

# **Barrier management within the oil and gas industry**

- a comparison study of the implementation and interpretation of Norway's and EU's regulations with focus on the environment

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**Report 5465, Lund 2014**



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**Lund 2014**

Titel: Barriärledning inom olja- och gasindustrin – en jämförelse av implementering och tolkning av Norges och EU:s lagstiftning med fokus på miljön

Title: Barrier management within the oil and gas industry – a comparison study of the implementation and interpretation of Norway's and EU's regulations with focus on the environment

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**Report 5465**

**ISSN: 1402-3504**

**ISRN: LUTVDG/TVBB--5465—SE**

Number of pages: 100

Illustrations: 9

Keywords: barriers, oil and gas, drilling, regulations, environment, safety, barrier management

Sökord: barriär, olja- och gas, borrning, lagstiftning, miljö, säkerhet, barriärledning

Abstract: This report examines how Norway's and EU's regulations set requirements to environmental barriers. The result is based on a review of relevant regulations and an interview study with personnel from the drilling industry. The result shows that the main difference between the regulations is that EU explicitly focuses on environmental critical elements and that the tradition within the industry is to focus on barriers related to safety for personnel. The report proposes improvement areas to decrease the risk of major accidents on the Norwegian Continental Shelf.

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## SUMMARY

This report examines how the environmental barriers and critical elements in the oil and gas industry are regulated in the regulations stipulated by the Petroleum Safety Authority (PSA) in Norway and in the Directive 2013/30/EU of the European parliament and of the council of 12 June 2013 on safety offshore oil and gas operations and amending directive 2004/35/EC. Due to this EU directive and the increased focus on environment, the report also examines how the Norwegian regulations with regards to barriers and the environment are implemented and interpreted in practice by drilling companies on the Norwegian continental shelf (NCS). The focus is on the definition of major accident, definition of barriers, execution of barrier management, identification of environmental barriers and the players' experience of the legislation. The study also briefly analyses the drilling companies' emergency preparedness.

The work started with a literature study and it was discovered that the literature does not contain much information about environmental barriers, which is why the focus in the literature study is on barriers in general. With help from the literature study, the aspects mentioned above were decided to be used as a foundation for the further work and questions used for the review of regulations were developed. To understand how the Norwegian regulations are implemented and interpreted in practice, an interview study was made with interviewees from drilling companies, personnel from DNV GL with experience from barrier management and personnel from PSA working with technical safety and barrier management. The interview guide was based on the literature study and on input from experienced personnel at DNV GL. To give further input to the thesis, audit reports from PSA were studied.

Aspects that were noted during the review of the regulations were that the Norwegian regulations apply to the HSE (health, safety and the environment) work on the Norwegian Continental Shelf, and hence cover both major and smaller accidents, while the EU directive only focuses on major accidents. The EU directive explicitly mentions both safety and environmental critical elements in contrast to the Norwegian regulations, which describe general requirements for barriers. Another main difference is that the EU directive requires the operator to conclude a major hazard report. The result from the interviews indicates that the players in the drilling industry might overlook the environmental aspect to some extent. Only a few of the interviewed companies take special consideration to environmental barriers and the majority argues that the barriers used to protect personnel, also protects the environment. An issue is the definition of a major accident with regards to the environment, since the consequences of a spill differs depending on the environmental conditions in the specific area. Also, the definitions of operational and organisational barriers are unclear to many players, as well as the link between risk assessment and barriers. The Norwegian regulations are based on the energy-barrier concept, which indicates that the same accident prevention strategy shall be used for both major and smaller accidents. However, this might increase the risk since the accidents have different origins. An impression is also that the connection between risk analyses and the barriers should be strengthened to optimise the function of the barrier and decrease the risk for a major accident.

Below, recommendations based on the challenges identified by the author during the work with the report, are presented.

- Develop a recommended practice to identify major accidents with regards to the environment
- Extend the accident models to include systemic models
- Clarify the meaning of the classifications of barriers
- Include resilience engineering as a strategy to decrease the risk of major accidents
- Harmonise the players definition of barriers
- Restructure the sections in the regulations that regulate barriers and clarify the requirements
- Organise awareness increasing activities to increase the understanding of barrier management
- Clarify the responsibility for the barriers
- Establish a recommended practice for environmental barriers
- Encourage management to increase the awareness of environmental aspects
- Assure that the drills and exercises are based on realistic scenarios

The author's impression is that the tradition within the Norwegian drilling industry is to focus on safety for personnel, which might be a reason to why the environmental barriers in many cases are not explicitly identified. Hence, the EU directive could be used as inspiration to clarify the sections that regulate protection of the external environment.

## SAMMANFATTNING

Denna rapport undersöker hur miljöbarriärer och miljökritiska element som används i olja- och gasindustrin, styrs i de norska och europeiska föreskrifterna. I Norge utfärdas dessa av Petroleumstilsynet (ptil), vilka jämförs med Europaparlamentets och rådets direktiv 2013/30/EU av den 12 juni 2013 om säkerhet för olje- och gasverksamhet till havs och om ändring av direktiv 2004/35/EC. Till följd av nämnda EU direktiv och dagens ökade fokus på miljöfrågor, undersöker rapporten även hur de norska föreskrifterna, med hänsyn till barriärer och miljö, i praktiken implementeras och tolkas av borrhingsföretag. Fokus ligger på definition av storolyckor, definition av barriärer, utförande av barriärledning, identifiering av miljöbarriärer och aktörernas erfarenhet av lagstiftningen. Rapporten analyserar även övergripande borrhingsföretagens krisberedskap.

För att besvara frågeställningarna, inleddes arbetet med en litteraturstudie. Resultatet från litteraturstudien visar att det inte finns så mycket information om miljöbarriärer och därför är fokus på generell barriärteori. Fokusområdena som nämns ovan är ett resultat av litteraturstudien, vilka användes för att analysera de norska föreskrifterna och EU direktivet. För att undersöka hur föreskrifterna implementeras och tolkas i praktiken, utfördes en intervjustudie med respondenter från borrhingsföretag, anställda på DNV GL med erfarenhet från barriärledning samt anställda på ptil som arbetar med teknisk säkerhet och barriärledning. Intervjuguiden baserades på litteraturstudien och synpunkter från erfaren personal på DNV GL. Även tillsynsrapporter från ptil studerades för att få ytterligare data till rapporten.

Under analysen av föreskrifterna och direktivet noterades att de norska föreskrifterna gäller för arbetet med HMS (hälsa, miljö och säkerhet) på den norska kontinentalsockeln, vilket innebär att föreskrifterna täcker både stora och små olyckor. EU direktivet, å andra sidan, fokuserar endast på storolyckor. EU direktivet nämner miljö och säkerhetskritiska element explicit i motsats till de norska föreskrifterna som beskriver krav till barriärer generellt. En annan skillnad är att EU direktivet kräver att operatören ska sammanställa en rapport för storolyckor. Resultatet från intervjuerna indikerar att miljöaspekten lätt kan förbises av aktörerna. Endast ett fåtal av de intervjuade menade att särskild hänsyn tas till miljöbarriärer och majoriteten av de intervjuade hävdade att barriärerna som skyddar människor även skyddar miljön. En utmaning är att definiera storolycka med hänsyn till miljön eftersom konsekvenserna av ett utsläpp varierar beroende på förhållanden som råder i ett specifikt område. Även definitionen av operationella och organisatoriska barriärer är oklar för många, vilket gör det svårare för aktörerna att uppfylla kraven. Den norska lagstiftningen baseras på barriär-energi modellen, vilket indikerar att samma metod för att förebygga alla typer av olyckor ska användas, oberoende av de bakomliggande orsakerna till olyckan. En uppfattning är också att sambandet mellan riskanalyser och barriärer bör stärkas för att optimera barriärernas funktion och minska risken för storolyckor.

Nedan presenteras de förbättringspunkter som är baserade på de utmaningar som författaren identifierat under arbetet med rapporten.

- Utveckla en rekommenderad metod för att identifiera storolyckor med hänsyn till miljön
- Utöka olycksmodellerna till att inkludera systemiska modeller
- Förtydliga klassifiseringen av barriärer
- Inkludera resiliens som en strategi för att minska risken för storolyckor
- Harmonisera aktörernas definition av barriärer
- Omstrukturera paragraferna i föreskrifterna som behandlar barriärer och förtydliga kraven
- Organisera aktiviteter för att öka medvetenheten och förståelsen för barriärledning
- Förtydliga ansvarsområden för personal som jobbar med barriärer
- Utveckla en rekommenderad metod för identifiering och krav till miljöbarriärer
- Uppmuntra ledningen att öka medvetenheten kring miljöbarriärer
- Försäkra att övningar för krisberedskap är baserade på realistiska scenarion

Författarens uppfattning är att traditionen i den norska borrhningsindustrin är att fokusera på säkerhet för människor, vilket kan vara en anledning till att miljöbarriärer inte identifieras explicit. EU direktivet kan således användas som inspiration för att förtydliga de paragrafer som behandlar skydd för den externa miljön.



## PREFACE

This thesis has been written as a master of science thesis at the division of Risk Management and Societal Safety at the Faculty of Engineering, Lund University in collaboration with the section Asset Risk Management at the DNV GL office in Høvik, Norway.

Finishing this thesis would not have been possible without help from my advisors Henrik Hassel, associate professor at Lund University and Atle Stokke, head of section at asset risk management at DNV GL. Henrik has contributed with valuable thoughts about the report writing, and challenged my conclusions and ideas to increase the quality of the work. Through Atle I have had access to information and expertise in the research area, a resource that has been invaluable to finalise the thesis. Thank you!

I would also like to thank everyone who has participated during interviews and who has answered questions by e-mail or during a coffee break, especially Ellen for always taking time to answer both small and big questions and Laura for proof reading while finishing her own thesis. The result would not be the same without the input from all of you.

Last, but not least, a big thank you to Magnus, family and friends for the support and encouragement during this last semester and the 5 years before that; it has been a great adventure!

Oslo, May 2014

*Sofie Gustafson*



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# 1 INTRODUCTION

## 1.1 BACKGROUND

In 1969, the first discovery of oil and gas was made on the Norwegian Continental Shelf (Norwegian Petroleum Directorate, 2013). The production started in 1971 and the findings have played a vital role for Norway's welfare. On the Norwegian continental shelf (NCS) activities as exploration, well development, production and decommissioning take place, activities that are associated with risks on humans, the environment and assets. Thankfully, major accidents are not common on the NCS, but to avoid them to the greatest extent and to increase the general level of safety, the barrier terminology was introduced in the legislation in 2001 (Midttun, 2013a).

In short terms, a barrier is something that either prevents an event from happening or impedes the consequences if an accident occurs (Hollnagel, 2006). An example of a barrier can be the railing along a road to prevent cars from leaving the road. The Norwegian Petroleum Safety Authority (PSA) has focused on barriers for many years, and during 2014 it is one of the main priorities (PSA, 2013a). Failure or weakening of barriers can cause severe damage and is a frequent cause of accidents in the petroleum industry. However, all operators have not come as far in implementing the regulatory requirements on barriers. Improvement of the robustness in the various phases of a facility's life cycle has been made in different ways, leading to different levels of maturity.

The regulations focus on both safety for personnel and the environment. However, the focus has mainly been on safety for personnel, an area in which there are standardised and recognised methodologies (Det Norske Veritas, 2013). This is not the case for environmental risk, which might make it hard for the industry to work with these issues. With regards to barriers that prevent or limit acute releases to sea, it might not always be possible to use the requirements for safety barriers (personnel) stipulated in the standards, immediately on the environmental barriers (Hauge et al, 2011). If an accident happens, the consequences on the environment after a major accident can be severe and an acute oil spill can have consequences on fish, marine mammals, seabirds and beach zones (Norwegian Petroleum Directorate, 2013).

The petroleum accident in the Gulf of Mexico in 2010 (from now the Macondo accident) caused the death of 11 people and extensive damage to the environment (DHS, 2011). According to the EU directive 2013/30/EU, there has been an increased public awareness regarding the risks associated with the offshore oil and gas industry, due to this accident. To achieve good environmental status by 2020, the EU directive 2013/30/EU of the European parliament and of the council of 12 June 2013 on safety of offshore oil and gas operations (from now referred to as "the EU directive") was published. The objective of the EU directive is to reduce the occurrence of major accidents related to oil and gas operations as far as possible, and to limit the consequences of the accidents, both with regards to safety for personnel and the environment.

Given the above circumstances, there is an interest in understanding how the Norwegian regulations regarding barriers and environmental consequences are applied in practice and how these regulations correspond to the mentioned EU directive. Knowing this might provide input to how PSA, DNV GL and the drilling industry can continue to work to increase the implementation of the Norwegian petroleum regulations regarding barriers and identify improvement areas.

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<sup>1</sup> DNV GL, the company that the master thesis is written in collaboration with. DNV GL is a leading company within risk and safety and works within e.g. the oil and gas and maritime markets.

## 1.2 AIM AND OBJECTIVE

The aim with this thesis is to understand how the Norwegian regulations for offshore operations with regards to environmental barriers are applied in practice. The aim is also to map potential gaps between the current Norwegian regulations and the new EU directive in order to understand if the same level of environmental safety is achieved regardless of regulation.

The objective is to map how the industry works with the current Norwegian regulations to avoid major accidents with environmental consequences. The analysis will have its foundation in the current regulations and literature and will provide DNV GL and the industry with information on how the regulations are applied in practice. The objective is also to develop recommendations of how potential challenges can be handled and how the new EU directive can be used in practice.

## 1.3 RESEARCH QUESTIONS

How are the regulations regarding environmental barriers for major accidents implemented in practice in the Norwegian oil and gas industry?

- What do the Norwegian regulations, issued by the Petroleum Safety Authority, require regarding environmental barriers to prevent major accidents?
- How is this interpreted and applied by the industry?
  - Are there specific environmental measures, or are the same barriers that are used for safety for personnel also used for environment related accidents?
  - Do the operators have additional requirements within their organisation?
    - If so, why? (Are those from PSA not enough?)
- What does the new EU directive say, in relation to the Norwegian regulations?
  - Do they align or is there a gap?
  - Could the EU directive facilitate the identification of environmental barriers and hence increase the level of environmental safety within the industry?

The comparison will be used to understand if the regulations are interpreted as intended (by PSA) or not. The comparison between the regulations from PSA and the EU directive will be done to find out if there is a gap between the regulations regarding environmental safety and how this should be handled.

## 1.4 DELIMITATIONS

The offshore industry consists of a range of different operations. Due to the limitations in time, it will not be possible to look into all of the activities. Hence, the following delimitations have been done:

- The interview part of thesis mainly looks into drilling of wells for oil and gas production on the Norwegian Continental Shelf. Hence, production, transportation of oil and decommissioning and abandonment are not included. Neither activities such as refining and distribution are included. Drilling activities are related to high risks on the environment since a blowout can cause severe consequences. It would be interesting to study how the production operators comply with the regulations as well but this is not possible due to time restrictions. Another reason for why the focus is on the drilling industry is since the accident in the Gulf of Mexico took place during drilling operations and caused severe consequences on the environment. Due to this, the author finds it interesting to investigate the level of environmental safety on the NCS.
- The review and comparison of the regulations focuses on barriers, but since the regulations apply to all steps of petroleum activities, specific focus on drilling activities is not done.
- The main focus will be on major accidents with consequences for the environment.
- The regulations reviewed are from the PSA since these regulations apply for the petroleum industry explicitly and set requirements for barriers. The most relevant act regarding pollution of

the external environment that is not established by PSA is the Pollution Control Act, issued by the Norwegian Environment Agency. PSA's regulations cover health, safety and the environment (HSE) and are issued together with the Norwegian Environment Agency. Hence, the requirements with regards to pollution that are regulated by the Norwegian Environment Agency, are also covered by or referred to in PSA's regulations.

- The number of interviewees is rather limited in this study. To be able to better generalise the result from the thesis, there should be a wide range of interviewees. Due to the time limitations this is not possible and the result should be used with care and mainly provide initial insights that should be considered in future research.

## 1.5 DISPOSITION OF THE REPORT

The report contains the following sections:

- Chapter 1, introduction: the background for the thesis is presented together with research questions, aim and objective and delimitations.
- Chapter 2, method: the research process and method for the thesis is described.
- Chapter 3, theory: the theory necessary to understand the result and analysis is provided.
- Chapter 4, result and analysis: the result from the work will be presented together with an analysis.
- Chapter 5, discussion: recommendations based on the result are discussed.
- Chapter 6, conclusion: the work and results are concluded and the answers to the research questions are commented. Also, suggestions for future work are presented.



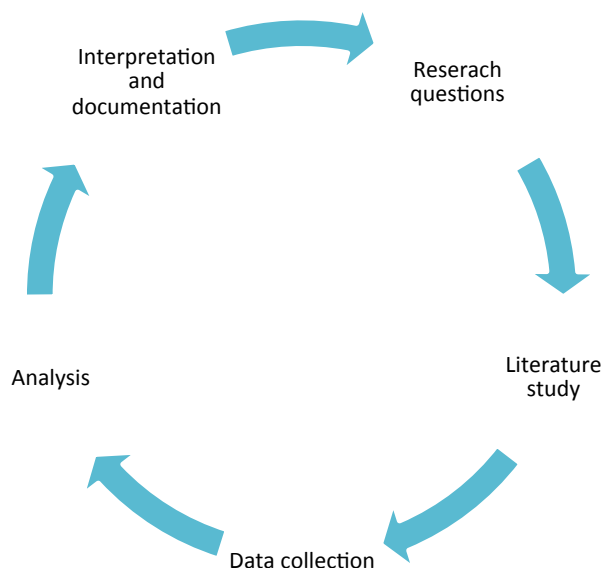


## 2 METHOD

This section describes the method used to answer the research questions. It mainly consists of two parts; a literature study and interviews. The research process is briefly described below.

