*

| ***Suggested equipment*** |
|---|
| *Protective clothing (hat, gloves, socks, face and neck protection, etc.)* |
| *Skin protection cream* |
| *Thermal protective aid* |
| *Sunglasses* |
| *Whistle* |
| *Drinking mug* |
| *Penknife* |
| *Polar survival guidance* |
| *Emergency food* |
| *Carrying bag* |

### *9.2 Sample group survival equipment*

*When considering resources to be included in the group survival equipment, the following should be taken into account:*

| ***Suggested equipment*** |
|---|
| *Shelter – tents or storm shelters or equivalent – sufficient for maximum number of persons* |
| *Thermal protective aids or similar – sufficient for maximum number of persons* |
| *Sleeping bags – sufficient for at least one between two persons* |
| *Foam sleeping mats or similar – sufficient for at least one between two persons* |
| *Shovels – at least 2* |
| *Sanitation (e.g. toilet paper)* |
| *Stove and fuel – sufficient for maximum number of persons ashore and maximum anticipated time of rescue* |

| |
|---|
| *Emergency food – sufficient for maximum number of persons ashore and maximum anticipated time of rescue* |
| *Flashlights – one per shelter* |
| *Waterproof and windproof matches – two boxes per shelter* |
| *Whistle* |
| *Signal mirror* |
| *Water containers & water purification tablets* |
| *Spare set of personal survival equipment* |
| *Group survival equipment container (waterproof and floatable)* |

The additional guidance to chapter 8 gives suggested equipment to fulfill the functional requirements given in the Polar Code. It does not say if these suggestions are minimum requirements.

### 3.3.3 LSA Code

The Maritime Safety Committee adopted the LSA Code in June 1996. It provides international requirements for the life-saving appliances that are required by the SOLAS Convention, including personal life-saving appliances (e.g. immersion suits, lifejackets, thermal protective aids and anti-exposure suits), survival craft (life rafts and lifeboats), launching and embarkation appliances and marine evacuation systems (IMO - LSA, 2010).

The LSA Code is very specific so it serves no purpose to go through it in its entirety in this review. However, a few parts of it will be presented, all text presented in italic in this chapter is extracted from the LSA Code (IMO - LSA, 2010).

***4.1.5 Life raft Equipment***

- *.18 a food ration consisting of not less than 10,000 kJ (2,400 kcal) for each person the life raft is permitted to accommodate. These rations shall be palatable, edible throughout the marked life, and packed in a manner which can be readily divided and easily opened, taking into account immersion suit gloved hands;*
- *.19 1.5 liters of fresh water for each person the life raft is permitted to accommodate, of which either 0.5 liters per person may be replaced by a de-salting apparatus capable of producing an equal amount of fresh water in two days or 1 liter per person may be replaced by a manually powered reverse osmosis desalinator capable of producing an equal amount of fresh water in two days;*
- *.21 anti-seasickness medicine sufficient for at least 48 hours and one seasickness bag per person the life raft is permitted to accommodate;*

***4.4.8 Lifeboat equipment***

- *.9 watertight receptacles containing a total of 3 liters of fresh water for each person the lifeboat is permitted to accommodate, of which either 1 liter per person may be replaced by a desalting apparatus capable of producing an equal amount of fresh water in two days or 2 liters per person may be replaced by a manually powered reverse-osmosis desalinator, capable of producing an equal amount of fresh water in two days;*
- *.12 a food ration totaling not less than 10,000 kJ for each person the lifeboat is permitted to accommodate; these rations shall be kept in airtight packaging and be stowed in a watertight container;*
- *.21 anti-seasickness medicine sufficient for at least 48 hours and one seasickness bag for each person;*

The Polar Code gives a maximum expected time of rescue of no less than five days. It is not stated if 3 liters of water and 10,000 kJ of food per person is enough for the five-day requirement.

The World Health Organization (WHO) states that the amount of water needed for survival (through drinking and moisture in food) is around 2.5-3 liters per day (World Health Organization, 2011). This depends on climate and individual physiology. It is easy to become dehydrated in very cold environments. Since cold air cannot hold much moisture, it dehydrates the body with every breath taken. The environment inside a lifeboat or a life raft can be very uncomfortable and seasickness is common. Vomiting will further increase the dehydration and make the persons inside the lifeboat or life raft want to ventilate and bring fresh cold air that further reduces the moisture inside.

All of these factors combined means that the amount of water and food needed to ensure survival for five days would probably be more than the 3 liters of water and 10,000 kJ of food required by the LSA Code. The amount of seasickness medicine would probably also need to be expanded beyond 48 hours to suit the maximum expected time of rescue of five days.

## 3.4 Life-saving appliances

### 3.4.1 Immersion suits

The arctic conditions are harsh and unforgiving, characterized by cold seas, sudden weather changes and long distance to infrastructure. Accidents in these areas can therefore have fatal outcomes. Because of this, rescue equipment used by anglers, offshore workers, tourists and others travelling these waters should be designed for arctic use. If an accident occurs, and the only option is to abandon the vessel by immersion into the sea, the immersion suit is a vital lifesaving appliance. This piece of equipment serves as a barrier between the human body and the cold waters, reducing the exposure and increasing the chance of survival.

To prevent fatalities, the immersion suit must provide sufficient flotation, thermal protection for the entire body and the necessary additional equipment. There are many types of immersion suits available on the market today, from various suppliers. Some suits are designed specifically for helicopter transportation, some for regular immersion from a vessel or installation, and others for work in exposed locations, for example suspended over sea. All of these provide a level of protection which regular life vests are incapable of providing. A life vest might be sufficient for evacuation in warm conditions, but in cold-water immersion situations, some sort of thermal protection is vital.

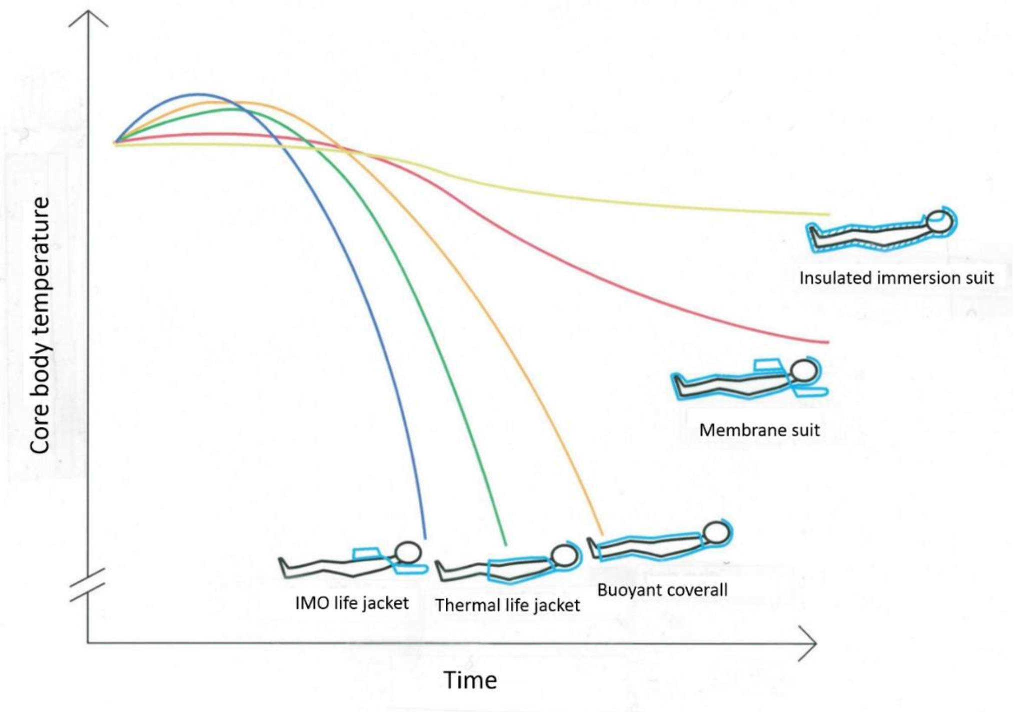


*Figure 19: Core body temperature development over time using various rescue equipment (Norwegian Oil and Gas Association, 2010). Translated.*

Figure 19 shows the difference in core body temperature development over time using various types of common rescue equipment. The traditional life jacket provides flotation, but does not prevent water from soaking the clothing, causing rapid heat loss. The thermal life jacket has slightly improved insulation qualities compared to the standard life jacket, but neither this one prevents clothing from becoming wet. A buoyant coverall will provide somewhat better thermal protection even though it does not prevent water from flowing in. The insulating qualities comes from air trapped in the flotation chambers, and because the coverall prevents loss of heat due to convection.

The membrane suit will, if used correctly, keep the person and clothing inside dry. This significantly improves the protection against heat loss, even though the suit has no integrated insulation material. The insulated immersion suit does an even better job of preventing heat loss from the body. In addition to keeping the person and clothing dry, this suit contains insulation materials that work together with the clothing to reduce the heat loss.

Water intrusion into the immersion suit can have drastic effects on the insulating performance. As little as one liter of water can reduce the insulation effect by 30-40%, thus increasing the heat loss and reducing the expected survival time (Færevik, 2014). It is therefore of high importance that the immersion suit is designed so that water intrusion is kept at a minimum. Leakage occur most commonly in the sealing region between the suit and the person’s neck or face. Integrating a splash hood can contribute to preventing such water intrusion in rough sea conditions, and help reduce the risk of inhaling water (Norwegian Oil and Gas Association, 2010).

To ensure optimal performance of an immersion suit, regardless of type, certain qualities must be in place. These are related to variables such as (Færevik, 2014):

- Freeboard and buoyancy, to maintain free airways
- Buoyancy as an integrated part of the immersion suit
- Natural floating position
- Ability to turn a (unconscious) wearer into the correct floating position
- Thermal insulation value
- Closing mechanisms and cuffs
- Correct underclothing
- Accessories
    - Gloves or mittens
    - Correctly designed splash hood
    - Buddy line and attachments
    - Emergency breathing equipment
    - Emergency beacon
    - Light source

The overall suit performance depends on how these qualities are incorporated in the design, and how well they function.

### 3.4.2 Lifeboats and life rafts

If an emergency at sea should occur, and abandoning ship is necessary, lifeboats and life rafts are an important resource in the evacuation process. The role of these life-saving appliances is to transport evacuated persons safely away from immediate danger, and to provide a temporary safe habitat until rescue arrives. The ideal way to embark a lifeboat or life raft is without having to enter the sea, a so-called dry evacuation. As explained in previous chapters, keeping dry is crucial in a survival situation.

Lifeboats have developed from regular wooden rowing boats. From around 1960, materials such as galvanized steel, aluminum and glass fiber plastic was introduced in the lifeboat designs, improving hull strength and reducing weight. Common sizes for lifeboats are around 7-12 meters in length, 2.5-4 meters wide and room for 20-100 persons. According to regulations from 1987, newly constructed passenger ships should have partially enclosed lifeboats, newly constructed cargo ships should have fully enclosed lifeboats and petroleum platforms should have lifeboats with deluge systems (Store norske leksikon, 2009a).

Lowering lifeboats in high seas, and when ships are listing to one side, has always been problematic. Critical issues related to davit-launched lifeboats are e.g. the long lowering time and the pendulum effect, which can make the lifeboat crash into the ship's side during lowering. Solving these problems by improving the conventional davit launch systems has not been achieved. Since around 1975, the development of freefall lifeboats that drop straight down or from a downward sloping slipway have been ongoing (Store norske leksikon, 2009b). These lifeboats are designed to "dive" into the water at an angle, and can be used safely despite extreme weather conditions. The drop trajectory and sea surface impact-angle is designed to give the lifeboat a horizontal momentum away from the installation or vessel after impact. This momentum ensures that the lifeboat quickly clears the hazardous area. Use of freefall lifeboats for evacuation is required for all petroleum installations except those registered as ships, and are widely used for other vessels within the offshore petroleum industry as well (Olje- og energidepartementet, 2012).

Another means of evacuation is by life rafts, which foremost is used in addition to the traditional lifeboats in order to provide the sufficient evacuation capacity. The original life raft design was barrel-shaped and made out of metal and wood. Nowadays, rigid life rafts are almost exclusively made of encapsulated foam plastic. Another widespread life raft design is based on flexible airtight materials such as rubberized textile, which are inflated by pressurized air. The raft inflation process is activated either manually on board the vessel, or automatically upon contact with water (Store norske leksikon, 2009c).

Regarding development of lifeboats and life rafts for use in the Arctic, it is sensible to look at recommendations and solutions developed for the offshore petroleum industry. Although most installations and vessels within the petroleum industry use freefall lifeboats, drop launch may be obstructed by sea ice when operating in arctic areas. It is possible to use the same lifeboats in such conditions, but they have to be lowered using the davit instead of being dropped. Arctic conditions present challenges not only to the operation of lifeboats, but also to storage and launching. Icing of the lifeboat when stowed in the cradle, and of the launching systems necessary to put the boat on water, may render the boat immobilized. These problems are relevant for all types of lifeboats and launching systems exposed to arctic conditions. There are several possible solutions to the icing problem, such as using heating elements to prevent freezing of mechanisms, or enclosing the lifeboat and arrangements partially or completely (Olje- og energidepartementet, 2012).

*Figure 20: Boat-In-A-Box in launch position during lowering (Nadiro, 2011)*

The Danish company Xervo offers a system called “Boat-In-A-Box”, illustrated in Figure 20, which encloses the lifeboat completely when in stowed position. This solution is based on keeping the boat stowed inside a container, which ensures protection from environmental effects. The system is designed so that it is possible to embark the lifeboat via doors in the container, minimizing the exposure time for persons during boarding. Launching involves davit arms which move the container from stowed to launch position, allowing the lifeboat to be lowered down to the sea surface by winch (Xervo, n.d.).

Once launched, the challenges presented by sea ice affects conventional lifeboats and life rafts in the same manner as the freefall boats. There are obvious difficulties related to propulsion and maneuvering in ice, and collisions with drift ice may lead to damage on the boats or rafts. Measures to reduce or mitigate icing on lifeboats and life rafts should be taken, as this may affect their stability (Olje- og energidepartementet, 2012). These problems were also identified in the gap analysis performed as a part of the SARiNOR (Search and Rescue in the High North) project (DNV GL, 2014), which states that operation in waters with sea ice requires lifeboats and life rafts that can operate in such conditions.

Evaluation of current evacuation equipment was a part of SARiNOR work package 5 “Cold climate survival”, and the project identified several important elements that should be included in lifeboats for polar conditions. These key factors are illustrated in Figure 21.

As previously mentioned, the structural integrity should be designed to cope with sea ice, and the propulsion system must be able to handle this as well. In addition, the lifeboat must carry enough fuel to ensure that the necessary systems are able to operate for an extended period, to comply with the five-day survival requirement from the Polar Code. The space inside a lifeboat is often crowded, at least if the maximum carrying capacity is filled. The main goal is to evacuate as many people as possible, but after the boat is clear of immediate danger, the limited space might present problems for the persons inside. Designing the ventilation arrangements properly can solve this problem, which will help maintain habitable surroundings. As the Polar Code includes new requirements to survival equipment, lifeboats must have the necessary storage capacity to carry such equipment for all persons on board.

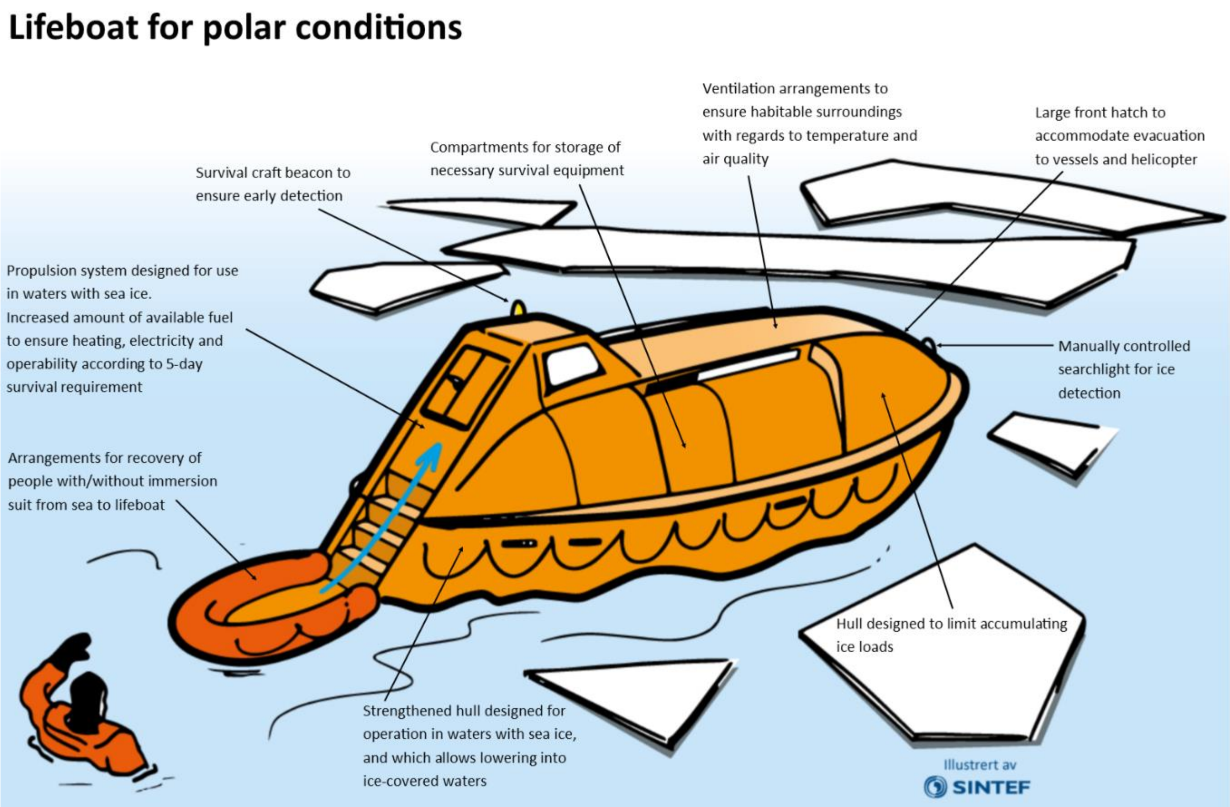


*Figure 21: Lifeboat for polar conditions (SINTEF/SARiNOR, n.d.). Translated.*

Loads from icing should be prevented by effective design solutions, to prevent instability. Other key elements are for instance a searchlight to aid navigation in ice, and an emergency beacon to enable rescue resources to locate the lifeboat quickly. To be able to extract persons from the sea, the lifeboat should include some sort of arrangement designed for such recoveries. Likewise, a large front hatch will accommodate easier evacuation from the lifeboat to any rescue vessel or helicopter.

Many of the mentioned elements are important for life rafts as well, and it may propose larger challenges to include these in inflatable rafts designed to be packed together in small containers when stowed. Life raft containers have lately been further developed, and several manufacturers have designed these to be functional in temperatures well below -40°C. Insulated containers with built-in heating, ensuring that the life raft always inflates, are now available from manufacturers such as Viking (Viking Life-Saving Equipment, n.d.). Life raft designs for use in waters with sea ice and on ice floes are also available on the market, e.g. from the American manufacturer Tulmar Safety Systems. An advantage with life rafts over lifeboats is the possibility of launching them onto ice floes, where they can be inflated and used as shelter. The 6XL Arctic Life Raft available from Tulmar is strengthened to avoid puncturing from ice interaction, and the entire raft can be anchored on top of an ice floe (Tulmar Safety Systems, n.d.). This particular raft design is targeted for aviation purposes, but the concepts presented is highly relevant for marine traffic in the Arctic.

## 3.5 Review of lifeboat habitability studies

In order to have sufficient background information to support the SARex exercise tests, the authors wanted to research previous lifeboat survival testing done in cold climate regions. The majority of papers that have been researched are from Canada.

The most relevant papers are summarized below:

- "Assessment of thermal protection and microclimate in SOLAS approved lifeboats". The objective of this study was to assess the thermal protection and ventilation rate of lifeboats in the Arctic environment. One 72-person lifeboat and one 20-person lifeboat was used during this study, both of them were SOLAS approved. In the 72-person lifeboat, without the engine running, the ventilation rate was 2 liters per second. In order to keep the carbon dioxide levels below 5000 ppm while half loaded and fully loaded you need a ventilation rate of 27 liters per second and 54 liters per second, respectively. To achieve thermoneutral heat loss you would need a ventilation rate of 100 liters per second when half loaded and 300 liters per second when fully loaded. This paper concluded that under simulated Arctic summer conditions the current risks are mainly carbon dioxide toxicity and heat stress (Mak, et al., 2010).
- "Lifeboat Habitability and Effects on Human Subjects". This study included an exercise conducted with a SOLAS approved 20-person lifeboat in Conception Bay, Newfoundland and Labrador, Canada. Two NRC (National Research Council of Canada) employees were in the lifeboat wearing certified immersion suit systems. Their skin temperature, deep body temperature and heart rate were measured while performing their assigned duties as coxswain and assistant. During the morning of July 24$^{th}$, 2009, the outside air temperature was 14°C and the water temperature was approximately 7.6°C, with little to no cloud cover. While maneuvering the lifeboat with the hatches closed, the temperature inside the lifeboat increased from 19.4°C to 28.5°C in about two hours. After these two hours, both the coxswain and the assistant reported moderate levels of thermal discomfort due to the heat and their clothing was heavily soaked with sweat. The paper concludes that there may be risks in operating fully enclosed lifeboats with occupants dressed in clothing that offers a high level of thermal protection. It also states that it can be expected that with more occupants inside the lifeboat, the rise in temperatures measured will increase to levels that may prove to be detrimental to the occupants' safety (Power & Simões Ré, 2010).
- "A preliminary ergonomic assessment of piloting a lifeboat in ice". This paper examines human factors associated with piloting a totally enclosed lifeboat. In addition to examining the coxswain's control panel and how easy the lifeboat is to maneuver in ice, it also examines the environmental conditions inside the lifeboat during evacuation. When the hatches were closed and three people were inside the 20-person lifeboat, the habitability assessment indicated that both CO and $CO_2$

levels approached maximum allowable limits within the first 10 minutes of data collection. The temperature with hatches closed reached approximately 14°C. However, this was the highest temperature reached before the run was cancelled due to the high CO and $CO_2$ values. Calculations done showed that the temperature would most likely have risen to approximately 35°C if the run had not been cancelled. The paper noted that heat stress combined with a continuously moving environment in which nearly all of the evacuees will have no visual reference may lead to a situation in which motion sickness becomes a considerable concern for many of the individuals waiting several days to be rescued (Taber, et al., 2009).

# 4. SARex research trip

The details surrounding SARex and the trip to Woodfjorden on the north side of Svalbard are presented in this chapter. It includes the planning and preparations done before the trip and an informative timeline of the events on the trip. It also presents the details regarding the lifeboat test that were the main focus for the authors, and the results from the logging and the equipment used during the test. Figure 22 shows the location of the lifeboat test.


*Figure 22: SARex test location in Woodfjorden, indicated with a red circle. Map © Norwegian Polar Institute*

## 4.1 About SARex

SARex was a full-scale exercise that wanted to identify and explore the gaps between the functionality provided by existing SOLAS approved safety equipment and the functionality required by the Polar Code. The full-scale exercise was held in Woodfjorden in northern Svalbard in late April, 2016. The exercise aimed to simulate relevant polar conditions and incorporate sea ice, sea swell, low air and water temperatures and also remoteness from rescue resources and infrastructure. Under these conditions the exercise wanted to address the following topics (Solberg & Gudmestad, 2016):

1. Functionality of life rafts and lifeboats under polar conditions.
2. Functionality of personal life-saving appliances (e.g. thermal protection/survival suits).
3. Additional training requirements for crew and passengers.
4. Evaluate Coast Guard search and rescue procedures, including handling of mass evacuations in polar regions.

This exercise was conducted together with leading experts from the industry, governmental organizations, academia and the Norwegian Coast Guard.

## 4.2 Planning and preparation

The authors assisted the SARex project group with developing the planning document that was circulated by email prior to the exercise. This document was a detailed representation of the exercise and the SARex research program.

The objectives of the research program were:

- Investigate the adequacy of the rescue program required by the Polar Code.
- Study the effectiveness of launching, accessing and rescuing people from lifeboats and life rafts when in ice infested waters.
- Study the adequacy of standard lifeboats and life rafts for use in ice infested waters.
- Study the adequacy of standard survival equipment for use in ice infested waters.
- Study winterization means to improve the suitability of equipment to be used for rescue operations in cold regions and ice infested waters.
- Train Norwegian Coast Guard personnel on emergency procedures in ice infested waters with particular reference to evacuation and rescue from cruise ships.

The research program was structured in work packages (WPs) as shown in Figure 23. Each work package had a separate delivery to WP6 - Synthesizes. WP6 gathered all findings and will produce a report containing all gathered data and a summary of all the findings. At the completion of this master thesis, this report was not yet published.

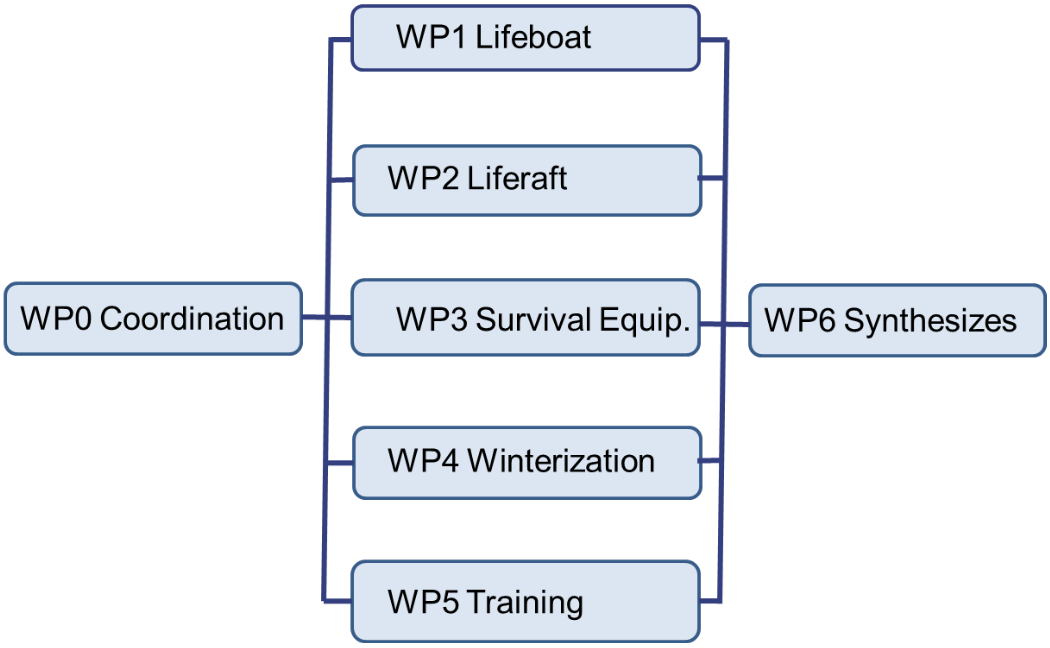


*Figure 23: SARex research program structure*

The authors were assigned to WP1 Lifeboat as it coincided the best with the focus of this thesis. The goals of WP 1 during the exercise was to:

- Study the effectiveness of launching, accessing and rescuing people from lifeboats when in ice infested waters.
- Study the effects on exercise participants from being in the lifeboat.
- Study the adequacy of standard lifeboats for use in ice infested waters.

To be able to study these factors closely, a list of parameters was chosen to be measured. Some of them by the medical staff, some by the manufactures of the lifeboat and a few by the authors as redundant measurements for use in this thesis. Table 1 shows the list of parameters to be measured.

*Table 1: Parameters to be measured during lifeboat test*

| Measured parameter | Method | Equipment | Reason |
|---|---|---|---|
| **Exercise participants** | | | |
| Fitness | Training bicycle (Evaluation by medical staff) | Training bicycle | Check fitness of participants |
| Lung capacity | Measure lung capacity (Evaluation by medical staff) | Medical instrument | Check physical condition of participants |
| Body temperature of participants | Manual (Evaluation by medical staff) | Thermometer | Is extra heat source required? |
| Cognitive ability | Manual (Evaluation by medical staff) | Test equipment<br>Stopwatch | Already in the early phases of a hypothermic condition, the cognitive ability is reduced. Cognitive abilities is essential to survive. |
| **Working environment** | | | |
| Air temperature inside vessel | Data logger | Data logger, batteries | Is heat source required? |
| $CO_2$/$O_2$ level inside vessel | Data logger | Data logger, batteries | Is air vents required? |
| **Vessel** | | | |
| Vessel's fuel consumption | Data logger | Data logger, batteries | Assess fuel consumption when operating in the ice for 5 days. |
| Vessel ice handling capabilities | Interview with vessel helms man<br>GPS logger | Interview form<br>GPS logger | Is the vessel ice handling capabilities sufficient for utilization in ice-covered areas? |
| Space requirements when wearing protective equipment | Interview with passengers | Interview form | Evaluate space needed per person when wearing protective suits |
| Qualitative.<br>Effectiveness of launching, accessing and rescuing people from life boat | Evaluation of performance in the mentioned phases | GoPro cameras (to be worn by Dalsand and Nese)<br>Observation form | Assess whether equipment/procedures are adequate for arctic use |

This was the complete list of parameters to be measured from the planning document. UiT – The Arctic University of Norway lent the authors logging equipment for CO, $CO_2$ and temperature measurements.

During the first day of the research trip the team had a meeting to plan the specifics of the trip and quickly made the decision to organize the testing and research in three phases instead of work packages. This was in part due to the limited time that was available, and several of the objectives and goals had to be studied simultaneously. The three phases were as follows:

- Phase one
    - Test survival times in lifeboat and life raft with participants wearing different kinds of personal protective equipment.
- Phase two
    - Training for the Coast Guard personnel on mass evacuation from lifeboat and triage of passengers.
- Phase three
    - Test the lifeboat and life raft in ice-infested waters. Test personal/group survival equipment and personal protective equipment on ice/close to ice.

## 4.3 Research trip timeline

**Friday 22nd of April**

The research team embarked KV Svalbard in Longyearbyen around 14:00 local time. At 16:50 the research team was served dinner in the mess. The ships chefs prepared excellent food on the entire trip. The ship departed Longyearbyen around 17:30, as shown in Figure 24.

*Figure 24: KV Svalbard departing Longyearbyen. Photo © Trond Spande*

The voyage north on the west side of Svalbard was challenging for some of the SARex personnel due to all the movement from the boat. A lot of people were on the bridge looking towards the horizon to minimize the chance of seasickness. The rest of the day was spent getting to know the boat, the crew and the other participants from SARex.

**Saturday 23rd of April**

Together with the Coast Guard personnel the research team decided that the best place to conduct the tests was in Woodfjorden. The conditions would be stable there and the safety of the participants would be high. There was also sea ice nearby which would be realistic in a cruise accident scenario. Further into Woodfjorden there was fast ice, which would be ideal to do phase three in.

For phase one the authors were in charge of the risk assessments for the lifeboat and life raft tests. Dalsand was in charge of the lifeboat risk assessment, and Nese was in charge of the life raft risk assessment. The people from SARex who were assigned to the lifeboat and life raft in the test participated in the corresponding risk assessment.

Appendix B shows the risk assessments done by the risk assessment groups which were led by the authors. These risk assessments had a basis in, but was not limited to, the PHA prepared by the authors ahead of the trip.

**Sunday 24th of April**

This was the day of the lifeboat test which were the authors main focus. The authors outfitted the lifeboat with 4 temperature sensors placed in strategic places inside the lifeboat. Another device that measured temperature and humidity was placed near the coxswain seat. A gas detector that measured CO and $CO_2$ was also placed in the same area.

Everyone that were to participate in the lifeboat and life raft tests gathered in the hangar at 09:00. The participants were given their assigned personal protective equipment and prepared to be transported to their assigned life-saving appliance. There were 16 participants in the lifeboat and 20 participants in the life raft.

*Figure 25: The lifeboat, life raft and MOB boats. Photo © Trond Spande*

The authors were transported from the ship to the lifeboat in a man overboard (MOB) boat at around 09:40. The devices and sensors were started at around this time. The experiences from phase one of the exercise is presented in Chapter 4.4 “Phase one details”. The exercise ended approximately 24 hours later, at which time the sensors and devices were turned off. Figure 25 is from the phase one test.

**Monday 25th of April**

Participants from the lifeboat and life raft test was given a few hours to rest before a workshop was conducted to summarize the experiences from the phase one test. The authors were responsible for documenting the workshop and summarizing the comments made. This document is presented in Appendix C.

The planning for phase two was handled mostly by the medical team from SARex which included one person from St. Olavs hospital and three from the Norwegian University of Science and Technology (NTNU), along with the Coast Guard personnel.

**Tuesday 26th of April**

The phase two exercise started at 12:00, after brunch. There were 38 participants who acted as cruise passengers in the lifeboat. All participants were wearing some type of immersion suit and were transported to the lifeboat prior to the exercise. This exercise gave the crew of KV Svalbard the chance to practice on rescuing people from a lifeboat in the Arctic.

The participants that were acting as passengers in need of rescue were divided into four groups. Group 1 consisted of five people that were severely injured with e.g. broken bones and lacerations. Group 2 consisted of five people who were unconscious. Group 3 consisted of ten people who had diminished cognitive function, were confused and irrational. The rest were cold, but could look after themselves.

When the rescue crew arrived they quickly figured out that they could not get the most injured passengers onboard the MOB boats first, due to the limited space available in the lifeboat. They had to change from their original plan and get the people who could walk on their own into the MOB boats first. This way they cleared enough space to treat and evacuate the most injured people that were left in the lifeboat.

Back on the ship the participants were triaged in the hangar. The confused people gave the crew a lot of problems, as they all had to be tended to and calmed down. In the hangar, all participants were examined and given the proper treatment. Those in need were given warm drinks and blankets, and those who were in good condition were escorted to an officers' lounge. The crew practiced a simulated helicopter evacuation, but as the authors were in good condition, they did not participate in this part of the exercise.

After phase two was concluded the Coast Guard debriefed the crew that participated in the exercise. In the afternoon the ship headed further into Woodfjorden and into fast ice. After positioning the ship in the ice, the gangway was installed on the starboard side of the ship. The life raft was then hoisted down in the open channel behind the ship.

Phase three was initiated with a test of the life raft in ice. 25 people boarded the life raft from the ice, which was maximum capacity. Everyone wore survival suits for this part of the exercise. The participants tried to navigate the life raft using the oars that come with the life raft. This proved to be very difficult if not impossible with 25 people onboard. The weather was ideal with wind speeds close to zero, clear skies and midnight sun. The life raft was then towed, by people on the fast ice, into slush ice further behind in the open channel. Navigating the life raft with oars in these conditions was impossible, the life raft stood still no matter how hard the Coast Guard personnel rowed with the oars.

After this the participants left the life raft by climbing onto the fast ice. The participants now tried to drag the life raft onto the fast ice. This was surprisingly easy, even with four people still in the life raft. The participants continued and dragged the life raft all the way back to the ship on the ice. This was a bit more challenging but not a big problem with enough people helping.

Phase three continued with the participants testing the equipment available in a PSK and a GSK. The GSK included a tent that had to be assembled, this assembly was hard and time consuming even for engineers and Coast Guard personnel in perfect weather conditions. A lot of the equipment came in packaging, some were packed with hard plastic that was almost impossible to open with only hands. It also contained a flashlight in packaging where batteries were not included.

**Wednesday 27$^{th}$ and Thursday 28$^{th}$ of April**

The rest of the trip was used for some leisure activities, discussions and a lot of paperwork. The ship departed the fast ice in Woodfjorden at around 13:00 on Wednesday and stopped in Ny-Ålesund at around 09:00 Thursday morning. A few hours later the ship departed Ny-Ålesund and was back in Longyearbyen at around 21:00.

## 4.4 Phase one details

### 4.4.1 Description of lifeboat

Norsafe, a Norwegian based manufacturer of marine life-saving systems for merchant and offshore markets, provided the lifeboat chosen for testing in the SARex project. The lifeboat was a conventional Totally Enclosed Lifeboat (TELB) with model name “Miriam 8,5”, and is according to the specifications designed and manufactured according to the latest SOLAS, Classification Society and National Authority requirements. Figure 26 illustrates the lifeboat in operation during the phase one SARex test.

The particular lifeboat brought for testing had previously been installed on an offshore platform, and was therefore equipped as a tanker version, meaning that it had a compressed air system and exterior deluge system. These systems were however not used during the tests. Compared to the standard version, it also had an internal equipment box and various other accessories due to its previous use. This additional equipment had no influence on the test, as none of it had an effect on the survival conditions. The water and food rations were of the standard type, in compliance with the LSA Code. Basic technical data is presented in Table 2 (Norsafe as, 2012), and technical drawings showing external and internal general arrangement are included in Appendix E.

*Table 2: General specifications - Norsafe "Miriam" TELB*

| | |
|---|---|
| Length, overall | 8,60 m |
| Length, hull | 8,50 m |
| Beam, overall | 3,25 m |
| Height, overall | 3,55 m |
| Hook distance | 7,80 m |
| Hook height | 2,25 m |
| Capacity (98kg/pers.) | 55 pers. |
| Weight, boat including all equipment | 4900 kg |
| Total davit load | 10290 kg |
| Speed, minimum | 6 knots |
| Standard hook | Tor 8,0T and Tor Mk2 8,0T |
| Materials | Glass-reinforced plastic (GRP) |
| Buoyancy material | Polyurethane foam |


*Figure 26: Lifeboat used during test. Photo © Jan Erik Jensen.*

The lifeboat is launched and retrieved using a davit, with two lifting wires that connects to the lifeboats' two release hooks. The on-load release hooks are operated from inside the lifeboat, by a handle mounted next to the coxswain position. The system prevents accidental release of the hooks by a hydrostatic interlock. When the boat is fully waterborne, the hook release mechanism provides simultaneous release of the two hooks. It is also possible to release the hooks manually, with access through the fore and aft hatches. When installed on a ship's side, the lifeboat is equipped with skates that allows it to slide easily on the ships' side, along with shock-absorbing fenders. Embarkation is done through the side hatches, or via the large hatch on top of the superstructure. Seating inside the lifeboat consist of GRP benches with safety belts.

The steering system is hydraulic, with a steering nozzle that provides good maneuverability. In case the main system is inoperable, there is also emergency steering. The lifeboat is equipped with a diesel engine and fuel tank capacity sufficient to run the boat, fully loaded, at 6 knots for 24 hours. Engine cooling is freshwater based, with header tank and external cooler. For maintenance and inspections, the engine can be run in the davit for 5 minutes without overheating. A suction relief valve in the superstructure prevents negative air pressure inside the lifeboat when the engine is running.

The lifeboat is equipped with electrical starter and two independent batteries. When stowed in the davit, batteries are charged from the ships' 42V power supply. The engine has a 12V alternator for battery charging when the boat is in operation.

### 4.4.2 Personal protective equipment

This is a presentation of the personal protective equipment used by the participants in the phase one test. Due to the objective of the test, only the basic specifications including the insulating properties are presented here.

**Kamp Vest**

The Kamp Vest is the standard type lifejacket used by the Coast Guard. It features an integrated neoprene hood. Figure 27 shows the lifejacket.

**Viking PV9720**

The Viking PV9720 is a thermal protective lifejacket. It consists of a lifejacket and a neoprene torso suit covering the core body, head and crotch area. Figure 27 shows the lifejacket (Viking Life-Saving Equipment, 2015a).

**Viking TPA**

The Viking thermal protective aid (TPA) offers protection against rain, wind and cold temperatures in life rafts and lifeboats. Figure 27 shows the TPA (Viking Life-Saving Equipment, 2014).

*Figure 27: Top left: Kamp Vest, photo © Katie Aylward. Top right: Viking PV9720. Bottom left: Viking TPA. Bottom right: Viking PS2004.*

**Viking PS2004**

The Viking PS2004 is a basic immersion suit made out of 5mm thick neoprene. It has fully integrated neoprene boots, and semi-detachable neoprene gloves. Figure 27 shows the suit (Viking Life-Saving Equipment, 2016a).

**Viking PS5003**

The Viking PS5003 is a non-insulated immersion suit with outer material made of polyurethane coated nylon. It has a thin polyester lining with material weight 120 g/m$^2$. The suit has fully integrated boots and semi-integrated neoprene gloves. Figure 28 shows the suit (Viking Life-Saving Equipment, 2015b).

**Nordkapp suit**

The Nordkapp suit is the standard work-type immersion suit used by the Coast Guard. It has thermal protection designed to protect against both cold water and heat from fire. The suit has fully integrated rubber boots, along with semi-integrated neoprene hood and gloves (Database for offentlige innkjøp, 2008). Figure 28 shows the Nordkapp suit.

**Viking PS5002**

The Viking PS5003 is an insulated immersion suit with outer material made of polyurethane coated nylon. It has a thick polyester lining with material weight 300 g/m$^2$. The suit has fully integrated boots and semi-integrated neoprene gloves. Figure 28 shows the suit (Viking Life-Saving Equipment, 2016b).

*Figure 28: Left: Nordkapp suit, photo © Erik Johan Landa. Middle: Viking PS5003. Right: Viking PS5002.*

### *4.4.2.1 Personal protective equipment in lifeboat test*

The results from the lifeboat test that pertains to the performance of the personal protective equipment is presented in this chapter, in order to be able to discuss the importance of thermal protection that maintains the core temperature of persons in an evacuation situation.

The goal was to see how long the participants could last in the lifeboat before they became too cold or their core temperature dropped too much to continue. This was a subjective assessment made by each participant. The time participants stayed in the lifeboat is shown in Figure 29. There were more participants in the lifeboat than those listed in Figure 29, but some of them were there to observe, and some participants aborted the test for reasons other than being too cold. These participants are not included in this list.

| Participant number | PPE | Time in lifeboat (hours) |
|---|---|---|
| 3 | Kamp Vest | 7,5 |
| 15 | Viking PS5003 | 8 |
| 4 | Viking PV9720 | 8,7 |
| 2 | Kamp Vest | 12,4 |
| 11 | Kamp Vest with Viking TPA | 13,2 |
| 10 | Kamp Vest with Viking TPA | 14,1 |
| 16 | Kamp Vest with Viking TPA | 18,2 |
| 12 | Viking PS2004 | 20,5 |
| 7 | Viking PS5002 | 20,6 |
| 14 | Viking PS5003 | 24 |
| 8 | Viking PS5002 | 24,1 |
| 13 | Viking PS2004 | 24,2 |
| 1 | Nordkapp suit | 24,3 |

*Figure 29: Lifeboat participants time in lifeboat*

The four participants that lasted 24 hours all stayed in the lifeboat until the test was ended by the organizers. However, they all felt colder at the conclusion of the test than when they started. The difference in time stayed is due to that their time was logged during the doctor examination, which was only done one participant at a time.  All other participants left the lifeboat due to feeling too cold at the times shown in Figure 29.

### 4.4.3 Logging equipment and data collected

#### *4.4.3.1 Logging equipment*

For phase one of SARex, the test of survival in lifeboat/life raft, a collection of equipment for measuring and logging various parameters inside the vessels was used. The following parameters was measured:

- Temperature
- Relative humidity
- $CO_2$
- CO

The following subchapters presents the various logging equipment that was used during the lifeboat test, including specifications and placement inside the lifeboat. The equipment can be seen in Figure 30, their placements inside the lifeboat can be seen in Figure 31.


*Figure 30: Logging equipment used during lifeboat test. Left: GasAlertMicro 5 IR gas detector. Top right: EasyLog EL-CC-1-003 temperature logger. Bottom right: RHTemp1000 humidity & temperature data logger*

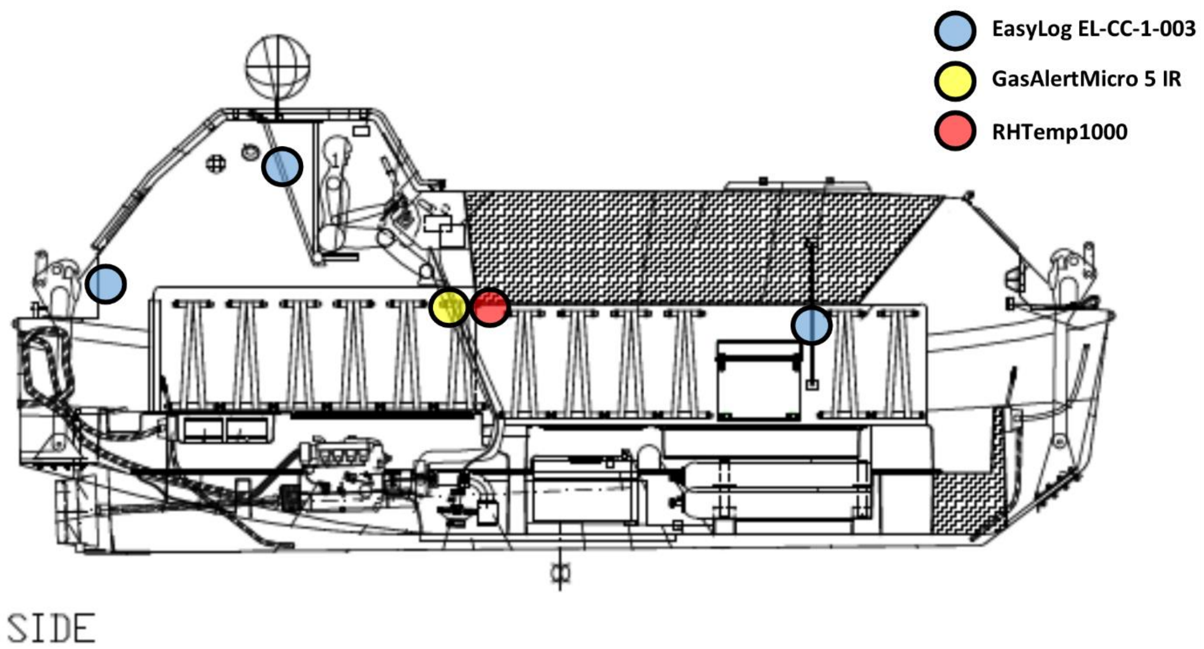


*Figure 31: Placement of logging equipment in lifeboat during test*

#### 4.4.3.1.1 Lascar Electronics - EasyLog EL-CC-1-003

The EasyLog EL-CC-1-003 temperature logger (Lascar Electronics, 2015) was originally designed for monitoring of chilled goods. It was chosen due to its specifications, which were well-suited for the lifeboat test. The logger was also inexpensive, meaning that several could be brought along. In total, four units were purchased and used for the test. One of these was not activated correctly, and therefore did not produce any results. Data logs were extracted after the SARex expedition ended. The temperature logger is depicted in Figure 30, and its specifications are listed in Table 3.

*Table 3: Specifications - EasyLog EL-CC-1-003*

| **Specifications - EasyLog EL-CC-1-003** | |
|---|---|
| Dimensions | 6.7 x 4.8 cm |
| Measurement range | -30 to +60°C |
| Accuracy | ±0.5°C maximum |
| Resolution | 0.1°C |
| Logging interval (preset) | 10 minutes |
| Battery life | 12 months (minimum) |
| IP rating | IP67 (when inside housing bag) |

Prior to the test, the temperature loggers were placed strategically in the lifeboat to be able to map any temperature differences between areas inside the lifeboat. Their exact positions in the lifeboat is illustrated in Figure 31. Plastic strips were used to attach them, and it was assured that the loggers were suspended freely so that they had no contact with any surfaces that could affect the temperature measurements. To prevent misreading, no passengers sat in close vicinity to the temperature loggers during the test.

#### 4.4.3.1.2 BW Technologies by Honeywell - GasAlertMicro 5 IR

The GasAlertMicro 5 IR is a portable gas detector that is capable of simultaneously monitoring up to five atmospheric hazards (Honeywell Analytics, n.d.). It was chosen for the lifeboat test due to its ability to monitor and log $CO_2$ and CO levels in the air inside the lifeboat. The detector was purchased by the university shortly prior to the expedition, and was therefore properly calibrated. Alarm set points were at factory standard levels during the test, which is according to the Occupational Safety and Health Association (OSHA). The gas detector is depicted in Figure 30 and specifications are presented in Table 4 (BW Technologies, 2009).

*Table 4: Specifications - GasAlertMicro 5 IR*

| **Specifications - GasAlertMicro 5 IR** | | |
|---|---|---|
| Dimensions | 14.5 x 7.4 x 3.8 cm | |
| Weight | 370 g | |
| Operating temperature | -20 to +50°C | |
| Alarms | Visual, vibrating, audible (95 dB) | |
| Data logging | Memory card (SD) | |
| Logging interval (set by user) | 5 seconds | |
| ***Sensor specifications (for selected types of gas)*** | | |
| *Gas* | *Measuring range* | *Default resolution* |
| $CO_2$ | 0-50,000 ppm<br>0-5.0% vol. | 50 ppm<br>0.01% vol. |
| CO | 0-999 ppm | 1.0 ppm |
| $O_2$ | 0-30.0% vol. | 0.1% vol. |
| ***Alarm set points – GasAlertMicro 5 IR*** | | |
| *Gas* | *Alarm set points* | |
| $CO_2$ | First alarm: 5,000 ppm (0.5% vol.)<br>Second alarm: 30,000 ppm (3.0% vol.) | |
| CO | First alarm: 35 ppm<br>Second alarm: 200 ppm | |
| $O_2$ | Low alarm: 19.5% vol.<br>High alarm: 23.5% vol. | |

During the lifeboat test, the gas detector was mounted in a location representing the approximate head position of a passenger sitting on the benches close to the center of the lifeboat, as shown in Figure 31. To prevent misreading, no passengers sat in close vicinity to the gas detector during the test. The data logs were extracted from the memory card after the SARex expedition ended.

#### 4.4.3.1.3 MadgeTech RHTemp1000

The RHTemp1000 is a humidity and temperature data logger ideal for use in harsh environments (MadgeTech, 2011). The unit used for the lifeboat test was borrowed from the KV Svalbard crew, which also assisted with extracting the data subsequent to the test. The simple and sturdy metal cylinder design was suitable for this type of test, and required no attention during operation. Figure 30 shows the logger, and its specifications are listed in Table 5.

*Table 5: Specifications - MadgeTech RHTemp1000*

| **Specifications – MadgeTech RHTemp1000** | |
|---|---|
| Dimensions | 13.8 cm x 2.6 cm diameter |
| Weight | 285 g (stainless steel version) |
| ***Temperature sensor*** | Semiconductor |
| Temperature range | -40 to +80°C |
| Temperature resolution | 0.1°C |
| Calibrated accuracy | ±0.5°C (0 to +50°C) |
| ***Humidity sensor*** | Semiconductor |
| Humidity range | 0 to 100%RH |
| Humidity resolution | 0.5%RH |
| Calibrated accuracy | ±3%RH (±2%RH typical at 25°C) |
| Specified accuracy range | +10 to +40°C, 10 to 80%RH |
| Response time | 90% change in 60 seconds in slow moving air (end cap fully open) |
| Logging interval (set by user) | 10 minutes |

Prior to the test, the RHTemp1000 was placed in a location representing the approximate head/upper body position of a passenger sitting on the benches close to the center of the lifeboat, as shown in Figure 31. It was attached using plastic strips, which suspended it freely to avoid any contact with nearby materials that could affect the measurements. To prevent misreading, no passengers sat in close vicinity to the humidity and temperature logger during the test. It was assured that the end cap was fully open during the entire test, to obtain the quickest possible response time.

### *4.4.3.2 Data collected*

This chapter presents the data that was recorded during the lifeboat test. In order to make the data sets easy to understand, they are all viewed as charts. Explanations and interpretations to each chart is provided, to link the measurements to significant events during the test period. Data on ambient air temperature and wind speed was measured and logged hourly by the weather station onboard KV Svalbard. Please note that two data points are missing from the weather station logs, 00:00 and 01:00. It is unsure why the instrument failed to record any data at these times. Data from the other instrumentation used does not have this error.

#### 4.4.3.2.1 Ambient temperature

The ambient temperature was measured by the weather station onboard KV Svalbard during the phase one test, and the data presented in Figure 32. The chart shows that the outside temperature was quite consistent during the test period, averaging at -9.2°C. There were no major discrepancies one or the other way, so it is presumable that the effect on the temperature inside the lifeboat was small.

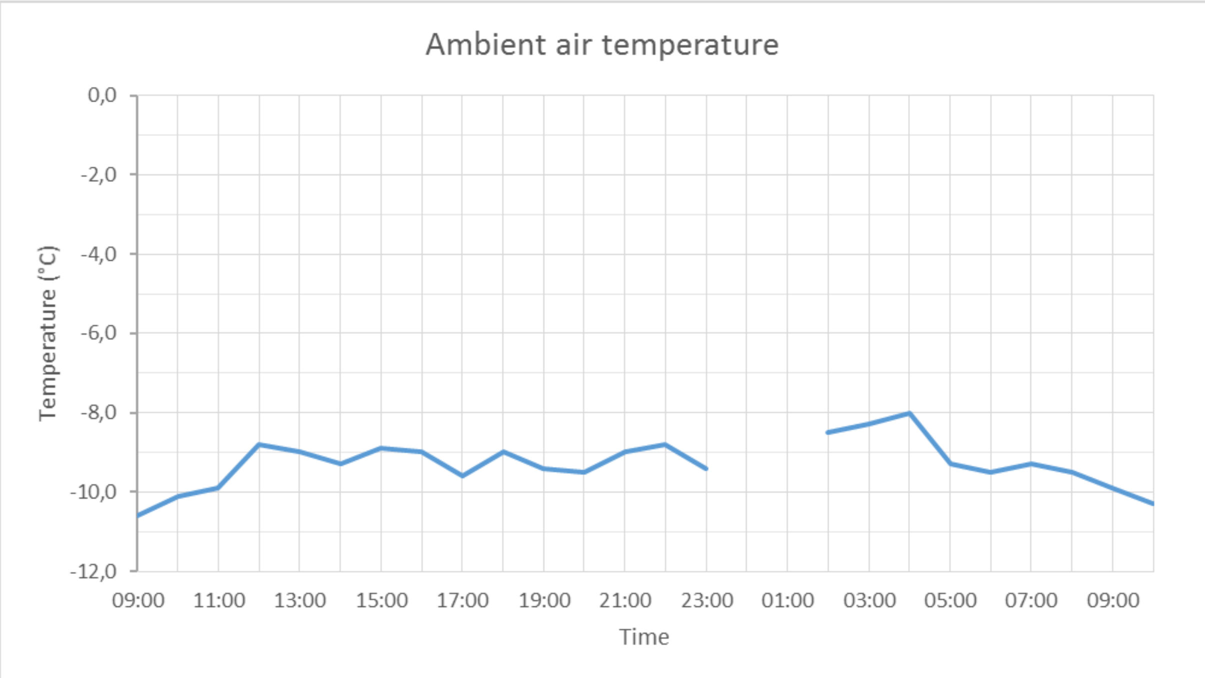


*Figure 32: Ambient air temperature during test*

#### 4.4.3.2.2 Wind speed

The KV Svalbard weather station also recorded wind speed and direction. Since the lifeboat was mostly drifting freely, and not orientated in any specific direction throughout the test, only the wind speed data is presented here. As the chart in Figure 33 shows, from the start of the test all through the evening and early night, there was a light breeze. Then, the wind started picking up a bit towards the end of the night and morning, to a moderate force. The increase in wind speed caused the sea state to change from small wavelets to small waves, resulting in amplified lifeboat movements.

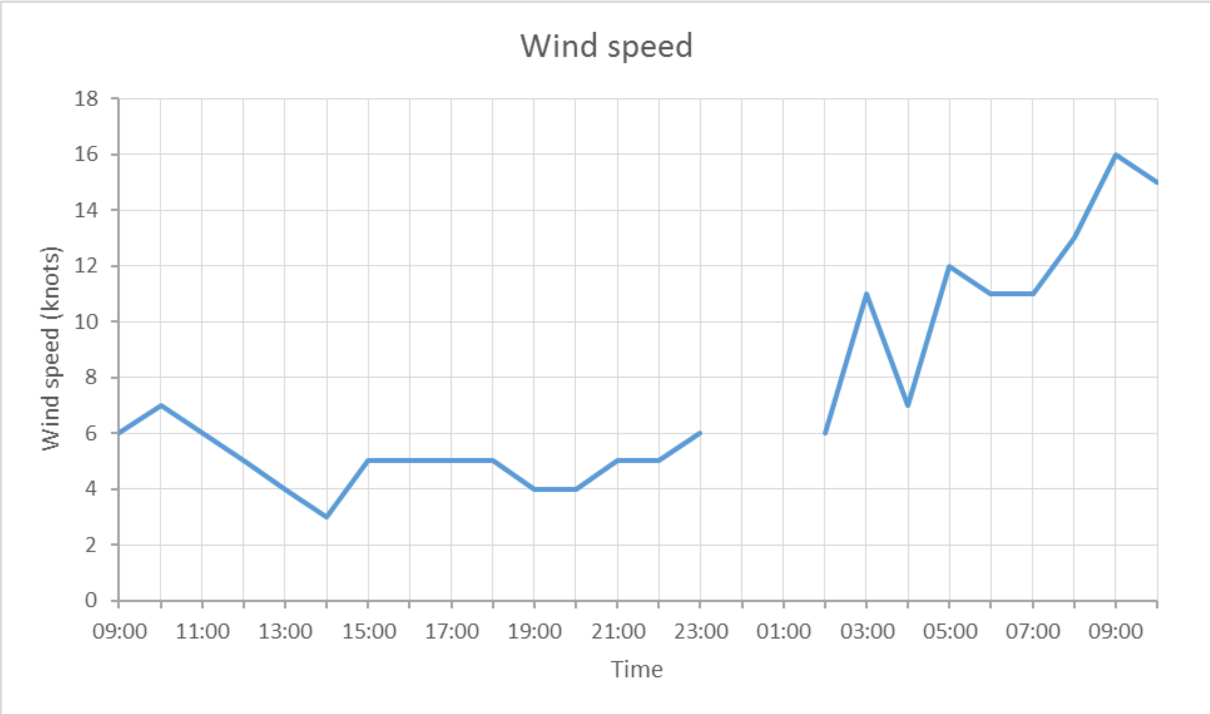


*Figure 33: Wind speed during test*

#### 4.4.3.2.3 Internal temperature

The internal temperature in the lifeboat was measured using two types of instruments, the MadgeTech RHTemp1000 and the EasyLog EL-CC-1-003. The RHTemp1000 is by far the most sophisticated of these instruments, and is therefore trusted to be the most accurate one. Its position in the lifeboat was about as far away from any hatches or windows as possible, meaning that it was able to measure the general inside temperature instead of the rapid fluctuations close to hatches or windows being opened and closed.