### 2.1 THE RESEARCH PROCESS

The research process for this thesis can be compared to the traditional research process. The traditional research process is based on the assumption that there is an objective reality, separated from the human (Backman, 2008). We try to explain the world on the basis of laws and rules by using theories and assumptions that are tested with help from observations. Figure 1 shows a sketch of how the research process has been conducted for this thesis. There are many similarities to the traditional research process that is described by Backman (2008), however, some changes have been done. The main difference is that this thesis is not based on a hypothesis but focuses mainly on the research questions that were established before the main literature study. Also, the interpretation and documentation is done in one step and not as two separate activities.



**Figure 1. Research process**

The process started with discussions with DNV GL regarding barriers and barrier management, with focus on barriers regarding environmental risks. From these discussions, the research questions for the thesis were formulated and discussed with the university to ensure that the academic goals were reached.

The work continued with a literature study. The literature study aims to map the current knowledge within the area and helps to further formulate a meaningful research question, something that is vital for the coming process. The literature study provides knowledge regarding relevant methods and their advantages and disadvantages. Section 2.2 describes the literature study in detail.

After a review of the literature, the research questions were further discussed with the advisors at DNV GL and Lund University. The methodology for the comparison and interviews was planned and conducted. Hence, data was collected to find answers to the research questions. In this thesis the data collection was done with help from literature and interviews. The method for the data collection is described in section 2.3.

After the collection of data, an analysis was performed. The data was systematically analysed and interpreted to answer the research questions, which is further described in section 2.3.3.

The process has been iterative. E.g., the literature study has also been conducted during the analysis when needed. However, the description above gives a general overview of how the work has been done.

## 2.2 LITERATURE STUDY

A literature study was conducted to deepen the knowledge and understanding regarding barrier theory, the Norwegian oil and gas industry and the regulations of interest.

Mainly three types of literature sources were used:

- Technical literature within the subject area,
- Scientific papers and
- Documents from authorities.

A literature study should be done to make sure that no learning has been missed and it also supports the goal of building on recent research (Höst, Regnell, & Runeson, 2006). Regarding the literature, it is important to consider the credibility of the source, which is why the literature and the search for the same are discussed below.

In the beginning, the search for literature was wide. Examples of the used keywords are barrier, safety barrier, environmental barrier, barrier theory, environmental critical elements (no results), requirement + barrier, reliability + barrier. Search engines such as Google and ScienceDirect were used.

With help from references in the reviewed articles, more sources were found. In the beginning, all sources were saved to sustain the width. The abstracts were read and those articles that were relevant for the thesis were saved. While reading the saved articles, the most relevant sources were selected and used.

It was hard to find specific literature regarding environmental barriers, which is why few authors have been used as a reference. Also, the literature mainly considers safety barriers. However, it is not defined whether safety only refers to personnel or if it also includes environment. The general information about barriers could be used though, since this theory is necessary to understand how and why barriers are used.

The result from the literature study can be found in section 3.

### 2.2.1 VALUING THE SOURCES

To assure quality of the research process, questioning and evaluating the sources is important. What can be regarded are for example the relevance, authority, validity and range (Backman, 2008).

For each source, one should question (Höst, Regnell, & Runeson, 2006):

- Is the material reviewed? By who and how?
- Who guarantees the credibility?
- Is the method used credible?
- Are the results developed in a context that is relevant for my research questions?
- Have the results been confirmed or resulted in acknowledgments and referred to by others?

### 2.2.2 SPECIALIST LITERATURE

To increase the knowledge regarding barrier theory, Hollnagel (2006) was used. This gives a basic understanding of the concept and examples of how barriers can be classified and what is important for the performance and requirements.

Erik Hollnagel is well known in the subject area and has been performing research for several years. His work is cited numerous times in reports concerning barriers, which is an additional reason to why he is used as one of the main sources for the thesis.

### 2.2.3 SCIENTIFIC PAPERS

To ensure the validity of the thesis, it is important to use information from different authors (Höst, Regnell, & Runeson, 2006). Hence, the literature search also included scientific papers published in scientific journals. The main keywords are mentioned above.

### 2.2.4 DOCUMENTS FROM AUTHORITIES

To get an overview of the challenges regarding barriers that the authorities have addressed and to find areas to focus on, audit documents from PSA were studied. The audit reports from PSA were also used to get input on how to narrow the questions for the interview. In the analysis, the audit reports were also used to give further input to answer the research questions. The audit reports are based on the supervisory work done by PSA (PSA, 2014a). During the supervisions, documents are inspected and interviews are performed with relevant personnel who need to demonstrate that the requirements are met.

When searching for documents from PSA and when reviewing the audit reports, special interest was paid to documents where environmental barriers for drilling activities were analysed. However, there has not been that much focus in research on this area why it was hard to find this kind of information. The documents that were found have also been used to widen the industry understanding.

## 2.3 DATA COLLECTION

The data for the thesis come from PSA regulations, the EU directive of interest and interviews with people from the industry. Data is considered as information about requirements for barriers in the different regulations as well as opinions and impressions from drilling companies, DNV GL and PSA. To complement the interviews, the audit reports from PSA were also used.

An alternative to the interviews was to study the documentation regarding barriers from a certain company. However, the focus has mainly been on interviews since it can provide the author with a lot of information during a shorter time. Another benefit is that during the interviews, the interviewee can provide thoughts of how the regulations should be implemented, which is harder to understand when reviewing documents.

### 2.3.1 INTERVIEWS

To get an understanding of how the regulations are applied, interviews with relevant people from the drilling industry were performed. To get a view of the "reality" as comprehensive as possible, employees from DNV GL were interviewed to supplement the information from the drilling companies.

Interviews are beneficial when the main reason is to analyse something, in contrast to when something is to be measured (Bibik, Milton, Månsson, & Svensson, 2003). It is also preferable since it can help the interviewer to get a more detailed analysis of a complex situation and at the same time collect a large quantity of data. However, it can be time consuming and it is hard to generalise the result. Something that also should be kept in mind is that it can be frightening for the interviewee since there is no one else to answer the question which can result in less useful answers.

To avoid pitfalls, the interviewee was informed on beforehand about the objective and aim of the interview (Kvale, 1997). The purpose was to give the interviewee a chance to feel more secure regarding the subject and also to prepare some of the answers.

Since the interviews were done to create a picture of how the regulations are interpreted in the industry, the interviewees were not chosen randomly but with regards to their experience within the industry. The criteria that were used to select the interviewees are presented below. To be able to generalise the result to the most possible extent, the goal has been to try to interview people who have extensive experience from the industry. However, the interviewees only represent a part of the industry and one should be careful with generalising the results.

#### 2.3.1.1 SEMI-STRUCTURED INTERVIEWS

The interviews that were held can be described as semi-structured. This means that the questions that are asked do not have any pre-formulated answers that the interviewee can choose from, as compared to a questionnaire that is performed orally (structured interview) (Höst, Regnell, & Runeson, 2006). The goal is to understand how an individual has experienced a certain phenomenon. This method is used since the purpose is to understand how the industry interprets and implements the regulations. Using fixed answers could make it easier to compare the results, but the goal is, as mentioned, to understand how a certain operator has interpreted and implemented the regulations. Constructing answers on beforehand could lead to important conclusions being missed.

An alternative could be an open interview. This type of interview does not have any structure at all and lets the interviewee lead the conversation (Bibik, Milton, Månsson, & Svensson, 2003). With this type of interview it is easier to understand feelings and the inner thoughts of the interviewee. However, this can be time consuming and hard to analyse, which is another reason for why the semi-structured method is chosen. Using the semi-structured method is preferable since it opens up for questions that will not be asked during a structured interview, but saves time and covers a certain number of topics that are decided on beforehand.

#### 2.3.1.2 STRUCTURE OF THE PERFORMED INTERVIEWS

The interviews were structured with help from the What- Why- How system, suggested by Kvale (1997) and based on six general questions. These questions correspond to the What-question, i.e. what is it that the interviewee shall answer. The what-questions were followed by a Why-question, which formulates the aim with the questions. Finally, the How-questions were formulated. These are the questions that are used to answer the What-questions and were hence used during the interviews.

Before the interviews, the interviewees were contacted and the purpose of the interview was described, as recommended by Kvale (1997). Also, information about the procedure, e.g. that the interview would be recorded, transcribed and sent to the interviewee after the interview to read through, was provided. The structure of the interviews was planned in advance, but there was a possibility to ask the questions in different order and also to let the interviewees give the details. During the interview, the answers were recorded and then transcribed. The answers were sent back to the interviewees to assure that the author correctly understood the answers.

During the interviews no questions were asked regarding the EU directive, since it was assumed that the operators focus on the Norwegian regulations rather than requirements that they are not deemed to follow.

### 2.3.1.3 INTERVIEWEES

Criteria for the interviewee were that he or she should have an overview of how the company works with barriers and that he or she had insight to the drilling activities. Table 1 shows a summary of the interviewees and their positions. One of the interviewees works at a petroleum company, i.e. does not work explicitly with drilling. However, the petroleum company is involved in the drilling operations and has a responsibility to make sure that the drilling company follows the regulations.

**Table 1. List of interviewees**

<b>Working place and position of interviewee</b>	<b>Number of interviewees during meeting</b>
DNV GL, interviewee has several years of experience from working with barrier management in the petroleum industry	1
DNV GL, interviewee has several years of experience from working with barrier management in the petroleum industry	1
PSA, interviewees work with technical safety and barrier management	2
Drilling company, interviewees work as technical safety engineer and environmental specialist	2
Petroleum company, interviewee works as HSE coordinator	1
Drilling company, interviewee works with HSE & Q	1
Company supporting the drilling companies during planning and daily operations, works with HSE & Q	1
Drilling company, interviewee works as maintenance manager	1
	$\Sigma 10$

### 2.3.1.4 INTERVIEW GUIDE

The following topics were used as a foundation for the interviews. The entire guide including the how-questions can be found in Appendix 1 and Appendix 2. Appendix 1 contains the questions that were asked to the drilling companies and DNV GL and Appendix 2 contains the questions asked to PSA. The difference between the interview guides is the how-questions, the overall what-questions were the same for all interviews. The questions are based on the research questions and the structure of the guide is based on the what-why-how method, described in 2.3.1.1. The what-questions are used to present the result and analysis from the interviews.

#### 2.3.1.4.1 MAJOR ACCIDENTS

*What:* how does the operator define the concept major accident?

*Why:* also major accidents is an expression that is mentioned frequently in the regulations. To have a common language when working with risk is important to make it easier to work towards common goals, and to set clear goals (Luko, 2013). If PSA and the operator define major accidents in different ways, it can result in different ways of interpreting the concept and thus working towards different goals.

#### 2.3.1.4.2 BARRIERS

*What:* what does the concept mean and how is it interpreted and defined within the organisation?

*Why:* barriers are used as an expression in the regulations and it has been discovered by PSA that there is a problem regarding implementation of the barrier requirements in the industry (Midttun, 2013a). To facilitate this, it is important that relevant terminology is fully understood. When working with risk, a common language is important to be able to e.g. formulate clear goals (Luko, 2013).

#### 2.3.1.4.3 WORKING WITH BARRIERS

For this topic, the main how-questions are also presented since they are used to structure the presentation of the result and the analysis.

*What:* how does the operator work with barriers to prevent major accidents?

*Why:* the requirement for working with barriers can be found in PSAs regulations. As mentioned, the concept can be found at several places in the regulations and the subject area of the question is hence important to create a picture of how the industry works with the concept and if this correlates to the intentions of the regulations. This question is central to answer the thesis's research questions.

#### 2.3.1.4.4 ENVIRONMENT AND SAFETY BARRIERS

*What:* has the operator a specific working procedure for environmental barriers or is this combined with the one for safety barriers (if there is a procedure)?

*Why:* the industry asks for methods to handle environmental critical elements in their equipment<sup>1</sup>. Due to this, it is of interest to investigate how this is handled today and if there is a need for a clearer legislation. The EU directive 2013/30/EU explicitly mentions environmental critical elements and aims to increase the safety for the environment in the European oil and gas industry, which could be a complement to the existing regulations.

#### 2.3.1.4.5 EMERGENCY PREPAREDNESS

*What:* how do the operator prepare for major accidents, is the legislation clear enough to prepare for major accidents and is the information spread through the organisation?

*Why:* knowing what do to and how to act if a major accident occurs is important to minimise the consequences. PSA's regulations contain requirements for this and the subject is investigated to see if the legislation is clear enough. The preparedness plan is a barrier used to minimise the consequences of a major accident, which is why this question is important for the thesis.

#### 2.3.1.4.6 LEGISLATION

*What:* is the legislation, regarding barriers, sufficient for the operator? Is there a need for further guidelines?

*Why:* to create a picture regarding whether the industry considers that the legislation is clear enough or if it needs to be clarified, this question is relevant. The question intends to investigate if the legislation provides the necessary support and guidance that it aims to do. The answer will, as when interviewing, probably give a highly subjective view of the question, but it is based on the experience of the interviewee and is thus regarded important to answer the research questions of the thesis. Uncertainties in the legislation can make the operator unsecure, which can impair the risk management work (Ödlund, 2010). The question can also give an indication of whether the EU directive could fill the, by the operator, identified gap.

### 2.3.2 REVIEW OF THE PSA REGULATIONS AND THE EU DIRECTIVE

The following regulations from PSA were reviewed:

- The framework regulations,
- The management regulations,
- The activity regulations and
- The facility regulations

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<sup>1</sup> Consultant Ellen Kristine Ombler, DNV GL, interview 2014-02-17.

The EU directive that was reviewed was the EU directive 2013/30/EU of the European Parliament and of the council of 12 June 2013 on safety of offshore oil and gas operations and amending directive 2004/35/EC.

### 2.3.3 DATA ANALYSIS

In this stage, the result from the review of the regulations and the answers from the interviews were analysed. Also, PSA's regulations were compared to the EU directive. The result and analysis of the interviews are presented with help from the overall What-questions. After each topic, an analysis of the result is done. The result is presented in descriptive text and is compared to the literature and regulations. The literature used focuses mainly on classification and qualities of a barrier.

#### 2.3.3.1 PSA AND EU DIRECTIVE

When further analysing the documents, the questions below were to be answered, which relates to aspects with respect to the barrier concept. The question regarding the purpose with the regulations is asked to understand if the regulations are applicable to the same areas, if not it might be harder to compare the contents. Barrier management is a part of risk reduction, which is why the second question is asked. Since the thesis focuses on major accidents, it is also of interest to examine if the regulations define this concept differently. How the different regulations define barrier and safety and environmental critical elements is a part of the main focus in the thesis, which is why this topic is of interest. If the EU directive would be implemented in Norway, a great difference in these concepts might lead to the need for extensive changes within the regulations and also for those who need to comply with the regulations. The last question deals with the requirements that the different regulations require for the barriers.

- What is the purpose with the regulation?
  - How are the requirements described?
  - What activities and accidents are covered? (Major/smaller accidents? Drilling etc?)
  - Who is the responsible party?
- To what extent should risk be reduced?
- How is a major accident defined?
- How are the concepts barrier and/or safety and environmental critical element defined?
  - Is there a specific definition of the concept environmental barrier?
  - What type of barrier is described in the regulation? (cf. classification of barriers, section 3.4.3)
  - Should the work with barriers be documented in a specific way?
- What requirements regarding the barriers are described in the regulation?
  - What kinds of standards are referred to?

The questions are based on the research questions, and discussions with employees at DNV GL.

## 2.4 LOGBOOK

To keep track of the process, a logbook has been used. The content of the logbook is not presented in the main report. It is rather used to collect the author's thoughts and reflections that are used to make decisions during the working period. Collecting these thoughts, which lead to decisions, will make it easier for the author to present them and argue for a certain path when writing the main report.





### 3 THEORY

In this section, a theoretical background is given. This background is helpful to understand the scope and the results. First, definitions relevant to the thesis are presented and followed by a short introduction of the Norwegian Petroleum industry, the Norwegian regulatory regime and the hazards and accidents related to the drilling activities. The last part consists of a review of theory related to barriers used to prevent the accidents.

#### 3.1 DEFINITIONS

It should be mentioned that there is no existing common terminology for barriers (Sklet, 2006). Below, the definitions regarding barriers and accidents, relevant to the thesis, are presented. Most of the definitions are proposed by PSA. These are used throughout the thesis since they are well established in the petroleum industry in Norway and hence used in the legislation. For some expressions PSA lacks definitions and for those cases other sources are used.

Major accident as described in the guidelines to section 9, Management Regulations:

An acute incident, such as major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets.

Barrier:

Technical, operational and organisational elements which are intended individually or collectively to reduce possibility/ for a specific error, hazard or accident to occur, or which limit its harm/disadvantages (PSA , 2013b)

Barrier function:

The task or role of a barrier. Examples include preventing leaks or ignition, reducing fire loads, ensuring acceptable evacuation and preventing hearing damage (PSA , 2013b)

Barrier element:

Technical, operational or organisational measures or solutions which play a part in realising a barrier function (PSA , 2013b)

In the literature it is often made a distinction between barrier functions and barrier systems (Hollnagel, 2006). PSA does not use the concept of barrier systems but describes barrier elements which, together or separately, play a part in realising a barrier function (PSA , 2013b). One could describe it as the barrier elements together form a barrier system, which could be compared to PSA's definition of a barrier.

Performance requirements:

Verifiable requirements related to barrier element properties to ensure that the barrier is effective. They can include such aspects as capacity, functionality, effectiveness, integrity, reliability, availability, ability to withstand loads, robustness, expertise and mobilisation time (PSA , 2013b)

Performance standard:

Grouping the established performance requirements in performance standards at the system/functions level (PSA , 2013b).