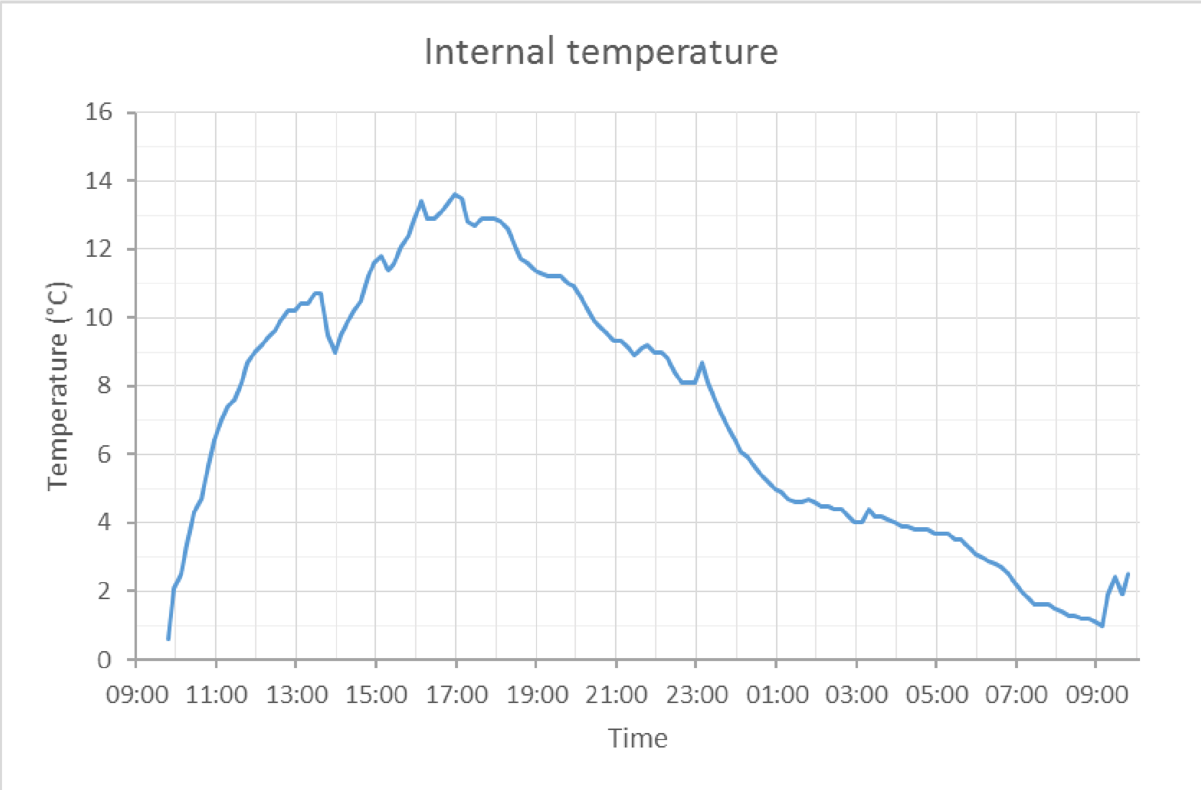


*Figure 34: Internal temperature (RHTemp1000)*

A chart illustrating the temperature data is shown in Figure 34. Before the test started, the lifeboat was maneuvered some distance away from KV Svalbard, and the participants boarded in two groups with an approximate 10-minute interval in between. Once everyone was onboard the lifeboat, the measurements were started. The pre-test activity explains why the starting temperature in the charts are different from the ambient temperature at that time.

When the test started, the temperature was close to 0°C inside the lifeboat. As the chart shows, it then rose relatively fast the first couple of hours. During this period, the hatches were mostly kept closed except for occasional ventilation, and the engine was running at idle from 10:23. The first peak was around 13:30, with a temperature of 10.7°C. The dip down to 9°C at around 13:58 was due to a walrus surfacing right next to the lifeboat, which led to almost all of the windows and hatches being opened for observation.

As the hatches were closed after this episode, the temperature started rising again. At 14:40, there was a session of physical activity in the boat, after which it was necessary to ventilate for a while. A little past 15:00, the engine was turned off. As the chart shows, the temperature continued to rise, suggesting that running the engine on idle had little effect on the inside temperature. One plausible cause is the fact that the engine draws air from inside the lifeboat for combustion, causing a suction relief valve to open in the bow. This process creates some airflow through the interior of the boat, and the cold air being drawn in might equalize the radiating heat from the engine.

The peak temperature of the test, 13.5°C, was reached at 17:08. Prior to, and when the peak temperature was measured, there was clear skies and the sun had therefore been shining on the boat for a while. This might have contributed to the high temperature. Just after the peak occurred, participants started to abort the test and leave. Throughout the rest of the test period, people left in more or less regular intervals, corresponding very well with the steady decline in temperature all through the evening, night and morning. The small dips of the graphs are caused by people aborting or having toilet breaks, which meant that hatches had to be opened. The two minor peaks correspond with points of time where collective physical activity sessions were being arranged. The small peak at the end of the graph is most likely due to a high activity level, and that the engine was being run at high load, right before the test ended.

The results from the three EasyLog EL-CC-1-003 data loggers are suitable for comparing the internal temperatures at different locations in the lifeboat. All temperature data from these loggers are presented in the chart in Figure 35.

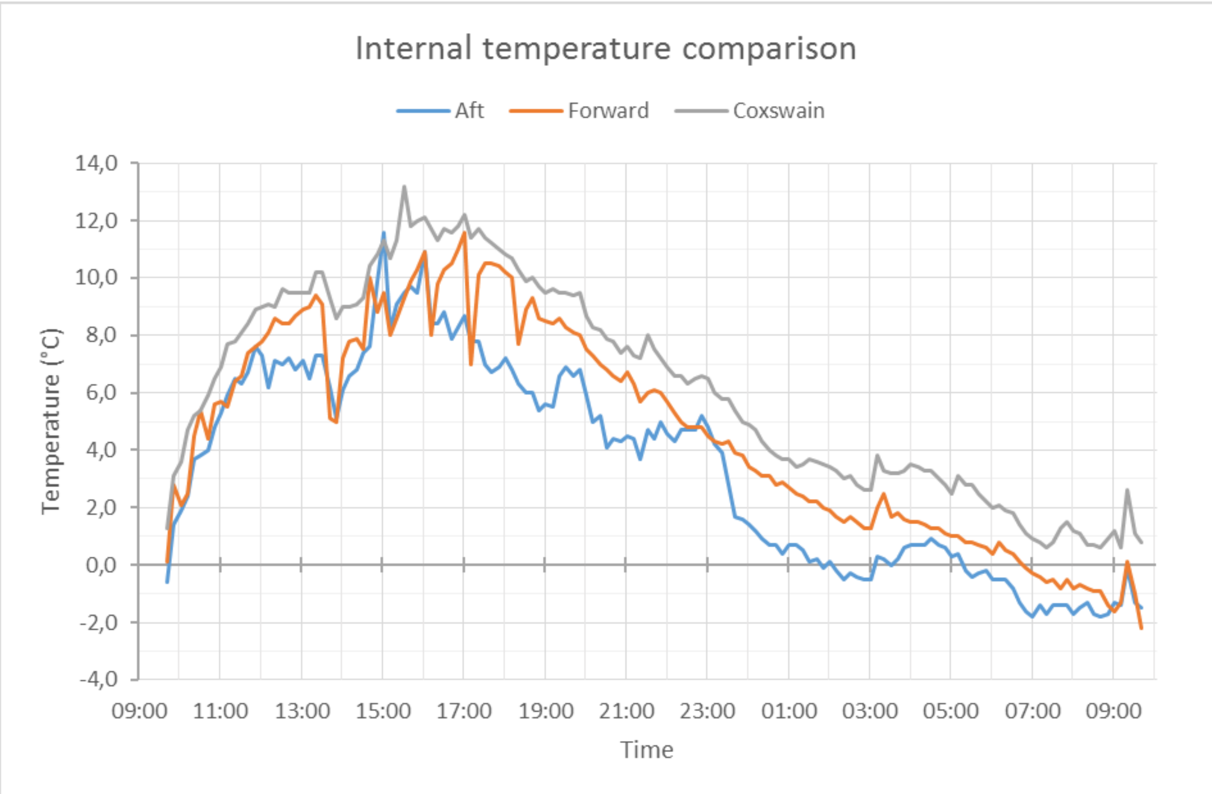


*Figure 35: Comparison of internal temperatures (EasyLog EL-CC-1-003)*

As the chart shows, there were some differences in temperature between the three locations. Some of the main peaks and characteristics can be recognized on all three graphs, while other are specific to each instrument. This is due to the various hatches and windows that was opened, some closer to one logger than the other. The instrument placed near the coxswain position generally logged the highest temperatures of the three, throughout the test. This is not surprising, as it was placed at a much higher point inside the lifeboat, where the warm air collected. Several test participants also commented that the temperature felt noticeably higher when sitting in the coxswain chair than in the lower areas of the boat.

The comparison also shows that the temperature in the forward part of the lifeboat was higher than in the aft part. This is slightly surprising, as the general opinion amongst the participants were the exact opposite. During the test, a portable thermometer was used to check temperatures in real time, and this showed that it was colder in the front of the boat than in the aft. A plausible explanation to why the logger data indicates the opposite is that the aft temperature logger was placed close to the rear window. This window was occasionally open, but that does not explain why the temperature measured was consistently lower than that in the forward area. There is however a possibility that there was some air draught even though the window was closed, or that the temperature logger was affected by the surface temperature of the hull despite the careful preparations.

#### 4.4.3.2.4 Internal humidity

The internal relative humidity (RH) was logged using the MadgeTech RHTemp1000 data logger, and the results is presented in Figure 36. The chart shows that the relative humidity was quite consistent, with an average of ~65.8% RH. As with the temperature data, it is possible to link some of the dips and peaks of the graph to specific events that occurred during the test. The first major dip, occurring at around 13:45, matches the walrus appearance to the point. As previously explained, during that episode almost all hatches and windows was open for a while. The resulting draught through the entire lifeboat seems to have transported a lot of the humid air out from the boat. Following the major dip is a small peak, which correspond with the first physical activity session.

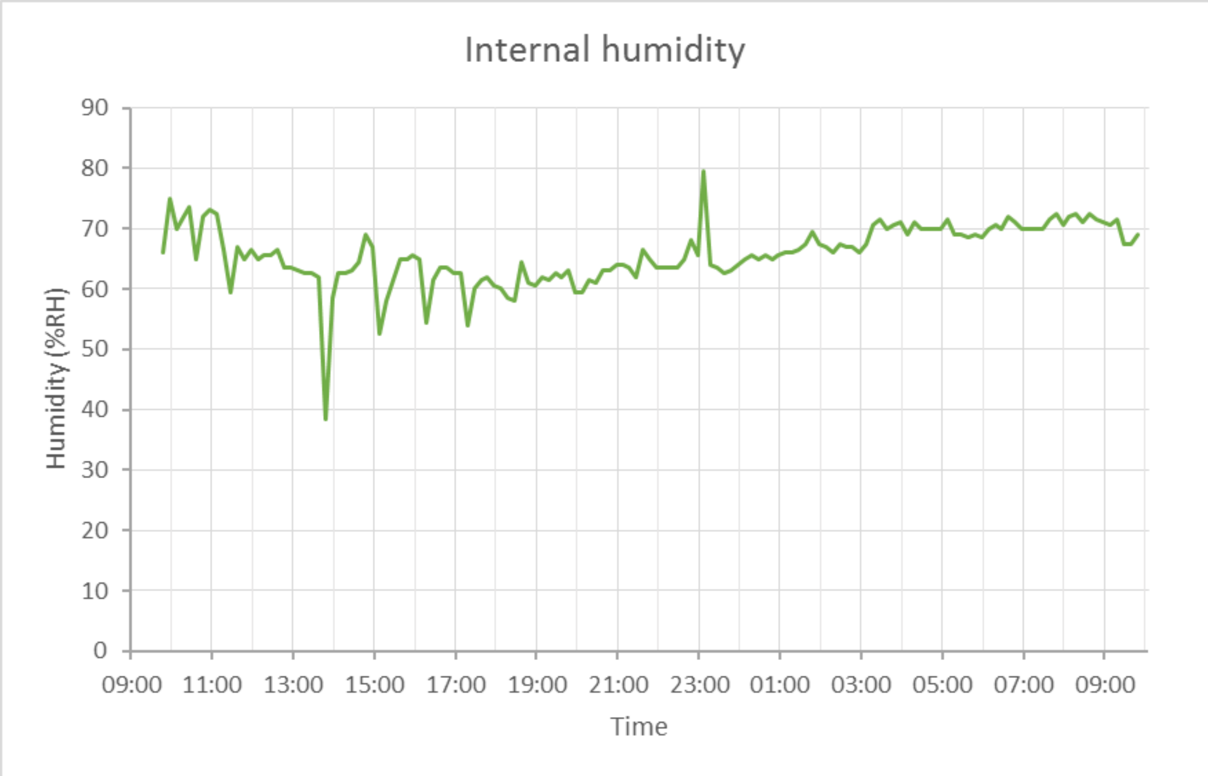


*Figure 36: Internal humidity*

Next, the graph has three smaller dips at 15:08, 16:18 and 17:18. These match the three dips of the EasyLog instrument in the forward part of the lifeboat, which was placed directly below the top hatch. The dips of this exact EasyLog instrument suggests that the top hatch was open at these times. The corresponding temperature and humidity dips indicates that opening the top hatch effectively ventilates the humid air, which is logical since humid air is lighter than dry air, and therefore rises.

The following minor dips and peaks is consistent with the various events that occurred, such as opening the hatches for toilet breaks or when people was aborting, and physical activity sessions. The major peak at 23:08 is thought to be linked to a physical activity session where the hatches was not opened during or right after the session, like they were at previous sessions, allowing the humidity to rise until a hatch eventually was opened. The peak is based on one single reading, so there is a possibility that this was a faulty measurement.

The second half of the chart shows a minor increasing trend overall. This is probably because the hatches were kept closed as much as possible in order to avoid letting the heat out. Although the number of occupants steadily declined from around 17:00, it seems as this had little effect on the relative humidity. The moisture was very visible inside the lifeboat, with the windows misting up and condensed water running down the internal walls. As the temperature declined, this moisture froze, covering the roof, walls and windows in a thin layer of frost.

#### 4.4.3.2.5 $CO_2$ concentration

The $CO_2$ concentration was measured and logged using the GasAlertMicro 5 IR portable gas detector. The data presented in this section was logged early in the test, when all participants were still onboard the lifeboat. In order to obtain readings for different scenarios, two parameters were set and controlled. The first parameter was the engine, which was kept off or running during the test scenarios. The other parameter was the hatches and windows, which were kept closed for the two short scenarios and occasionally closed/open for the long scenario. If or when the $CO_2$ concentration reached 5000 ppm, the first alarm set point, the logging was stopped.

In the first scenario, the engine was off and all hatches and windows were closed at 09:46:45. A chart illustrating the logged data is presented in Figure 37.

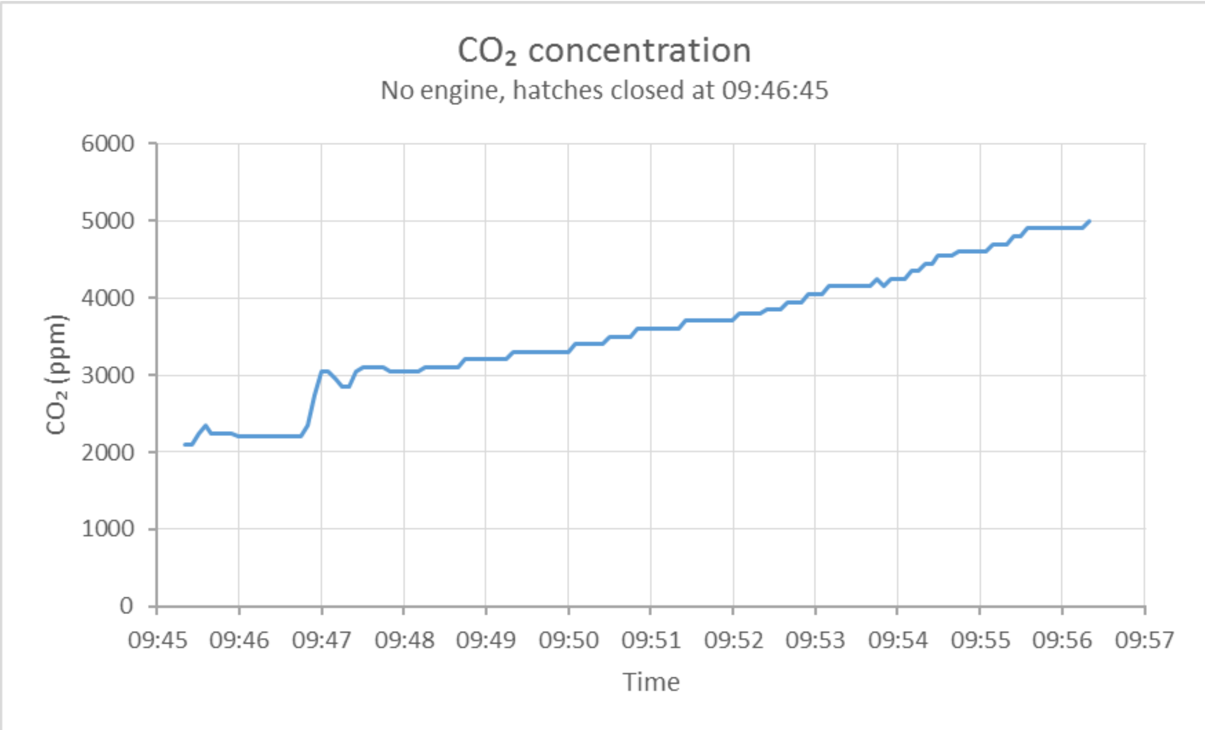


*Figure 37: $CO_2$ concentration - no engine and hatches closed*

As the chart shows, the $CO_2$ concentration rose quickly after the hatches were closed. Subsequently, the increase was close to linear all the way to 5000 ppm. The time from the hatches were closed until the $CO_2$ concentration reached 5000 ppm was less than 10 minutes.

In the second scenario, the engine was running at idle and all hatches and windows were closed. The data is presented in Figure 38.

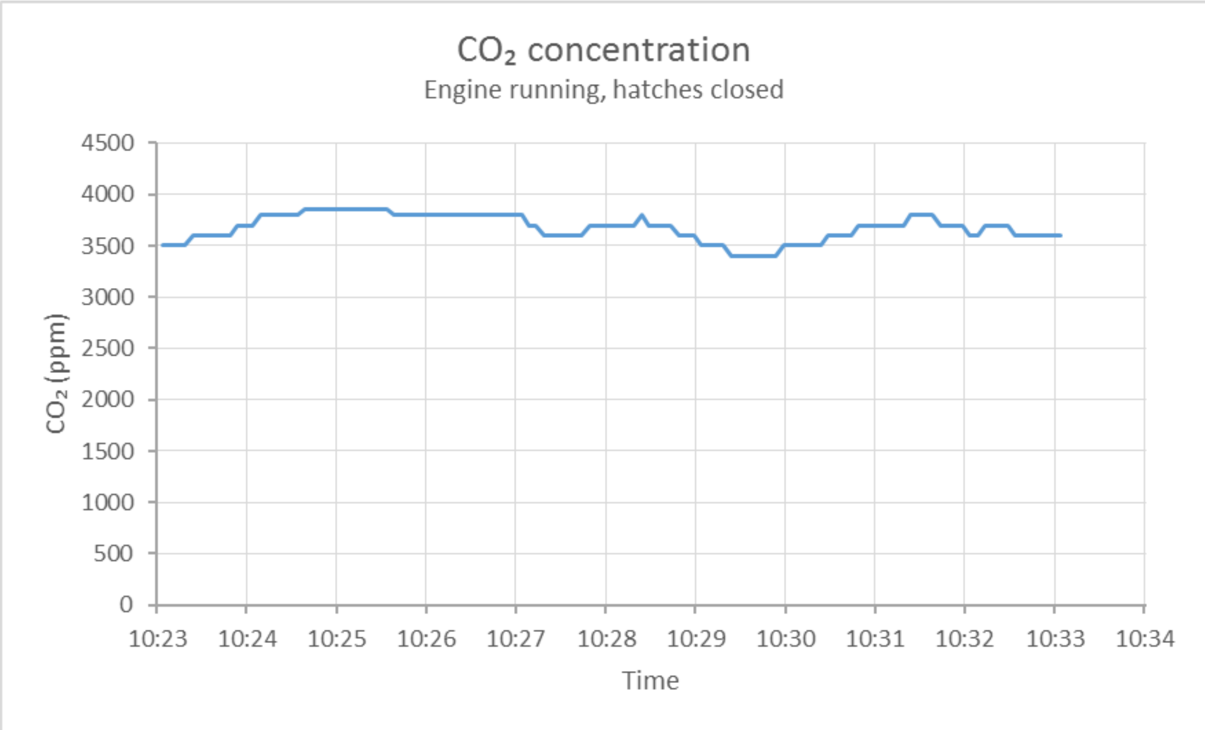


*Figure 38: $CO_2$ concentration - engine running and hatches closed*

The chart shows that the $CO_2$ concentration in this scenario was consistent, averaging at 3675 ppm. Judging from the data from this short time span, running the engine at idle should provide enough airflow through the interior of the lifeboat to prevent the $CO_2$ concentration from increasing. This is probably not the reality, as the data for the next scenario shows.

The third and last scenario spans over a longer period than the previous two, including the data presented in the second scenario. In this setting, the engine was running on idle, and the hatches were occasionally open. This is a more accurate representation of the activities that was performed in the test. The data from the third scenario is presented in Figure 39.

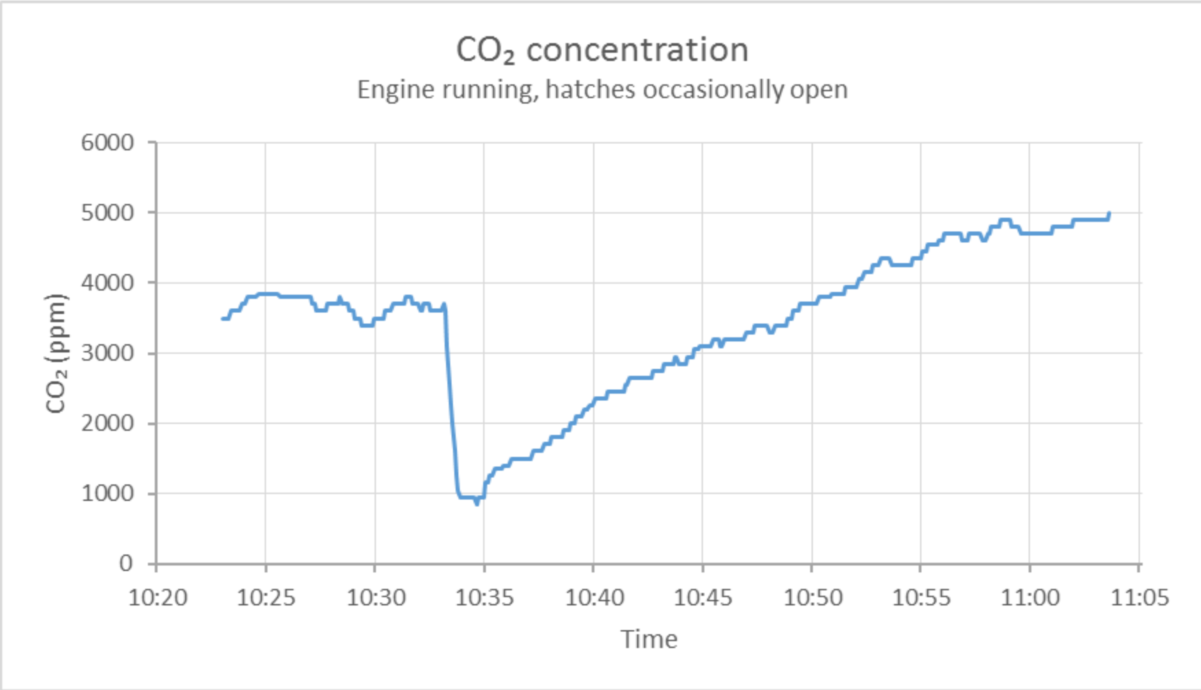


*Figure 39: $CO_2$ concentration - engine running and hatches occasionally open*

The data from the first 10 minutes of this scenario has already been discussed above. At around 10:33 the hatches were opened to let some fresh air into the lifeboat. This brought the $CO_2$ concentration down to 850 ppm for a short while, before it started rising again. Over a period of around 30 minutes, the concentration rose to 5000 ppm. The increase was close to linear, despite the hatches being occasionally open. These results indicate that despite the engine running, the $CO_2$ concentration will rise. The airflow created by the engine helps keeping the levels stable for a short period of time, but it is not sufficient in the long run.

#### 4.4.3.2.6 CO concentration

The CO concentration was measured and logged using the GasAlertMicro 5 IR portable gas detector. No CO gas was measured during the test, and therefore no data is presented here. The lack of any CO gas inside the lifeboat indicates that the exhaust system did not leak, and that no exhaust entered the lifeboat from the outside.

### 4.4.4 Objective report

This chapter contains information about the preparations that was carried out prior to the phase one test. It also includes an objective description of how the participants in the lifeboat experienced the test, as well as the performance of the equipment that was tested.

#### *4.4.4.1 Preparations*

The extensive scope of the phase one test required a lot of preparation before the test could be carried out. While a lot of preparatory work was done in the weeks leading up to the exercise, some remaining elements required the SARex team and KV Svalbard crew to be gathered. By performing the last preparations onboard KV Svalbard while travelling to the designated exercise location, the tests could be planned in detail, with all necessary resources available.

To identify possible hazards that could arise during the tests, and raise the test participants' awareness of risk, a risk assessment session was carried out. This assessment was based on a PHA, where possible problems, causes and consequences were identified and described by the analysis group. The session was performed in two separate groups, one for the lifeboat participants and one for the life raft participants. These risk assessments were led by the authors, and contributes to the SARex project report. The results from these assessments are presented in Appendix B.

One member of the KV Svalbard crew arranged a polar bear safety information presentation, which gave all participants a good understanding of the dangers related to being in areas frequented by these predators. In addition, a general pre-test information and safety briefing for all participants and other involved personnel was arranged. Here, both SARex team and KV Svalbard crew contributed with important information to ensure that the following activities would be carried out as safely as possible.

To be able to assess the health effects of staying in a survival craft for a longer period, a selected group of participants was chosen as test subjects. These were taken hand of by the medical team, who performed various baseline tests and fitted them with equipment for measurements and data logging.

An important part of the phase one test was to obtain an indication of the performance of various personal protective equipment when used in a lifeboat and life raft. More specifically observe how long the participants could last in the lifeboat before they became too cold or their core temperature dropped too much to continue. This was a subjective assessment made by each participant. The test participants were assigned with different types of PPE. In order to have comparable results, all participants wore approximately the same underclothing.

The lifeboat was launched from the aft deck of KV Svalbard using the deck crane, as seen in Figure 40. Transport between KV Svalbard and the survival crafts was carried out using the two MOB boats, and these were also utilized for toilet breaks. In addition, there were at least one MOB boat stationed close to the survival crafts during the test for safety reasons.

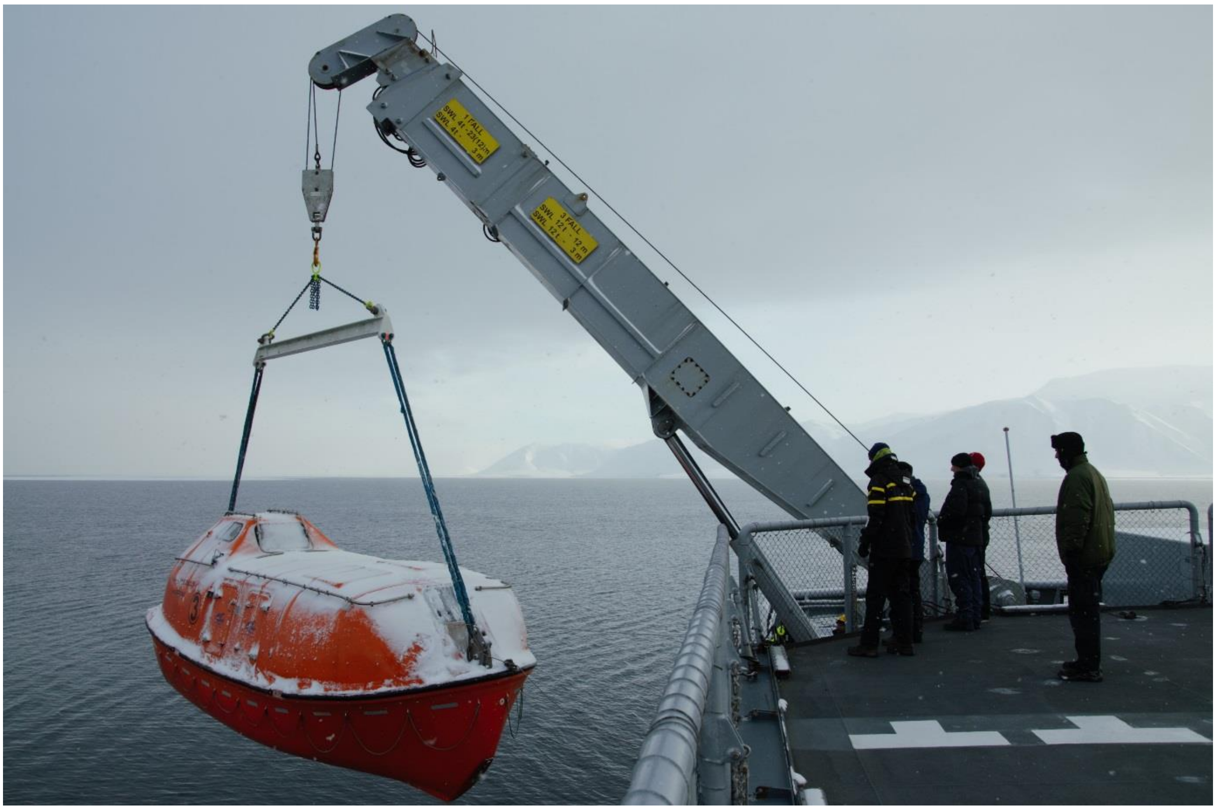

*Figure 40: Lifeboat being lowered into the water with the deck crane. Photo © Jan Erik Jensen*

To prevent participants from getting dangerously cold, a set of criteria for assessing their health state was determined. The SARex medical team set the criteria, in order to control the safety of the participants. The criteria represented obvious signs of lowered body temperature, and if participants experienced one of them, they were instructed to abort the test. All participants were told to look for these signs amongst the other participants, in case someone was unable to understand that his or her condition was eligible for test abortion. The three criteria were as follows:

- Core body temperature: Uncontrollable shivering
- Extremities: The participant should be able to fully screw and unscrew a nut and bolt
- Cognitive abilities: Speaking incoherently, or not responding

In addition to being observant of the other participants' condition, everyone was instructed to find a "buddy" in the survival craft once the test started. By doing this, two people could look after each other during the test, and make sure that the other was doing well.