Safety and environmental critical elements, SCE/ECE (this term is not used by PSA, but is central in the EU directive where it also is defined):

Means part of an installation, including computer programmes, the purpose of which is to prevent or limit the consequences of a major accident, or the failure of which could cause or contribute substantially to a major accident.

Since the thesis focuses on barriers against major accidents, the SCE/ECE and barriers will be regarded as equal. A deeper discussion about differences, advantages and disadvantages can be found in section 4.3.4.

Barrier management:

Coordinated activities to establish and maintain barriers so that they maintain their functions at all times (PSA , 2013b)

Figure 2 shows a schematic picture of how the different definitions relate. The performance standard is not included but would be the performance requirements for the two barrier elements collected in one document. The main barrier function in Figure 2 is to kill a well kick, i.e. stop uncontrollable flow of hydrocarbons from the well. This function has sub-functions, which are to shut in the well or to circulate out the kick to prevent it from reaching e.g. the platform. These sub-functions consist of barrier elements, e.g. a blowout preventer, a person who activates the BOP, a choke and kill system and valve regulation. Each of the elements has performance requirements e.g. the shortest time required to close the BOP, training to activate the BOP, the designed pressure that the choke and kill system shall be able to handle and the closing time of the valve to circulate out the kick.

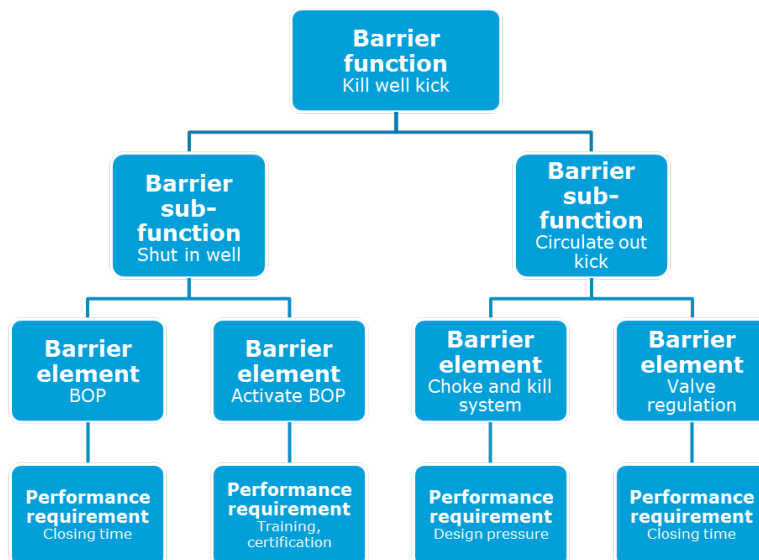


Figure 2. Barrier functions, barrier elements and performance requirements.

## 3.2 THE NORWEGIAN PETROLEUM INDUSTRY

After the findings of gas in the Netherlands in 1959, optimism was born concerning petroleum resources at the North Sea (Norwegian Petroleum Directorate, 2013). In 1969, the first discovery was made at the field Ekofisk, and the production started in 1971. The main activity has been in the North Sea, where the most important fields have been discovered. These fields still dominate the production in Norway. However, the production starts to decline and the petroleum activities are spread over a larger number of fields compared to before.

As the production in the North Sea starts to decline, operators are looking north for new findings (Anda, 2014). The northern parts of the North Sea and Arctic are associated with new challenges and sources of risk. Darkness, ice and long distances to shore are challenges that the industry and authorities are facing. To increase the safety and avoid major accidents when facing the new challenges, barriers play an important role.

Independent on the site for petroleum activities; the arctic, the North Sea or the waters in Australia, the activities can be divided into four main steps; exploration, well development, petroleum production and decommissioning and abandonment (U.S Environmental Protection Agency, 2000). They can be generalised to activities both onshore and offshore and to give further understanding of the scope of the thesis as well as the context of the same, the four steps are described below and illustrated in Figure 3.



**Figure 3.**The main four steps of petroleum activities.

### 3.2.1 EXPLORATION

To find potential sources of hydrocarbons, geologic activities are performed (Norwegian Petroleum Directorate). This includes seismology to map potential resources in the subsurface and also geologic surveys to understand the formation of the shelf e.g. the porosity. The data from the seismic activities is analysed and the size of the discoveries is estimated. To investigate the reservoir further, one or several exploratory wells are drilled (U.S Department of Energy, n.d.). From this well, a core sample can be brought up to the surface and be examined. In addition to the exploratory wells, appraisal wells are drilled to map the boundaries of the field.

### 3.2.2 WELL DEVELOPMENT

Well development is the next step after the exploration has identified a location that will be economically recoverable (U.S Environmental Protection Agency, 2000). About 30 meters segments are drilled at a time and the further down the drill reaches, the stronger are the forces on the equipment (Devold, 2013). As the hole is drilled, a casing is placed in the well to prevent caving and to stabilise the well (U.S Environmental Protection Agency, 2000). There are several casings that e.g. prevent sediment to reach the well.

Except from the well and its accoutrements, infrastructure is needed for production (U.S Environmental Protection Agency, 2000). For offshore operations, a ship, floating structure or a fixed platform can be used. When the drilling of the well is done, and tests of the hydrocarbon in the field have been conducted

to ensure that the field can produce a certain amount, the necessary production structures are taken to the field to begin the production.

### 3.2.3 PETROLEUM PRODUCTION

The major part of the petroleum production is to bring the hydrocarbons to the surface and separate the liquid and gas components as well as remove impurities (U.S Environmental Protection Agency, 2000). Offshore, a wide range of different structures are used, depending on the size and water depth (Devold, 2013). E.g. at shallow waters there can be several independent platforms that have different parts of the process and utilities linked with gangway bridge ways. Some of the facilities have all the systems topside, instead of subsea. To regulate and monitor the extraction of hydrocarbons a wellhead is used at the beginning of the well and can be either dry or subsea. Dry completion means that the well is onshore or on a topside structure on an offshore installation whereas a subsea completion means that the wellheads are located under water on a special sea bed template.

In many cases the natural reservoir pressure can, in the beginning of the production, be used to move the oil. As the volume of oil decreases, the pressure in the reservoir decreases and e.g. pumps and gas lift valves may be needed to recover the oil. This is called the primary recovery of the oil. For the second recovery of the oil, the reservoir is re-pressurised by e.g. water. A third method is to use material that is normally not found in the reservoir, to move the oil. An example could be surfactants to wash the oil from the reservoir by improving the permeability characteristics.

### 3.2.4 DECOMMISSIONING AND ABANDONMENT

The final step is the decommissioning and abandonment of the facility. The process consists of several steps that e.g. include project management, well plugging and abandonment and removal of the platform (Rigzone, n.d.). The planning of the decommissioning starts some years before the wells run dry to make sure that the right vessels and services needed are available. If the production has taken place on a platform, the platform needs to be cleaned and residual hydrocarbons need to be disposed of.

The plugging and abandonment of the well is one of the major costs of the project. During the well abandonment several activities are conducted, the well is e.g. filled with fluid and the wellbore is cleaned. The plugs that are used to close the well needs to be pressure tested to verify integrity.

Removing the platform can be done in several ways but the most common is to dismantle the facility in reverse order as it was built and dispose the structure onshore. Another option is to remove the structure and place it in the ocean.

### 3.2.5 MAINTENANCE

The equipment that is used during well drilling and petroleum production requires significant maintenance sessions (U.S Environmental Protection Agency, 2000). During these sessions, several tasks may be undertaken, e.g. repair leaks in the casing, replace motors and other equipment and cleaning the equipment.

To maintain the integrity of the safety barriers, the barriers depend on maintenance (Okoh & Haugen, 2013). However, the control of hazards might sometimes be lost due to failure that is introduced by maintenance. It could be e.g. that the maintenance is performed by personnel who do not possess the right competence, that the equipment that has been maintained is not put together properly or that valves are in incorrect position after maintenance (Health and Safety Executive, n.d.).

Another aspect of maintenance with regards to major accident is that it might cause accidents directly by triggering unwanted events, this could happen e.g. due to human failure (Okoh & Haugen, 2013). It has been estimated that over 65 % of the major hydrocarbon leaks on the Norwegian sector of the North Sea were linked to maintenance. Hence, it is of importance to include the barrier management, see section 3.4.6, in the maintenance program.

### 3.2.6 REGULATORY REGIME

A number of acts and regulations organise and regulate the petroleum activities in Norway. The acts concern e.g. the external environment, health, working environment and safety. This thesis focuses on barriers against major accident with environmental consequences during drilling activities, and how this is regulated in PSA's regulations. To give the reader an overview of the existing acts, the organisation and where PSA and their regulations fit in, a short summary is given below.

Regarding safety and the environment, there are mainly three authorities of importance; PSA, the Norwegian Environment Agency and the Norwegian Coastal Administration (Norwegian Petroleum Directorate, 2013). The responsibility of PSA is the technical and operational safety as well as emergency preparedness and working environment in the petroleum activities. The Norwegian Environment Agency is responsible for following up the Pollution Control Act and provides the Ministry of Climate and Environment with advice and technical background material. The Norwegian Coastal Administration is responsible for the oil spill preparedness.

The regulating acts are formulated by the parliament (Stortinget, 2013). The regulations regulate and expand on the rules that are set in the acts. Together, the acts and the regulations are legally binding. To help the user to understand how to fulfil the requirements in the acts and regulations, guidelines and standards are issued but are not legally binding. The standards are used to describe a common understanding of technical terms and how things should be done. Also, these can help the user to fulfil the requirements. Figure 4 illustrates the relationship between the acts, regulations, guidelines and standards and also which organisation that issues the documents.

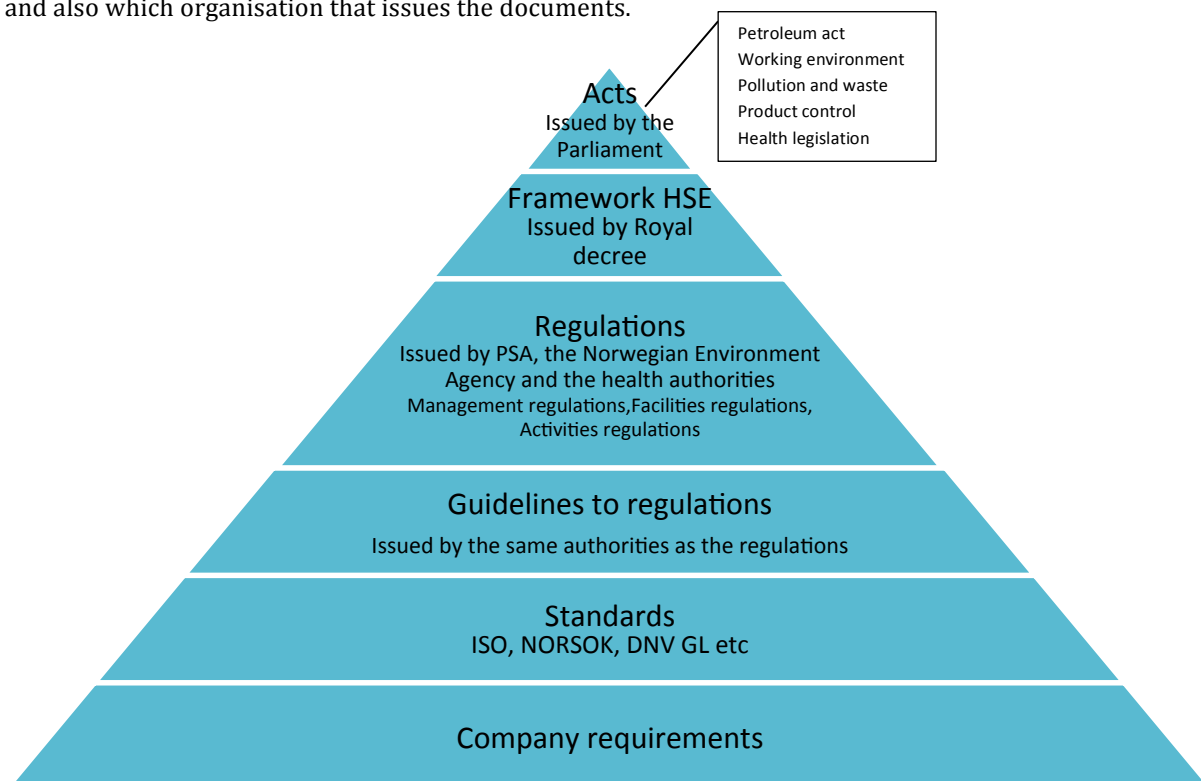


Figure 4. Organisation in Norway<sup>2</sup>

The Petroleum Act contains the general legal basis for the licensing system concerning Norwegian petroleum activities (Norwegian Petroleum Directorate, 2013). Licenses can be awarded for exploration, production and transport of petroleum.

<sup>2</sup> Picture from presentation by Associate Director Anne Cathrine Johnson and Senior Consultant Pippa Brown, DNV GL, 1/5 2014

The emissions and discharges from the activities from the Norwegian petroleum activities are regulated through the Petroleum Act, the CO<sub>2</sub> Tax Act, the Sales Tax Act, The Greenhouse Gas Emission Trading Act and the Pollution Control Act. The Ministry of Climate and Environment is responsible for setting requirements for emergency preparedness against acute pollution in municipal and private enterprises. The Norwegian Environment Agency approves the preparedness plan and also does supervising.

The Ministry of Climate and Environment has the main responsibility for the external environment (Norwegian Petroleum Directorate, 2013). PSA has, as mentioned, the responsibility for operational and technical safety, and is an authority which explicitly works with petroleum activities. Since one of the main topics that PSA works with is major accidents, they also have requirements for the safety of the external environment since consequences of a major accident affects the external environment. The requirements that PSA stipulate with regards to pollution of the environment can be connected to those in the Pollution Control Act. Hence, there is a strong link between the work and tasks for PSA and the Norwegian Environment Agency. This is described in the guidelines to section 1, the Framework Regulations.

In the guidelines to section 34, Management Regulations, a description of the Pollution Control Act is given. The Pollution Control Act has a general prohibition against having, doing or implementing anything that can entail a danger of pollution. Pollution can be lawful, which is controlled in the act. Also if there is a danger of pollution, the instance is covered by the law. The act also says that pollution can be regulated in regulations and one example of this is the HSE regulations for petroleum activities. In case of acute pollution, the responsible party has a duty to take action and the enterprises which activities include a risk for acute pollution, need to maintain their emergency preparedness. The Pollution Control Act holds for all activities that can result in pollution, i.e. not only activities that are related to petroleum activities. In section 38 (the Pollution Control Act) an acute pollution is defined as (freely translated):

Acute pollution means pollution of significance, which happens suddenly, and which is not allowed with regards to regulations of this law

Since PSA's regulations either refer to or quote the Pollution Control Act and since the Norwegian Environment Agency participate in developing PSA's regulations, the Pollution Control Act is not studied in detail. The sections in PSA's regulations and the Pollution Control Act that align, are reviewed together.

#### 3.2.6.1 PSA'S REGULATIONS

A set of regulations exists regarding HSE in Norway. Regarding HSE in the petroleum sector PSA has issued four regulations that will be reviewed in this thesis. These regulations apply to all petroleum activities, i.e. activities associated with subsea petroleum deposits which include exploration, exploration drilling, production, transportation, utilisation and decommissioning and planning of the activities but not transport of petroleum in bulk by ship. The regulations are the Framework Regulations (FrR), the Management Regulations (MR), the Facilities Regulations (FR) and the Activities Regulations (AR).

- **The Framework Regulations:** the regulations apply to activities both offshore and onshore (PSA, 2014b). They provide a framework for comprehensive and prudent activities and include provisions on scope of the regulations, responsible parties, risk reduction principles, application of maritime regulations as an option to technical requirements in the petroleum regulations for mobile facilities and also principles for HSE which includes requirements for a good HSE culture.
- **The Management Regulations:** as the FrR, the MR applies both onshore and offshore. They are issued by PSA together with the Norwegian Environment Agency and the health authorities. The regulations gather all management requirements for HSE and have specific requirements for risk reduction, barriers, management elements, resources and processes, analyses and measurements and handling of nonconformities and improvements.
- **The Facilities Regulations:** the FRs only cover offshore activities and are enforced by PSA together with the Norwegian Environment Agency and the health authorities. The regulations handle the design and outfitting of facilities and give requirements for aspects such as safety

functions and loads, physical barriers, emergency preparedness, drilling and well systems and maritime facilities.

- **The Activities Regulations:** as the FRs, the ARs only cover offshore activities and are planned and enforced by PSA and the Norwegian Environment Agency as well as the health authorities. The regulations govern how the different activities are conducted and hence specify requirements for aspects such as planning and monitoring, the natural environment, emergency preparedness, drilling and well activities, maritime operations and maintenance.

This thesis also seeks to compare the EU directive 2013/30/EU to the regulations from PSA. Therefore, the EU directive is described below.

### 3.2.6.2 THE EU DIRECTIVE 2013/30/EU

In an EU directive, EU stipulates the goals that the member states shall meet but the states decide for themselves how to reach the goals (European Commission, 2012). To make sure that the principles that are stipulated in the directive affect the citizens of a country, the member states need to implement the directive in the national legislation within a given timeframe.

Norway is not a member state in EU, but is a partner with EU through the European Economic Area (EEA) (Regjeringen, 2013). The EEA enables free movement of goods, services, people and capital on the internal market. The EEA agreement does not give Norway the right to take part in the decisions that are made in the EU parliament but the EEA countries can give input to those proposals that will be a part of the agreement (Regjeringen, 2012). The directives developed but not related to the EEA do not have to be implemented by Norway.