#### *4.4.4.2 Test*

The test started Sunday 24th of April, at approximately 09:40, when all participants had been transported to the lifeboat with the MOB boats, depicted in Figure 41. The first hour or so was eventful, with many things happening. The participants found themselves places to sit, and since the number of people onboard was far from the total capacity of the lifeboat, the interior was rather spacious. The majority of the occupants chose to sit in the rear section of the lifeboat, where most of the activity was happening and the windows in the coxswain position provided light. The participants that was wearing the Viking TPA were also sitting in the rear, and since wearing these rendered them rather immobile, they mostly stayed in that area until disembarkation.


*Figure 41: MOB boat used during test. Photo © Trond Spande*

Leadership structure was clarified quickly after the test started. The designated leader, along with the second in command, were participants from KV Svalbard. The leader managed the situation by performing some tasks himself, and delegating other to participants. A question about the general condition of the passengers was asked, and no one reported having any problems. Shortly after this, a participant was given the task of collecting information about knowledge and experiences among the other participants, which could be useful in the survival situation. This was performed quickly but thoroughly, through a brief conversation with each participant. The resulting information was written down in a small notebook.

The lifeboat was searched to get an overview of the available rations and equipment onboard. When all of the food and water had been located, the leader proposed a plan for handing out rations based on the total amount available. All the participants agreed upon this plan. The water rations were handed out one pouch at a time, which contained 500 ml of water packed in portions of 50 ml each. It was announced that one 500 ml pouch was supposed to last 8 hours, then everyone would receive a new ration. It was strongly suggested that everyone should make an effort out of drinking all of the water from the first ration within the first 8 hours, to avoid getting dehydrated. The first handout of food was planned to be performed in the afternoon, approximately dinnertime. This decision was made because all participants had eaten breakfast shortly prior to the test.

Approximately 40 minutes into the test, radio contact with KV Svalbard was established, and they informed that the estimated time of rescue would be in approximately 48 hours. With this information in place, the leader proposed a watch arrangement where two people would be on watch for 2 hours, and then the next duo would take over. The two people on watch would spend 1 hour in the coxswain chair each, while the other would be responsible for keeping the one in the coxswain chair awake and perform necessary tasks. A watch list with names and times was prepared in a notebook and announced to everyone in the lifeboat. The leader also announced that an hourly radio contact with KV Svalbard were to be made, reporting the status of the situation. All throughout the first hours of the test, the leaders ensured to keep the spirits of the passengers high.

Almost immediately after test start-up, the windows in the coxswain position started to mist up, a minor problem that continued throughout the test. The first general impression was that the habitability inside the lifeboat was decent, except for the benches being quite cold and the need to open hatches often due to poor air quality. The benches along the outer edges of the lifeboat were the coldest, along with some of the ones closer to the centerline. The centerline benches to the rear of the lifeboat doubled as access hatches for the engine room, so when the engine was running these were logically warmer to the touch.

*Figure 42: Lifeboat test participants in survival suits. One trying to sleep. Photo © Trond Spande*

After the first eventful hour and a half, the activity level decreased. Some of the participants utilized this time to sleep, while others occupied themselves with the fishing gear that was included in the lifeboats' survival equipment. Earplugs was handed out to everyone, which was handy because when the engine was running the noise was quite loud and annoying for some. Since some of the participants wished to sleep, while others wanted to be social, the lifeboat was divided into two zones. The forward zone was dedicated to those who wanted to sleep, and the aft zone was for those who wanted to be awake and social. Figure 42 shows the inside of the lifeboat.

Around 13:45, a large walrus started to show interest in the lifeboat and life raft, which was attached to the lifeboat by a rope. It surfaced multiple times, on some occasions within only a couple of meters from the raft. The MOB boat was present throughout this episode, and succeeded in chasing the animal away after a few attempts. For the occupants in the lifeboat, this experience was mostly entertaining, but it seemed to be somewhat disturbing for the life raft occupants. They had very limited view from inside the raft, and only thin sheets of rubber separated them from the nearby walrus. Figure 43 shows the walrus between the lifeboat and the life raft.


*Figure 43: A walrus came close to the lifeboat and life raft during the test. Photo © Tord Nese*

During the walrus appearance, the lifeboat occupants opened most of the hatches on the lifeboat so that they could see the animal. This brought down the inside temperature considerably, and the hatches were therefore closed to get the temperature rising again. A general inquiry revealed that the occupants felt all right concerning their body temperature, a bit colder than perfect, but not bad. It was again noted that the cold benches were the main reason for heat loss. Shortly after, a session of collective physical activity was organized, including rounds of walking, walking lunges, squats and push-ups. The activities had apparent positive effects on both body temperature and spirits.

At approximately 15:00, the lifeboat had drifted close to the nearby sea ice, and KV Svalbard radioed instructions to maneuver some distance away from it. After relocating the lifeboat, the engine was shut down to see how the internal temperature would develop without it running. Because the engine could not be used, the MOB boat had to tow the lifeboat and life raft away from sea ice several times during the evening, night and early morning.

The first meal onboard the lifeboat was undertaken at 15:40 in the afternoon, as planned. Each passenger received one paper-wrapped ration, containing two square biscuits. It was suggested that everyone should make sure to drink water along with the biscuits, to make them easier to digest. A new water ration was scheduled to be handed out at 19:00, so there was no need to save water for later. There was split opinions about the taste and consistency of the biscuits, but there was no doubt that it would have served its purpose in an actual survival situation.

After spending some time wearing the various personal protective equipment, the major complaint was concerning the moisture build-up inside the suits and thermal protective aids. Those wearing such equipment described it as uncomfortable, and that the damp underclothing was chilling. Secondly, participants complained about cold feet.

Late in the afternoon, the first participants aborted the test. Throughout the rest of the test period, people left in more or less regular intervals. The early evening was otherwise not very eventful, with the exception of a delivery from KV Svalbard containing a quiz book and a deck of cards. The quiz book was used actively for a period, and many of the remaining participants joined this activity. Others were playing card games for several hours, while some slept. There were regular physical activity sessions to stay warm, and alternative pastime activities such as rocking the boat.

Around 21:00, a watch list for the night was prepared, with teams of two people on 1-hour shifts. Names and times were noted on a piece of paper, which was put on top of the steering console. The MOB boat crew delivered a pack of cookies that was split amongst the participants, giving a small spirit boost. The late evening entertainment consisted of telling jokes and having conversations. It was apparent that the inside temperature declined, especially after several participants aborted around midnight. Because of this, there was more focus on staying warm.

Through the night, many means of staying warm was utilized. The remaining participants huddled together in the aft section of the lifeboat, and in the coxswain chair the searchlight was used to heat fingers and hands. Some even took the covers off a lamp to use the heat from the light bulb to warm their fingers. Having the internal lights and headlamp on used a fair amount of battery power. After a while, the electric lights were turned off to save power for starting the engine.

Around 03:30, those who were awake ate some biscuits from the ration, and performed a physical activity session. The general opinion amongst the remaining participants was that sleeping was difficult due to the low temperatures. Most of them had tried to get some sleep by then, and everyone experienced being cold when waking up. It was therefore necessary to perform physical activity to regain some body temperature. The entertainment throughout the rest of the night and early morning consisted mostly of conversations. These were periodical, in some periods there were no talking at all.

*Figure 44: Lifeboat drifted into a belt of ice during the test. Photo © Trond Spande*

Around 08:00 in the morning, the lifeboat drifted into a belt of ice as seen in Figure 44. By then, the wind had picked up as well, and there were more waves than previously. This caused the boat to roll, and the ice hitting and scraping along the hull was clearly audible. As the test was nearing the end, there were discussions among the participants whether it would have been possible to survive for several more days in the lifeboat. It was commonly agreed that it would have been possible to survive for some days, but that it would become harder and harder to find motivation to perform physical activity in order to stay warm. It was also mentioned that in a real situation, the motivation to stay alive probably would have made a big difference compared to the motivation during the test.

The test was officially ended when the lifeboat was safely attached to KV Svalbard with a towing rope. This operation required some lifeboat maneuvering, so the engine was used. Shortly after starting the engine, which had been off for 18 hours, the overheating alarm sounded. Norsafe representatives diagnosed the failure to a problem with the cooling system, which could have been caused by air bubbles in the system. Having no engine power complicated the mooring process to some degree, but the MOB boat crew provided good assistance. When the lifeboat was safely moored, the remaining participants were returned to KV Svalbard in a MOB boat.

#### *4.4.4.3 After the test*

Immediately after return to KV Svalbard, each participant went through a medical check. Since the participants aborted at different times, the ships' doctor was on stand-by during the entire test period. The following medical parameters was checked on all participants:

- Body temperature
- Pulse
- Blood pressure

In addition, the participants in the selected medical test group were put through the same tests they had performed prior to the survival craft stay. The SARex team also conducted interviews with all participants shortly after return to the ship. The interviewers followed an interview guide developed specifically for the purpose of the test, to document the personal experiences of each participant.

To conclude the phase one test, a workshop was held where the SARex team and involved KV Svalbard crewmembers participated. The objective of this workshop was to gather and discuss experiences and opinions regarding the survival crafts and personal protective equipment. The workshop findings, which were documented by the authors, are presented in Appendix C.

# 5. Preliminary hazard analysis

The complete PHA analysis form is presented in Appendix A. This chapter will explain the focus of the PHA and the process in which it was conducted. The hazards identified are presented in a 5x5 risk matrix, both before and after implementation of risk-reducing measures.

In search of a suitable analysis technique for the risk analysis, a set of desired qualities were made. The main requirement to the analysis technique was that it could produce the wanted results; a structured review of the hazards connected to a cruise ship evacuation in the Arctic. Due to the nature and extent of the analysis object, the technique had to be relatively basic and easy to perform, without affecting the quality of the results negatively. Another requirement was that the technique should facilitate a qualitative analysis.

Based on the set requirements, the PHA method was chosen as basis for the analysis. This method had the desired qualities, and additionally provided a structured methodology for the analysis approach. The PHA method, along with the methodology flow chart, is presented in Chapter 3.1.2.

In the planning stages for the project the authors prepared a PHA for a cruise ship accident scenario in polar waters, with input and help from the project planning group. Since the PHA was done in connection with SARex, it was sensible to utilize the knowledge and expertise of the persons participating in this project. The analysis group consisted of the authors along with participants from the SARex team, to ensure a high-quality result.

The focus was on evacuation to a lifeboat with regards to a cruise accident scenario in polar waters. The PHA was originally prepared before the research trip, then revised as it was used as a basis for the risk assessments performed prior to the tests done in Woodfjorden. It was also revised after the trip with help from the SARex project group.

The first step of the analysis process was to describe the analysis object. The objective was to analyze a scenario where cruise passengers had to perform a dry evacuation from a ship in the Arctic, using a lifeboat, and survive for at least five days in the lifeboat after the evacuation. The analysis object was therefore quite complex, consisting of a cruise ship and lifeboat as well as launching arrangements. The cruise ship used for the analysis was a generic one, as the analysis focused on evacuation from several types of cruise vessels. However, it was decided that the lifeboat should be of the conventional type, launched by davit. This was because conventional lifeboats launched from the ship by davit-arrangements are the most common means of primary evacuation from cruise ships.

Further, it was decided that the lifeboat, launching arrangements and other equipment should be of the standard type, in compliance with SOLAS and LSA Code requirements. By structuring the scenario as described, the results of the analysis would provide information about the hazards associated with evacuation from a cruise ship in an arctic environment. It would also give some indications to whether the existing life-saving appliances would be sufficient for use in the arctic areas.

The primary focus point for the analysis was the lifeboat, and in order to have reliable information about this, the manufacturer of the lifeboat tested in SARex provided the necessary material. Technical information about the lifeboat is presented in Chapter 4.4.1, and technical drawings are included in Appendix E.

The next step was to split the analysis object into modules, to simplify the assessment process. It was decided to divide the scenario into five stages, each representing an important phase in the process from evacuation to rescue. The five stages were:

- Stage one: Evacuation to lifeboat.
  This first stage describes the period from the evacuation orders are given, until the lifeboat is ready for launch.
- Stage two: Launch of lifeboat.
  The second stage describes the period from the lifeboat launch is initiated, until it is fully waterborne and the lifting hooks are released.
- Stage three: Initial operation.
  The third stage describes the period from the lifeboat is fully waterborne, until it is at a safe distance from the ship.
- Stage four: Operation
  The fourth stage describes the period following the initial operation, lasting until rescue arrives.
- Stage five: Rescue
  The fifth and final stage describes the rescue process.

After the five modules had been established, the hazard analysis process could be started. The analysis was performed for one module at a time, starting with identification of hazards. The identification process was performed in a brainstorming session, with special focus on events and problems linked to arctic conditions. Other, more general events were included as well, in order to provide a realistic hazard presentation. Each observation was assigned with a hazard number in the analysis form, and the problem was briefly stated. An example from the PHA is shown in Table 6.

*Table 6: Example from Appendix A: Preliminary Hazard Analysis*

| **Stage four: Operation** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.7 | Sea spray icing on lifeboat | Sea spray combined with low temperatures | Skew loads, hinges and locks on hatches stuck, ventilation compromised. | **Probability: 3 Consequence: B** | -Lifeboat design, winterization | **Probability: 2 Consequence: B** |
| **Pre RRM comments** | | Probability set to medium (3) because even though a standard lifeboat has a design that relatively effectively prevents build-up of ice, the conditions in the Arctic are often ideal for icing. A lifeboat also has some small details that are extra vulnerable to icing, such as hinges, handles, locks, etc. Consequences are set to low (B) because a lifeboat has hatches on multiple sides, so that if one is stuck due to icing, another will probably be possible to open. | | | | | |
| **Post RRM comments** | | With a proper winterized design, protecting small details from ice build-up, the probability is reduced to low (2). | | | | | |
| | 4.8 | $CO_2$ build-up inside lifeboat | Insufficient ventilation, many people breathing. | Headaches, sleepiness, poor concentration, loss of attention, increased heart rate, slight nausea, oxygen deprivation. | **Probability: 5 Consequence: B** | -Proper ventilation design (adjustable)<br>-Opening hatches | **Probability: 3 Consequence: B** |
| **Pre RRM comments** | | Probability is set to very high (5) because several tests reveal that the $CO_2$ concentration in a lifeboat will increase rapidly when no hatches or windows are open, even with few passengers onboard. Consequences are low (B) because it is highly probable that someone will open the hatches to ventilate long before any serious health effects occur. | | | | | |
| **Post RRM comments** | | If an effective passive ventilation design is in place, it is not necessary to ventilate so often using the hatches. This solution will also improve the general survival situation by providing airflow through the boat, preventing seasickness. Implementing the risk-reducing measures lowers the probability to medium (3). | | | | | |

Each hazard discovered was then assessed in terms of probable causes and possible consequences. These were noted in the analysis form, along with the respective probability and consequence grades. The grading was qualitative and based on the 5x5 risk matrix shown in Figure 45, which was used actively in the analysis process.

| **Consequence →**<br>**Probability↓** | **A**<br>**Minimal** | **B**<br>**Low** | **C**<br>**Medium** | **D**<br>**High** | **E**<br>**Very high** |
|---|---|---|---|---|---|
| **5 - Very high** | | | | | |
| **4 - High** | | | | | |
| **3 - Medium** | | | | | |
| **2 - Low** | | | | | |
| **1 - Minimal** | | | | | |
| **Consequence categories** | Negligible injuries, and/or long-term survival chances minimally reduced | Minor injuries, and/or long-term survival chances slightly reduced | Major injuries, and/or long-term survival chances reduced | Life-threatening injuries, and/or long-term survival chances severely reduced | Fatalities, and/or long-term survival chances minimal |

*Figure 45: Risk matrix with consequence categories*

Probability was ranked from minimal (1) to very high (5), and consequence was ranked from minimal (A) to very high (E). Comments explaining the assessment were noted in the analysis form. The consequence grades were also linked to categories, as shown in Figure 45, describing the assumed outcomes. The consequence categories for this analysis were only concerning the safety and health of persons, because that is the absolute main focus in an evacuation situation. Other consequences affecting the environment, assets or reputation are less relevant in the analysis scenario. Based on the assigned probability and consequence grades, the hazard was placed in the risk matrix. Depending on the placement, it was within either the green, yellow or the red area of the matrix.

The risk acceptance criteria were based on the ALARP principle, presented in Chapter 3.1.3. The red area in the risk matrix represent the unacceptable region. All hazards in this area required risk-reducing measures. The yellow area represents the tolerable region, also called the ALARP region. Hazards in this area required measures unless the associated costs were grossly disproportionate to the risk-reducing effect. The green area represents the broadly acceptable region. Hazards in this area does not normally require risk-reducing measures, but this principle was not practiced in this particular analysis. Ship evacuations and abandonments involves many hazards, and even if all single problems are considered to be within the green area of the risk matrix, the total risk may still be high. Therefore, risk-reducing measures was suggested for all hazards in the analysis regardless of risk level.

When feasible measures had been identified, a new assessment of probability and consequence was performed based on the risk-reducing effect of the measures. Comments explaining the new assessment were noted in the analysis form. When one stage had been analyzed successfully, the process was repeated for the next stage, until the analysis was complete.

## 5.1 Graphic presentation of identified hazards

This part will present the hazards graphically in a risk matrix both before and after the risk-reducing measures were taken into consideration.

Initially, the analysis gave the following results:

- Green area: 15 hazards
- Yellow area: 18 hazards
- Red areas: 5 hazards

The hazards are plotted in the risk matrix presented in Figure 46, identified by their hazard number from the analysis form.

| **Consequence →<br>Probability↓** | **A<br>Minimal** | **B<br>Low** | **C<br>Medium** | **D<br>High** | **E<br>Very high** |
|---|---|---|---|---|---|
| **5 - Very high** | **1.6** | **4.8, 4.14** | | **4.15** | |
| **4 - High** | **4.16** | **1.2, 4.1, 4.3, 4.10, 4.13** | **4.2, 4.12, 5.1** | **1.4, 3.5, 4.17** | |
| **3 - Medium** | | **1.7, 3.1, 3.2, 4.4, 4.7** | **1.1, 1.5, 2.5, 4.11** | **2.1, 2.2, 5.2** | |
| **2 - Low** | | **3.3, 3.4, 4.5, 4.6, 4.19** | **1.3** | **2.3** | |
| **1 - Minimal** | **4.18** | | | **2.4, 4.9** | |
| **Consequence categories** | Negligible injuries, and/or long-term survival chances minimally reduced | Minor injuries, and/or long-term survival chances slightly reduced | Major injuries, and/or long-term survival chances reduced | Life-threatening injuries, and/or long-term survival chances severely reduced | Fatalities, and/or long-term survival chances minimal |

*Figure 46: Risk matrix – results from PHA without risk-reducing measures*

When considering risk-reducing measures for each hazard, the result distribution was as follows:

- Green area: 32 hazards
- Yellow area: 7 hazards
- Red areas: 0 hazards

The risk matrix in Figure 47 shows the results from the PHA when risk-reducing measures were considered.

| **Consequence →**<br>**Probability↓** | **A**<br>**Minimal** | **B**<br>**Low** | **C**<br>**Medium** | **D**<br>**High** | **E**<br>**Very high** |
|---|---|---|---|---|---|
| **5 - Very high** | | | | | |
| **4 - High** | **1.6** | **1.4** | | | |
| **3 - Medium** | **4.16** | **2.5, 4.1, 4.8, 4.10, 4.11** | **4.12, 5.1** | **4.17** | |
| **2 - Low** | | **1.3, 1.7, 3.1, 3.2, 4.3, 4.4, 4.7, 4.13** | **1.5** | **2.2, 3.5, 5.2** | |
| **1 - Minimal** | **1.2, 1.8, 4.18** | **3.3, 3.4, 4.5, 4.6, 4.14, 4.19** | **1.1, 4.2** | **2.1, 2.3, 2.4, 4.9, 4.15** | |
| **Consequence categories** | Negligible injuries, and/or long-term survival chances minimally reduced | Minor injuries, and/or long-term survival chances slightly reduced | Major injuries, and/or long-term survival chances reduced | Life-threatening injuries, and/or long-term survival chances severely reduced | Fatalities, and/or long-term survival chances minimal |

*Figure 47: Risk matrix – results from PHA with risk-reducing measures*

## 5.2 Main findings regarding hazards and possible gaps

### 5.2.1 Stage one: Evacuation to lifeboat

#### *5.2.1.1 Hazards*

- The lifeboat is somehow not accessible or usable.
- Icing.
- Injuries when getting to or into the lifeboat.
- Passengers clothing is not suited for the cold climate and gets onboard without proper clothing.
- Lifeboat does not have sufficient space to accommodate the maximum number of passengers wearing additional polar clothing and bringing along PSK/GSK.

#### *5.2.1.2 Possible gaps*

- Exposed escape routes may not be accessible or safe, taking into consideration the potential for icing of structures and snow accumulation. All life-saving appliances might not provide safe evacuation and be functional under the possible adverse environmental conditions.
- Adequate thermal protection might not be provided for all persons on board.
- Means might not be provided to remove or prevent ice and snow accretion.
- Escape routes and embarkation arrangements might not be arranged for and adequate for persons wearing additional polar clothing.
- Lifeboat might not have enough space to accommodate persons equipped with thermal protection adequate for the environment.

### 5.2.2 Stage two: Launch of lifeboat

#### *5.2.2.1 Hazards*

- Mechanical/electrical failures.
- Icing.
- Wind and waves making the launch procedure dangerous.

#### *5.2.2.2 Possible gaps*

- Survival craft might not provide safe abandonment of ship, taking into consideration the possible adverse environmental conditions during an emergency.
- All life-saving appliances and associated equipment might not provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue.
- Means might not be provided to remove or prevent ice and snow accretion.

- If devices that require a source of power are added to achieve the needed functionality, they might not be able to operate independently of the ships' main source of power.

### 5.2.3 Stage three: Initial operation

#### *5.2.3.1 Hazards*

- Mechanical/electrical failure.
- Wind and waves making maneuvering difficult.
- Collision and/or damage to lifeboat.
- Unable to rescue survivors from sea to lifeboat.

#### *5.2.3.2 Possible gaps*

- Lifeboat might not be properly winterized.
- Life-saving appliances and associated equipment might not take into account the potential of operation in long periods of darkness and the intended voyage.
- Lifeboat might not be suited for extracting persons from the sea, especially those that are cold and unable to climb onboard without assistance.

### 5.2.4 Stage four: Operation

#### *5.2.4.1 Hazards*

- Unable to navigate properly.
- Engine failure.
- Communication devices are not available/working.
- Lifeboat runs out of fuel.
- Sea spray icing.
- Seasickness.
- Lifeboat environment not habitable.
    - Temperature hot/cold.
    - Low air quality/$CO_2$ build-up.
    - No toilet facilities causing hygiene problems.
    - Nowhere to sleep comfortably.
- Not enough food and water for 5 days.
- Lack of medical equipment and medicine.

#### *5.2.4.2 Possible gaps*

- Lifeboat might not provide a habitable environment.

- Lifeboat might not provide sufficient space for all persons to wear additional polar clothing and have access to their PSK/GSK, in turn lacking equipment that will provide sufficient thermal insulation to maintain the core temperature of persons and protection to prevent frostbite of all extremities.
- Lifeboat might not have sufficient food and water to provide sustenance for the maximum expected time for rescue.
- Lifeboat might not have means to communicate with rescue assets.
- Lifeboat might not be designed for polar conditions.

### 5.2.5 Stage five: Rescue

#### *5.2.5.1 Hazards*

- Problems occurring during the transfer of persons from lifeboat to rescue vessel/helicopter.
    - Complicated process.
    - Injuries/fatalities.
    - Time consuming.
    - Wind and waves.

#### *5.2.5.2 Possible gaps*

The Polar Code does not mention these problems.

# 6. Discussion

## 6.1 Arctic cruise challenges

The following discussion presents the findings from research objective one. It highlights the main challenges that cruise ships will encounter in the Arctic, while incorporating historical accidents, regulations and existing life-saving appliances.

The arctic cruise season normally lasts from the beginning of June to the middle of September. Cruise ships on voyages around the Svalbard archipelago and especially north of Svalbard must always consider the possibility of encountering sea ice during the months in which they operate in these waters. The presence of sea ice means all cruise ships either must look to avoid it or be built to be able to withstand it with a proper ice class design. Figure 48 shows sea ice encountered during the research trip.

*Figure 48: KV Svalbard encountered sea ice on the west side of Svalbard during the research trip. Photo © Trond Spande*

The weather in this region proposes challenges related to search and rescue operations in addition to the long distances. High wind speeds, low temperatures, fog and large waves all create their own set of problems. All of these challenges play a factor in how the life-saving appliances will have to be designed to have the desired effect in these waters. As seen in Chapter 3.2.10, for the TS Maxim Gorkiy and the MS Explorer, weather in these cases were very good for rescue operations and both accidents could have ended with far more serious consequences had the weather been worse.

The midnight sun, which lasts from the end of April to the end of August at the latitude of Longyearbyen, makes the light conditions during the polar cruise season advantageous for search and rescue operations in these waters. Navigating in the polar waters surrounding the Svalbard archipelago is inherently high risk due to the insufficient navigational charts in these areas. In 2015, a full compulsory pilotage for Svalbard internal waters entered into force. The requirements serve to ensure that experienced personnel pilot any ship sailing in the hazardous waters around Svalbard. Communication is a key element for safety at sea, especially if an emergency should occur. A recent gap analysis performed as a part of the SARiNOR project revealed that the available radio links and satellite communication in the Arctic lacks in reliability, and therefore presents a safety hazard in major accident scenarios.

It is a plausible scenario that a cruise ship on its voyage around Svalbard encounters fog and either cannot see any approaching drift ice and hits it or runs aground in uncharted waters. At the north side of Svalbard, their means of communication has low reliability and depending on the severity of the situation they might need to abandon ship before receiving any response about their distress call being heard. The nearest Coast Guard vessel will most likely be several hours from their location and helicopters from Longyearbyen has a limited range and capacity. Abandoning a ship in this kind of scenario will require that every person on board have access to life-saving appliances designed for polar waters. To maximize their chances of survival, all passengers will want to be in an enclosed lifeboat if they manage a dry evacuation, or in case of a wet evacuation, an insulated immersion suit designed for polar water survival. The chances of prolonged survival in polar waters are drastically reduced without these life-saving appliances. Figure 49 shows drift ice and poor visibility.

*Figure 49: Poor visibility and drifting sea ice west of Svalbard during the research trip. Photo © Trond Spande*

In polar waters, it is not enough to keep people afloat with either life jackets, lifeboats or life rafts. People must also be kept dry and warm to be able to survive in such a harsh climate. With a maximum expected time of rescue of five days, it is also important that people have access to food and water to sustain them for this time. The most important life-saving appliances in polar waters is the immersion suit and a lifeboat stocked with the necessary equipment. All of the life-saving appliances made for polar waters must allow the people using them enough space when dressed with thick and warm polar clothing. Accidents are unpredictable and it is not likely that people can always manage a dry evacuation. In case of a wet evacuation, an immersion suit together with personal survival equipment is crucial to survival, but even then, people cannot survive for long if they cannot get into a lifeboat or onto land or ice. New immersion suits with technology that allows people to be kept warm for a longer period of time is available, however these cannot guarantee survival for five days.

As seen in Chapter 3.3, the LSA Code and Polar Code both give demands for life-saving appliances that have to be fulfilled. The LSA Code demands are not suited to fit the maximum expected time of rescue of five days. In the case of food and water, the LSA Code is lacking in the five-day scenario. The Polar Code says that the food and water has to last for at least five days, but it does not say how much food and water should be available per person. It is also important that the life-saving appliances can function under all the environmental conditions they are subjected to in the Arctic. Cruise traffic is relevant in the summer season, but it can still be cold and icing may occur. Making sure the life-saving appliances are functional under any circumstance in the Arctic means they have to be designed to work with the presence of low temperatures, snow and ice. The five-day requirement is most likely linked to the limited capacity of SAR-resources and the long response time due to the vast distances from civilization.

The Polar Code gives goals, functional requirements to fulfill the goals, and regulations. The arctic cruise ship industry will have to fulfill the goals with life-saving appliances that meets all the functional requirements. Means of fulfilling functional requirements are subject to interpretation. In the case of immersion suits, the Polar Code says, "*for passenger ships, a proper sized immersion suit or a thermal protective aid shall be provided for each person on board; and where immersion suits are required, they shall be of the insulated type* (IMO - Polar Code, 2014)". It is hard to imagine immersion suits not being required in Arctic waters, where any extended period of immersion will most likely be fatal. Without specific demands the interpretation lies in what kind of insulated immersion suit is required to fulfill the demands.

A cruise ship operator is thinking about costs, space and weight, and will most likely only want to cover the minimum requirements to fulfill the demands. This might be a conscious effort done by the legislators. If the demands were very specific and strict, it might make the large cruise ships stop their arctic cruise business. Having top-notch immersion suits that fits every passenger on a cruise ship that holds over 3000 passengers will probably be expensive. The cruise ship operators will most likely procure their life-saving appliances that meets all demands at the lowest cost possible. This will force the life-saving appliances manufacturers to provide what the cruise ship operators need for the lowest amount of money possible. This is where the regulations have to be strict enough to ensure the life-saving appliances are up to par when on voyages in polar waters.

## 6.2 Hazards and possible gaps

This part of the discussion will include the findings from the PHA presented in Appendix A and the tests done in Woodfjorden as part of research objective two. Most of the identified main hazards during an evacuation situation in the Arctic and the possible gaps between existing life-saving appliances and the level of safety the Polar Code tries to ensure, are discussed.

In an evacuation situation, getting to the lifeboat can be hazardous if the walkways are unsheltered and slippery due to ice and snow accumulation. Cruise passengers are often elderly persons that can have a difficult time moving around. They can also be in need of some sort of assistance. In these cases, a slippery walkway can be a daunting task to maneuver through safely. The Polar Code requires exposed escape routes to be accessible and safe when taking into consideration the potential for icing of structures and snow accumulation. This can be achieved with sheltered walkways. Figure 50 shows snow accumulation on the deck of KV Svalbard.