The objective of the EU directive 2013/30/EU is to reduce the occurrence of major accidents relating to offshore oil and gas operations as far as possible and thus increase the protection of the marine environment and coastal economies against pollution. The objective is also to establish minimum conditions for safe offshore exploration and exploitation of oil and gas, limit possible disruptions to Union indigenous energy production, and to improve the response mechanisms in case of an accident.

The directive was issued after the Macondo accident in 2010 (Leirgulen, 2013). The directive addresses the member states of the union, but states that it also has relevance for the members of EEA. The accident at the Deepwater Horizon platform increased the awareness of preparedness, risk and management both among people in the industry and the public (Leirgulen, 2013). Further reasons to the initiative of the directive were that smaller companies were taking over mature assets and new exploration in traditional areas. The bigger companies were heading towards new areas where the cumulative operational experience is small, including emergency preparedness for major accidents.

There was a need to gather the best practices and create a coherent legal framework for the member states of EU (Leirgulen, 2013). In EU, safety regarding drilling is based on a safety directive from 1991 that applies to all minerals on- and offshore. It is implemented with varying stringency in the countries and does not reflect upon best regulatory practices for major accident or environmental consequences of a major accident. The existing regulations that integrate safety and the environment is the Seveso directive, however this does only apply for onshore activities.

## 3.3 HAZARDS, RISKS AND ACCIDENTS IN DRILLING ACTIVITIES

The activities that are executed during the four steps mentioned above are associated with hazards that create risks to life, property and the environment. The likelihood and consequences of the hazards differ and the focus in this thesis is on hazards with low likelihood but severe consequences that are related to drilling operations. These hazards can, if not properly controlled, lead to the so called major accident.



### 3.3.1 MAJOR ACCIDENTS

The way a major accident is defined will have an effect on how the barriers that shall prevent or mitigate consequences of a major accident are identified<sup>3</sup>. In order to achieve good barrier management, the link between major accidents and barriers needs to be understood<sup>4</sup>. The barriers are identified with regards to the specific hazards and if it is unclear from the beginning what a major accident is, the identification of the barrier that can protect or prevent the vulnerable target might be more difficult.

During the 1900's, several accidents occurred within the oil and gas industry that can be classified as a major accident (Okoh & Haugen, 2013). Some examples are, except from the Macondo accident described in 3.3.3, the Alexander Kielland Disaster in 1980 where 123 people lost their lives (Midttun, 2013b) and the accident in Texas City in 2005, which led to severe discharges and an explosion of leaking gas in addition to 15 lost lives (Anda, 2013).

Preventing the major accidents from happening is vital to secure safe operations, and the main mission for PSA (PSA, 2014c). To enhance the work with risks, a common language is important (Luko, 2013). However, how the concept of major accident is defined differs between both countries and industries (Okoh & Haugen, 2013). In the hydrocarbon and process industries, words such as adverse, unplanned, acute and sudden are used with different meanings. Also, the events that mainly are focused on are the release of flammable and toxic material. The main aspect however, is the consequences of the accident. Different definitions include different consequence dimensions, but life, health, the environment and assets are usually considered. Some definitions require a consequence to have happened and some mention the potential for a serious consequence. Another aspect is whether both immediate and delayed events should be considered.

At PSAs webpage and in the guidelines to section 9, management regulations (MR), a definition of a major accident can be found, which is also mentioned in section 3.1:

An acute incident, such as major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets (PSA, 2014c)

Another definition can be found in a report regarding risk trends in the Norwegian petroleum industry, issued by PSA in 2012:

Major accident is an accident caused by a failure of one or more of the safety and emergency barriers in the system (freely translated by the author) (PSA, 2012a)

a second definition in the same report is:

A major accident is an accident where more than 5 persons are exposed (freely translated by the author) (PSA, 2012a)

When referred to major accidents in the thesis, the definition that can be found in the guidelines to PSA's regulations will be used. This is also the definition that was referred to by PSA during the interviews (see section 4.4.1) and hence the definition that PSA wants the industry to use.

Another aspect of major accidents is that they need to be separated from the occupational accidents<sup>5</sup>. After the accident at BPs refinery in Texas City, where 15 people died and more than 170 were injured, the industry became aware of the importance of managing major accidents specifically and that they do not origin from the same hazards as the occupational accidents (Allars, 2007). It was found that the process safety was not as prioritised as the personal safety and environmental performance. Process safety

<sup>3</sup> Senior consultant Sondre Øie, DNV GL, interview 27/2 2014

<sup>4</sup> Consultant Ellen Kristine Ombler, DNV GL, interview 27/2 2014

<sup>5</sup> Principal consultant, Anne Marie Wahlstrøm, DNV GL, interview 27/2 2014

includes the handling and use of dangerous substances that have the potential to cause major hazards with consequences not only on the workers (as occupational accidents), but also on the public nearby and the environment. Process safety hazards can cause major accidents with catastrophic effects that can result in multiple injuries and fatalities, and cannot be prevented with the same measures as those used to prevent incidents related to personal safety and occupational accidents. After the accident in Texas City, there was a change of focus also in the Norwegian petroleum industry with regards to major accidents and barriers<sup>6</sup>.

### 3.3.2 POLLUTION OF THE ENVIRONMENT

The definition of a major accident (as stipulated by PSA) includes consequences on the environment. Oil and gas activities are associated with hazards that come with great consequences on the environment and accidental releases of hydrocarbons at the facilities can arise from e.g. spills due to leaking tanks, leakage during transfer or leaking flowlines, valves or gauges (U.S Environmental Protection Agency, 2000). The range of the volume of the released hydrocarbon can be large but the spills are often small in quantity and relatively easy to prevent. A special case of a spill is a blowout, if a blowout is not prevented it can cause great consequences on both human life and the environment and is one of the worst-case scenarios for drilling operations.

Hauge et al (2011) differs between non-planned releases and planned releases. The non-planned releases are hydrocarbon leaks that result from unwanted events or accidents. The quantities of these can be large and are most acute. They can also be regarded as continuous when left undetected for a longer period, e.g. a very small subsea leak. The planned releases however, are non-accidental releases and associated with normal offshore operations. They are often integrated and an inevitable part of conducting offshore operations and have thus been accepted by the authorities.

Well blowouts are non-planned releases that seldom happen (U.S Environmental Protection Agency, 2000). The blowout may occur when drilling into an unexpected pressurised zone or when the equipment is removed from the hole (tripping) resulting in that the pore pressure from the formation may become higher than the pressure exerted by the drilling or work over fluid. If this happens, the formation fluid (fluid from the reservoir) and the drilling or work over fluid may rise uncontrollably through the well to the surface. If there is a significant amount of natural gas in the reservoir, there might be an ignition. To prevent blowouts, a blowout preventer (BOP) can be part of the drilling installation and serve to close off the drill pipe (U.S Environmental Protection Agency, 2000). They can be activated both manually and automatically and there are usually several training programs for the personnel to make sure that the BOP can be operated correctly and that the workers can escape safely. Blowouts that occur offshore, may take months to cap and control, as happened in 2010 in the Macondo accident (Read, 2011).

When talking about offshore installations, the conditions for oil spill response might be different depending on where the installation is located, i.e. deep water or coastal and calm or choppy sea (U.S Environmental Protection Agency, 2000). However, the initial response is to try to stop the leakage and contain spilled hydrocarbons. If a blowout occurs, material as oil, salt and heavy metals can reach the environment. The environmental effects of acute oil discharges depend on more than just the size of the spill (Norwegian Petroleum Directorate, 2013). Factors that affect the consequences are e.g. the discharge site, the season, wind speed, currents and the efficiency of the emergency preparedness. An acute oil spill can harm fish, sea mammals, seabirds and beach zones.

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<sup>6</sup> Consultant Ellen Kristine Ombler, DNV GL, interview 27/2 2014

### 3.3.3 THE MACONDO ACCIDENT

In April in 2010, a blowout occurred at the Macondo field in the Gulf of Mexico, the blowout caused severe damage on the environment and took the life of 11 people (PSA, 2011). The accident became an eye opener for authorities, politicians and the public in the entire world. However, experts and people working within the field were not surprised that this kind of accident happened. The petroleum activities are related to high risks and being aware of this is a prerequisite to be able to work preventive and manage the risks to make them as low as possible.

The Macondo site was located in deep water i.e. depths more than 350 m (Bai & Bai, 2010), in the Gulf of Mexico and operated by BP (Read, 2011). The accident occurred during the drilling of a well, which was done by the drilling company Transocean. The blowout occurred after the cementing, which is done to anchor the casings to the formation and eliminate leak paths behind the casings. The drilled well already had challenges with escaping hydrocarbons. When the team on the rig were preparing to leave, gas with high pressure shot through the drill column all the way up to the drilling platform and resulted in explosion and fire. It took 87 days before the oil stopped leaking and the environmental oil spill was finally estimated to almost 5 million barrels (Tinmannsvik, et al., 2011)

A conclusion is that accidents as the one at the Macondo field, must be seen as the result of a system failure (PSA, 2011). This means that it is a failure that occurs over time in a system of actors and processes that are coupled and sometimes dependent on each other. There is not just one cause to the failure, but several which are based on technical, operational and organisational factors. An important message is that complex systems fail in complex ways and major accidents cannot be explained through simplified models or prevented with simple solutions. However, there is a need to put the reality in a model to be able to understand as much as possible but when doing this, it is also vital to be able to relate to the complexity.

The Macondo accident has raised the attention regarding safety culture, management and requirements regarding safety for well operations and protection of the external environment in the petroleum industry offshore (PSA, 2011). To prevent major accidents, PSA has increased the focus on barriers as a measure to increase the level of safety.

## 3.4 BARRIER THEORY

As mentioned, barriers are one of the measures to prevent major accidents and there are several ways to describe how an accident evolves and hence means to prevent the accidents from happening. The idea of barriers origins from the barrier-energy concept, which was established by William Haddon in 1970 (Rosness, et al., 2010). As mentioned in the introduction, PSA has set barriers as one of their four focus areas for 2014 and to describe accidents, PSA uses the energy-barrier concept (Anda, 2013).

### 3.4.1 THE ENERGY – BARRIER CONCEPT

The energy-barrier concept (Figure 5) is an accident model that describes the role of the barriers in preventing an accident (PSA, 2013b). The idea is that the threat, i.e. the energy, shall be separated from the target with help from barriers. The energy, which can be e.g. chemical or kinetic, can cause damage on a specific target, such as life, environment and assets (Rosness, et al., 2010). Within the oil and gas industry, the energy is typically the hydrocarbons. To avoid the energy from causing damage, a barrier can either stop it, or the target can be protected with help of a barrier. If the target is a person, the barrier could be personal protection equipment. The energy-barrier model is a simplification of a complex world but the concept is to see the energy as the driving force of an accident. If the energy is under control, the situation is safe, but loss of this control might cause an accident (Rasmussen & Grønberg, 1997).

Hence, the barrier is an obstacle, an obstruction, or a hindrance that may either *prevent* an event from taking place or impede or lessen the consequences (*protect* the target) if an accident happens (Hollnagel, 2006). Hollnagel (2006) argues that barriers are an important part of understanding the origin of accidents and the reason for why an accident has occurred usually is because of failure of one or several barriers. The accident occurs either because the barriers did not serve their purpose or because they were missing.

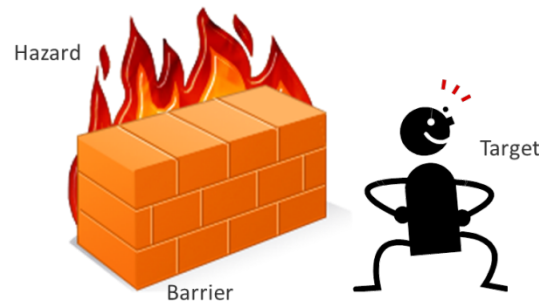


Figure 5. The energy model (Sklet, 2006)

Through the history, barriers can be found at a lot of places, one of the most famous examples is the Great Wall of China (Hollnagel, 2006). Walls have been used for a long time as barriers and it is a prototypical example that prevents unwanted visitors to access a certain area. The romans had a more systematic use of barriers. They used ditches, earth walls and wooden palisades to guard the interior. During the Middle Ages the levels of defence were further used with outer wall and one or more lines of moats in front of a gateway to protect a castle. The gateways were also protected by e.g. sliding gates and doors.

Today, the barriers are not only of physical nature. The barriers can vary from protection against radioactive release to event reporting and safety policies. This thesis focuses on environmental barriers, which at a drilling facility could be e.g. a drain system that serves to not release hydrocarbons and chemicals to the marine environment. Different barriers will be needed in the different stages of the escalation of a hazardous event. In recent years, the concept of having several barriers in line has been institutionalised as defence-in-depth.

### 3.4.2 DEFENCE IN DEPTH

The concept of defence in depth can be explained with James Reason's "The Swiss Cheese Model", Figure 6 (Drangeid, 2003). The escalation of a hazardous event can only be fully controlled if each event in the chain can be prevented. Each cheese slice represents a barrier and an accident will occur if the holes in the cheese slices are in the same position and the energy (arrow) succeeds to pass the slices. If some of the barriers have common weaknesses, the situation can escalate and reach an uncontrollable state. The model gives a holistic view of how accidents occur and can describe accident causation with respect to how different barriers affect each other (Underwood & Waterson, 2013).

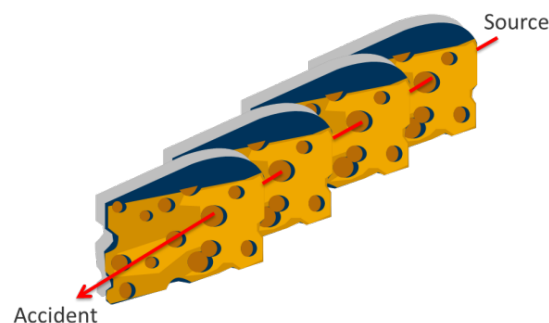


Figure 6. The Swiss cheese model (Brunicon, n.d).

The holes can arise from active or latent failures (Reason, 1990). The active failures can be described as errors and violations that have an immediate adverse effect. They are often associated with activities performed by “frontline” operators, e.g. control room personnel, ships’ crews and train drivers. The latent failures on the other hand, are the decisions or actions that lie inactive but cause great damage and severe consequences when triggered. They have always been in the system long before the actual accident sequence occurs. Those who are not in direct contact with the human-machine interface, e.g. designers, high-level decision makers and managers, usually generate the latent failures.

The Swiss cheese model is used by PSA to describe how accidents occur. It is one of the most popular accident models and therefore widely used throughout various industries (Underwood & Waterson, 2013). Other ways of describing layers of barriers and the origin of an accident is e.g. the hazard-barrier-target diagram that shows the integration of barriers within the system (Shahrokhi & Bernard, 2010). Today, safety barrier bowtie diagrams are common to describe and analyse the scenarios and to define the safety and environmental critical elements, Figure 7. A safety bowtie diagram visualises the barriers that are used to prevent an accident from happening, as well as the barriers that are used to protect vulnerable targets if the accident occurs.

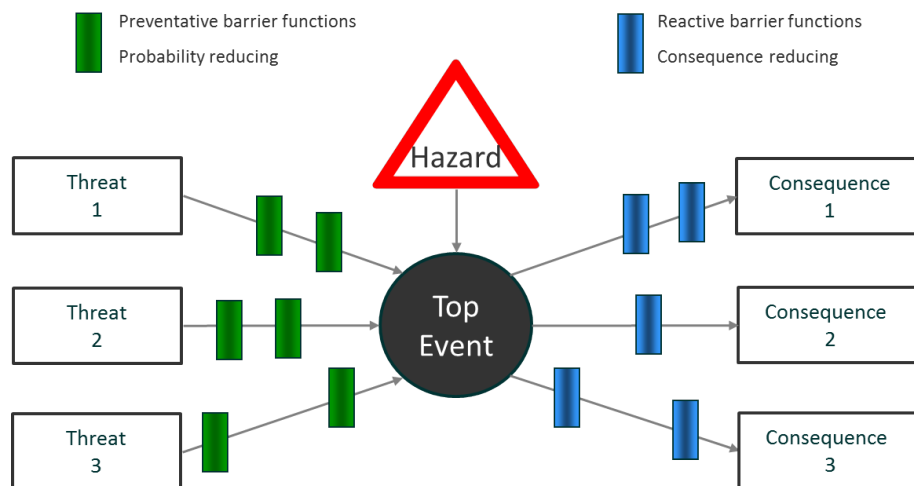


Figure 7. Safety bowtie diagram<sup>7</sup>

The Swiss cheese model is one way to describe why it is useful to have a system of barriers to fulfil a barrier function. An accident happens when the holes in the cheese slices move or change in size, which can happen if there is a change in operation type, management or external environment etc. The cheese slices, i.e. the barriers, can be of different type and to enhance the use of barriers, they can be classified into specific groups.

### 3.4.3 CLASSIFICATION OF BARRIERS

Hollnagel (2006) argues that the use of the barrier concept should be based on a systematic description of various types of barrier systems and functions. This will help to identify specific systems and functions and to understand the role of the barriers after an accident. Hollnagel (2006) bases the classification of barriers, with regards to systems and elements, on the nature of the barrier. Four classes of barriers are described, i.e. the physical or material barriers, functional barriers, symbolic barriers and incorporeal barriers. The physical or material barriers are barriers that physically prevent something from happening or protect a target from an accident by blocking or mitigating the effects, e.g. a fire wall. The physical barriers work without having to be understood by an acting agent. The functional barriers, e.g. a safety valve, should impede the action and have certain pre-conditions that need to be met before the barrier is

<sup>7</sup> Picture from presentation by Head of Section Asset Risk Management Atle Stokke, DNV GL, 1/5 2014

activated. This activation can be done by a person or by a technological component. The symbolic barrier on the other hand, needs an intelligent agent who understands how the barrier works for it to achieve its purpose, e.g. a warning sign. Finally, the incorporeal barriers are barriers that do not have a material form or substance where it is applied. Instead, it relies on knowledge by the user to be able to achieve its purpose. These barriers are in industrial contexts often referred to as organisational barriers. The classification described above means that the barriers can range from physical hindrance to rules and laws.