*Figure 50: Snow accumulation on deck of KV Svalbard. Photo © Trond Spande*

If these cannot be sheltered, heated walkways where ice and snow cannot accumulate can be another solution. Making sure the walkways are covered with friction material is another measure that can help fulfill the Polar Code, but ice and snow would have to be removed manually throughout the journey. As some passengers might need assistance getting to their muster station, they will most likely need assistance getting into the lifeboat. This will without procedures in place for the crew to help them, lead to the evacuation process being delayed. However, this will rarely have large consequences. Exceptions to this would be if the captain ordered the evacuation too late compared to the rate in which the ship was sinking, or in case of a rapidly spreading fire. Another problem during this part of the evacuation is that passengers go to the wrong muster station, and not the one they were assigned to. This might lead to one lifeboat becoming full and passengers have to go to another lifeboat to evacuate. The other lifeboats might already be launched and they will have to settle for a life raft, most likely reducing their survival chances. This will at the least lead to the evacuation process being delayed. Proper information routines for passengers and crew training will be paramount in evacuation situations, and needs to be a priority for safe operations.

*Figure 51: Lifeboat test participants wearing various PPE. Photo © Tord Nese*

When evacuating from a cruise ship in the Arctic it is important that the passengers have sufficient polar clothing. It cannot be expected that the cruise passengers will walk around inside the cruise ship with clothing that is suited for arctic evacuation. It can also not be expected, on a large cruise ship, that passengers will have time to return to their cabins and change clothes or pick up polar clothing before they have to meet at their muster stations. This makes the presence of PSKs close to the muster stations really important. PSKs includes equipment and clothing that needs to be in the correct size for every passenger, like boots and woolen underclothing. A possible way to solve this could be to assign every passenger their own PSK when they arrive on the ship, mark it with their name and then let the passengers put their assigned PSK in a storage compartment next to the muster station they have been assigned to. This can both help with making sure the passengers remember their PSK and remember which muster station to go to in case of an evacuation. The Polar Code requires that all passengers are provided with adequate thermal protection and a PSK that, in combination with life-saving appliances, provide sufficient thermal insulation to maintain their core temperature and provide sufficient protection to prevent frostbite of all extremities. The fact that every passenger needs a PSK will put a strain on the lifeboat regarding sufficient space to accommodate its maximum capacity of persons together with their PSK. This will require lifeboats that were certified for a certain amount of passengers, to be re-evaluated and certified for an appropriate amount of passengers with room for their PSK. The Polar Code requires that life-saving appliances shall provide space to accommodate persons equipped with thermal protection adequate for the environment, and the thermal protection they need will most likely be in each passengers PSK. Figure 51 shows various PPE.

When launching a lifeboat under arctic conditions, one of the main risk factors are icing on parts and components. If a lifeboat is unable to launch properly, the passengers' survival chances are drastically reduced.  The Polar Code requires that survival craft and muster and embarkation arrangements shall provide safe abandonment of ship, taking into consideration the possible adverse environmental conditions during an emergency. There is a large amount of systems that have to work to make sure the evacuation goes smoothly, and most of them can acquire high reliability with the proper measures in place. Providing the launching appliances with lubrication, inspection and manual ice removal are measures to consider, but providing them with shelter and heating will most likely be the more effective measures. A possible measure for shelter is to set up a canopy around the lifeboat and the corresponding launch appliance. A more robust solution is to utilize the so called "boat-in-a-box" or other similar concepts to completely shelter the lifeboat. This solution also makes it easier to keep the lifeboat and launch appliances heated if needed, and ensures a dry and sheltered embarkation area.

When launching the lifeboat, it is important to get the lifeboat engine running. Low temperatures increase the risk for complications when it comes to getting an engine started. The engine fluids might be frozen when attempting to start the engine, as the SARex team experienced during the lifeboat test. The Polar Code requires all life-saving appliances to be functional under the possible adverse environmental conditions during the maximum expected time of rescue. To achieve this, proper winterization of the lifeboat and its engine system is needed.

*Figure 52: Standard ropes along the side of a lifeboat. Photo © Norsafe*

Perhaps the most crucial aspect of the initial operation stage is the ability to rescue survivors out of the sea and into the lifeboat. The low sea water temperatures in the Arctic means that persons immersed will quickly become cold and unable to help themselves climb into a lifeboat by their own power. This puts an additional strain on the lifeboat design. The standard ropes along the side shell of a lifeboat will not be sufficient to solve this problem. It is also very likely that these ropes will accumulate ice in the cold arctic environment, as seen in Figure 52, rendering them more or less useless. The Polar Code does not mention the important issue of having a lifeboat design that is suited for easy rescue of survivors out of the water. A possible solution is to design the stern of the lifeboat as described in Chapter 3.4.2 and Figure 21, to facilitate easy rescue where persons in the lifeboat can easily assist a survivor out of the water and into the lifeboat, as well as making it easier for a survivor to get into the lifeboat by their own power.

When operating a lifeboat in the Arctic, there is a high probability that the coxswain will have poor sight when navigating. The lifeboat experienced snow accumulation before the test, as seen in Figure 53. In this environment fog and snow squalls occur frequently, and especially fog is very common in the summer season. The lifeboat test also highlighted another problem that led to poor sight, which was mist building up on the inside of the lifeboat windows. This mist build-up forced the coxswain to wipe the windows continuously to be able to see out of them. When the temperature dropped due to participants leaving the test, the mist build-up froze and had to be scraped off for the coxswain to be able to see properly. The Polar Code requires life-saving appliances to be functional under the possible adverse environmental conditions during the maximum expected time of rescue, and this problem certainly affects that. A possible measure would be heating in the windows, and air vents that can be opened at the highest point in the lifeboat, namely the roof above the coxswain seat.

*Figure 53: The lifeboat experienced snow accumulation during the test. Photo © Trond Spande*

Extra ventilation is a big topic when it comes to air quality inside a lifeboat. With 16 participants inside a lifeboat certified for 55 persons, the $CO_2$ levels reached a concentration of 5000 ppm after only 10 minutes. This forced the participants to open hatches due to the deteriorating air quality, which in turn lowered the temperature in the lifeboat. During the test, the weather was extraordinarily good with little wind, almost no waves and stable temperatures at around -9°C. It is highly likely that with worse weather, opening the hatches could cause the temperature to drop drastically inside the lifeboat and sea spray to enter the lifeboat. With the lifeboat stacked with 55 persons, it is highly likely that the air quality problem would become exacerbated to the point where having hatched closed even for short periods of time would be problematic. The air quality problem is not easy to solve, but more vents that are manually adjustable would help the situation.

Temperature is another issue that is connected to the amount of people inside the lifeboat and the amount of ventilation available. In the lifeboat test, the temperature increased steadily up to 13.5°C with only 16 people until participants started to leave. With the lifeboat filled to capacity with 55 people, the temperature would be expected to rise a lot quicker and to a much higher maximum. This in combination with the low air quality will almost surely lead to the hatches having to be open for most of the time. Having the hatches open for most of the time will require the people in the lifeboat to have sufficient polar clothing to maintain the core temperature of persons and prevent frostbite of all extremities as the Polar Code requires. This will also be the case if there are few people in the lifeboat. Figure 54 shows open hatches during the lifeboat test.

*Figure 54: Opening hatches were necessary to avoid poor air quality. Photo © Trond Spande*

With only a few people left in the lifeboat during the test, the temperature dropped to close to 0°C. When it comes to air quality and temperature inside the lifeboat, the Polar Code only requires a habitable environment. This is a rather vague requirement and should perhaps be more clearly specified. However, to be certain that peoples' core temperature is maintained and all extremities are protected from frostbite, a PSK is a good solution in both the case of the lifeboat being filled and if there are few people in the lifeboat. Another possible solution for the low temperature problem is a diesel heater. This sort of cabin heater would require a minimal amount of fuel to keep the lifeboat warm, and would be a rather low-cost solution compared to the benefits, at least if included already in the design stage. During the test, the participants noted that the benches in the lifeboat were very cold and a significant amount of heat loss was due to the cold benches, especially when laying down to sleep. An easy solution to this could be to have some sort of insulating material on top of the benches.

When it comes to having a habitable environment, seasickness and hygiene issues have to be addressed. Only being able to go to the toilet by using a bucket in a crowded lifeboat is a harsh way to live for five days. Not that it is paramount in a survival situation, but the implementation of some sort of toilet in a lifeboat designed for arctic use would not necessarily have to require too much space or be too costly, if designed cleverly. Seasickness can also make the lifeboat an uncomfortable place to be, as well as cause dehydration and starvation. Little can be done to avoid this except provide the passengers with enough seasickness medication, and plenty of water and food. According to the Polar Code, it is required that there shall be means to provide sustenance for the maximum expected time of rescue. Especially water is crucial, little water in combination with seasickness can easily lead to dehydration.

Icing, shown in Figure 55, on the lifeboat after it is launched can be a problem for multiple reasons. The stability of the vessel can be compromised if enough ice is allowed to accumulate on the lifeboat. Hinges and locks can get stuck, making it difficult to open hatches. In addition, icing can build up and clog the vents. This can be made worse by moisture from inside the lifeboat freezing as it gathers in the vents. This can cause the air quality to deteriorate even quicker, and completely clogged vents can create a vacuum inside the lifeboat since the engine draws air from inside the lifeboat.

*Figure 55: Icing on the MOB boat used during the test. Photo © Tord Nese*

On a cruise ship in the Arctic there is a high probability that many of the passengers will be elderly people with significant health problems. These people are likely to need special medicines, and to be without them for five days would mean they are at risk of health complications. A measure to address this issue could be that the passengers that require special medicines to stay healthy, always walk around with five days' worth of medicine on their person. Another possible measure is to have lifeboats supplied with selected basic medicines, but with the amount of different medicines people can need, this might not be enough for everyone. Due to the high risk of cardiac arrest connected to hypothermia, having a defibrillator could be a good idea. However, this is costly and someone on board the lifeboat would have to know how to use it. A crew member bringing it along that is trained in how to use it is a possibility. The Polar Code does not address the medicine problem, but the cruise operators and their organizations will need to consider it carefully.

Being rescued from the lifeboat onto a rescue vessel or into a helicopter can also be risky. As of now there are not really any set ways of doing it, it all depends on the rescue vessel and the lifeboat design. An example from the test is shown in Figure 56. A possible design measure that can be taken is to have large hatches that facilitate easy rescue operations, especially if passengers are injured and need to be taken out on a stretcher. A problem that came up during SARex phase two was the fact that with a crowded lifeboat, it became hard for rescue personnel to evacuate the most injured people first since they had no room to operate in. They were forced to get the people that were able to help themselves off first so they had room to handle the people that required assistance. Solutions to these problems are hard to come by, and more research is needed on this topic.

*Figure 56: Lifeboat together with the MOB boat used as rescue vessel in the test. Photo © Jan Erik Jensen*

# 7. Conclusions

Based on the literature review, risk analysis and practical test conducted as part of this thesis, the following results were produced to accomplish the research objectives:

- A review of arctic region characteristics, historical accidents, regulations and existing life-saving appliances.
- A description of the main hazards associated with evacuation from a cruise ship in an arctic environment, and the corresponding gaps between the performance of existing SOLAS-approved life-saving appliances and the level of safety the Polar Code tries to ensure.

Below is a summary, based on the results and discussion, of the main challenges related to cruise traffic in the Arctic, and the main hazards associated with evacuating from a cruise ship in an arctic environment. These are combined with suggestions on how to deal with the possible gaps between the hazards and the level of safety the Polar Code tries to ensure.

There are many challenges surrounding cruise ship voyages in the Arctic, and even more challenges arise if there is an accident on the voyage. Weather, ice and navigational challenges can all lead to accidents. Communication, long distances, lack of infrastructure and SAR resources make search and rescue difficult. The chances of long-time survival in the harsh conditions are low without the proper life-saving appliances.

Due to low temperatures and icing, lifeboats and the corresponding launching and embarkation arrangements need to be properly winterized. Sheltering and heating seems to be the most efficient way of ensuring a high reliability of these systems.

The lifeboat test gave a clear indication that a properly equipped PSK with the correct sizes of gear seems to be one of the most crucial parts of ensuring peoples' survival chances in an arctic evacuation. A PSK can be quite large and heavy, to accommodate for this the capacity lifeboats are certified for needs to be evaluated.

The lifeboat test also highlighted the problem with air quality and temperature inside a closed lifeboat. Ventilation arrangements will need to be improved in order to solve this problem.

Rescuing survivors from the sea to a lifeboat is not mentioned in the Polar Code. People immersed in low sea temperatures will quickly become unable to help themselves into a standard lifeboat. A lifeboat design that facilitates easy rescue can become important in arctic conditions.

## 7.1 Suggestions for further research

Based on the findings presented in this thesis, the following suggestions for research were made:

- Testing of lifeboat habitability in a controlled environment:
  - Investigation of air quality development inside lifeboats filled with their certified number of passengers
  - Multiple scenarios, with combinations of open/closed hatches and engine on/off
- Assessment of lifeboat capacity that is suited for polar evacuation with room for PSK/GSK
- Possible innovations in lifeboat design that facilitates easy rescue of survivors from the sea
- Assess ways to make transfer of people from lifeboat to vessel or helicopter easier
- Perform new PHA after the Polar Code has entered into force on equipment the industry believes fulfills the demands

# References

ACCESS, 2015. *IMO Polar Code for Ships Operating in Polar Waters.* [Online]
Available at: http://www.aeco.no/wp-content/uploads/2013/06/2015-04-ACCESS-PolicyBrief-Polar-Code.pdf
[Accessed 2 January 2016].

Amble, B., 2011. Skipsfart gjennom Nordøstpassasjen: Ulønnsomt risikoprosjekt?. *Navigare*, pp. 8-11.

Aven, T., Røed, W. & Wiencke, H. S., 2008. *Risikoanalyse.* 2. edition 2010 ed. Oslo: Universitetsforlaget AS.

Balto, A. K., 2016. *Norsk Polarinstitutt.* [Online]
Available at: http://www.npolar.no/no/arter/isbjorn.html#pageindex2
[Accessed 25 May 2016].

BarentsWatch, 2013. *Søk og redning i norsk ansvarsområde.* [Online]
Available at: https://www.barentswatch.no/Tema/Sjotransport/Redningstjenester/Sok-og-redning-i-norsk-ansvarsomrade/
[Accessed 4 January 2016].

Barstein, G., 2015. *Rekordstort cruiseskip i byen: - Dette er helt på grensa. Svalbardposten.* [Online]
Available at: http://svalbardposten.no/index.php?page=vis_nyhet&NyhetID=6002&sok=1
[Accessed 11 January 2016].

BW Technologies, 2009. *GasAlertMicro 5 User Manual.* [Online]
Available at: http://www.honeywellanalytics.com/~/media/honeywell-analytics/products/gasalertmicro-5-series/documents/english/gasalertmicro5usermanuald56155en.pdf?la=en
[Accessed 7 May 2016].

Cambridge Dictionaries Online, n.d.. *Echo sounder.* [Online]
Available at: http://dictionary.cambridge.org/dictionary/english/echo-sounder
[Accessed 16 January 2016].

Database for offentlige innkjøp, 2008. *Technical specification for Nordkapp suit.* [Online]
Available at:
https://kgv.doffin.no/app/docmgmt/downloadPublicDocument.asp?DVID=305519&FMT=1&AT=15&ID=14374
[Accessed 26 May 2016].

DNV GL, 2014. *SARiNOR WP1 Gap-analyse Prosjektrapport,* Harstad: DNV GL.

Encyclopædia Britannica, n.d.. *Salinity.* [Online]
Available at: http://www.britannica.com/science/salinity
[Accessed 17 January 2016].

Flaaten, G., 2015. *Lager sine egne sjøkart. Maritime.no.* [Online]
Available at: http://www.maritime.no/nyheter/lager-sine-egne-sjokart/
[Accessed 14 January 2016].

Ford, R., 2009. *Report of Investigation in the Matter of Sinking of Passenger Vessel EXPLORER,* Monrovia, Liberia: The Bureau of Maritime Affairs.

Færevik, H., 2014. *Hypotermi, overlevelse i sjø, redningsdrakter.* Tromsø, SINTEF.

Gemini, 2012. *Polare prøvelser.* [Online]
Available at: http://gemini.no/2012/09/polare-provelser/
[Accessed 13 January 2016].

Global CCS Institute, n.d. *Risk and uncertainty assessment.* [Online]
Available at: http://hub.globalccsinstitute.com/publications/guideline-selection-and-qualification-sites-and-projects-geological-storage-co2/d2-risk
[Accessed 13 April 2016].

Gonzalez, A., 2007. *Audrey's blog.* [Online]
Available at: http://www.audreygonzalez.org/2007/11/serious-day-and-rescue.html
[Accessed 12 January 2016].

Grønås, S., 2004. *Havets miljø 2004 - Barskt vær i Barentshavet,* Bergen: Institute of Marine Research.

Honeywell Analytics, n.d. *GasAlertMicro 5 Series.* [Online]
Available at: http://www.honeywellanalytics.com/~/media/honeywell-analytics/products/gasalertmicro-5-series/documents/english/gasalertmicro5datasheet561215en.pdf?la=en
[Accessed 7 May 2016].

Hovden, S. T., 2012. *Redningsdåden.* 1. ed. Sandnes: Commentum Forlag.

IMO - LSA, 2010. *Life-Saving Appliances including LSA Code.* 2. ed. London: International Maritime Organization.

IMO - Polar Code, 2014. *www.imo.org.* [Online]
Available at:
http://www.imo.org/en/MediaCentre/HotTopics/polar/Documents/POLAR%20CODE%20TEXT%20AS%20ADOPTED.pdf
[Accessed 1 January 2016].

IMO - SOLAS, 2014. *SOLAS Consolidated Edition.* 6. ed. London: International Maritime Organization.

IMO - web, 2015. *www.imo.org.* [Online]
Available at: http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx
[Accessed 1 January 2016].

Ingerø, O. O., 2013. *Svalbard - Risiko- og sårbarhetsanalyse 2013,* Longyearbyen: Sysselmannen på Svalbard.

International Hydrographic Organization, 2015. *Definition & Importance of Hydrography.* [Online]
Available at:
https://www.iho.int/srv1/index.php?option=com_content&view=article&id=299&Itemid=289&lang=en
[Accessed 16 January 2016].

ISO, 2012. *NS-EN ISO 15027-1:2012 Immersion suits Part 1: Constant wear suits, requirements including safety.* Lysaker: Standard Norge.

Justis- og beredskapsdepartementet, 1999. *St.meld. nr. 9 (1999-2000).* [Online]
Available at: https://www.regjeringen.no/no/dokumenter/stmeld-nr-9-1999-/id192642/?ch=10
[Accessed 14 January 2016].

Kristiansen, S., 2001. *Risk Analysis and Safety Management of Maritime Transport.* Trondheim: Norwegian University of Science and Technology.

Kystverket, 2014. *Utfordrende å lose ved Svalbard.* [Online]
Available at: http://www.kystverket.no/Nyheter/2014/September/Utfordrende-a-lose-ved-Svalbard/
[Accessed 16 January 2016].

Kystverket, 2015. *Svalbard - Losplikt og Farledsbevis.* [Online]
Available at: http://www.kystverket.no/Maritime-tjenester/Farledsbevis/Svalbard---Losplikt-og-Farledsbevis/
[Accessed 14 January 2016].

Lascar Electronics, 2015. *EL-CC-1 Cold Chain Data Logging Solutions.* [Online]
Available at: http://www.lascarelectronics.com/pdf-usb-datalogging/data-logger0578931001446808507.pdf
[Accessed 6 May 2016].

MadgeTech, 2011. *LSTechnology.* [Online]
Available at: http://www.loggershop.co.uk/PDF/Madgetech/Data%20Sheets/RHTemp1000.pdf
[Accessed 7 May 2016].

Mak, L. et al., 2010. *Assessment of Thermal Protection and Microclimate in SOLAS Approved Lifeboats,* St. John's: National Research Institute Canada, Institute of Ocean Technology.

MARINTEK, n.d.. *Hva er problemet med kommunikasjon i Arktis?.* [Online]
Available at: http://www.sintef.no/marintek/prosjekter/maritim/hva-er-problemet-med-kommunikasjon-i-arktis/
[Accessed 15 January 2016].

Merriam-Webster, n.d.. *Winterize.* [Online]
Available at: http://www.merriam-webster.com/dictionary/winterize
[Accessed 16 January 2016].

MetLex, n.d.. *Polare lavtrykk.* [Online]
Available at: https://metlex.met.no/wiki/Polare_lavtrykk
[Accessed 18 January 2016].

Nadiro, 2011. *Nadiro Boat-In-A-Box NORSOK R-002.* [Online]
Available at:
http://www.ptil.no/getfile.php/PDF/Seminar%202011/Livb%C3%A5tseminar/Nadiro_NORSOK-R002_spec_Rev3.pdf
[Accessed 15 January 2016].

National Snow & Ice Data Center, 2015. *Arctic sea ice reaches fourth lowest minimum.* [Online]
Available at: http://nsidc.org/arcticseaicenews/2015/09/2015_arctic-minimum/
[Accessed 8 January 2016].

National Snow & Ice Data Center, n.d.. *Cryosphere Glossary.* [Online]
Available at: http://nsidc.org/cryosphere/glossary-terms/snow?page=5
[Accessed 17 January 2016].

Naturhistorisk museum, 2015. *www.nhm.uio.no.* [Online]
Available at: https://www.nhm.uio.no/fakta/zoologi/pattedyr/isbjorn/bjornevett/
[Accessed 25 May 2016].

Norsafe as, 2012. *Internal General Arrangement - 8,5m "Miriam" Totally Enclosed Lifeboat - Tanker Version,* s.l.: Norsafe as.

Norsk Polarinstitutt, n.d.. *Det arktiske system - Havet og havstrømmer.* [Online]
Available at: http://www.arcticsystem.no/no/outsideworld/oceancurrents/
[Accessed 7 January 2016].

Norwegian Meteorological Institute, 2015a. *Hav og is.* [Online]
Available at: http://157.249.32.242/archive/2015/20150225/general_20150225.png
[Accessed 8 January 2016].

Norwegian Meteorological Institute, 2015b. *Hav og is.* [Online]
Available at: http://157.249.32.242/archive/2015/20150911/general_20150911.png
[Accessed 8 January 2016].

Norwegian Oil and Gas Association, 2010. *Kalde utfordringer - Helse og arbeidsmiljø på innretning i nordområdene,* s.l.: Norwegian Oil and Gas Association.

Olje- og energidepartementet, 2012. *Beredskap og støttefunksjoner,* Oslo: Olje- og energidepartementet.

ORBCOMM, n.d.. *Networks: Satellite.* [Online]
Available at: http://www.orbcomm.com/en/networks/satellite-ais
[Accessed 16 January 2016].

Oxford Dictionaries, n.d. *Davit.* [Online]
Available at: http://www.oxforddictionaries.com/definition/english/davit
[Accessed 17 January 2016].

Petroleum Safety Authority Norway, 2014a. *Cold.* [Online]
Available at: http://www.psa.no/facts-the-far-north/cold-article10447-1143.html
[Accessed 17 January 2016].

Petroleum Safety Authority Norway, 2014b. *Mørketid.* [Online]
Available at: http://www.ptil.no/fakta-naturgitte-forhold/moerketid-article10411-1134.html
[Accessed 17 January 2016].

Petroleum Safety Authority Norway, 2014c. *Vær og varsling.* [Online]
Available at: http://www.ptil.no/fakta-naturgitte-forhold/vaer-og-varsling-article10412-1134.html
[Accessed 17 January 2016].

Poole, I., n.d.. *Iridium satellite technology, theory and frequency bands, Radio-Electronics.com.* [Online]
Available at: http://www.radio-electronics.com/info/satellite/communications-systems/iridium-theory-history-technology-frequency.php
[Accessed 16 January 2016].

Power, J. T. & Simões Ré, A. J., 2010. *Lifeboat Habitability and Effects on Human Subjects,* St. John's: National Research Council of Canada.

Rausand, M. & Utne, I. B., 2009. *Risikoanalyse - teori og metoder.* Trondheim: Tapir Akademisk Forlag.

Regjeringen.no, 2014. *Fiskevernsonen ved Svalbard og fiskerisonen ved Jan Mayen.* [Online]
Available at: https://www.regjeringen.no/no/tema/mat-fiske-og-landbruk/fiske-og-havbruk/rydde-internasjonalt/fiskevernsonen-ved-svalbard-og-fiskeriso/id445285/
[Accessed 9 January 2016].

Seascanner, 2015. *MSC Cruises to Svalbard.* [Online]
Available at: http://www.seascanner.com/cruises-msc-to-svalbard-d9-r16
[Accessed 11 January 2016].

SINTEF/SARiNOR, n.d. *Behovsområder knyttet til overlevelse og redning i nordområdene,* s.l.: Unpublished.

Solberg, K. E. & Gudmestad, O. T., 2016. *SARex - Assessment of Polar Code requirements through a full-scale exercise,* Stavanger: s.n.

Store norske leksikon, 2009a. *Livbåt.* [Online]
Available at: https://snl.no/livb%C3%A5t
[Accessed 13 January 2016].

Store norske leksikon, 2009b. *Fritt fall-livbåt.* [Online]
Available at: https://snl.no/fritt_fall-livb%C3%A5t
[Accessed 13 January 2016].

Store norske leksikon, 2009c. *Redningsflåte.* [Online]
Available at: https://snl.no/redningsfl%C3%A5te
[Accessed 14 January 2016].

Store norske leksikon, 2014. *Barentshavet.* [Online]
Available at: https://snl.no/Barentshavet
[Accessed 7 January 2016].

Store norske leksikon, 2015. *Arktis.* [Online]
Available at: https://snl.no/Arktis
[Accessed 17 January 2016].

Sysselmannen, 2013. *Dårlig kartlagte farvann rundt Svalbard.* [Online]
Available at: http://www.sysselmannen.no/Nyheter/Darlig-kartlagte-farvann-rundt-Svalbard/
[Accessed 13 January 2016].

Sysselmannen, 2015. *Reiselivsstatistikk for Svalbard 2014,* Longyearbyen: Sysselmannen.

Taber, M. J., Simões Ré, A. & Power, J., 2009. *A preliminary ergonomic assessment of piloting a lifeboat in ice,* Halifax: Elsevier Ltd.

Teknisk Ukeblad, 2015. *Nytt satellitt-senter i Vardø gir sikrere skipstrafikk i Arktis. Teknisk Ukeblad.* [Online]
Available at: http://www.tu.no/industri/2015/05/07/nytt-satellitt-senter-i-vardo-gir-sikrere-skipstrafikk-i-arktis
[Accessed 17 January 2016].

Transportøkonomisk institutt, 2003. *Skipstrafikken i området Lofoten - Barentshavet,* Oslo: Transportøkonomisk institutt/Kystverket.

Tulmar Safety Systems, n.d. *6XL Arctic Life Raft.* [Online]
Available at:
http://www.tulmar.com/index.php?option=com_content&view=article&id=29&Itemid=183&jsmallfib=1&dir=JSROOT/Brochures/Defence&download_file=JSROOT/Brochures/Defence/6XL_Arctic_Life_Raft.pdf
[Accessed 16 January 2016].

UNEP/GRID-Arendal, 1997. *GRID-Arendal.* [Online]
Available at: http://www.grida.no/prog/polar/bsc/fig5.htm
[Accessed 7 January 2016].

Viking Life-Saving Equipment, 2014. *Thermal Protective Aid without sleeves, TPA.* [Online]
Available at: http://admin.sds.viking-life.com/fileexplorer/fetchfile.aspx?id=14992
[Accessed 25 May 2016].

Viking Life-Saving Equipment, 2015a. *PV9720 VIKING Thermal Protective Lifejacket.* [Online]
Available at: http://admin.sds.viking-life.com/fileexplorer/fetchfile.aspx?id=22390
[Accessed 25 May 2016].

Viking Life-Saving Equipment, 2015b. *PS5003 VIKING Non-insulated Immersion Suit.* [Online]
Available at: http://admin.sds.viking-life.com/fileexplorer/fetchfile.aspx?id=24027
[Accessed 26 May 2016].

Viking Life-Saving Equipment, 2016a. *PS2004 VIKING Neoprene Immersion Suit.* [Online]
Available at: http://admin.sds.viking-life.com/fileexplorer/fetchfile.aspx?id=24523
[Accessed 26 May 2016].

Viking Life-Saving Equipment, 2016b. *PS5002 VIKING PU Coated Nylon Immersion Suit.* [Online]
Available at: http://admin.sds.viking-life.com/fileexplorer/fetchfile.aspx?id=24919
[Accessed 26 May 2016].

Viking Life-Saving Equipment, n.d. *Polar liferaft.* [Online]
Available at: http://www.viking-life.com/viking.nsf/public/products-polarliferaft.html
[Accessed 16 January 2016].

Viñas, M.-J. & Garner, R., 2015. *2015 Arctic Sea Ice Maximum Annual Extent Is Lowest On Record.* [Online]
Available at: https://www.nasa.gov/content/goddard/2015-arctic-sea-ice-maximum-annual-extent-is-lowest-on-record
[Accessed 18 January 2016].

Walrus-world, 2013. *Walrus-world.* [Online]
Available at: http://www.walrus-world.com/humans-and-walruses/
[Accessed 26 May 2016].

Wikimedia Commons, 2009. *Arctic Region.* [Online]
Available at: https://commons.wikimedia.org/wiki/File:Arctic.svg
[Accessed 17 January 2016].

World Health Organization, 2011. *How much water is needed in emergencies.* [Online]
Available at:

http://www.who.int/water_sanitation_health/publications/2011/tn9_how_much_water_en.pdf
[Accessed 14 January 2016].

Worldatlas, 2015. *Arctic Ocean - Map & Details.* [Online]
Available at: http://www.worldatlas.com/aatlas/infopage/oceans/arcticocean.htm
[Accessed 7 January 2016].

Xervo, n.d. *Xervo - Products.* [Online]
Available at: https://www.xervo.dk/products/our-technologies.html
[Accessed 15 January 2016].

# Appendix A

# Preliminary Hazard Analysis

# Preliminary Hazard Analysis

| Stage one: Evacuation to lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 1.1 | Slippery walkways and surfaces (gunwale, stairs, etc.) | Icing on surfaces (atmospheric/sea spray)<br>Wet surfaces (rain/sea spray) | Injuries from falling. | **Probability: 3**<br>**Consequence: C** | -Sheltered walkways<br>-Heated walkways<br>-Enclosed/sheltered lifeboats/stations<br>-Surfaces covered with friction material | **Probability: 1**<br>**Consequence: C** |
| **Pre RRM comments** | 1.1 | Note: This problem does not cover incidents where people stumble, twist their ankles, etc., only falling accidents due to low-friction surfaces. Probability is set to medium (3). On a boat, there are usually slippery surfaces due to wet floors, snow, ice etc. If the lifeboat station is unsheltered, slipping might be a relevant problem for a cruise ship. Consequences are set to medium (C) due to the possibility of relatively serious injuries from falling. | | | | | |
| **Post RRM comments** | 1.1 | If the suggested risk-reducing measures are implemented, the probability is reduced to minimal (1). | | | | | |
| | 1.2 | Insufficient space in lifeboat | Polar clothing, PSK and GSK takes extra space | Passengers cannot evacuate to the lifeboat they are assigned to.<br>Available lifeboat capacity insufficient.<br>All passengers are not able to bring along their PSK. | **Probability: 4**<br>**Consequence: B** | - Lifeboat passenger capacity with full polar clothing, PSK and GSK to be certified/determined prior to operation | **Probability: 1**<br>**Consequence: A** |
| **Pre RRM comments** | 1.2 | Note: Problem is based on today's lifeboats and their capacity, with polar clothing and PSK & GSK equipment brought along. Probability is set to high (4). Polar clothing requires some extra space, but not a lot. If a sufficient amount of PSK's and GSK's are to be brought along in the lifeboat, these will require some space. This problem depends on whether the total lifeboat passenger capacity is needed in an evacuation. Consequences are set to low (B). If there is insufficient space in the lifeboat for all necessary passengers and the required amount of PSK & GSK, the kits will have to be left behind. Polar Code requires space for passengers with all necessary equipment, if the risk assessment requires this. | | | | | |
| **Post RRM comments** | 1.2 | If the cruise ship has lifeboats with capacity to take all passengers with the necessary equipment (PSK & GSK), this problem is eliminated. Probability reduced to minimum (1), consequence reduced to minimum (A). | | | | | |

<table>
<tr><th colspan="8">Stage one: Evacuation to lifeboat</th></tr>
<tr><th></th><th>Hazard number</th><th>Problem</th><th>Cause</th><th>Possible Consequences</th><th>Pre risk-reducing measures risk</th><th>Risk-reducing measures</th><th>Post risk-reducing measures risk</th></tr>
<tr><td></td><td rowspan="3">1.3</td><td>Lifeboat not usable</td><td>-Fire in area<br>-Lifeboat damaged (due to collision etc)</td><td>-Not enough total lifeboat seats remaining to evacuate all passengers<br>-Passengers entering hazardous area</td><td>Probability: 2<br>Consequence: C</td><td>-Ensure additional evacuation possibilities<br>-Emergency routines</td><td>Probability: 2<br>Consequence: B</td></tr>
<tr><td>Pre RRM comments</td><td colspan="6">Probability is set to low (2) because it is not very likely that the ship has list/trim over design limits before the evacuation is finished. Depending on what the emergency is (fire, collision, etc.), one or more lifeboats can be unavailable or too damaged to be used for evacuation, but the probability of this is also low. Consequences are set to medium (C) due to the fact that if a lifeboat is unavailable, there are not enough space in the remaining lifeboats to accommodate the extra passengers. These will therefore have to evacuate by using other means, e.g. life rafts. Having to do this, might require them to remain onboard the ship longer than if their lifeboat was operable.</td></tr>
<tr><td>Post RRM comments</td><td colspan="6">By ensuring additional means of evacuation, the consequences of this problem is reduced to low (B).</td></tr>
<tr><td></td><td rowspan="3">1.4</td><td>Clothing not sufficient for evacuation</td><td>-Poor information routines onboard<br>-Chaotic evacuation situation (passengers don't remember information)</td><td>Reduced chance of prolonged survival</td><td>Probability: 4<br>Consequence: D</td><td>-Improve information routines and emergency drills<br>-PSK and GSK easily accessible close to muster station and embarkation. Polar Code requirement.</td><td>Probability: 4<br>Consequence: B</td></tr>
<tr><td>Pre RRM comments</td><td colspan="6">Probability is set to high (4), because it is likely that people are wearing less than ideal clothes in a chaotic evacuation situation. The consequences are set to high (D), severely reducing the long-term survival chances. Even though the passengers are informed of recommended clothing for evacuation in e.g. a standard pre-journey safety briefing, it is likely to be a problem. PSK and GSK can be vital in such situations, so it is important to bring these along in the evacuation vessel.</td></tr>
<tr><td>Post RRM comments</td><td colspan="6">With PSK and GSK available, and brought along in the lifeboat in an evacuation situation, the consequences are reduced to low (B). This is because the PSK and GSK contains spare clothing and equipment that can be put on once in the lifeboat. The Polar Code requires that the PSK & GSK equipment provide sufficient thermal insulation to maintain the core temperature of persons. Despite information routines, the probability is unchanged. This is because in reality, the passengers are indoor, and it cannot be expected that they wear e.g. woolen underclothing at all times. In addition, even though emergency routines might say that passengers are to change to/bring along extra clothing in case of an emergency, this is entirely dependent on each passenger and the nature of the emergency.</td></tr>
</table>

| Stage one: Evacuation to lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 1.5 | PSK and GSK are not available or not brought along in lifeboat | Human/organizational error<br>Polar Code risk assessment did not require PSK/GSK | Reduced chance of prolonged survival | **Probability: 3**<br>**Consequence: C** | -Ensure proper information routines<br>-Crew training<br>-Qualified and experienced personnel handling risk assessment | **Probability: 2**<br>**Consequence: C** |
| **Pre RRM comments** | | Note: This problem presumes that the Polar Code requirement to PSK & GSK has entered into force. This requirement is based on the Polar Code risk assessment, which are to be performed prior to voyage. Whether PSK and GSK is available onboard the ship is therefore entirely dependent on the conclusions from the risk assessment.<br><br>Probability is set to medium (3). PSK and GSK are to be stored (easily accessible) close to the muster/embarkation stations, so they will have to be manually moved into the lifeboats pre-launch. It is therefore likely that there are too few PSK & GSK in each lifeboat compared to the number of passengers. Consequences are set to medium (C), at least if the number of PSK & GSK is very low compared to the passenger count. | | | | | |
| **Post RRM comments** | | Assumed that PSK and GSK is available in ideal locations. The probability of this problem can be reduced significantly by ensuring that the risk assessment is performed thoroughly by an experienced analysis group, and by sound emergency procedures and crew training. If this is in place, probability is reduced to low (2). Due to the stressful nature of an evacuation situation, it is difficult to lower the probability further. | | | | | |
| | 1.6 | Passenger unable to evacuate to lifeboat without assistance | -Health problems/injuries, combined with complicated boarding arrangements | Passenger needs extra assistance when boarding<br>Evacuation process is delayed | **Probability: 5**<br>**Consequence: A** | -Design boarding arrangements for easy access<br>- Information on passenger health problems prior to sailing<br>-Procedures in place for crew to help | **Probability: 4**<br>**Consequence: A** |
| **Pre RRM comments** | | Probability is set to very high (5). It is very likely that a cruise passenger, of which many are elderly and unfit, will need some sort of assistance when embarking the lifeboats. Consequences are set to minimal (A), but can include negative impacts on the overall evacuation time. | | | | | |
| **Post RRM comments** | | By designing the boarding arrangements to be as easily accessible as possible, excluding ladders or steps, the number of people requiring assistance can be reduced. This will in turn reduce the probability of this entire problem. With such measures in place, the probability is reduced to high (4). These measures will also require less effort from the crew, which then can concentrate on other important tasks. | | | | | |

| Stage one: Evacuation to lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 1.7 | Passengers go to «wrong» muster station | -Poor information routines onboard<br>-Chaotic evacuation situation (don't remember information) | Delayed evacuation process | **Probability: 3**<br>**Consequence: B** | -Ensure proper information routines<br>-Crew training | **Probability: 2**<br>**Consequence: B** |
| **Pre RRM comments** | | Probability is set to medium (3), because an evacuation situation is likely to be very chaotic. It is probable that some of the passengers will escape to another lifeboat station than they are preassigned to, hence this problem. Consequences are set to low (B), due to possible delays in the overall evacuation process, and because in a worst-case scenario passengers can be left behind in the confusion. | | | | | |
| **Post RRM comments** | | To limit this risk, there must be good communication between the lifeboat crews, and sound routines in place. Combined, this lowers the probability to low (2). | | | | | |
| | 1.8 | Sea ice conditions around ship unsuited for launch of lifeboats | Dense/thick sea ice | Lifeboat evacuation not possible | **Probability: N/A**<br>**Consequence: N/A** | Avoid using lifeboats for evacuation by:<br>-Evacuating passengers directly onto ice sheet<br>-Deploying inflatable life rafts on the ice sheet | **Probability: 1**<br>**Consequence: A** |
| **Pre RRM comments** | | This problem was included prior to conversations with a lifeboat manufacturer (Norsafe), but the risk was not estimated due to lack of information. | | | | | |
| **Post RRM comments** | | Norsafe revealed that the lifeboats can be lowered onto fast ice without problem, and will due to a shallow keel lay relatively stable on the ice. In addition, cruise ships does not normally venture into areas with fast ice. The probability of this problem is therefore set to be minimal, and the consequences equally low. The problem is not removed from this analysis due to informational value. | | | | | |

| Stage two: Launch of lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 2.1 | Mechanical failure on launching mechanisms | Icing on parts and components | -Lifeboat launching process cannot be initiated<br>- Lowering obstructed during launching process<br>- Release hooks do not function as intended | **Probability: 3 Consequence: D** | -Sheltered components/mechanisms<br>-Heated components/mechanisms<br>-Release hook redundant override function<br>-Manual inspection<br>-Manual removal of ice | **Probability: 1 Consequence: D** |
| **Pre RRM comments** | | Probability is set to medium (3). At sea, one are exposed to two types of icing (sea spray and atmospheric). The temperatures in the Arctic, even during the summer months, are often low enough to cause icing. The lifeboats and launching arrangements are likely to be fitted relatively high on a cruise ship, but in harsh weather and with rough seas, the altitude above the sea is still not enough to prevent sea spray icing altogether. The fact that launching arrangements are constructed from steel members, and has small-diameter details such as steel members and wire ropes, facilitates icing. The consequences of this problem is set to high (D). This is because mechanical failure on the launching mechanisms can render a lifeboat unusable, or in worst case, a failure can occur during the lifeboat lowering. There is also a probability that icing can prevent the release hooks from functioning properly, which would render it impossible to get away from the ship. | | | | | |
| **Post RRM comments** | | The suggested risk-reducing measures can effectively prevent the formation of icing, reducing the probability to minimal (1). | | | | | |
| | 2.2 | Mechanical failure on launching mechanisms | Poor maintenance<br>Corrosion<br>Material fatigue | -Lifeboat launching process cannot be initiated<br>- Lowering obstructed during launching process<br>- Release hooks do not function as intended<br>-Cable breaks | **Probability: 3 Consequence: D** | -Ensure proper maintenance routines | **Probability: 2 Consequence: D** |
| **Pre RRM comments** | | Probability is set to medium (3). This is mainly due to the operational environment of the launching equipment. Salt water and marine air facilitates corrosion, and low temperatures can cause metal to get brittle. It is therefore very important that inspections and maintenance is performed regularly as per requirements. The consequences of this problem are set to high (D). This is because mechanical failure on the launching mechanisms can render a lifeboat unusable, or in worst case, a failure can occur during the lifeboat lowering. Mechanical problems can also prevent the release hooks from functioning properly, which would render it impossible to get away from the ship. | | | | | |
| **Post RRM comments** | | Following the inspection and maintenance routines can prevent failures from occurring, given that it is performed thoroughly and with quality. Still, there is always a risk of failure in mechanical systems, due to a number of reasons. The probability is therefore reduced to low (2). | | | | | |

| Stage two: Launch of lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 2.3 | Power (electric/hydraulic) for launching arrangements not available | Ship's main/secondary/emergency power is out | Lifeboat launch not possible | **Probability: 2 Consequence: D** | -Gravity based launching systems (not dependent on power systems)<br>-Redundant systems | **Probability: 1 Consequence: D** |
| **Pre RRM comments** | | Probability is set to low (2) because if the launching arrangements depend on power, there will almost certainly be redundant back-up systems. Consequences are set to high (D) due to the fact that if multiple lifeboats are unavailable, the evacuation possibilities is reduced to secondary means (e.g. life rafts). This will also complicate the evacuation process a lot. | | | | | |
| **Post RRM comments** | | If all launching systems are gravity based only, there will be no need for any type of power to launch the lifeboats. Hence, the problem is eliminated, and the probability is reduced to minimal (1). | | | | | |
| | 2.4 | Stress on lifeboat and davit exceeds design limits | Lifeboat launch is initiated when ship has list/trim angle above what the lifeboats and arrangements are designed for | -Injuries/fatalities due to mechanical failure | **Probability: 1 Consequence: D** | -System/procedures to avoid launch when ship has too high list/trim angle | **Probability: 1 Consequence: D** |
| **Pre RRM comments** | | Minimal probability (1) for this problem to occur, because the arrangements probably have a maximum working load much higher than the safe working load. Consequences are set to high (D) because if the stress on the lifeboat and davit exceeds the design limits, there is a slight chance that a mechanical failure might occur, and in a worst case scenario e.g. the lifting cables can snap and send the lifeboat into a freefall. | | | | | |
| **Post RRM comments** | | Some sort of system or procedures can be implemented to prevent lowering of lifeboats when the list or trim angle is too high. This will have minor impacts on the probability, but there will be no changes in the probability grade since it is already minimal (1). | | | | | |

| Stage two: Launch of lifeboat | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 2.5 | Uncontrolled lifeboat movement during lowering | -Rough sea state<br>-Strong winds<br>-Ship rolling | Lifeboat crashing into the ship side/other lifeboats, subsequent consequences includes passenger injuries | **Probability: 3**<br>**Consequence: C** | -Shock-absorbing fenders and skates on lifeboat exterior hull<br>-Passengers using seatbelts in lifeboat | **Probability: 3**<br>**Consequence: B** |
| **Pre RRM comments** | | Probability set to medium (3) because it is quite likely that the sea conditions will cause the ship to move, and controlling the subsequent lifeboat movements during lowering is close to impossible. Strong winds can also be a factor that initiates lifeboat movement. The consequences are set to medium (C) because if the lifeboat moves uncontrollably and crashes into the ship's hull at relatively high speeds, the passengers will be thrown around inside the lifeboat. The lifeboat itself shall be designed to withstand an impact with the ship's hull of at least 3,5 m/s. | | | | | |
| **Post RRM comments** | | The risk-reducing measures will reduce the consequences to low (B). Fenders and skates on the lifeboat will to some degree absorb energy from crashes, and seatbelts will ensure that the passengers remain in their seats even when the lifeboat movement is substantial. Minor injuries can still be expected. | | | | | |

| Stage three: Initial operation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 3.1 | Unable to start engine | Mechanical/electrical failure | Lifeboat unable to maneuver away from ship;<br>-possible collision with ship<br>-lifeboat drifting helplessly, affected by waves and wind<br>-lifeboat stuck in sea ice | **Probability: 3<br>Consequence: B** | -Winterization<br>-Ensure proper maintenance routines | **Probability: 2<br>Consequence: B** |
| **Pre RRM comments** | | Probability set to medium (3) because there is always a possibility that mechanical or electrical failures occur. This might be due to poor inspections/maintenance, or the harsh conditions (engine fluids freeze). Consequence low (B), because if the engine does not work, the lifeboat is dead in the water. This can lead to collisions in this critical stage, which may in turn cause injuries. | | | | | |
| **Post RRM comments** | | Following the inspection and maintenance routines can prevent failures from occurring, given that it is performed thoroughly and with quality. Still, there is always a risk of failure in mechanical systems, due to a number of reasons. Probability reduced to low (2). | | | | | |
| | 3.2 | Maneuvering difficulties | Heavy sea, sea ice, wind | Little or no control of lifeboat position/heading<br>Lifeboat cannot be positioned correctly in the waves, heavy lifeboat motion (uncomfortable for passengers) | **Probability: 3<br>Consequence: B** | Lifeboat designed for arctic use, with:<br>-Sufficient engine power<br>-Steering (nozzle, rudder, etc) designed for operation in ice<br>-Hull for operation in ice<br>-Lifeboat pilot training | **Probability: 2<br>Consequence: B** |
| **Pre RRM comments** | | Note: Same problem as hazard number 4.4.<br>Probability set to medium (3) because it is likely that the weather and sea conditions are rough in arctic areas, and because lifeboats usually have a design less than ideal for stable operation in such conditions (shallow keel, hull shape, etc.). It is also likely that there might be some type of sea ice, which complicates maneuvering. Consequences are set to low (B) because even if the maneuvering is difficult, the lifeboat will continue to provide a safe habitat. Smaller consequences such as that the lifeboat cannot be positioned correctly in the waves can cause a lot of lifeboat motion, which in turn is uncomfortable for passengers. | | | | | |
| **Post RRM comments** | | If the lifeboat is designed with specific features for arctic operation, and the lifeboat pilot has sufficient training in maneuvering lifeboats in harsh conditions, the probability is reduced to low (2). | | | | | |

| Stage three: Initial operation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 3.3 | Lifeboat integrity compromised | -Collision with ship during/after launch<br>-Collision with ice floes | Flooding of lifeboat | **Probability: 2<br>Consequence: B** | -Shock-absorbing fenders<br>-Reinforced gunwale<br>-Reinforced hull<br>-Buoyancy capabilities | **Probability: 1<br>Consequence: B** |
| **Pre RRM comments** | | Probability set to low (2) because it is not very likely that a lifeboat crashes into something hard enough to break the hull. There is still a possibility, because the hull of a standard lifeboat is not very thick, and a collision at full speed with solid sea ice can probably do some damage. The same goes for a collision with the ship. Consequences is set to low (B) because the LSA code requires lifeboats to have sufficient buoyancy even if there is a breach in the hull below the waterline. | | | | | |
| **Post RRM comments** | | Implementing the suggested risk-reducing measures will reduce the probability to minimal (1). | | | | | |
| | 3.4 | Maneuvering of lifeboat not possible | Damage to steering system/ rudder/steering nozzle due to impacts with ice. | Lifeboat unable to maneuver away from ship;<br>-possible collision with ship<br>-lifeboat drifting helplessly, affected by waves and wind<br>-lifeboat stuck in sea ice | **Probability: 2<br>Consequence: B** | Lifeboat designed for arctic use, with:<br>-Steering (nozzle, rudder, etc.) designed for operation in ice | **Probability: 1<br>Consequence: B** |
| **Pre RRM comments** | | Probability set to low (2) because it is not likely that a lifeboat's rudder or propeller is damaged by for instance sea ice. Consequences are set to low (B) because even if maneuvering is disabled, the lifeboat will continue to provide a safe habitat. Smaller consequences such as that the lifeboat cannot be positioned correctly in the waves can cause a lot of lifeboat motion, which in turn is uncomfortable for passengers. | | | | | |
| **Post RRM comments** | | If the lifeboat is designed for arctic use, with steering components that can handle the impact from ice, the probability is reduced to minimal (1). | | | | | |

| Stage three: Initial operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 3.5 | Difficult rescuing passengers from sea to lifeboat | Insufficient arrangements on lifeboat for extraction of people from sea. | Unable to rescue survivors from sea. Will require a lot of manpower. | **Probability: 4 Consequence: D** | -Lifeboat design, e.g. (retractable) ladder or stern is designed for easy rescue<br>-Life buoy | **Probability: 2 Consequence: D** |
| **Pre RRM comments** | | Probability set to high (4) because it is likely that it will be difficult to rescue someone from the sea into the lifeboat. This is because on a normal SOLAS-approved lifeboat, there are usually not arrangements that makes it possible to get onboard on your own, and the distance from the hatches down to the sea surface means that at least one person inside the lifeboat will have to drag or lift a person from the sea onboard. Consequences are set to high (D), because if someone cannot get out of the water, the survival chances are severely reduced in any circumstances. It is therefore very important to get out of the water as soon as possible, making it critical to be able to get onboard a lifeboat. | | | | | |
| **Post RRM comments** | | If the lifeboat has arrangements for extraction of people from the sea (for instance a ladder which one can use to get oneself up, or a platform that facilitates people onboard the lifeboat lifting people onboard from the sea), the probability is reduced to low (2). There will however always be a possibility that persons immersed are too cold to climb onboard a lifeboat on their own. | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.1 | Poor sight | Fog, snow squalls, low light (no searchlight/headlights)<br>Icing (sea spray) on windows<br>Icing/moisture on the inside of windows | Navigation difficulties<br>Possible collision | **Probability: 4<br>Consequence: B** | -Lifeboat pilot training<br>-Searchlights/headlights<br>-Heating/anti-ice solution on windows<br>-Air vent at the highest point in the lifeboat | **Probability: 3<br>Consequence: B** |
| **Pre RRM comments** | 4.1 | Probability is set to high (4) because it is likely that one or more of the causes for poor sight will be present at any time when in a lifeboat. Consequences are low (B), because even though navigation is difficult due to poor sight, the lifeboat will continue to provide a safe habitat. | | | | | |
| **Post RRM comments** | 4.1 | Risk-reducing measures will mitigate some of the causes for poor sight, reducing the probability to medium (3). Other causes, however, such as fog and snow squalls, are impossible to eliminate. | | | | | |
| | 4.2 | Communication devices not available/working | No power (engine not running), or battery not charged<br>LSA code does not require more than a radar reflector or survival craft radar transponder. | Time to rescue is prolonged<br>Delay/difficulties in rescue operation | **Probability: 4<br>Consequence: C** | -Maintenance (battery)<br>-Battery charging possibilities in lifeboat<br>-Polar Code requirements<br>-All devices required by Polar Code could be permanently installed in lifeboat | **Probability: 1<br>Consequence: C** |
| **Pre RRM comments** | 4.2 | Probability is set to high (4) because currently, there are no requirements to communication devices onboard survival crafts. When the Polar Code enters into force, it is only required that such equipment are brought along in the lifeboat, not permanently fixed. The chances that some crewmember forgets to bring along a radio is still present. If the radio is brought along, it might still be low on battery due to lack of charging prior to evacuation, or due to excessive use post evacuation. Consequences are set to medium (C), because if there are no devices for communication onboard a lifeboat, the only means of keeping in contact with nearby vessels is the signaling mirror. The range of portable radio equipment is not very long, but it might still make a difference when it comes to rescue time. | | | | | |
| **Post RRM comments** | 4.2 | If all risk-reducing measures are implemented, the probability is reduced to minimal (1). This is because if all communication equipment is permanently fixed in the lifeboat, there is no risk of crewmembers forgetting to bring the equipment with them during evacuation. With either charging possibilities or power directly from the lifeboat's batteries, it is possible to overcome the Polar Code requirement stating that the communication devices shall be operative for the maximum expected time of rescue. | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.3 | Lifeboat runs out of fuel | Not enough fuel available for maximum expected time of rescue | -Lifeboat drifting uncontrollably<br>-Loss of battery charging | **Probability: 4 Consequence: B** | -Additional fuel to accommodate Polar code 5-day survival requirement<br>-Oars for rowing<br>-Only use engine at very low speeds (idle) to conserve fuel | **Probability: 2 Consequence: B** |
| **Pre RRM comments** | | Probability is set to high (4) because the amount of fuel currently required in lifeboats shall only be sufficient to run the boat at 6 knots for 24 hours. When the Polar Code enters into force, the maximum expected time of rescue is no less than 5 days. According to Norsafe, the current amount of fuel is enough to run the lifeboat tested in SARex at idle for 5 days. This means that for 5 days of survival time, it will be possible to run the engine, but not get anywhere without running out of fuel. Consequences are set to low (B), as the lifeboat will continue to provide a safe habitat even though the propulsion possibilities is gone. | | | | | |
| **Post RRM comments** | | It is possible to add bigger fuel tanks capable of carrying more fuel. Supposing that the lifeboat should have enough fuel to run at 6 knots for the maximum expected time of rescue, the amount of necessary fuel is 5 times what is currently required. For the specific Norsafe lifeboat used in SARex, that means carrying 800 liters of fuel instead of 160. A possible solution is to have enough fuel to run at 6 knots for 48 or 72 hours, and in addition instruct the crew to ration the fuel by running the engine at idle when possible. This all comes down to how the Polar Code requirements are interpreted. With double amount of fuel compared to the current requirements, together with fuel rationing, the probability is reduced to low (2). | | | | | |
| | 4.4 | Maneuvering difficulties | Heavy sea, sea ice, wind | Little or no control of lifeboat position/heading Lifeboat cannot be positioned correctly in the waves, heavy lifeboat motion (uncomfortable for passengers) | **Probability: 3 Consequence: B** | Lifeboat designed for arctic use, with:<br>-Sufficient engine power<br>-Steering (nozzle, rudder, etc.) designed for operation in ice<br>-Hull for operation in ice<br>-Lifeboat pilot training | **Probability: 2 Consequence: B** |
| **Pre RRM comments** | | Note: Same problem as hazard number 3.2.<br>Probability set to medium (3) because it is likely that the weather and sea conditions are rough in arctic areas, and because lifeboats usually have a design less than ideal for stable operation in such conditions (shallow keel, hull shape, etc.). It is also likely that there might be some type of sea ice, which complicates maneuvering. Consequences are set to low (B) because even if the maneuvering is difficult, the lifeboat will continue to provide a safe habitat. Smaller consequences such as that the lifeboat cannot be positioned correctly in the waves can cause a lot of lifeboat motion, which in turn is uncomfortable for passengers. | | | | | |
| **Post RRM comments** | | If the lifeboat is designed with specific features for arctic operation, and the lifeboat pilot has sufficient training in maneuvering lifeboats in harsh conditions, the probability is reduced to low (2). | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.5 | Clogging/blocking of ventilation | Warm and moist air from inside the lifeboat condensates and freezes around the ventilation outlet | Reduced ventilation, rapid deterioration of air quality | **Probability: 2 Consequence: B** | -Ventilation design (winterized) | **Probability: 1 Consequence: B** |
| **Pre RRM comments** | | Probability set to low (2) because the temperature conditions must be ideal for this to happen, and the ventilation must be designed so that it is vulnerable to this problem. Consequences are set to low (B) because even though the ventilation arrangement is not functional, it is possible to ventilate by opening windows or hatches. The ice blocking the ventilation will probably be possible to remove as well. | | | | | |
| **Post RRM comments** | | By winterizing the ventilation design, the probability of this problem to occur is reduced to minimal (1). | | | | | |
| | 4.6 | Sea spray into lifeboat | The lifeboat hatches are open (ventilation, extracting persons from sea, etc.) | People get wet and cold. Water inside the lifeboat. | **Probability: 2 Consequence: B** | - Proper ventilation design (adjustable), to avoid having to ventilate using hatches<br>-System/equipment for draining water from lifeboat (Manual bilge pump, bailers) | **Probability: 1 Consequence: B** |
| **Pre RRM comments** | | Probability set to low (2) because for this to happen, hatches or windows will have to be open. If the weather is bad, the hatches will probably be kept closed as much as possible, with exceptions for ventilation etc. Consequences are set to low (B) because even though a significant amount of water enters the lifeboat, there are bilge pumps to drain the water from the boat. People getting wet is also a consequence, which can have minor effects on the survival situation. If immersion suits or TPA is used, this problem is not so relevant. | | | | | |
| **Post RRM comments** | | With a proper passive ventilation design in place, it will not be necessary to open the windows or hatches often for ventilation purposes. This will in turn prevent sea spray into the lifeboat. With this risk-reducing measure, the probability is reduced to minimal (1). | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.7 | Sea spray icing on lifeboat | Sea spray combined with low temperatures | Skew loads, hinges and locks on hatches stuck, ventilation compromised. | **Probability: 3 Consequence: B** | -Lifeboat design, winterization | **Probability: 2 Consequence: B** |
| **Pre RRM comments** | | Probability set to medium (3) because even though a standard lifeboat has a design that relatively effectively prevents build-up of ice, the conditions in the Arctic are often ideal for icing. A lifeboat also has some small details that are extra vulnerable to icing, such as hinges, handles, locks, etc. Consequences are set to low (B) because a lifeboat has hatches on multiple sides, so that if one is stuck due to icing, another will probably be possible to open. | | | | | |
| **Post RRM comments** | | With a proper winterized design, protecting small details from ice build-up, the probability is reduced to low (2). | | | | | |
| | 4.8 | $CO_2$ build-up inside lifeboat | Insufficient ventilation, many people breathing. | Headaches, sleepiness, poor concentration, loss of attention, increased heart rate, slight nausea, oxygen deprivation. | **Probability: 5 Consequence: B** | -Proper ventilation design (adjustable)<br>-Opening hatches | **Probability: 3 Consequence: B** |
| **Pre RRM comments** | | Probability is set to very high (5) because several tests reveal that the $CO_2$ concentration in a lifeboat will increase rapidly when no hatches or windows are open, even with few passengers onboard. Consequences are low (B) because it is highly probable that someone will open the hatches to ventilate long before any serious health effects occurs. | | | | | |
| **Post RRM comments** | | If an effective passive ventilation design is in place, it is not necessary to ventilate so often using the hatches. This solution will also improve the general survival situation by providing airflow through the boat, preventing seasickness. Implementing the risk-reducing measures lowers the probability to medium (3). | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.9 | CO build-up inside lifeboat | Leak from exhaust system | Headaches, nausea, vomiting, dizziness, fatigue, asphyxiation. Confusion, disorientation, visual disturbance, fainting and seizures. | **Probability: 1 Consequence: D** | -Engine exhaust system designed and tested to be leak proof<br>-Opening hatches | **Probability: 1 Consequence: D** |
| **Pre RRM comments** | | Probability is set to minimal (1). This is because the only source of CO-gas in a lifeboat is the engine, and if the exhaust system has leaks that causes gases to enter the lifeboat habitat, this is clearly a manufacturer or maintenance error. The consequences are set to high (D) because CO-gas is very dangerous to humans. | | | | | |
| **Post RRM comments** | | The only risk-reducing measures for this problem is that the exhaust system is designed and assembled so that it does not leak. The manufacturer and maintenance crew must ensure this. If the problem actually occur, the only option is to open the hatches. The probability grade is already at the lowest level, and cannot be reduced further. | | | | | |
| | 4.10 | High temperature inside lifeboat | Insufficient ventilation, many people generating heat | Dehydration caused by perspiration. Nausea which can lead to vomiting, causing further dehydration. | **Probability: 4 Consequence: B** | -Proper ventilation design (adjustable)<br>-Opening hatches | **Probability: 3 Consequence: B** |
| **Pre RRM comments** | | Probability is set to high (4). The temperature depends on how many passengers there are onboard, compared to the total capacity of the lifeboat. Assuming that the lifeboat is full, the temperature would probably be very high. Consequences are set to low (B), and mainly involves dehydration from perspiration. The consequences are low because opening hatches to ventilate periodically will help lower the temperature. | | | | | |
| **Post RRM comments** | | With a good adjustable passive ventilation design, airflow will help to maintain the right temperatures without having to keep the hatches open, which can be problematic in rough weather. This will reduce the probability to medium (3). | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.11 | Low temperature in lifeboat | Outside temperature. Few people in lifeboat generating heat. | Core body temperature of passengers dangerously low (hypothermia)<br>Frozen extremities | **Probability: 3**<br>**Consequence: C** | -Passengers wearing warm (waterproof) clothing<br>-Lifeboat design (hull insulation, efficient adjustable ventilation, etc.)<br>-Polar Code clothing and PPE requirements<br>-Survival strategy<br>-Insulated seats/benches<br>-Diesel heating system<br>-Tarp or canopy to close off an area in the lifeboat to preserve heat if there are few people onboard | **Probability: 3**<br>**Consequence: B** |
| **Pre RRM comments** | | Probability is set to medium (3). The temperature depends on how many passengers there are onboard, compared to the total capacity of the lifeboat. Assuming that there are few passengers compared to the total capacity, and the weather is cold, there is a probability that the temperature inside the lifeboat will be low. Consequences are set to medium (C), and involves low core body temperatures and freezing extremities. | | | | | |
| **Post RRM comments** | | The equipment in a PSK and GSK required by the Polar Code will provide good means of staying warm in a cold lifeboat. Insulation on the benches is a low-cost measure that will reduce the heat loss significantly. A tarp to close off a section of the lifeboat is also a very low-cost measure that can be helpful if there is few passengers compared to the total capacity. These measures will contribute to lower the consequences to low (B). Adding a diesel warmer is a more extensive measure, but it does not necessarily have to be very costly. Improving the hull insulation can also be effective, but this is a more costly upgrade. These solutions will be probability reducing. | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.12 | Seasickness | Lifeboat movements | Vomiting, inducing dehydration and starvation. | **Probability: 4 Consequence: C** | -Anti-seasickness medicine sufficient for all passengers<br>-Maintaining fresh air inside lifeboat | **Probability: 3 Consequence: C** |
| **Pre RRM comments** | | Probability is set to high (4) because it is likely that passengers in a lifeboat will get seasick. A standard lifeboat construction with shallow keel means that if the sea state is anything else than calm, the lifeboat will have a lot of rocking motion. In addition, the majority of the passengers will have no windows to look out of, which increases the probability of getting seasick. It is also likely that the air quality in a full lifeboat will be poor, which increases the probability. Consequences are set to medium (C), because if a person gets seasick and does not improve, there is a possibility for dehydration. This would not be ideal in an extended survival situation. | | | | | |
| **Post RRM comments** | | Anti-seasickness medicine is a useful risk-reducing measure, but it does not always work well on everyone. Providing airflow through the boat can also prevent seasickness. Having sufficient medicine for the maximum expected time of rescue, along with fresh air inside the lifeboat, lowers the probability to medium (3). | | | | | |
| | 4.13 | Hygiene | No toilet available | Insanitary conditions | **Probability: 4 Consequence: B** | -Lifeboat design to accommodate disposal of human waste | **Probability: 2 Consequence: B** |
| **Pre RRM comments** | | Probability is set to high (4) because hygiene is likely to be a problem when passengers in the lifeboat needs a toilet. Currently, standard lifeboat has no toilet facilities, and with a maximum expected time of rescue of 5 days, this will become an issue. A simple solution might be to use buckets, but in a full lifeboat this can still be highly problematic. Consequences are set to low (B) because even though this problem will have major effects on the comfort, it will not affect the survival chances more than slightly. | | | | | |
| **Post RRM comments** | | The Polar Code sets the maximum expected time of rescue to 5 days, meaning that there should be some solution to this hygiene problem. A simple but crude solution is to have a hole in one or more of the benches, with lid on top and a tank below, to function as a toilet. There would be little privacy, but that is not paramount in a survival situation. Adding this feature to the lifeboat will reduce the probability to low (2). A more sophisticated solution is to integrate a small separate toilet room, for example like in an aircraft. This would however require more space, and be more costly. | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.14 | Not enough food | LSA demands not sufficient for 5-days survival. Poor execution of rationing the food. | Starvation. | **Probability: 5 Consequence: B** | -Ensure lifeboat carries enough food for maximum passenger capacity (5 days survival) (Polar Code requirement)<br>-Information/guide for rationing of food | **Probability: 1 Consequence: B** |
| **Pre RRM comments** | | Probability is set to very high (5) because the current requirements (LSA code) is not sufficient for 5 days of survival. Consequences are starvation, set to low (B) because a person can survive for a long time without eating anything. | | | | | |
| **Post RRM comments** | | If the lifeboat carries enough food for each passenger for the maximum expected time of rescue, this problem is eliminated. Information about rationing should be included in the packaging. Probability reduced to minimal (1). | | | | | |
| | 4.15 | Not enough water | LSA demands not sufficient for 5-days survival. Poor execution of rationing the water. Water might be frozen. | Dehydration. | **Probability: 5 Consequence: D** | -Ensure lifeboat carries enough water for maximum passenger capacity (5 days survival) (Polar Code requirement)<br>-Information/guide for rationing of water<br>-Heating of lifeboat when stored in davit to avoid water rations from freezing | **Probability: 1 Consequence: D** |
| **Pre RRM comments** | | Probability is set to very high (5) because the current requirements (LSA code) is not sufficient for 5 days of survival. Consequences are set to high (D), because dehydration is a major threat to the human body. | | | | | |
| **Post RRM comments** | | If the lifeboat carries enough water for each passenger for the maximum expected time of rescue, this problem is eliminated. Information about rationing should be included in the packaging. Probability reduced to minimal (1). | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.16 | Lack of sleep | Uncomfortable seating, stressful situation (physical and psychological) | Sleep deprivation, fatigue. | **Probability: 4 Consequence: A** | Seat design:<br>-Angled seatbacks<br>-Head rests with side support<br>-Insulated benches | **Probability: 3 Consequence: A** |
| **Pre RRM comments** | | Probability is set to high (4) because it is likely that one will get less sleep than needed in a survival situation. The consequences are set to minimal (A), because eventually one will fall asleep if the body needs it, especially inside a relatively safe habitat such as a lifeboat. As long as the temperature inside the boat is ok, or the passengers wear proper polar clothing or insulated suits, sleeping will only have positive effects on the survival chances. There will probably always be someone among the passengers that are at least somewhat rested, and can take care of the necessary tasks. | | | | | |
| **Post RRM comments** | | A simple measure that can improve the sleep situation is to have insulated benches, which will provide a more comfortable seating and reduce heat loss. This will reduce the probability to medium (3). More extensive measures, such as angled seatbacks and headrests with side support, would improve the situation further. It is however not realistic that these measures are implemented due to costs and space. | | | | | |
| | 4.17 | Lack of basic medical equipment (sedatives, defibrillator, common medicines) | Emergency planning/requirements | Deteriorating health/fatalities<br>Unable to treat injuries | **Probability: 4 Consequence: D** | -Supply lifeboat with selected basic medical equipment. Some of this can e.g. be included in GSK brought along in lifeboat.<br>-Passengers dependent on special medicines should be advised to carry these with them at all time | **Probability: 3 Consequence: D** |
| **Pre RRM comments** | | Probability is set to high (4), because the normal cruise passengers are often elderly and not necessarily healthy. They might therefore need several medications on a daily basis, which is not available in the first-aid equipment onboard a lifeboat. Persons that are severely cold, for example from being immersed, can also experience cardiac arrest. In such cases, a defibrillator would be critically important. Consequences are set to high (D) because any severe illness that are left untreated can be life-threatening. | | | | | |
| **Post RRM comments** | | It is impossible to provide medicines for all types of illnesses that passengers may have. Passengers that are dependent on special medicines should therefore be advised to carry these with them at all time during the cruise, which would be a very good risk-reducing measure. This will bring the probability down to medium (3). It would also be useful to have a defibrillator onboard each lifeboat, but this is costly equipment. | | | | | |