In PSA's regulations, barriers and their role in the Norwegian petroleum industry are described. It is said that the barriers can be technical, operational or organisational. In the guidelines to the regulations it is further described that the barriers can be either physical or non-physical measures, where the non-physical part may be referred to as the organisational barriers. A technical barrier, could be e.g. fire or gas detectors whilst the operational barrier is a barrier that has to be initiated by a person, e.g. that an operator needs to manually activate the blowout preventer (BOP) (PSA, 2013b). An organisational barrier is described as the person who does the activation.

With regards to the classification done by Hollnagel (2006), PSA's technical barrier could be classified as a physical/material barrier or as a functional barrier that is activated automatically when a signal is received. The operational barriers are the tasks that a person has to perform and can be compared to the functional barrier when the barrier is activated manually. This type of functional barrier is most likely applied in combination with a symbolic barrier that is interpreted and understood by the intelligent agent. As mentioned about incorporeal barriers, they are often synonymous with organisational barriers within the industry.

Øie et al (2014) states that an operational barrier is a task performed by an operator that realises one or several barrier functions and that an organisational barrier is personnel responsible for and directly involved in realising one or several barrier functions. Due to the link and overlap between organisational and operational barrier elements, Øie et al (2014) do not consider it practical or useful to apply both terms. Instead they argue that the organisational barrier rather is a performance requirement for the operational barrier. Hollnagel (2006) also discusses the concept of organisational barriers and argues that an organisation itself cannot be a barrier. The barriers are rather the rules or procedures that are carried out by the people working in the organisation, hence the tasks, which by PSA are, classified as operational barriers.

Barriers and their functions may be combined in different ways to decrease the likelihood that a single failure leads to an accident in a system. To decrease the likelihood of failure of a barrier, it also needs to possess certain qualities, which should be kept in mind when designing the barrier.

#### 3.4.4 QUALITIES OF A BARRIER

Both Hollnagel (2006) and Sklet (2005) discuss the aspects that are important to assure the quality of the barrier. These qualities can be compared to the performance requirements described by PSA in the regulations (see below). Sklet (2006) has done a review of literature and from experience from projects made a suggestion of the attributes that are important to address with regards to the quality of a barrier that is used within oil and gas production. Not all attributes are relevant for all barriers.

- Functionality/effectiveness; the ability to perform a specified function under certain technical, environmental and operational conditions. This deals with the effect the barrier has on the event or an accident sequence. E.g. be that a barrier which function is to pump water, should be able to pump between 100 and 110 l/min

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<sup>1</sup>A blowout preventer is a large valve that prevent the fluids in a well to reach the rig if there is a well-kick (uncontrolled flow of fluids from the well) (Schlumberger, 2014)

- Reliability/availability; the ability to perform a function with an actual functionality and response time while needed or on demand. The reliability/availability may be expressed as the probability of failure to carry out a function. This corresponds to safety integrity requirements. The difference between the functionality/effectiveness and the reliability/availability is that the functionality/effectiveness rather describes *what* the barrier is supposed to do and how efficient this is to reduce the potential damage whereas the reliability/availability describes the likelihood that the actual function is performed. An example can be gas detectors. The effectiveness of the detectors to discover a leakage is influenced by e.g. the type of detector and number of detectors while the reliability is the probability of signal from the detectors if gas reaches them.
- Response time; the time it takes from a deviation occurs that activates the barrier, until the specified safety barrier function is fulfilled. This could be the time it takes for a human to activate the BOP after a signal has been registered.
- Robustness; the ability to resist certain accident loads and functions. This is relevant both for passive and active barrier systems. An example is environmental load such as the force from a wave.
- Triggering event or condition; this is the event or condition that triggers the barrier and activates it, e.g. the release of hydrocarbons. This aspect is important to completely understand how the barrier can be activated even if the triggering event is not part of the barrier itself.

In PSA's regulations it is stipulated that the performance requirements of a barrier shall be known for personnel. Further, the guidelines say that the performance can include capacity, reliability, accessibility, efficiency, ability to withstand loads, integrity and robustness. These aspects are based on the standard ISO 13702 that classifies barriers with regards to functionality, integrity and vulnerability. Hauge et al (2011) explains the requirements that PSA sets as follows:

- Functional requirements: qualities such as capacity and efficiency related to the effect that the barrier has on the event/accident chain that it functions
- Integrity requirements: qualities such as availability and reliability related to the barrier's ability to function when required and/or demanded
- Vulnerability requirements: qualities that are related to robustness and the barrier's ability to withstand relevant accidental loads.

To assure the quality of the barriers, PSA uses established literature and standards. With regards to barriers that prevent or limit acute releases to sea, it might not always be possible to use the requirements for safety barriers for personnel in the standards, immediately on the environmental barriers (Hauge et al, 2011). E.g. the safety integrity level (SIL) requirements are based on good engineering design practice to avoid human fatalities and injuries and may not reduce the risks on the environment in the best way.

### 3.4.5 CHALLENGES

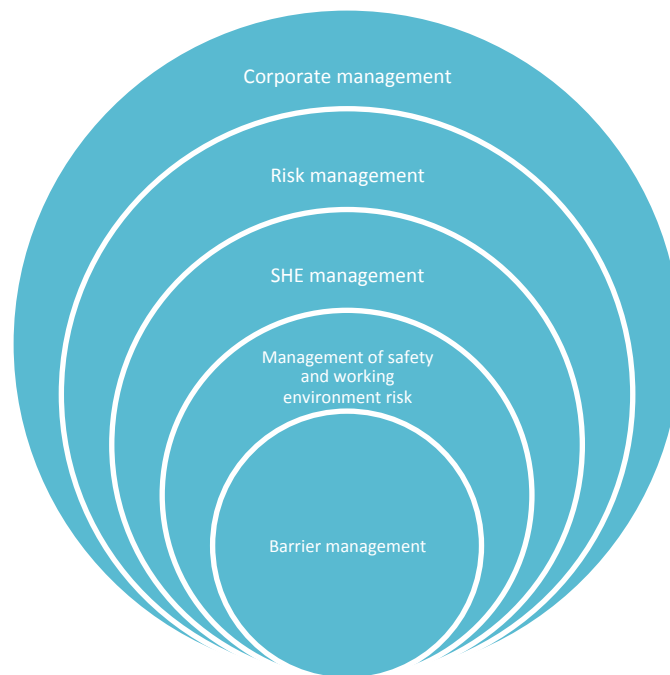
Different models used to describe reality have different challenges. The Swiss cheese model has been criticised for not considering the complex interaction of system components and thereby oversimplifying accident causation (Underwood & Waterson, 2013). Also, there are thoughts about that the prescriptive application focuses too much on the role of senior management and their role in accident causation. This could lead to not considering the role of the individuals at the frontline. However, it should be remembered that the model is not intended to be used as a detailed accident analysis method. The Swiss cheese model is used by DNV GL and by other actors in different industries. It gives a holistic view of barrier systems, which is important when developing barrier strategies and hence the performance requirements and standards.

In this thesis, dependencies between barriers are not taken into consideration, i.e. the barriers are assumed to be independent. However, today's systems are becoming more and more complex and coupled (Hollnagel, 2006). Adding active technical barriers can result in increased complexity of the system, which

can increase the maintenance-induced errors and operator errors (Rosness, et al., 2010). For example, an automatic control system may be introduced with the aim to decrease the vulnerability to errors due to operators. However, if the system fails, it might be difficult for the operator to handle the situation since the person lacks experience of the operation. The system might also add to the total complexity of the system and due to this make it more difficult to operate. This kind of paradox inspired Charles Perrow to formulate a theory called Normal Accidents (Rosness, et al., 2010). Perrow argued that it is necessary to expect that accidents will happen since the systems cannot be fully controlled due to the complexity and coupling. Using different ways of explaining accidents might also affect how they are controlled. The root cause of a major accident can be hard to identify and the complexity of both technology and organisational factors are often mentioned as aspects that have influenced the outcome (Tinmannsvik, et al., 2011).

### 3.4.6 APPLICATION OF BARRIER THEORY IN NORWAY

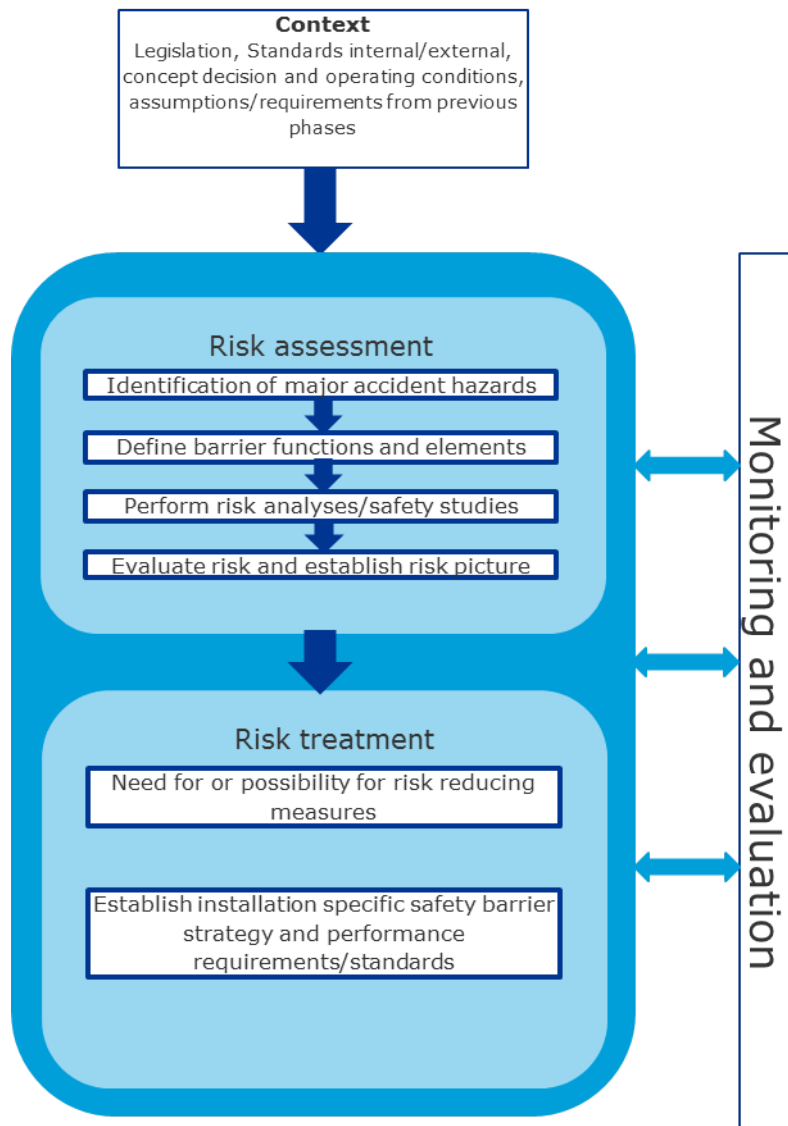
To enhance the implementation of the regulations regarding barriers, PSA has with help from standards such as ISO 31000 (Risk management – principles and guidelines) established a model for barrier management (PSA , 2013b). PSA wants the industry to make a clear link between risk assessments and barriers and barrier management gives this relationship a clear place in the management of the enterprise. According to PSA (2013b), the barrier management is a part of the HSE work in a company and hence a part of the corporate governance, Figure 8.



**Figure 8. Barrier management and the relation to corporate governance (PSA, 2013b)**

Barrier management is defined as a concept that focuses on coordination of activities to maintain barriers so that they can fulfil their function at all times (PSA, 2013b). The barrier management process starts with defining the context, which means everything that can be important when implementing the process and shaping the strategy that is ultimately adopted for managing the identified risk. Conditions that can be significant when implementing the process can be requirements and guidelines in the regulations and standards and also the actual design.





**Figure 9. The iterative process of barrier management (PSA, 2013b)**

In Figure 9, the different phases of the risk assessment and risk treatment are showed. During the risk assessment, the barrier functions that are needed to prevent or mitigate the hazards are identified and the work with performance requirements is started. The result will be compared to the established decision criteria, which can be based on organisational goals and external and internal contexts. They can also be derived from standards and regulations. To optimise the performance requirements, this process needs to be iterative. PSA (2013b) states that it is not enough to only use the acceptance criteria for personnel safety and/or loss of main safety functions, and in the MR, section 9, there are requirements also for acceptance criteria for environmental risk.

The risk treatment is the step where the need for additional and/or more effective barriers or risk reducing measures is evaluated. If there is no need for this, specific strategies and performance requirements shall be established. The barrier strategy shall contribute to give everyone involved a shared understanding of why a certain barrier has a certain requirement and how it contributes to reduce the risk. Further, it shall be updated when required and the role or task of the various barrier functions shall be identified. The requirements are set for technical, operational and organisational barrier elements, which is described in detail in section 3.4.4.

During the entire process, monitoring and evaluation of the barriers are done and the risks and strategies should be communicated throughout the organisation. The monitoring and review of the barriers is important and includes e.g. maintenance and verification. The entire process is iterative since the risk picture needs to be continuously updated and the status of the barriers needs to be monitored to make sure that they fulfil their purpose during their entire life cycle.

It is of importance that those who influence the risk picture direct or indirect are aware of this and have an understanding of the consequences of their choices. Hence, the technical aspect is just as important as the organisational and to ensure good barrier management, the processes should be implemented in the maintenance program<sup>8</sup>. To implement the barrier management to the maintenance program means that the maintenance activities are linked to the performance requirements from the design phase<sup>9</sup>. The result when testing the barriers shall be compared to the requirements that are set, and followed up to assure the status of the barrier. If necessary, improvements shall be suggested and the maintenance program updated.

#### 3.4.6.1 MANAGEMENT SYSTEMS

As mentioned, barrier management can be based on standards for management systems such as ISO:9000 (quality management) and ISO:31000 (risk management). A management system describes the procedures an organisation needs to follow to be able to meet its objectives (ISO, n.d.). In a smaller organisation, the procedures might not be official but rather norms and values of how things shall be done. In a bigger organisation though, there can be written instructions about how things shall be done. To write things down is a way to make sure that nothing is left out and that everyone is aware of who should do what, when and how. The management system systemises how these things should be done.

Important aspects of management systems are policy, incentives for employee participation, managers' commitment, training, communication, planning and control (Fernández-Muñiz et al 2007). The employees play an important role in the safety performance of the organisation. Fernández-Muñiz et al (2007) argue that the employees are the final barrier to hazards and that their behaviour is crucial to avoid damage. Also, the involvement can increase the motivation of the employees if they feel that their opinions and contributions are valued by the managers. Hence, a good system on the paper does not assure safer operations if it is not combined with involvement from both employees and managers. Factors that can make the management system inefficient is e.g. if the employee lacks risk awareness, is not trained well enough and if the management is not engaged.

When working with barriers, the participation of employees is of importance to assure that the risk is well understood, but as mentioned above, the role of the managers shall not be underestimated. To ensure safe operations, one cannot rely on either technical solutions or the organisational aspects but both parts need to be considered and worked with.

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<sup>8</sup> Consultant Ellen Kristine Ombler, DNV GL, interview 27/2 2014

<sup>9</sup> Head of Section Asset Risk Management Atle Stokke, DNV GL, interview 23/4 2014

### 3.5 SUMMARY

In this chapter, the theory with regards to barriers, the Norwegian oil and gas industry and barrier management has been reviewed. PSA uses the energy-barrier concept to explain how accidents occur. The energy-barrier concept is an accident model that separates the hazard (energy) from the target. An accident is explained by the failure of one or several barriers and the concept defence in depth is used to describe how layers of barriers can increase the overall safety. In order to facilitate the understanding of the role of a barrier after an accident, the barriers can be classified and in Norway, PSA divides the barriers into technical, operational and organisational. Hollnagel (2006) presents a classification system that aligns with PSA's system in many aspects. In the following text, the classification that PSA does will mainly be used since this is the system that the players need to comply with and Hollnagel's system will instead be used as a reference.

To increase the safety at a facility, certain qualities of a barrier can be identified and monitored. This aspect will not be studied in detail, but the information is important since it creates a foundation for how the players need to monitor and follow-up their barriers. If the barriers are not fully controlled, the safety level might decrease. Also, using standards that mainly focus on the protection of human life, might not take the environment into account. Hence, the qualities of a barrier might adventure the safety of the environment if this is not considered in the design phase. To minimise the likelihood of an accident to happen or the consequences of the same, the barriers can be classified and evaluated with regards to different aspects. To systemise this, PSA has developed principles for barrier management that are based on management systems, such as ISO 31000 and ISO 9000.

The theory that has been concluded in this chapter is used as a foundation to analyse how the different Norwegian players (drilling companies, authority and consultants) use the concept and how this might affect the level of safety. In the following sections, the result and analysis from the review of the regulations and the interviews is presented.

## 4 RESULTS AND ANALYSIS

This section presents the data collection results from the review of the regulations and the interviews together with analysis of the same. The chapter consists of two main parts; a review and comparison of the Norwegian regulations and the EU directive and a presentation and analysis of the result from the interviews. The analysis and presentation of the regulations is based on the questions presented in section 2.3.3 while the structure of the presentation and analysis of the interviews, are based on the interview guide (cf. section 2.3.1.4). The questions and topics used for the analyses are repeated below.