| Stage four: Operation | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 4.18 | Polar bear attack | The polar bear can attack humans if it:<br>-is hungry enough<br>-feels threatened<br>-is curious<br>-is injured and desperate | Injury and/or death of people | **Probability: 1 Consequence: A** | -Bear spray<br>-Weapons<br>-Flare guns<br>-Polar bear guards/lookout | **Probability: 1 Consequence: A** |
| **Pre RRM comments** | | Probability is set to minimal (1). This risk is considering a polar bear attack on a lifeboat with hatches closed. It is regarded as very unlikely that a polar bear can force its way into the lifeboat, and the consequence is minimal (A) because there is no real danger that a polar bear will get into the lifeboat. If the passengers choose to leave the lifeboat and move onto ice instead, the danger is much more real. | | | | | |
| **Post RRM comments** | | Risk-reducing measures will be helpful if the passengers choose to leave the lifeboat. Risk unchanged. | | | | | |
| | 4.19 | Engine failure | Coolant freezes due to coolant not being suitable for low temperatures. | -Lifeboat drifting helplessly, affected by waves and wind<br>-Lifeboat stuck in sea ice<br>-Lifeboat cannot be positioned correctly in the waves, heavy lifeboat motion (uncomfortable for passengers) | **Probability: 2 Consequence: B** | -Ensure that engine coolant is effective in very low temperatures | **Probability: 1 Consequence: B** |
| **Pre RRM comments** | | Probability is set to low (2) because the engine coolant should be suited for arctic operation when the lifeboat is delivered from the manufacturer. This must also be ensured if the coolant is changed during maintenance. Any water or air in the cooling system can cause the fluid to freeze. Consequences are set to low (B), as the lifeboat will continue to provide a safe habitat even though the propulsion possibilities is gone. | | | | | |
| **Post RRM comments** | | If the manufacturer ensures that the coolant it designed for operation in cold environments, and this is followed in the maintenance as well, the probability is reduced to minimal (1). | | | | | |

| Stage five: Rescue | | | | | | | |
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| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 5.1 | Transfer of persons from lifeboat to rescue vessel | -Insufficient/no arrangements for moving passengers from one craft to another<br>-Passengers have physical problems after long time in lifeboat<br>-Heavy seas/strong winds | Complicated rescue process, potential injuries/fatalities<br>Time consuming | **Probability: 4**<br>**Consequence: C** | -Lifeboat design optimized for easy rescue | **Probability: 3**<br>**Consequence: C** |
| **Pre RRM comments** | | This is a split problem. One side of the problem is the design of the lifeboat to accommodate easy rescue, and the other side is the ability of the rescue ship to get the lifeboat passengers onboard. The scope of this analysis is limited to the lifeboat and its arrangements. Probability is set to high (4) because it is likely that there will be difficulties when many people are to be rescued from a lifeboat to a rescue vessel. The passengers are likely to be in poor shape after long time in the lifeboat, and might therefore have reduced physical capabilities. Consequences are set to medium (C) because there is always some danger involved in the process of transfer from one craft to another. In a situation like this, people can end up in the water, or become injured. | | | | | |
| **Post RRM comments** | | The lifeboat design can be optimized for easy rescue by implementing some simple features. For instance, an exterior platform on the stern of the lifeboat, with access hatch, can provide an easy pick-up point for MOB boats and other small rescue vessels. It is difficult to estimate the risk-reducing benefits of such measures, and transfer of people will always involve some hazard. Without knowing anything about the capabilities and design of the potential rescue vessel, it is hard to determine what types of design features the lifeboat should have, except facilitating easy disembarkation. If the lifeboat design is optimized for easy rescue, the probability is lowered to medium (3). Further risk reduction is connected to the rescue vessels, and there is too many unknowns involved in this problem to suggest specific measures. | | | | | |

| Stage five: Rescue | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Hazard number** | **Problem** | **Cause** | **Possible Consequences** | **Pre risk-reducing measures risk** | **Risk-reducing measures** | **Post risk-reducing measures risk** |
| | 5.2 | Transfer of persons from lifeboat to helicopter | -Insufficient arrangements on lifeboat for helicopter extraction<br>-Heavy seas/strong winds | Complicated rescue process, potential injuries/fatalities<br>Time consuming | **Probability: 3**<br>**Consequence: D** | -Lifeboat design to accommodate rescue swimmers being lowered onto/into lifeboat to extract passengers | **Probability: 2**<br>**Consequence: D** |
| **Pre RRM comments** | | Probability is set to medium (3), because it is difficult to accommodate for helicopter extraction from lifeboat, and such rescue processes involves many potential hazards. Consequences are set to high (D), because if a helicopter rescue is necessary, it is likely that any vessels are some distance away. This is because a lifeboat-to-vessel rescue is less risky than a lifeboat-to-helicopter rescue. If the process in that case is further complicated by insufficient arrangements on the lifeboat, it can be critical in terms of survivability. It is probable that a rescue helicopter prioritizes to evacuate passengers with critical health problems only, as long as the lifeboat is still habitable and rescue vessels will arrive within a relatively short period. | | | | | |
| **Post RRM comments** | | The only thing that can be done to better this problem, is to design the lifeboat with specific features for this rescue method. One must consider the need for using a stretcher for lift of critical patients, and this is considered a problem with a standard lifeboat. Evacuation method is of course up to the helicopter crew to decide. The only risk-reducing measure in terms of the lifeboat is to accommodate for patient extraction. If these measures are in place, the probability is reduced to low (2). | | | | | |

# Appendix B

# Risk Assessments

# SARex Phase 1 Risk assessment – Lifeboat

| Hazard nr. | Problem | Cause | Consequence | Risk-reducing measures | Comments |
|---|---|---|---|---|---|
| 1 | Maneuvering difficulties | Heavy sea, sea ice, wind | Little or no control of lifeboat position/heading<br>Lifeboat cannot be positioned correctly in the waves, heavy lifeboat motion (uncomfortable for passengers) | -Lifeboat pilot training/experience | |
| 2 | Maneuvering of lifeboat not possible | Damage to steering system/ rudder/steering nozzle | Lifeboat unable to maneuver away from ship;<br>-possible collision with ship<br>-lifeboat drifting helplessly, affected by waves and wind<br>-lifeboat stuck in sea ice | | |
| 3 | Lifeboat integrity compromised | -Collision with ship during/after launch<br>-Collision ice floes | Water intrusion, exercise stopped. | | |
| 4 | Rescuing passengers from sea to lifeboat | Insufficient arrangements on lifeboat for extraction of people. Mob boat far away. | Difficult/impossible to rescue survivors from sea | Mob boat nearby. | |
| 5 | Transfer of persons from lifeboat to rescue vessel | -Insufficient/no arrangements for moving passengers from one craft to another<br>-Passengers have physical problems after long time in lifeboat<br>-Heavy seas/strong winds | Complicated rescue process, potential injuries/fatalities<br>Time consuming 30 minutes? | Helmet<br>Evenly distribute the weight in the mob boat<br>Hold onto the rail in the boat | Mob boat is used primarily in all instances by KV Svalbard. |
| 6 | Danger getting down to lifeboat | Hoisted down in mob boat | Falling into sea/injury | Helmets, life-vest or survival suit, instructions on holding on while lowering. | |
| 7 | Falling into sea | Transfer of persons between lifeboat and mob boat. Trying to urinate | Becoming soaking wet and very cold. Exercise over for that person. | Assistance from mob boat crew. Mob boat always nearby, KV Svalbard also nearby. | |

| | | | | | |
|---|---|---|---|---|---|
| | | from either lifeboat or mob boat. | | | |
| 8 | Tripping and falling | -Passengers not used to heavy suits/equipment<br>-Slippery surfaces | -Fall damage (injuries, broken bones)<br>-Ending up in the water | -Be cautious<br>-Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |
| 9 | MOB boat lifting hook swinging after release | -Hook operator error<br>-Rough seas | -Hook arrangement hits passengers in MOB boat, leading to injuries. | -Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |
| 10 | Exercise participant becomes ill/injured needs immediate assistance | Decease, accident, medical issues. | They are in need of medical assistance. | Mob boat nearby, KV Svalbard nearby. Helicopter from Longyearbyen next option. | |
| 11 | MOB boat occupied when an accident occurs | -MOB boat have many tasks | -Long time to rescue<br>-People getting seriously chilled | -Use both MOB-boats for redundancy | |
| 12 | Passengers not noticing getting severely cold (core and extremities) | -Individual differences<br>-Little or no experience with being cold<br>-Sleeping | -Risk of injuries/fatalities | -Have buddies near you which can check on you<br>-Leader onboard raft should keep overview. | Reception routines for chilled people? Check on safety briefing |
| 13 | Freezing body extremities | -Getting wet<br>-Little clothing | -Frost bite leading to injuries | -Bring hats, gloves, etc. for backup in case.<br>-Low threshold for returning people to KV Svalbard<br>-Additional immersion suits in lifeboat for emergencies (for those not wearing suits during tests) | Reception routines for chilled people? Check on safety briefing |
| 14 | Personal protective equipment not functioning | Damaged, production error, not maintained correctly. | PPE does not work as intended. | Maintenance and functionality check before use. | |

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|---|---|---|---|---|---|
| 15 | Pilot is incapable of leading | Injury, death, pilot has to abort exercise and return to ship. | Anarchy? Without leadership people might not survive as long. | Find a new leader/next in command | |
| 16 | Immersion suit integrity compromised | -Improper entering of suit - -Openings not properly closed (zippers), etc | -Exposure to cold water with potential injuries/chilling of body | -Buddy check on suit after putting it on, prior to test | |
| 17 | Lack of sleep | Uncomfortable seating, stressful situation (physical and psychological) | Sleep deprivation | | Due to short duration of exercise, not expected to be a problem. |
| 18 | CO and CO2 build-up inside lifeboat | Insufficient ventilation, many people breathing. Leak from exhaust system | Headaches, sleepiness, poor concentration, loss of attention, increased heart rate, slight nausea, oxygen deprivation. | -Detectors will measure CO and CO2 build-up and give alarms.<br>-Opening hatches | |
| 19 | High temperature inside lifeboat | Insufficient ventilation, many people generating heat | Dehydration caused by perspiration. Nausea which can lead to vomiting, causing further dehydration. | -Opening hatches | |
| 20 | Low temperature in lifeboat | Outside temperature. | Core body temperature of passengers dangerously low (hypothermia) | -Passengers wearing warm (waterproof) clothing | |
| 21 | Hygiene | No toilet available | Insanitary conditions | Bucket or other solutions?<br>-Bottles used in hospitals/small aircraft? | |
| 22 | Clogging/blocking of ventilation | Warm and moist air from inside the lifeboat condensates and freezes around the ventilation outlet | Reduced ventilation, rapid deterioration of air quality | Opening hatches | |
| 23 | Not enough food | Lifeboat not stocked | Hunger | -Ensure lifeboat carries enough food for exercise duration | |
| 24 | Not enough water | Lifeboat not stocked | Thirst | -Ensure lifeboat carries enough water for exercise duration | |

| | | | | | |
|---|---|---|---|---|---|
| 25 | Seasickness | Lifeboat movements | Vomiting, inducing dehydration and starvation. | -Anti-seasickness medicine<br>How to handle this if exercise participants starts vomiting? | |
| 26 | Sea spray into lifeboat | The lifeboat hatches are open (ventilation, extracting persons from sea, etc.) | People get wet and cold. Water inside the lifeboat. | -Close hatches | |
| 27 | Poor sight | Fog, snow squalls.<br>Icing (sea spray) on windows | Navigation difficulties<br>Possible collision | -Lifeboat pilot training | |
| 28 | Sea spray icing on lifeboat | Sea spray combined with low temperatures | Skew loads, hinges and locks on hatches stuck, ventilation compromised. | | |
| 29 | Rapid weather changes | -Weather in this region can change in minutes | -Exercise gets much more difficult<br>-Stopping the might be necessary | -Check weather report prior to/during test<br>-Procedure for rapid evacuation of all participants<br>-Ensure that MOB boat is close to lifeboat during test, for emergency preparedness | |
| 30 | Communication difficulties | -Wind noise<br>-Many people talking at the same time<br>-Routines for how to communicate<br>-Radio equipment failure | -Important messages cannot be communicated via radio | -Backup radio equipment/battery<br>-Clarify communication routines prior to test | |
| 31 | Disturbance from other vessels in area, not part of exercise | -Nearby vessels not informed of test | -Interruption of test<br>-Possible collisions and hazard for participants | -Notify any nearby vessels of the test<br>-Establish safety zone around test area | |
| 32 | Polar bear attack<br>(from underwater…?) | -Animal curiosity/hunger/threatened | -Injuries/fatalities | -Polar bear guard (KV Svalbard)<br>-Armed personnel onboard MOB-boat<br>-Flares/signal rockets | Could be dangerous if lifeboat drifts into ice floes. |

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| | | | | -Situation awareness<br>-Sonar…? | |

# SARex Phase 1 Risk assessment – Life raft

| Hazard nr. | Problem | Cause | Consequence | Risk-reducing measures | Comments |
|---|---|---|---|---|---|
| 1 | Life raft damaged | -Production error | -Equipment unusable | -Check prior to launch (Viking) | |
| 2 | Life raft integrity compromised | -Collision with ship during/after launch<br>-Collision ice floes | -Water intrusion, exercise stopped | -Abortion if the ice conditions gets too severe<br>-Procedures for rapid evacuation of all participants | |
| 3 | Transfer of persons from life raft to rescue vessel | -Insufficient/no arrangements for moving passengers from one craft to another<br>-Passengers have physical problems after long time in life raft<br>-Heavy seas/strong winds | -Complicated rescue process<br>-Potential injuries/fatalities<br>-Time consuming | -MOB boats will be used for transfer of passengers from life raft to KV Svalbard, piloted by experienced crew. | |
| 4 | Disturbance from other vessels in area, not part of exercise | -Nearby vessels not informed of test | -Interruption of test<br>-Possible collisions and hazard for participants | -Notify any nearby vessels of the test<br>-Establish safety zone around test area | |
| 5 | Tripping and falling | -Passengers not used to heavy suits/equipment<br>-Slippery surfaces | -Fall damage (injuries, broken bones)<br>-Ending up in the water | -Be cautious<br>-Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |
| 6 | MOB boat lifting hook swinging after release | -Hook operator error<br>-Rough seas | -Hook arrangement hits passengers in MOB boat, leading to injuries. | -Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |
| 7 | Falling into water during transfer between MOB boat and life raft | -Slippery surfaces<br>-Distance between raft and MOB boat (e.g. due to poor mooring) | -Rapid cooling of persons in the sea | -KV Svalbard personnel entering life raft first, to assist with keeping the life raft and MOB boat | Will passengers be wearing immersion suits during transport to raft? |

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| | | -Rough seas | | close, and to help passengers from one vessel to the other | Yes, some sort of suit shall be used during transit. |
| 8 | Many people ending up in the water at the same time | -Life raft integrity compromised<br>-Capsizing<br>-Etc. | -Mass injuries/hypothermia<br>-Possible fatalities | -Establish procedures for rapid evacuation of all participants if necessary | |
| 9 | MOB boat occupied when an accident occurs | -MOB boat have many tasks | -Long time to rescue<br>-People getting seriously chilled | -Use both MOB-boats for redundancy | |
| 10 | Long distance from MOB boat to life raft during test | -MOB-boat have many tasks<br>-MOB-boat not on the water during test | -Long time to rescue<br>-People getting seriously chilled<br>-Long rescue time if people fall into the sea | -Ensure that MOB boat is close to raft during test for emergency preparedness<br>-Use both MOB-boats for redundancy | |
| 11 | Rescuing passengers from sea to life raft | -Insufficient arrangements on life raft for extraction of people | -Difficult/impossible to rescue survivors from sea | -Ensure that MOB boat is close to raft during test for emergency preparedness | Most relevant for phase 3, REMEMBER |
| 12 | Communication difficulties | -Wind noise<br>-Many people talking at the same time<br>-Routines for how to communicate<br>-Radio equipment failure | -Important messages cannot be communicated via radio | -Backup radio equipment/battery<br>-Clarify communication routines prior to test | |
| 13 | Insufficient observation during test (of the entire area) | -Poor overview | -People fall into water without someone noticing | -Crew onboard KV Svalbard and MOB boats ensures lookout | |
| 14 | Immersion suit integrity compromised | -Improper entering of suit -<br>-Openings not properly closed (zippers), etc | -Exposure to cold water with potential injuries/chilling of body | -Buddy check on suit after putting it on, prior to test | |
| 15 | Poor sight | -Fog<br>-Snow squalls<br>-Sea spray | -Impact with drift ice<br>-Difficulties with keeping an overview (polar bear lookouts, spot/locating participants falling into sea, etc.) | -Abort test if weather conditions gets too severe<br>-Ensure that MOB boat is close to raft during test for emergency preparedness | |

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| 16 | Sea spray into life raft | -The life raft canopy are open (ventilation, toilet breaks, extracting persons from sea, etc.) | -People get wet and cold<br>-Water enters the life raft. | -Keep canopy closed whenever possible | |
| 17 | Sea spray icing on life raft | -Sea spray combined with low temperatures | -Change in life raft buoyancy qualities<br>-Zippers and other small details frozen stuck | -Shaking canopy from the inside to loosen any ice | Unlikely |
| 18 | Clogging/blocking of ventilation | -Warm and moist air from inside the life raft condensates and freezes around/in the ventilation outlet | -Reduced ventilation<br>-Deterioration of air quality | -Opening canopy for ventilation | Unlikely |
| 19 | CO2 build-up inside life raft | -Insufficient ventilation, combined with many people breathing. | -Headaches, sleepiness, poor concentration, loss of attention, increased heart rate, slight nausea, oxygen deprivation. | -Opening the canopy<br>-Air quality measurement instruments onboard life raft<br>-Ensure control of air vents. | |
| 20 | High temperature inside life raft | -Insufficient ventilation, combined with many people generating heat | -Heat stress:<br>Dehydration caused by perspiration. Nausea, which can lead to vomiting, causing further dehydration. | -Opening canopy when necessary | |
| 21 | Low temperature in life raft | -Outside temperature. | -Core body temperature of passengers drops dangerously low (hypothermia) | -Bring hats, gloves, etc. for backup in case.<br>-Low threshold for returning people to KV Svalbard<br>-Ensure that MOB boat is close to raft during test for emergency preparedness | |
| 22 | Rapid weather changes | -Weather in this region can change in minutes | -Exercise gets much more difficult<br>-Stopping the might be necessary | -Check weather report prior to/during test<br>-Procedure for rapid evacuation of all participants | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | -Ensure that MOB boat is close to raft during test, for emergency preparedness | |
| 23 | Passengers not noticing getting severely cold (core and extremities) | -Individual differences<br>-Little or no experience with being cold<br>-Sleeping | -Risk of injuries/fatalities | -Have buddies near you which can check on you<br>-Leader onboard raft should keep overview. | Reception routines for chilled people? Check on safety briefing |
| 24 | Freezing body extremities | -Getting wet<br>-Little clothing | -Frost bite leading to injuries | -Bring hats, gloves, etc. for backup in case.<br>-Low threshold for returning people to KV Svalbard<br>-Additional immersion suits in life raft for emergencies (for those not wearing suits during tests) | Reception routines for chilled people? Check on safety briefing |
| 25 | Medical problems of passengers | -Latent health issues<br>-Other medical condition factors | -Possible medical emergencies for participants | -Low threshold for returning people to KV Svalbard | |
| 26 | Seasickness | -Lifeboat movements<br>-Seasickness medicine not effective immediately | Vomiting, inducing dehydration and starvation. | -Anti-seasickness medicine<br>-Take medicine prior to test<br>-Check with KV personnel on advice | |
| 27 | Not enough food | -Lifeboat not stocked | -Hunger<br>-Exercise must be stopped | -Ensure lifeboat carries enough food for exercise duration | Raft stocked with enough for 24 h |
| 28 | Not enough water | -Lifeboat not stocked | -Thirst<br>-Exercise must be stopped | -Ensure lifeboat carries enough water for exercise duration | Raft stocked with enough for 24 h |
| 29 | Hygiene | -No toilet available | -Insanitary conditions | -Bucket or other solutions?<br>-Transport people with MOB boat to KV Svalbard for toilet visits | |

| | | | | | |
|---|---|---|---|---|---|
| 30 | Lack of sleep | Uncomfortable seating, stressful situation (physical and psychological ) | -Sleep deprivation:<br>Reduced cognitive abilities<br>Ability to take care of yourself reduced, etc. | -Try to sleep when possible | Unlikely, due to short duration of exercise. Not expected to be a problem. |
| 31 | Polar bear attack<br>(from underwater…?) | -Animal curiosity/hunger/threatened | -Raft puncture<br>-Injuries/fatalities | -Polar bear guard (KV Svalbard)<br>-Armed personnel onboard MOB-boat<br>-Flares/signal rockets<br>-Situation awareness<br>-Sonar…? | Sonar suggested, as the sounds it emits (possibly) can scare polar bears in the water.<br><br>NOTE to HAZID: Evaluate having bear spray in life rafts/boats for arctic use? |
| 32 | Walrus/orca attack | -Animal curiosity/hunger/threatened | -Raft puncture<br>-Injuries/fatalities | -Armed personnel onboard MOB-boat<br>-Flares/signal rockets<br>-Situation awareness | |