Questions used for the review of the regulations:

- What is the purpose with the regulation?
  - How are the requirements described?
  - What activities and accidents are covered? (Major/smaller accidents? Drilling, operation etc.?)
  - Who is the responsible party?
- To what extent should risk be reduced?
- How is a major accident defined?
- How are the concepts barrier and/or safety and environmental critical element defined?
  - Is there a specific definition of the concept environmental barrier?
  - What type of barrier is described in the regulation? (cf. classification of barriers, section 3.4.3)
  - Should the work with barriers be documented in a specific way?
- What requirements regarding the barriers are described in the regulation?
  - What kinds of standards are referred to?

Main topics discussed during the interviews (cf. section 2.3.1.4):

- The definition of a major accident
- The definition of barriers
- The work with barriers (barrier management)
- Environmental barriers
- The legislation
- Emergency preparedness

Table 2 shows a summary of the result from the review of the regulations with comments regarding the major differences and Table 3 shows the result from the interviews. The details are discussed in section 4.1 and 4.2.

**Table 2. Summary of review of regulations.**

	<b>PSA</b>	<b>EU</b>	<b>Comment</b>
<b>Purpose</b>	<ul style="list-style-type: none"> <li>-Promote high standards for health, safety and the environment (HSE).</li> <li>-Include all petroleum activities; exploration, exploration drilling, production, transportation, utilisation and decommissioning and planning of activities</li> <li>-The responsible party is the operator or others who participate in operations</li> </ul>	<ul style="list-style-type: none"> <li>-To prevent and mitigate consequences of a major accident.</li> <li>-Includes all activities including design, planning construction, operation and decommissioning thereof, relating to exploration and production of oil or gas.</li> <li>-It is the responsibility of the member state to require operators to ensure that all suitable measures are taken.</li> </ul>	<ul style="list-style-type: none"> <li>-PSA's regulations apply to all types of accidents. The EU directive only applies for major accidents. This is one of the major differences.</li> <li>-The regulations apply for the same petroleum activities</li> <li>-PSA's regulations require the operator or others who participate in operations to fulfil the requirements whilst the EU directive requires that the member states shall require the operators to ensure that all measure are taken.</li> </ul>
<b>Risk reduction</b>	ALARP	ALARP	Same philosophy
<b>Major accident</b>	An acute incident, such as a major spill, fire or explosion, that leads to multiple serious personal injuries and/or loss of human lives, serious harm to the environment and/or loss of major financial assets.	An incident involving an explosion, fire, loss of well control, release of dangerous substances that leads to fatalities or serious personal injury. Incident that leads to serious damage to the installation involving, or with potential to cause serious injury to five or more people. Another incident that leads to fatalities or serious injury to more than 5 people. Any major environmental incident resulting from incidents referred to in the incidents above.	<ul style="list-style-type: none"> <li>-PSA's regulations have no quantification of number of fatalities.</li> <li>-When mentioning accidents that can lead to a major accident, PSA mentions major spill whilst EU states that the environmental damage is a consequence of other accidents.</li> </ul>
<b>Definition of barrier/SCE, ECE</b>	<ul style="list-style-type: none"> <li>-Barrier: reduce and/or limit possible harm and disadvantages.</li> <li>-Technical, operational or organisational</li> <li>-Personnel shall be aware of what barriers that have been established and which function they intend to fulfil.</li> <li>-Requirement for independence</li> <li>-Performance can include capacity, reliability, accessibility, efficiency, ability to withstand loads, integrity and robustness</li> <li>-Strategies and policies that form the basis for design, use and maintenance shall be documented. The aim with the documentation is to safeguard the barrier through the lifetime.</li> </ul>	<ul style="list-style-type: none"> <li>-SCE/ECE: parts of an installation, including computer programmes, the purpose of which is to prevent or limit the consequences of a major accident, or the failure of which could cause or contribute substantially to a major accident.</li> <li>-A major hazard report needs to be written. The report shall include e.g. a description of the facility, the possible major accident hazards and the measures that are taken to prevent and limit these.</li> </ul>	<ul style="list-style-type: none"> <li>-The barrier concept (PSA) does not explicitly refer to a major accident, as the SCE/ECE definition in the EU directive.</li> <li>-The barriers (PSA) can be technical, operational or organisational. This is not described in the EU directive regarding SCE/ECE.</li> <li>-The EU directive mentions ECE explicitly, which PSA's regulations do not. This is one of the major differences and the part that might be needed to implement in the Norwegian practice.</li> <li>-The documentation is one of the major differences between the regulations. The major hazard report is a central part of the EU directive whilst the documentation in PSA's regulations is not as specific.</li> </ul>
<b>Requirements</b>	Standards such as ISO, NORSOK and DNV GL can be used to fulfill the requirements.	No specific standards are referred to but it is stipulated that the requirements shall be met with help from recognised standards.	

## 4.1 REVIEW OF PSA REGULATIONS

### 4.1.1 PURPOSE

The purpose of PSA's regulations, stipulated in section 1, FrF, is to promote high standards for and further develop and improve the health, safety and the environment in the petroleum activities.

The regulations issued by PSA are performance-based (PSA, 2014d). This means that the regulations shall describe the level of safety that shall be reached, and not the specific standards and procedures to enhance safety (Kirwan, Hale, & Hopkins, 2002). For details of how to fulfil the requirements, the guidelines to the regulations refer to standards such as NORSOK, ISO and IEC. The responsible party to assure that the requirements are fulfilled is the operator or others who participate in operations. However, if an operator chooses to not follow the recommended standard, it has to demonstrate that the chosen solution is at least as safe as the level given by the standard.

The activities that are covered are all petroleum activities, i.e. activities associated with subsea petroleum deposits which include exploration, exploration drilling, production, transportation, utilisation and decommissioning and planning of the activities but not transport of petroleum in bulk by ship.

The regulations also include requirements for emergency preparedness; analyses, personal protective equipment, materials for action against acute pollution, coordination of offshore emergency preparedness and offshore emergency preparedness cooperation.

### 4.1.2 RISK REDUCTION

The reduction of risks is regulated in sections 11, FrR and 4, MR. In section 11, FrR, it is said that

Harm or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with the health, safety and environment legislation, including internal requirements and acceptance criteria that are of significance for complying with requirements in this legislation. In addition, the risk shall be further reduced to the extent possible.

To reduce the risks, the technical, operational and organisational solutions that offer the best results shall be chosen, as long as the costs are not significantly disproportionate to the risk reduction, which is the same as the ALARP (as low as reasonably practicable) principle (Jones-Lee & Aven, 2011).

Section 4, MR refers to section 11, FrR and says that the responsible party shall select technical, operational and organisational solutions that reduce the probability that harm, errors and hazard, and accident situations occur. In this section it is also mentioned that barriers shall be established.

### 4.1.3 MAJOR ACCIDENTS

A major accident is described in the guidelines to section 9, MR.

Major accident means an acute incident such as a major spill, fire or explosion that immediately or subsequently entails multiple serious personal injuries and/or loss of human lives, serious harm to the environment and/or loss of major financial assets

The same section describes what an environmental risk is; meaning the risk of acute pollution (acute pollution is described in section 3.2.6). Section 9, MR also sets requirements regarding acceptance criteria for major accident risk and environmental risk. The guidelines state that acceptance criteria must be set for major accident risk and environmental risks. Major accident includes a major spill, whereas environmental risk is risk for acute pollution. No clear distinction is made.

#### 4.1.4 BARRIERS

Barriers are mentioned in several places in the regulations. In section 5, MR, barriers are defined:

Barriers shall be established that:

- a) reduce the probability of failures and hazard and accident situations developing,
- b) limit possible harm and disadvantages

Where more than one barrier is necessary, there shall be sufficient independence between barriers.

The operator or the party responsible for operation of an offshore or onshore facility, shall stipulate the strategies and principles that form the basis for design, use and maintenance of barriers, so that the barriers' function is safeguarded throughout the offshore or onshore facility's life.

Personnel shall be aware of what barriers have been established and which function they are intended to fulfil, as well as what performance requirements have been defined in respect of the technical, operational or organisational elements necessary for the individual barrier to be effective.

Personnel shall be aware of which barriers are not functioning or have been impaired.

The responsible party shall implement the necessary measures to remedy or compensate for missing or impaired barriers.

The section states that there should be strategies and principles that form the basis for design, use and maintenance of barriers to ensure that the barriers' function is safeguarded over the lifetime of the barrier. To fulfil this, the guidelines refer to the standard ISO 13702, regarding development and stipulation of strategies for risk-reducing measures and functions. As discussed in section 3.4.3, the barriers can be technical, operational or organisational.

In the guidelines to the same section, the performance requirements are described. These correlate with the qualities of a barrier that Hollangel (2006) presents and are discussed in section 3.4.4.

The requirement for independence, as mentioned in the second subsection, means that it should not be possible for multiple barriers to be impaired or malfunction at the same time, e.g. as a result of a single fault or a single incident. Strategies and principles should be designed so that they contribute to provide all of the involved parties with a common understanding of the requirements for the individual barriers, including the connection between risk and hazard assessments and requirements for and relating to barriers. Barriers can also be measures designed to prevent or limit the spread of an acute pollution.

Performance as it is described in the fourth subsection can include capacity, reliability, accessibility, efficiency, ability to withstand loads, integrity and robustness.

In the guidelines, there is a note that barriers can *also* be measures designed to prevent or limit the spread of an acute pollution. The definition of a barrier in the regulations does not mention major accidents explicitly, but it says that the barriers shall reduce the probabilities *of failures and hazard accident situations* to develop. Barriers can also be either physical or non-physical.

The AR also sets requirements for well barriers. A requirement is e.g. independence and that activities shall not be carried out if a barrier fails, except from the restoration of the failed barrier. When the wells are handed over, the barrier status will be tested, verified and documented.

#### 4.1.4.1 SAFETY SYSTEMS

The FR includes regulations and requirements regarding safety systems and safety functions. The safety functions shall be defined so that safety for personnel is ensured and pollution is limited.

In section 3, FR, a safety functions is defined as:

Physical measures that reduce the probability of a hazard and accident situation occurring, or that limit the consequence of an accident

In the same section, a safety system is defined as:

A system that realises one or more active safety functions

The regulations are hence mentioning *both* safety systems and barriers. The separation between safety function and safety system parallels the classification defined by Hollnagel (2006) concerning barrier systems and barrier functions. In section 7, FR, the main safety functions are regulated. It says that they should be defined in a clear manner for each individual facility so that personnel safety is ensured and pollution is limited. Section 8, FR, says that requirements shall be stipulated for the performance of safety functions and the status of active safety functions shall be available in the central control room. This is more or less the same requirement that is given for the barriers and handles both safety for personnel and the external environment.

#### 4.1.4.2 ENVIRONMENTAL BARRIERS

The environmental aspect can be found in several places in PSA's regulations and the concept "safety" includes personal safety, working environment, assets and external environment<sup>10</sup>. However, there is not a clear distinction between safety and environmental barriers. Often, health, environment and safety are mentioned as a whole and that measures shall be taken with regards to these three aspects. Major accidents and risk of pollution are sometimes mentioned at the same time and then distinguished. E.g., in section 4, FR, both major accidents and risk of pollution shall be considered when choosing a development concept.

Section 5 in the MR says that barriers also can be measures to prevent pollution. Further, in the FR, Chapter V handles physical barriers. In this chapter, emergency shutdown systems are included, which protects from both loss of lives and pollution of the environment. In addition, requirements for open drainage systems that can divert oil and chemicals to reduce the risk of fire, harm to personnel and pollution are stipulated. If there is a discharge, this should lead to the least possible pollution of the marine environment. This barrier should be designed so that it fulfils the requirements in AR, chapter XI, emissions and discharges to the external environment. Here, section 60 sets requirements for discharge of oily water. This section refers to all discharges that occur during the daily activities and refers to the Pollution Control Act.

In section 17, MR, about risk analyses and emergency preparedness assessments, it says that risk analyses shall be carried out and form part of the basis for making decisions. It shall be done when e.g. identifying the need for and function of necessary barriers and also to help identify specific performance requirements of barrier functions and barrier elements. This also includes which accident loads that are to be used as a basis for designing and operating the installation/facility and systems and/or equipment. In the guidelines to the section information regarding environmental risk analyses that should be taken into account for the specific site is described.

An aspect to be considered is how a conflict between environmental and safety barriers will be handled. In the guidelines to section 1, the FrR (purpose) it is said that:

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<sup>10</sup> Consultant Ellen Kristine Ombler, DNV GL, interview 27/2 2014



Measures implemented in one of these areas will normally also have a positive effect on the other areas. To the extent measures would be in conflict, the consideration for human life and health shall prevail.

Hence, if there is a conflict between e.g. environment and safety for human lives, human life should always be prioritised.

#### 4.1.4.3 DOCUMENTATION

The only reference to documentation is done in section 5, MR. The section states that there should be strategies and principles that form the basis for design, use and maintenance of barriers to make sure that the barriers' function is safeguarded over the lifetime of the barrier. Section 6, MR, regulates management systems with regards to health, safety and the environment but there is no reference to barriers.

#### 4.1.5 REQUIREMENTS

The requirements regarding barriers are described in section 4.1.4. The requirements can be reached with help from the standards referred to in the guidelines to the regulations.

##### 4.1.5.1 STANDARDS

To help the users of the regulations to fulfil the requirements, PSA's regulations refer to a number of standards. Regarding environmental aspects, there is only one standard that explicitly describes how work should be conducted, the NORSOK S-003, Environmental care standard. The standard is a guideline that applies to field development, design, construction, installation, modification and decommissioning of installations for offshore drilling, production and transportation of petroleum. Specifically, one section describes the requirements for acute discharges and barriers. Requirements are e.g. that there should be two physical barriers in loading/unloading lines and pits and that the valves connected to the closed drain system shall be designed so that the open/closed position can easily be opened in cold freezing weather.

Other standards, such as IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety-related systems (general requirements)) do not mention environment explicitly, but the scope of the standard covers safety systems, which failure could have an impact on the safety of personnel and/or the environment. The following standards of relevance for drilling, well maintenance and subsea production operations have requirements for safety barriers that also have importance for environmental consequences:

- NORSOK S-001 Technical safety
- NORSOK D-001 Drilling facilities
- NORSOK D-002 System Requirements Well Intervention
- NORSOK D-010 Well integrity of drilling and well operations
- NORSOK Z-013 Risk and emergency preparedness assessment
- OLF Guideline 070 Guidelines for the application of IEC 61508 and IEC 61511 in the petroleum activities on the continental shelf
- IEC 61508 Functional safety of electrical/electronic/programmable electronic safety related systems
- ISO 13628 Petroleum and natural gas industries- design and operation of subsea production systems
- ISO 13624 Petroleum and natural gas industries- drilling and production equipment
- ISO 10417 Petroleum and natural gas industries-subsurface safety valve systems-Design, installation, operation and redress.

## 4.2 REVIEW OF THE EU DIRECTIVE 2013/30/EU

### 4.2.1 PURPOSE

The EU directive focuses on how to prevent and mitigate consequences of a major accident. The directive was established after the tragic accident at the Macondo field (referred to in the directive as Deepwater Horizon) and explicitly includes environmental critical elements in addition to safety critical elements. The directive also includes other aspects concerning the major accident prevention, e.g. emergency response and sharing of accident data.

As mentioned, an EU directive stipulates the goals that the member states shall reach, but the member states themselves decide *how* the goals shall be reached. To fulfil the directive, European and international standards can be used. The directive includes all activities associated with an installation or connected infrastructure including design, planning construction, operation and decommissioning thereof, relating to exploration and production of oil or gas.

The directive mainly refers to the “Member state” and operators when mentioning the party that shall ensure that the petroleum activities are carried out in a safe manner. It is the responsibility of the member state to require operators to ensure that all suitable measures are taken to prevent major accidents, article 3, section 1.

### 4.2.2 RISK REDUCTION

With regards to risk reduction, section 14 in the directive introduction says that:

Operators should reduce the risk of a major accident as low as reasonably practicable, to the point where the cost of further risk reduction would be grossly disproportionate to the benefits of such reduction.

Hence, the operators should reduce the risk according to the ALARP principle.

### 4.2.3 MAJOR ACCIDENTS

A major accident is defined in article 2, section 1:

‘major accident’ means, in relation to an installation or connected infrastructure:

- a) An incident involving an explosion, fire, loss of well control, or release of oil, gas or dangerous substances involving, or with a significant potential to cause, fatalities or serious personal injury;
- b) An incident leading to serious damage to the installation or connected infrastructure involving, or with a significant potential to cause, fatalities or serious personal injury;
- c) Any other incident leading to fatalities or serious injury to five or more persons who are in the offshore installation where the source of danger occurs or who are engaged in an offshore oil and gas operation in connection with the installation or connected infrastructure; or
- d) Any major environmental incident resulting from incidents referred to in points a,b, and c.

### 4.2.4 SAFETY AND ENVIRONMENTAL CRITICAL ELEMENTS

There is no definition of a barrier, however, safety and environmental critical elements are defined in article 2, section 33:

‘Safety and environmental critical elements’ means parts of an installation, including computer programmes, the purpose of which is to prevent or limit the consequences of a major accident, or the failure of which could cause or contribute substantially to a major accident;

The expressions SCE and ECE are used throughout the directive but there is no clear classification of the elements as e.g. technical, operational or organisational.

#### 4.2.4.1 DOCUMENTATION

To receive permission to execute offshore oil and gas operations, the directive requires a document called “major hazard report” to be submitted, Article 11 (1). The member state has the responsibility to make sure that the operator writes this document and it shall be submitted both for production facilities and non-production facilities. The document shall include:

- A description of the installation and any association with other installations or connected infrastructure including wells
- A demonstration that all the major hazards have been identified together with their likelihood and consequences.
- A description of the environmental, meteorological and seabed limitations on safe operations and the measures, including safety and environmental critical elements, to ensure that the risk of major accidents is as low as possible.
- A description of the equipment and arrangements to ensure well control, process safety, containment of hazardous substances, prevention of fire and explosion, protection of the workers from hazardous substances, and protection of the environment from an incipient major accident.
- Information about standards, codes and guidance used
- The operator’s safety and environmental management systems
- Prevention of damage of the environment as a consequence of a major accident due to operations that have been conducted on the installation.
- An assessment of the identified potential environmental effects resulting from the loss of containment of pollutants arising from a major accident and a description of the technical and non-technical measures that are used to prevent, reduce or offset them, including monitoring.