# SARex Phase 2 Risk assessment

| Hazard nr. | Problem | Cause | Consequence | Risk-reducing measures | Comments |
|---|---|---|---|---|---|
| 1 | Transfer of persons from lifeboat to rescue vessel | -Insufficient/no arrangements for moving passengers from one craft to another<br>-Passengers have physical problems after long time in lifeboat<br>-Heavy seas/strong winds | Complicated rescue process, potential injuries/fatalities<br>Time consuming 30 minutes? | Helmet<br>Evenly distribute the weight in the mob boat<br>Hold onto the rail in the boat | Mob boat is used primarily in all instances by KV Svalbard. |
| 2 | Falling into sea | Transfer of persons between lifeboat and mob boat. | Becoming soaking wet and very cold. Exercise over for that person. | Assistance from mob boat crew. Mob boat always nearby, KV Svalbard also nearby. | |
| 3 | Transferring injured passengers on a ledger/backboard from lifeboat to mob boat | Injured/sick/unconscious | High risk if person falls into water while strapped onto a ledger/backboard. | Use a dummy or have participants acting as injured passengers walk onboard mob boat then get strapped into the ledger/backboard | |
| 4 | Tripping and falling | -Passengers not used to heavy suits/equipment<br>-Slippery surfaces | -Fall damage (injuries, broken bones)<br>-Ending up in the water | -Be cautious<br>-Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |
| 5 | Mechanical failure, davit for mob boat | Poor maintenance, frozen hooks. | Mob boat unusable for transferring passengers onboard KV Svalbard. | Use the crane<br>Redundancy<br>Ladders | |
| 6 | MOB boat lifting hook swinging after release | -Hook operator error<br>-Rough seas | -Hook arrangement hits passengers in MOB boat, leading to injuries. | -Follow instructions<br>-Detailed safety information and procedures from KV Svalbard crew | |

| | | | | | |
|---|---|---|---|---|---|
| 7 | Polar bear attack<br>(from underwater…?) | -Animal curiosity/hunger/threatened | -Injuries/fatalities | -Polar bear guard (KV Svalbard)<br>-Armed personnel onboard MOB-boat<br>-Flares/signal rockets<br>-Situation awareness<br>-Sonar…? | |
| 8 | Disturbance from other vessels in area, not part of exercise | -Nearby vessels not informed of test | -Interruption of test<br>-Possible collisions and hazard for participants | -Notify any nearby vessels of the test<br>-Establish safety zone around test area | |
| 9 | Insufficient observation during test (of the entire area) | -Poor overview | -People fall into water without someone noticing | -Crew onboard KV Svalbard and MOB boats ensures lookout | |

# Appendix C

# Workshop phase one

**<u>Workshop after lifeboat/life raft test</u>**

**Walkthrough no-play planning**

- People says they felt safe in the life raft, with mob boat close and ready
- In a real life scenario, there should be some sort of security measure when transferring between lifeboat/life raft and MOB
- Interviews revealed that some people would have liked to receive more information prior to test
- Perhaps there should have been clear notifications on how to behave during the tests, e.g. can you use any means in the raft/boat? Clap your hands, move around etc.? Could participants use survival strategy?
- SARex participants was very pleased with risk analysis/session prior to test, but we could have included KV Svalbard personnel in addition to SARex participants.
- General: everyone felt safe and secure during the test

**MetOcean – Was it representative?**

- We were lucky with the conditions, they could have been worse.
    - Wind could have been a lot worse, experienced some effect during towing of raft
    - We had the best possible conditions
    - Calm waters, no significant waves
    - -1 degree water temperature
    - -9 degrees air temperature

**Data presentation**

- Medical
    - Medics felt comfortable regarding the criteria for stopping the exercise for each participant, buddy system worked
    - One of three test subjects (people rigged with core-temperature measurement equipment) had a rapid decline in body temperature (it is mentioned by NTNU medic that this is a misreading…? This is discussed, but no specific conclusion), the two others show a slower decline
    - Large discrepancies between cont. monitoring and ear measurements
        - Can be caused by various unknown reasons
    - Other test solution (for bigger budgets, maybe?) might be measurements using pills that are wireless and can be swallowed.
    - Discussions around peaks in body temperature measurements, no conclusion on why. Toilet break is suggested as a possible reason, as core temperature can go up during urination, caused by higher blood flow during urination (medic's opinion).
    - No change in reaction time tests (10 KV Svalbard crewmembers) before and after exercise exposure.
      Uncertainties regarding whether this reaction time method (designed for ADHD purposes) is suitable for this test, needs some further medical evaluation.
    - The persons with the worst protection used around twice as much energy on staying warm as the ones with the best protection. Needs more calculations that are thorough.
- Temperature measurements

  - Quite constant ambient temperature
  - More "even" temperature graph for lifeboat than raft
  - Raft temperature fluctuates more than boat temperature
  - The correlation between the sun and heat generation of people versus temperature is unknown, when the sun was disappearing there was also people stopping the exercise
  - Temperature dropped 3-4 degrees from when there was 2 people in the raft to when there were no people left
    - Number of people matters for temperature inside raft especially
- Humidity measurements
  - People in raft complained more about condensation than the people in the lifeboat
- People leaving crafts
  - Reasonably gradually
  - Is it possible to estimate after about 15 hours, whether it is possible to stay for 5 days…?
    - Medics comments that the build-up of moisture has a long-term effect on this matter, so this may not be reasonable to estimate
    - Moisture gradually builds up and you will have less insulation. An assumption was that the first 24 hours would not be identical to the next 24 hours due to build-up of moisture. Being wet in the raft would be a big problem in the long run.
    - Humidity very relevant in raft, again mentioned. Raft crew says that the moisture turned into water which collected around the heaviest people. Moisture in raft was reduced when people kept their suits closed.
- PPE
  - Interesting distributions, no specific comments

**Definition of survival**

  - A lot of people was able to take care of themselves, but they were not far away from being unable to do this; comments from participants:
    - Some people from the raft were borderline to not be able to take care of themselves
    - Body temperature is very individual; it is more about whether you are able to take care of yourself.
    - Exposure to cold surroundings during MOB transit from crafts to KV Svalbard might affect the results, hard to be exposed to harsher conditions during "rescue", this uses the last bit of energy for the participants.
    - Noted that there was a significant difference between the conditions of the participants when they were leaving the raft/boat and when they arrived at KV Svalbard
    - Participants comment that the MOB transit was harsh
  - Some of the persons getting off were actually really cold, but many said that they could have lasted longer. Impression from interviews, there was a motivational factor as well as a physical.

- Taking into consideration the condition of the participants when arriving at KV Svalbard, how much further could they have lasted in the crafts (question for medical people)?
    - Several could have lasted for at least 12 more hours
        - Nobody shivered seriously, which would have been a critical point
        - Everyone were able to be reasonable and take proper care of themselves.
        - They were far from the point where they would be the subject of external forces and unable to resist.
        - Most people from the boat were in good physical condition.
    - Not possible to say exactly how long (Ship's doctor)
    - Shivering phase can last for long time, as long as the body has enough energy reserves and does not get hypothermic
    - If this was a real 5-day survival situation, would there be any casualties?
        - Most experiment participants (not necessarily SARex) are healthy individuals
    - Leadership very good onboard raft and boat; in a real incident, it is thought that the leaders would have included measures to avoid fatalities.
        - Shared PPEs, warmed each other, etc.
    - Exhaustion will make you lay down on raft floor for sleep (-1degree), and this will severely affect survival time and chances.
    - Most people thought that the test participants were lasting longer than expected, especially the ones wearing only lifejackets.
    - Ove Tobias mentions that his survival was ok; he had much clothing on though. Also mentions that he does not think he would survive as long in the raft as in the boat.
    - In the raft people were cold on their feet, could not really test that with the pre-defined exclusion tests.

**Leadership**

- Fantastic social arrangements in the rafts got everyone engaged.
    - Language barrier can be present in a real scenario
- Limited how long a leader can perform his role perfectly
    - Would the leaders have credibility in a cruise situation? Are people tolerant and will they listen to the leader in such a situation?
    - "Guests are like fish, they become rotten in 3 days". One would need more time to figure out how people would react and behave in a real survival situation.
- Leadership in lifeboat; a bit hard to communicate at times, due to engine noise. It is commented that the leaders and participants onboard the lifeboat "had more up their sleeves" in terms of socialization. However, the social activities were rationed out over the course of the stay.
- Life raft leader mentions that this test was somewhat similar to e.g. tent exercises from military, etc.
- They were trying to get everyone involved, and focus on something else than the situation, during hand out of rations and water, and instructions on how to use.
- Difficult to determine whether people was actually cold and should leave, or whether they could have stayed longer (comment from participants in the life raft).

Leader let persons decide themselves, this turned out to be correct, as many was actually cold without him noticing the severity.

- Everyone got food when they were hungry (in the life raft), leader says that in a real scenario, he would have been much more strict about the rations.
- Important to have a deputy, to take care of additional tasks and which can take over if leader needs to sleep.
- Boat: Deputy says that leader managed the situation for most of the time. If leader had to leave, deputy took over.
- Worst part of lifeboat stay was opening hatches for various reasons, which affected temperature. This was commented on by participants wearing less protective suits/lifejackets.
  - Simulated doing toilet breaks in buckets by opening hatches briefly and doing them in the mob boat.

**PPE**

Noted challenge that life-saving appliances did not fit everyone, the KampVest was too small for one person. Some of the suits were very tight on several participants even though they were within the suits size ranges.

- Survival suits
  - Biggest challenges:
    - Buildup of moisture
    - Leader in the raft with insulation suit: Got very sweaty, had to choose between venting his suit or keeping the warm and sweat inside. Clothing inside suit make a difference? Could the suit have been taken off?
    - Sweat and heat problem during some stages in life raft, maybe we should have taken more notice of the overheating problem. Since some participants did not have insulated suits or even suits at all, the raft had to be kept closed to keep a high enough temperature in the raft. If all participants had a good suit on, the inside temperature of the raft could perhaps have been kept lower (by ventilating the raft) to avoid sweat.
    - Functionality and suggestions for improvement:
      - There should be pockets on the suits, for storing food/water/garbage etc.
      - Hard to eat with the suit gloves, suggested having external gloves or thin gloves/liners underneath
      - Two-way zipper to simplify bathroom visits
      - Valve systems for peeing
      - Ventilation, can this be increased or improved by a solution?
        - Other fabrics available, but these are much more expensive
      - Exercise simulated "dry evacuation", and it might be necessary to have other qualities for suits depending on whether the evacuation is dry or wet. However, the life raft becomes wet, especially the floor.

    - No vapor barrier on the inside of insulation/liner in suits, so the material absorbs the moisture/sweat and “fills up”. This can be solved using other materials, but again these are expensive.
    - Highest heat loss in life raft from the feet and lower body due to cold floor.
        - In the life raft, one would need insulation of the lower body and it would have to be waterproof.
    - Viking suit with/without liner; size adjustment solution worked very well, and the Velcro ankle straps worked. How the suit fits the person is very important, and the solution of this suit worked well. Inside sole should have more friction and insulation, to avoid the foot from slipping inside the “boot”.
    - 307 suit had very thin insulation underneath the sole

- Vests
    - Not big performance difference between the insulated vest and the Kamp vest
    - Neoprene vest was very uncomfortable in the raft
    - Life jackets with thermal protection was not very usable for the arctic conditions:
        - The lower part of body is not covered by the vest, so in the raft the available neoprene did not cover the most important body parts
        - Uncomfortable hoods

- TPA (bags)
    - Made a huge difference for the ones in the raft, especially to not get wet. It was a waterproof layer.
    - More criticism from lifeboat, much humidity inside, and difficult to move around in the boat.
    - Overall, the TPA had an effect.

- PPE: What is necessary?
    - Whole-body covering suit (watertight) to stay dry
    - Insulation wanted

- Lifeboat
    - Suggestions:
        - Something to sit on, because the seats (benches) were cold.
        - Air vent system to avoid $CO_2$ build-up and drop in $O_2$
        - Heating: Diesel heater (separate from engine). This sort of solution will only need to be type approved to be used for this purpose in a

lifeboat, according to Sjøfartsdirektoratet. No issues related to implementation, so this should be investigated. No Norsafe representatives present during this discussion.

- Canopy/tarp included in lifeboat, to close off a small area in lifeboat if there are few passengers compared to total capacity. This would increase the heat within the closed off area.
- Insulation in benches
- Food with different flavors/colors etc.

- Life raft
  - Positives:
    - More stable than expected
      - Five people stood in one opening in the raft to watch the walrus, not a lot of movement.
    - Insulation (canopy)
    - Good performance compared to the simple design (basically a tent)
    - Good temperature in the "tent" itself, the only large problem was the floor insulation (or lack of)
  - Negatives:
    - Air quality a problem. During exercise, the weather was good. If a lot of waves, rain, wind, etc. It could be a big problem.
    - In harsh weather, the raft will take in water if not completely sealed.
    - A lot of movement in rough seas.
  - Suggestions:
    - Bottom insulation (e.g. double bottom): to provide extra distance from the sea water underneath, and reflect heat on the surface inside
    - Cushion so people do not have to sit on the floor where there might be water.
    - Storage pockets/bags to sort and store equipment
    - Food with different flavors/colors etc.
    - Drainage channel of some sort, to collect water flowing in the raft, and to facilitate easy pumping
    - Drainage pump broke during test; this should be stored in a pocket or some sort of mount to avoid this. Sturdier pump design wanted.
    - Only one lookout position (air vent hole), should have two or more, because one person can only look to one side of the raft (for polar bear watch etc.). This can improve air venting as well.
    - The lookout hole let a lot of cold air in, better solution for closing when not in use is wanted.
    - Downgrade max carrying capacity of raft (max nr of occupants) to ensure enough space to facilitate polar clothing and immersion suits. This can be done by Sjøfartsdirektoratet

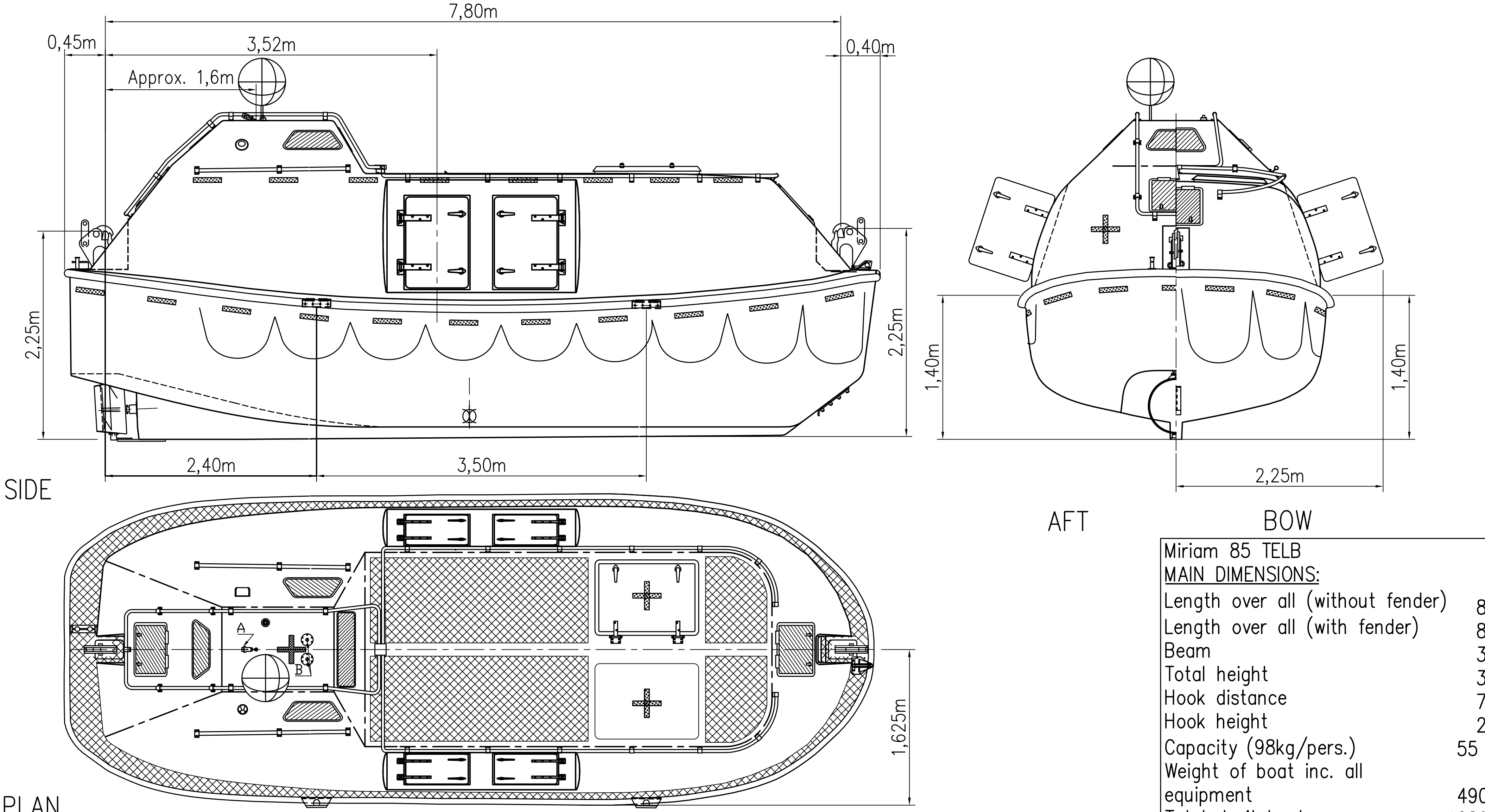
# Appendix D

# List of SARex participants

# SARex – List of participants

| Name | Institution or company |
|---|---|
| Aylward, Katie | American Bureau of Shipping |
| Batalden, Bjørn-Morten | UiT – The Arctic University of Norway |
| Borch, Odd Jarl | Nord University |
| Dahle, Lars Gunnar | University of Stavanger |
| Dalsand, Raymond | UiT – The Arctic University of Norway |
| Gaustad, Svein Erik | Norwegian University of Science and Technology/UiT – The Arctic University of Norway |
| Gudmestad, Ove Tobias | University of Stavanger/UiT – The Arctic University of Norway |
| Hansen, Ole | Eni Norge AS |
| Jensen, Jan Erik | Petroleum Safety Authority Norway |
| Kvamme, Bjarte Odin | University of Stavanger |
| Landa, Erik Johan | Norwegian Maritime Authority |
| Mostert, Erik | Norsafe AS |
| Nese, Tord | UiT – The Arctic University of Norway |
| Njå, Ove | University of Stavanger |
| Olsen, Terje | Viking Life-Saving Equipment Norge A/S |
| Schartner, Ronald | Norsafe AS |
| Schmidt, Jette Næss | Viking Life-Saving Equipment, DK |
| Schmied , Johannes | Nord University |
| Skogvoll, Eirik | Norwegian University of Science and Technology |
| Solberg, Knut Espen | GMC Maritime/University of Stavanger |
| Spande, Trond | GMC Maritime |
| Vangberg, Gunnar | St. Olavs Hospital/The Norwegian Armed Forces |
| Wisløff, Ulrik | Norwegian University of Science and Technology |

# Appendix E
# Technical drawings of lifeboat




SIDE

AFT

BOW

PLAN

Miriam 85 TELB

MAIN DIMENSIONS:

| | |
|---|---|
| Length over all (without fender) | 8,50m |
| Length over all (with fender) | 8,60m |
| Beam | 3,25m |
| Total height | 3,55m |
| Hook distance | 7,80m |
| Hook height | 2,25m |
| Capacity (98kg/pers.) | 55 pers. |
| Weight of boat inc. all equipment | 4900 kg |
| Total davit load | 10290 kg |

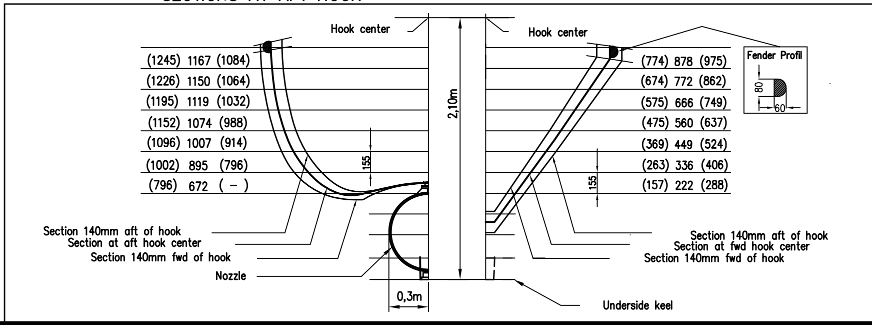
A = Power supply plug approx. 1,6m from aft hook

B = Winch brake wires approx. 2,2m from aft hook. To be installed at the yard

Due to manufacturing reasons dimensions may vary up to 50mm

SECTIONS AT AFT HOOK

SECTIONS AT FWD HOOK




| ISSUE No. | REASON FOR ISSUE | Drawn | Checked | Appr'd | DATE |
|---|---|---|---|---|---|
| 0 | Issued for construction | KOT | | | 25.01.12 |

**Norsafe as**

Lifeboatbuilder since 1903

P.O. Box 115, N-4818 FÆRVIK, NORWAY



Drawing size A1 SCALE 1:20

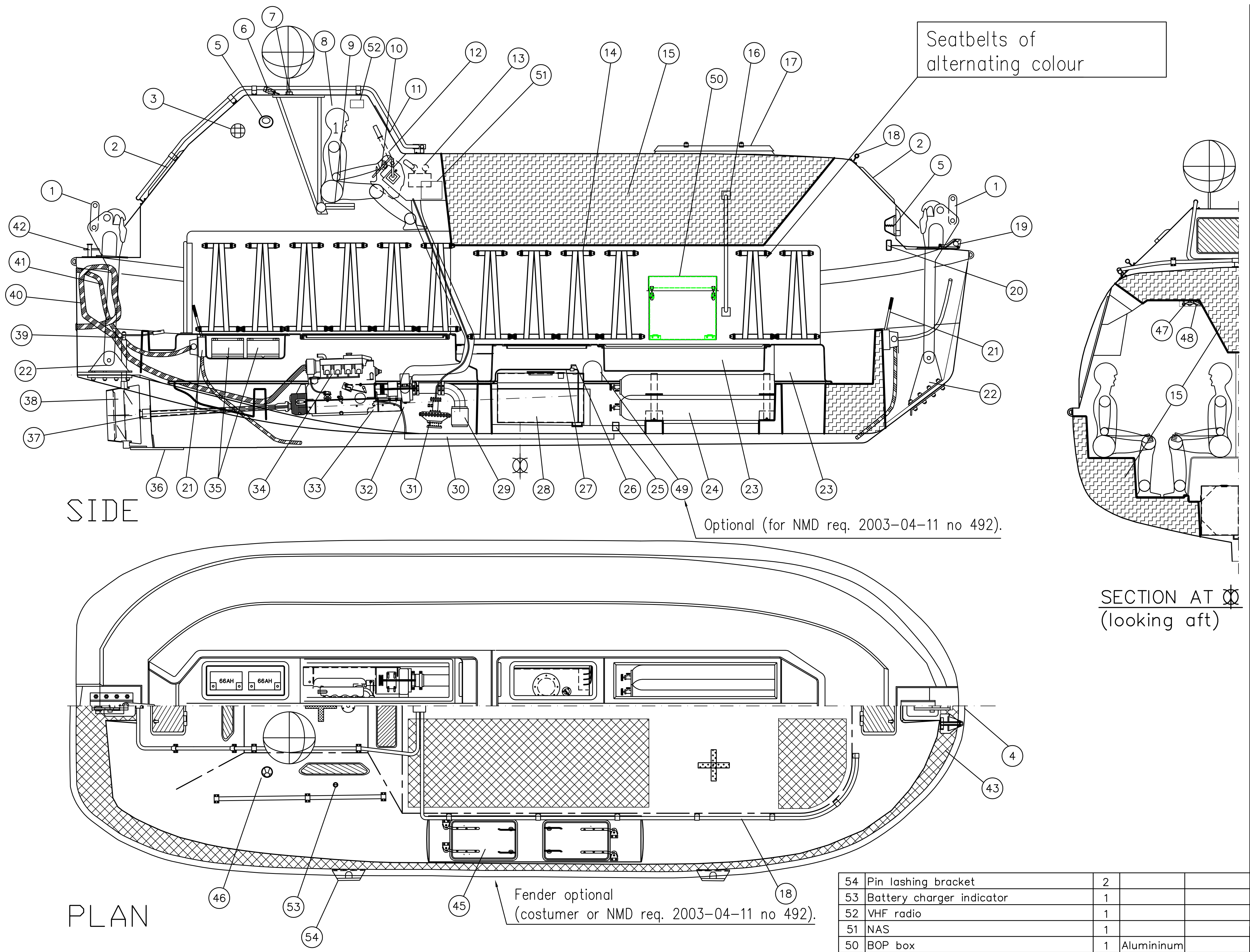
PROJECTION METHODE:

Project: Transocean Leader

TITLE: External General Arrangement Miriam 85 Totally Enclosed Life boat Tanker Version

DWG file: 5376-DWG-20_0

DRAWING No.: 5376-DWG-20




SECTION AT ⌽
(looking aft)

Due to manufactoring reasons
dimensions may vary up to 50mm

| Item. | Description | No.Off. | Material | Drawing No. |
|---|---|---|---|---|
| 54 | Pin lashing bracket | 2 | | |
| 53 | Battery charger indicator | 1 | | |
| 52 | VHF radio | 1 | | |
| 51 | NAS | 1 | | |
| 50 | BOP box | 1 | Alumininum | |
| 49 | Cover plate (NMD reg 11.04.2003/492) | 2 | GRP | |
| 48 | Oar | 2 | Wood | |
| 47 | Boat hook | 1 | | |
| 46 | Over pressure release valve | 1 | GRP/Brass | |
| 45 | Side hatches | 2 | G.R.P. | |
| 44 | Compass | 1 | | |
| 43 | Non slip deck | – | G.R.P. | |
| 42 | Bollard | 1 | Galv .steel | |
| 41 | Bilge hose | 2 | | |
| 40 | Exhaust hose | 1 | St. steel | |
| 39 | Rudder stock | 1 | St. steel | |
| 38 | Steering nozzle | 1 | G.R.P. | |
| 37 | Stern gland | 1 | Brass | |
| 36 | Keel shoe | 1 | Galv. steel | |

| Item. | Description | No.Off. | Material | Drawing No. |
|---|---|---|---|---|
| 35 | Batteries | 2 | | |
| 34 | Diesel engine | 1 | Cast Iron | |
| 33 | Engine fundation | 1 | Galv. steel | |
| 32 | Sprinkler Pump | 1 | Bronze | |
| 31 | Hydrostat | 1 | Cast alu. | |
| 30 | Keel cooler | 1 | Bronze | |
| 29 | Sprinkler intake valve | 1 | Brass | |
| 28 | Fuel tank | 1 | Aluminium | |
| 27 | Fuel supply and return | – | | |
| 26 | Fuel shut off valve | 1 | Brass | |
| 25 | Automatic drain valve | 1 | Brass | |
| 24 | Compressed air bottles | 4 | Steel | |
| 23 | Storage lockers | 4 | G.R.P. | |
| 22 | Lift shoe | 2 | Galv. steel | |
| 21 | Bilge pump | 2 | Nylon | |
| 20 | Painter release handle | 1 | | |
| 19 | Painter release | 1 | Galv. steel | |
| 18 | Sprinkler system | 1 | Aluminium | |
| 17 | Top hatches | 1 | G.R.P. | |
| 16 | Escape ladder | 1 | Aluminium | |
| 15 | Buoyant foam | – | Polyureth. | |
| 14 | Seat belts | 73 | Nylon | |
| 13 | Compressed air regulator | 1 | | |
| 12 | Hook release handle | 1 | Galv. steel | |
| 11 | Front window 800 x 400mm | 1 | Polycarb. | |
| 10 | Steering position w/instruments | 1 | GRP | |
| 9 | Helmsmans seat | 1 | Al/Plywood | |
| 8 | Window | 4 | | |
| 7 | Marker light and radar reflector | 1 | Alu. | |
| 6 | Power supply plug | 1 | | |
| 5 | Under pressure release valve | 2 | GRP/Brass | |
| 4 | Fender | 1 | Plastic | |
| 3 | Cabin light | 4 | Brass | |
| 2 | Forward/aft hook hatch | 2 | Alu./Persp. | |
| 1 | Tor MK2 on-load release hook | 2 | Galv.-Steel | |

## 8,5 T.E.L.B. "MIRIAM"

**MAIN DIMENSIONS:**

| | |
|---|---|
| Length over all | 8,60m |
| Length of hull | 8,50m |
| Beam | 3,25m |
| Total height | 3,55m |
| Hook distance | 7,80m |
| Hook height | 2,25m |
| Capacity (98kg/pers.) | 55 pers. |
| Weight of boat inc. all equipment | 4900 kg |
| Total davit load | 10290 kg |

| ISSUE No. | REASON FOR ISSUE | Drawn | Checked | Appr'd | DATE |
|---|---|---|---|---|---|
| 0 | Issued for contruction | KOT | | | 25.01.12 |


Norsafe as
Lifeboatbuilder since 1903
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Drawing size A1 SCALE 1:20
PROJECTION METHODE: ⊖
Project: Transocean Leader
DWG file: 5376-DWG-21_0
DRAWING No.: 5376-DWG-21

TITLE: Internal General Arrangement 8,5m "Miriam" Totally Enclosed Lifeboat Tanker Version