For the non-production installations, there should also be a description of the plant and arrangements to ensure well control, process safety, containment of hazardous substances, prevention of fire and explosion, protection of the workers from hazardous substances, and protection of the environment from a major accident.

#### 4.2.5 REQUIREMENTS

Contrary to PSA’s regulations, no specific standards are referred to, but it is described that the requirements shall be fulfilled with help from standards.

### 4.3 SIMILARITIES AND DIFFERENCES BETWEEN THE PSA REGULATIONS AND THE EU-DIRECTIVE

PSA’s regulations and the EU directive have many similarities. Given the differing regulatory regimes, the main aspects identified are regarded as differences in regulatory formulation, despite a common overall goal.

#### 4.3.1 PURPOSE

The PSA regulations apply to all types accidents, both smaller and major accidents related to both personnel and the environment, whereas the EU directive focuses on how to avoid major accidents with help from the identification of safety and environmental critical elements. PSA’s regulations cover a wider scope since it includes daily HSE work.

#### 4.3.1.1 COVERED ACTIVITIES AND ACCIDENTS

The PSA regulations apply to all activities associated with the oil and gas industry, i.e. exploration, exploration drilling, production, transportation, utilisation and decommissioning and planning of the activities. The EU directive includes all activities associated with an installation or connected infrastructure including design, planning construction, operation and decommissioning thereof, relating to exploration and production of oil or gas. With other words, PSA's regulations and the EU directive hold for the same activities.

#### 4.3.2 RISK REDUCTION

Both the directive and PSA's regulation use the ALARP principle regarding risk reduction. The ALARP principle is widely applied in safety decision-making and requires that those, who are responsible for the safety, reduce the risk to a level that is acceptable (Jones-Lee & Aven, 2011). This way of viewing risk is widely used but interpretations may vary between countries (Jones-Lee & Aven (2011) mentions e.g. UK and the Netherlands) and therefore, might cause different risk reducing measures in practice. Using the ALARP principle for risk reduction will affect how the requirements for the barriers are set compared to if the regulator would set a fixed acceptable level. The ALARP principle requires the responsible party to have a clear picture of the risks and evaluate to what extent the risk can be reduced and includes both the aspect of safety for personnel and the environment.

#### 4.3.3 MAJOR ACCIDENT

There are a few differences in the regulations concerning the definition of a major accident. E.g. does the directive quantify the number of fatalities to five whereas the regulation from PSA only says serious personal injury and/or loss of human lives. For the environment, both PSA and the directive say serious harm to the environment, hence there is no quantification. The definition in the EU directive also includes accidents that can *lead* to a major accident. The range of the consequences will influence which hazards that will be regarded as major risk hazards which will influence which parts of the equipment that will be regarded as barriers and SCE/ECE (to prevent major accidents)<sup>11</sup>. In PSA's definition, a major accident can be an accident that only has environmental consequences, whereas the definition in the directive only says that a major accident can be an environmental incident that is a result from incidents where asset and humans are hurt or lost.

#### 4.3.4 BARRIER AND SAFETY AND ENVIRONMENTAL CRITICAL ELEMENT

In PSA's regulations, a barrier shall be established to reduce the probability of failures and hazards and accident situations developing and also to limit possible harm and disadvantages. The SCE and ECE in the directive are elements that are parts of an installation that have the purpose to limit or reduce the consequences of a major accident, or the failure that could contribute to a major accident. The barrier concept does not, in PSA's regulations, refer to major accidents, which the SCE and ECE explicitly focus on. However, in practice this is mainly how the barriers are used<sup>12</sup>. Another aspect that differs is that the barrier concept includes technical, operational and organisational aspects while the SCE/ECE concept only focuses on technical aspects.

The directive refers to safety and environmental critical elements (SCE/ECE) whereas PSA's regulations use the term barriers. The term SCE originates from the UK Offshore Installations regulations 2005 (Øie, Wahlstrøm, Fløtaker, & Rørkjær, 2014). The regulations state that a record of SCE shall be established for hazards with the potential to cause a major accident. In the industry there are discussions concerning the relation between a barrier and a SCE. Usually, the lists of SCEs consist of safety systems that also have subsystems and sub-elements that can be compared to the barriers on the Norwegian Continental Shelf. The lists can also contain measures that are more relevant to occupational safety, which might cause confusion when comparing to the barrier elements for major accidents. However, a barrier or SCE shall be

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<sup>11</sup> Senior consultant Sondre Øie, DNV GL, interview 27/2 2014

<sup>12</sup> Principal consultant Anne Marie Wahlstrøm, DNV GL, interview 27/2 2014

identified through a structured process, e.g. bowtie analysis and not from a generic list. The definition of a SCE includes that the element is related to a major accident and thus, the barrier concept in PSA's regulations and the SCE/ECE in the directive can be considered the same. However, the different terminology (barrier/SCE) might cause confusion if using the different words in the same context.

The PSA regulations also refer to safety systems. This part is left from older regulations<sup>13</sup> and causes confusion for those who have to comply with the current regulations<sup>14</sup>. To use both safety functions and barriers might complicate the work with barriers, both concerning safety for personnel and environmental safety.

#### 4.3.4.1 DOCUMENTATION

To carry out offshore operations, the directive requires a report on major hazards. The major hazard report originates from the safety case that is a part of the UK regulations (Leirgulen, 2013). The safety case is required according to the Offshore installations (safety case) Regulations 2005, which aim to reduce the risk of major accident hazards on offshore installations with regards to health and safety (Health and Safety Executive, 2006). The regulations require the duty holders to identify, and effectively manage, the SCEs on their installations. The safety case e.g. needs to include details of the systems on board the unit, which are considered safety critical, summarise the safety management system, detail the risk assessment process completed to identify and reduce the frequency and consequences of major hazards and detail the emergency procedures and systems. In the major hazard report that the directive requires, ECEs also need to be included.

This document can be compared to the management of barriers in Norway<sup>15</sup>. However, the barrier management system and documentation is not explicitly mentioned in PSA's regulations. Section 5 in the MR requires that strategies and principles shall be stipulated, which can be compared to the major accident report, when assuming that the barriers are used to prevent from major accidents.

#### 4.3.5 REQUIREMENTS

To fulfil the requirements, both the PSA regulations and the EU directive refer to standards. In the guidelines to the PSA regulations, specific NORSOK and ISO standards etc. are referred to. These standards include technical requirements to the equipment. The EU directive refers to standards, but does not specify which standards shall be used.

#### 4.3.6 SUMMARY

The main difference between the PSA regulations and the EU directive is that the directive focuses only on major accidents, whereas PSA's regulations focus both on smaller and major accidents. The terms barrier and SCE/ECE might be more or less synonymous when looking at their definitions, but due to the different focus in the regulations, barriers might also be identified for accidents that do not cause major accidents. Also, the requirement to conclude a major accident report differs from PSA's regulations. The differences between the requirements regarding barriers, SCE and ECE in the EU directive and the PSA regulations are not, by the author, considered as major. The main difference is that ECE are mentioned explicitly in the EU directive whilst barriers are mentioned on a general level in the PSA regulations.

The critical elements can be used in the same way as a barrier when talking about major accidents. Hence, when working with barrier management, there should be focus also on determining the ECE as the SCE (or safety and environmental barriers) if the requirements in the EU directive shall be met. Because of this, it is valuable to have a clear picture of what is included in the concept major accident and environmental consequences.

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<sup>13</sup> Einar Ravnås and Asbjørn Ueland, PSA, interview 11/3 2014

<sup>14</sup> Consultant Ellen Kristine Omblør, DNV GL, interview 26/2 2014

<sup>15</sup> Head of Section Asset Risk Management Atle Stokke, DNV GL, interview 27/3 2014

If the directive would be implemented in the Norwegian legislation, the requirements regarding establishing a major accident report would be needed. Harris and Johnsen (2012) compared the UK Safety Case and Norwegian regulations to investigate to what extent the Norwegian regulations represent the same safety standards as the Safety Case. The study was conducted on behalf of Shell and focused on mobile offshore drilling units and safety for personnel, and it was concluded that there were no major differences that adventure the safety. Some of the differences, e.g. that the UK uses SCE and Norwegian regulations use barriers, were thought to be considered but not seen as a major source of risk. Since the directive is, to a large extent, based on the British legislation, an analogue reasoning can be done and the major difference between PSA's regulations and the new EU directive is the use of ECE. However, to get a better understanding whether the difference changes the risk picture, a deeper investigation than the one done in this thesis is necessary.

An aspect that was not part of the review but still regarded as relevant to note, is that the EU directive has a focus specifically on the Arctic waters. The Arctic waters is an area that is a hot topic today with regards to oil and gas production. They are a neighbouring marine environment that is of particular importance for the Union and the area plays an important role in mitigating climate change. The section (52) emphasise that the Arctic waters require special attention to ensure the environmental protection of the area in relation to any offshore and gas operation, including exploration. One challenge in the arctic is e.g. response to a major accident due to ice, darkness and low temperatures (Brundtland, 2014). The arctic is not explicitly mentioned in the PSA regulations, but the topic was discussed during the interviews and PSA is investigating what challenges that need to be met and how these should be handled<sup>16</sup>.

To sum up, the major difference is the clear focus on the ECE that cannot be found in the Norwegian regulations. The Norwegian industry needs to comply with PSA's regulations that include the environmental aspect. To meet the requirements in the EU directive, the Norwegian industry would need to also explicitly focus on the environmental barriers. To make sure what an ECE actually is, the definition of a major accident should rather be the main focus. This is further discussed in section 5.1.

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<sup>16</sup> Einar Ravnås and Asbjørn Ueland, PSA, interview 11/3 2014

#### 4.4 INTERPRETATION AND IMPLEMENTATION IN PRACTICE

Below, the result from the interviews is presented. The result presentation is structured with help from the overall topics from the interview guide. The topic regarding barrier management is further divided into subsections based on the how-questions regarding barrier management in the interview guide (Appendix 1). First, the answers from the five companies are presented. These are followed by the opinions of the consultants at DNV GL and PSA. Each section is followed by an analysis where the result from the interviews is linked to the literature study and the author's own reflections. The aim with the analysis is to understand how PSA's regulations, with regards to barriers in general and environmental barriers specifically, are understood and implemented in practice, and to compare this to recommendations from the literature.

To further find information about how the companies comply with the regulations, audit reports were studied. Information was found regarding environmental barriers and awareness of barriers. The result from the audit reports is presented together with the result from the interviews. Table 3 shows a summary of the result from the interviews.

**Table 3 . Summary of the result from the interviews.**

	Answers from the interviews	DNV GL	PSA	Comments
<b>Major accident</b>	<ul style="list-style-type: none"> <li>-All companies include human life, environment and assets in their definitions. Two of the companies quantify the number of fatalities to five, but none quantifies the consequences on the environment.</li> <li>-Three of the companies say that it is hard to know what a major accident with regards to the environment is.</li> </ul>	The definition is not clear enough and it can be confusing for the industry since more than one definition can be found at PSA's website.	Refers to section 9, MR	It is hard to define what a major accident with regards to the environment is. This might make it harder to identify the environmental barriers.
<b>Barriers</b>	<ul style="list-style-type: none"> <li>-All of the companies except from one use PSA's definition, which includes technical, operational and organisational barrier elements..</li> <li>-Many of the interviewees mention that it can be hard to differ between operational and organisational barriers.</li> <li>-Barriers are used for all types of accidents but focus on major accidents.</li> <li>-The company that does not use PSA's has a definition of technical, operational and organisational barriers.</li> </ul>	Says that PSA makes it difficult for the industry. Hard to interpret operational and organisational barriers.	Refers to section 5, MR	Players know what a barrier is, but the concepts of operational and organisational seem to be confusing. It is harder to set requirements to monitor and follow up for these groups.
<b>Barrier management</b> <i>The execution of barrier management</i>	<ul style="list-style-type: none"> <li>-Risk analysis is done continuously during the design phase with personnel from different parts of the organisation.</li> <li>-NORSOK D-010 is mainly used to fulfil the requirements for drilling.</li> <li>-Two companies mention that the barrier strategy is implemented in the maintenance system and one of them says that that the link between major accidents and barriers is unclear and that there are no clear guidelines.</li> </ul>	Says that it is hard for the companies to use e.g. risk analysis and bow ties in the operational phase.	<ul style="list-style-type: none"> <li>-Refers to the document "Principles for barrier management in the petroleum industry". Has experienced that the regulations are hard for the industry to comply with.</li> <li>-Good technical solutions shall be used. PSA says that it is hard for some companies to see the link to the maintenance system.</li> </ul>	The companies have developed strategies, but the challenge is to implement and maintain these during the daily operations.
<b>Barrier management</b> <i>Documentation</i>	<ul style="list-style-type: none"> <li>-Differs, one company keeps the information about barriers in the drilling program and another has a main register with information about risk analyses and barriers.</li> <li>-Three companies have implemented only the barrier strategy in the maintenance program.</li> </ul>	Would be good if PSA set requirements for documentation during design phase that can follow the equipment to the operational phase. The companies that have seen the connection between maintenance and barriers have succeeded with barrier management.	Documentation can be a problem since a lot of the equipment is produced abroad which can make it hard for the operators to get an overview.	Documenting the assurance activities with the maintenance program seems to be an efficient strategy.
<b>Barrier management</b> <i>Assuring the status of the barrier</i>	<ul style="list-style-type: none"> <li>-One of the companies says that the status of barriers is assured through operation offshore.</li> <li>-Three of the companies say that the assurance activities are implemented in the maintenance program.</li> <li>-One of the companies says that they update the barrier strategy at least every 5<sup>th</sup> year. The status of the barriers is assured through verification activities.</li> </ul>	<ul style="list-style-type: none"> <li>-Again, those who have implemented the assurance activities in the maintenance program have a good overview.</li> <li>-Issue with internal verifications: tester and maintainer is the same person.</li> <li>-DNV GL also argues that the assurance of the operational and organisational barriers can be hard since the requirements can be hard to understand.</li> </ul>	No information	Many of the companies explain that the assurance of the operational and organisational barriers is hard. The companies try to combine the assurance activities with the maintenance work.



<b>Barrier management Responsibility</b>	<ul style="list-style-type: none"> <li>-One company says that it is not common to have a person who is explicitly responsible for the barriers.</li> <li>-Usually the drilling engineer in the planning phase and the drilling leader during operations in the rig.</li> <li>-One company has divided the responsibility into three units; technical, operational and organisational.</li> <li>-One company has the responsible persons within the HSE and technical department and one has given the responsibility to the technical manager.</li> </ul>	<p>Not common with one responsible person. Responsibility is often divided between HSE and technical departments. Only having HSE as responsible might cause problems since they usually do not have the technical insight.</p>	<p>Says that it is common that the responsibility is divided between technical, operational and organisational units. The most important thing is to assure that there is a link between the risks and the barriers which needs to be spread from the management.</p>	<p>Some companies use the technical managers and some the HSE section. According to DNV GL it is important to have the technical understanding with regards to barriers.</p>
<b>Barrier management Awareness of barriers</b>	<ul style="list-style-type: none"> <li>-One company says that the awareness differs depending on the leaders on the rigs and another company tries to increase the awareness and "barrier-thinking" through observation and reporting.</li> <li>-Two companies make the barrier management public by activating everyone in the process and give people ownership. The companies also produce literature and trainings to increase the awareness. One of them implements the barrier strategy into the governing documents.</li> <li>-Another company holds courses for personnel. The course is also given to new personnel within a certain time after the first day.</li> </ul>	<p>Challenge to spread the understanding of what a barrier shall do and what hazards it controls.</p>	<p>Hard for the industry to understand how different barrier functions interact. Room for improvements regarding how the barriers are understood throughout the organisations.</p>	<p>The difficulty is to spread the information and use the result from the bow ties and risk analyses in the operational work. The companies try to do this through different awareness raising activities.</p>
<b>Environmental barriers</b>	<ul style="list-style-type: none"> <li>-All companies say that the safety barriers cover also environmental risks and that it is hard to find events that only have environmental consequences. Two of the companies say that identifying environmental critical elements could mean that the focus on environment would increase.</li> <li>-Only two companies could answer how the environmental risk acceptance criteria are set.</li> <li>-Only one of the companies says that the regulations are clear and that specific environmental barriers are identified.</li> <li>-The fourth and fifth company argue that the focus is not specifically on environment of safety but on all possible hazards.</li> </ul>	<ul style="list-style-type: none"> <li>-The safety barriers cover also environmental consequences.</li> <li>-If there is a conflict between the environmental and safety barriers, some kind of investigation needs to be done.</li> </ul>	<ul style="list-style-type: none"> <li>-The safety barriers cover also environmental consequences.</li> <li>-PSA does not treat environment as its own area. The ministry of Climate and Environment has the main responsibility but does also mention that the legislations align.</li> </ul>	<ul style="list-style-type: none"> <li>-Many of the companies argue that the safety barriers also apply for environmental consequences.</li> <li>-The environmental risk acceptance criteria can be hard to decide since it needs to be site specific.</li> <li>-Many of the companies have had internal discussion with regards to environmental critical elements and also PSA says that it is a subject that is discussed more and more.</li> </ul>
<b>Legislation</b>	<p>Some believe that it is very clear while some say that it is open to interpretation. Many of the companies seem to be satisfied with PSA's approach.</p>	<p>The companies do not fully understand what they are supposed to do and why. Especially the definition of a major accident is hard to interpret.</p>	<p>Understand that is sometimes can be confusing since barriers are described in one section and safety systems in another.</p>	<p>Many of the companies are satisfied with the legislation but some say that the requirements regarding environment are unclear.</p>
<b>Emergency preparedness</b>	<p>All of the companies say that they have clear preparedness plans and trainings every week.</p>	<ul style="list-style-type: none"> <li>-Exercises are not always based on scenarios, which makes it hard for the employees to act correctly when there is a real accident.</li> <li>-The legislation is not good enough.</li> </ul>	<p>Not discussed during interview.</p>	<p>DNV GL and the companies have different views of how the well prepared the operators are.</p>

#### 4.4.1 MAJOR ACCIDENT

##### 4.4.1.1 INDUSTRY

All companies include environment and assets in their definition of a major accident, and mention that it is hard to know what a major accident, only with regards to the environment is. One of the companies explains that they use a risk matrix to define the amount of release that classifies the accident as a major hazard.

One interviewee explains that PSA's definition applies for very severe accidents but the company uses also the expression major accidents for smaller, but still severe, accidents. The part that includes a spill of hydrocarbons is not quantified. Two of the companies quantify the number of lost lives to 5, and refer to SINTEF and the UK safety case regulations. Those that do not use the quantification as SINTEF does, refer to the definition by PSA.

One of the interviewees believes that the organisation Norsk Olje og Gass should define what the companies should measure when monitoring the major accidents and that there should be a difference between a fixed installation and a mobile unit. The industry does not differ between these and many of the companies have tried to figure out what they actually need to measure to try to avoid major accidents. The interviewee also mentions that there has been a survey regarding how smaller oil companies define and monitor major accidents and it was shown that everyone had their own definition. If the information from the different companies was collected, a best practice could have been developed.

##### 4.4.1.2 DNV GL

During the interviews with personnel at DNV GL, the interviewees said that the definition of a major accident is diffuse. They experience that it might be hard for the companies to know which definition to use and also to decide the range of the definition.

*“The definitions of a major accident are vague and it is hard for the operators to work with them. The fact that also NORSOK has a definition makes it even more complicated”*

The interviewees believe that the definition should include a description of the events that can lead to a major accident and not only the consequences. One of the interviewees says that confusion can be caused since many of those working at the installations are used to the concept of occupational accidents and it is important to understand the difference between these accidents and major accidents. The interviewee continues to say that it would be useful if the definition of a major accident included the underlying causes as for example the failure of barriers.

##### 4.4.1.3 PSA

The interviewees from PSA refer to section 9, MR and say that the quantification of e.g. how many lives that should be lost or the volume of released hydrocarbons shall be decided by the operator themselves.

##### 4.4.1.4 ANALYSIS

Many of the interviewees refer to PSA or SINTEF when defining a major accident. However, it seems as there is confusion of what a major accident is with regards to the environment. PSA argues that the definition has to be interpreted by each player so that the specific risks can be mapped and handled.

The definition that PSA suggests involves aspects that are common in the definition of a major accident, e.g. that the incident is acute and what the incident could be (cf. Okoh & Haugen (2013)). Further, it involves the aspect of damage or loss of life, environment and assets. Not knowing what a major accident is can make it harder to comply with the regulations regarding barriers. The requirements for the barriers, and if equipment actually is a barrier, will be identified when the potential hazards and accidents have

been identified. Since the consequences on the environment differ depending on where the accident takes place, it would probably not be useful to quantify the volume of spilled oil, but rather the restitution time (Hauge et al, 2011). The question would rather be if it is useful to quantify the consequences instead of letting the players examine what would be a major accident in the specific area where they operate. Not quantifying could mean that the players become more involved during the process of deciding the limit for a major accident, but it could also mean that e.g. lack of time or knowledge make the result misleading and instead increases the environmental risk.

Two of the companies argue that the definition of a major accident not only refers to loss of lives or very severe consequences on assets and environment. Hence, these companies have chosen to have a wide range for their definition of a major accident and the work that is required to avoid major accidents will also be done to prevent “smaller” accidents. It was not mentioned if the definition is also used for occupational accidents, but this could be included in “smaller accidents”. It is of importance to divide the occupational, smaller and major accidents, since they usually originate from different sources, which also is the general way of handling the different accidents (Gnoni & Bragatto, 2013). The issue might not be that barriers are used to prevent both the major accidents and occupational accidents, but rather the way of thinking about how the different types of accidents need to be prevented and mitigated. Hence, using the same way of thinking for different types of accidents might result in that hazards are not properly prevented. If including in the definition of a major accident that the underlying causes are of complex nature, maybe there would be an increased insight into the different courses of events that causes major and smaller accidents. This could facilitate how the preventive work is performed and increase the level of safety for personnel, environment and assets.

When examining why barriers have failed with regards to well operations and drilling, increased complexity is often found to be a common denominator (Tinmannsvik, et al., 2011). The complexity can be of both technical and organisational character, due to technological advances with regards to deeper wells and more complex reservoirs as well as a large number of involved actors who must interact and frequent reorganisations. Lessons have been learned e.g. after the Macondo accident and focus should be shifted to this topic when talking about major accidents. Also, this is something that needs to be spread throughout the entire organisation and not just be information or a mind-set that the management has.

During the interviews, the interviewees often referred to blowouts as a major accident. A blowout seems to be the typical major accident with consequences on the environment. The definition that can be found in the regulations says that a major accident can be an acute incident with serious harm to the environment, which can be caused by more accidents than a blowout. If not considering also these accidents, the safety level could decrease. However, for a drilling facility, which is the focus in the thesis, this might be the most relevant hazard which could be a reason to why this is mainly mentioned by the interviewees.

#### 4.4.2 BARRIER

##### 4.4.2.1 INDUSTRY

Regarding the definition of a barrier, many of the companies use the description in section 5, MR. All companies say that their definition includes the technical, operational and organisational elements.

One of the interviewees says that it is relatively easy to identify the technical barriers. The operational barriers are more about the procedures e.g. management systems and the organisational are about the relevant competence and the ability of the organisation to give the personnel the relevant competence. The interviewee explains that the organisational elements create a foundation for the performance of the personnel, but that the concepts can be confusing.

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· The time needed for a resource to return to its original state after being affected by a pollution (Hauge et al, 2011).

*“It can be hard to differ and identify the operational and organisational barriers; an organisational barrier could e.g. also be the working environment.”*

In this company, barriers are used as a concept to avoid all hazardous events. However, those that get the most focus are those that are connected to major accidents. Another company claims that the organisational and operational barriers can be people or barriers from the management system.

The fifth company uses the definition used by the Norwegian ship-owners association, for which DNV GL has published a document with good practices for barrier management. The definition is “Barriers refer to measures established with an explicit purpose to (1) prevent a hazard from being realized, or (2) to mitigate the effects of a hazardous event.” (Øie, Wahlstrøm, Fløtaker, & Rørkjær, 2014). Further, the company has their own definition of technical, operational and organisational barriers. The organisational barriers are defined as management systems. The operational barriers are the tasks that shall be performed by an employee.

#### 4.4.2.2 DNV GL

Regarding the definition of a barrier, the consultants at DNV GL mention that PSA sometimes makes it difficult for the industry.

*“PSA defines too much as a barrier when they say that a barrier can be technical, operational or organisational”*

The interviewee believes that the industry get too much work when starting to work with the barrier strategies and it might have been easier and more efficient if PSA started with the technical and operational aspects.

The consultants at DNV GL experience that not all the companies are aware of the definition of a barrier, which makes the work hard since the way a barrier is defined will influence how it is identified. Further, the way that the barrier is identified will influence how it is followed up.

The interviewees say that there has been a lot of discussion about what an organisational barrier is and it is mentioned that PSA said that management of change is barrier since it has a risk reducing effect. However, the interviewee argues that a barrier should control a specific hazard and if it is not known which hazard that is controlled, is it then a barrier and how should it (the barrier) be controlled? The operational barriers are based on a task, e.g. the procedure when activating a system. Activating a certain system includes understanding why the system shall be activated and when to activate it.

Requirements can be set to competence but it is then important to specify the competence for a certain task and not competence generally. The interviewee experiences that it is mainly PSA and the consultants that are aware of this and that the regulations are too general in this area. The document conducted by PSA called “Principles for barrier management in the petroleum industry” (PSA, 2013b) is often used in the drilling industry but the interviewee thinks that it might be an idea with a standard for barrier management that could function as a bridge between maintenance and technical safety.

#### 4.4.2.3 PSA

For the definition of a barrier, PSA refers to the regulations, sections 4 and 5, MR. PSA has definitions of technical, operational and organisational barriers and especially the operational and organisational are discussed. The organisational barrier elements are the personnel that have a defined role as a part of realising the function of the barrier. E.g. procedures or policies are not organisational barriers themselves but a part of the barrier element. Also, competence is a barrier element but using it is another. The organisational barrier is the person performing a certain activity and the activity is an operational barrier.

This part is something that PSA works with together with the industry to enhance the implementation of the barrier management.

#### 4.4.2.4 AUDIT REPORTS

With regards to barriers and major accidents, one of the audit reports that was based on the requirements in section 4 and 5, MR (risk reduction and barriers) was looking at follow-up and operation of equipment that can lead to acute spills (PSA, 2012b). Equipment that was referred to was e.g. drainage system, mud tanks and drilling equipment. Hence, major accidents were not mentioned even if the regulations that focus on barriers were the main focus. Thus, it seems as PSA include more equipment in the barrier concept than those only relevant to major accidents.

#### 4.4.2.5 ANALYSIS

The interviewees define a barrier as a measure to prevent or limit consequences of a hazard or accident, which also is how it is described in the literature. It does not seem as a problem to understand the idea of a barrier, but rather how the different types of barriers are defined. PSA describes the barriers as technical, operational and organisational, which corresponds to how Hollnagel (2006) describes how barriers can be classified, with some exceptions to how the organisational barrier is defined. How the different barriers can be identified, or how the barriers identified can be divided into technical, operational or organisational is not described in the regulations and also seems to be something that PSA itself struggles to define. The organisational aspect is important (and further discussed below) but the interviewee at DNV GL says that focusing on all three aspects from the beginning might lead to missing important aspects and also the company's lack of full control.

At least according to the author, it is hard to find good definitions of organisational and operational barriers that the industry can use. Most of the companies seem to agree on the technical barriers and that the operational barriers are specific tasks. But, with regards to the organisational, some refer to it as Hollnagel (as e.g. rules, guidelines and management systems) while others, e.g. PSA, argue that the organisational barriers are the personnel that perform the task. The confusion might also lead to difficulties when describing the requirements to these barriers. With regards to the requirements mentioned in section 3.4.4, it is probably quite straight forward to set requirements to technical. The requirements are important to ensure the performance of the barrier and unclear definitions might lead to unclear requirements, which might adventure the level of safety for both personnel and the environment.

The organisational aspect is important since it is a foundation for the safety culture, which sets the tone for safety in a company (Blair, 2013). Accident investigations report that lack of safety culture played an important role in causing an accident, e.g. the Macondo accident. There seems to be a problem with regards to how it should be interpreted when it comes to barriers and also to find indicators to measure the performance of the barrier. DNV GL and PSA claim that an organisational barrier is the personnel who perform a task and aspects such as competence are rather performance shaping factors that influence the barrier. The safety culture is important for both personnel and the environment, but it might be too complex in practice to consider it as a barrier, when thinking about the requirements to measure and monitor barriers. Barriers are not the only way a major accident can be prevented and the point is then that not all aspects need to be covered by the barrier concept. I.e., the organisational aspects shall be prioritised to decrease the level of risk, but might not fit in to the barrier management strategy as it is defined by PSA today.

During the interviews, it was discussed whether the companies use the barrier concept only with regards to major accidents or not. There is no common approach and PSA explains that when the work with barrier management started, the main focus was on major accidents but now the concept is widened to all accidents. Furthermore, the regulations do not mention major accident explicitly when regulating barriers. The guidelines to section 5, MR, say that barriers can also be measures to prevent or limit the spread of an

acute pollution. In the audit reports with regards to the external environment, PSA refers to sections 4 and 5 in MR (which regulate risk reduction and barriers) and examines how equipment such as drainage system and mud tanks (which are specific environmental barriers) that can lead to acute spills, are taken care of. It then seems as PSA also in the practical work focus not only on equipment that is related to safety of personnel with regards to barriers. Hence, the companies need to determine what acute pollution is and identify the barriers that prevent and limit consequences of this. However, if the concept of barriers is used for both major and occupational accidents, it should be remembered that the accidents have different causes, as discussed in section 4.4.1.4.

#### 4.4.3 WORKING WITH BARRIERS

Since this section of the presentation of the results covers more information, it is structured differently compared to the previous result sections. First, the answers from the drilling companies are presented with headings based on the questions regarding barrier management that were used during the interviews. This section is followed by the answers from PSA and DNV GL. For this topic (barrier management), some of the interviewees were not able to answer all the questions and some of the headings only have answers from a few of the companies.

Some of the companies refer to barrier strategies and policies that have been or are about to be implemented. How far the companies have come in their work with barriers seems to vary, but most of the interviewees mention that they try to involve all levels in the organisation through e.g. workshops and risk assessment. A struggle can be to actually spread the understanding of risks in relation to the barriers among those working offshore.

##### 4.4.3.1 THE EXECUTION OF BARRIER MANAGEMENT

###### 4.4.3.1.1 INDUSTRY

One of the companies mainly refers to a standard, NORSOK D-010 (Well integrity in drilling and well operations) when it comes to barrier management. The interviewee thinks that this standard is very clear regarding the barrier elements needed for the well operations. The interviewee also says that the company has management systems that are based on this standard.

In the early phase of the design and planning, risk evaluations are done continuously with help from personnel from different parts of the organisation.

*“Those who participate during the risk evaluation are a critical factor to make sure that the evaluation is well performed.”*

Management is involved in the early stages of the process, before the risk assessment becomes more detailed and requires personnel with specialised competences in maintenance. The NORSOK standards are used to fulfil the requirements from the PSA and the interviewee has not experienced that the companies have their own standards. Also, the second company describes that the barriers are identified through the risk analysis with help from personnel from different levels of the organisation.

A third company has recently received help from DNV GL to form their barrier strategy and barrier management. During the establishment of the strategy, the rig teams are involved through workshops to make them engaged in the process. It is explained what they are doing (with regards to barrier management), why it is done and what they aim to achieve. The barrier management strategy is implemented in the management system and is available for everyone.

The same company says that a bowtie analysis is used to identify the barriers for each major accident hazard. Each technical barrier element needs to achieve a certain level of performance to be effective. The requirements for each barrier element are decided with help from standards, e.g. NORSOK or DNV GL. The requirements are implemented with the maintenance system, which the company considers a major

development. The red thread goes from the identified hazards, to the bowtie analysis and then to the performance standards and maintenance program. The interviewee argues that this increases the understanding of the barriers in place against major accident hazards. However, the barrier strategy has not been used for that long, so it might be too early to make any conclusions but all indications suggest that the understanding is increasing.

A fourth interviewee says that the link between barriers and major accidents can be a little fuzzy. The company has completed a project where they developed a barrier philosophy on a company level, but the interviewee thinks that some parts of the concepts are unclear.

*“The link between barriers and major accidents can be a little fuzzy.”*

On the rig level, a barrier strategy has been put together and technical, organisational and operational performance standards have been developed. The work with barrier management starts in the design phase by outlining the overall strategy and identifying barriers and associated requirements. The documentation is then transferred to practical documentation, i.e. governing documents with guidelines that are based on the result from the design phase. The company is in the beginning of the process and experiences that there are no clear guidelines of how it should be done and it is hence up to the company to decide what and how to do it. The company uses internal requirements which are based on long experience and are sometimes more stringent and stricter than the standards. The requirements for operational and organisational barriers are usually regarding competence.

The fifth company that was interviewed says that their work with barriers starts with the risk analysis for the rig and mainly mentions the maintenance program and how the barriers are managed there. The maintenance program can help those working with barriers to prioritise which barriers they should focus on.

#### 4.4.3.1.2 DNV GL

The consultants at DNV GL experience that it is clear from PSA how the barrier management process should be carried out during the design and construction phase when identifying e.g. the hazards and risk analysis. The issue is rather how the barrier management should be performed during operation, which is not as clear. One problem is especially when new players are coming in, e.g. when a drilling operator hands a well over to an operational team from the field operator. The interviewee experiences that the handover of information and implementation of barrier management principles into operational procedures and maintenance programme often is insufficient. DNV GL argues that PSA is clear about that there should be a barrier strategy, but how it should be used is unclear.

#### 4.4.3.1.3 PSA

PSA refers to the document “Principles for barrier management in the petroleum industry” (PSA, 2013b) when talking about barrier management. PSA developed this document since they experienced that the regulations concerning barriers were hard for the industry to interpret and comply with. The interviewees refer to section 4, MR and argue that the solutions and barriers that have the greatest risk-reducing effect shall be chosen and that the requirements are met if this is done.

*“If the design of the equipment is good, the result of the barrier will also be very good”*

One of the main challenges for the operators is to understand the different risks that exist in the different areas of the facility. The challenge is to understand what the risk is and if a certain barrier should be used. A gas detector for example should be adapted for the certain area based on the risks that are identified and it is important to see the link between the risk analysis and the barriers.

Another challenge that was discussed during the interview is to find the link between the maintenance and barrier management. The interviewees have a strong belief that this is possible, but since there are

different structures and traditions in different companies, it can take time before the linking is done and it is thus hard to say anything about how it actually works today, it is still a work in progress.

The interviewees' experiences from the industry are that the operators wish to reduce the costs. Sometimes it seems as the philosophy is rather how safe can it be without using too much economic resources and how little can be used without jeopardising safety and still comply with the regulations. However, after a big event has happened, there seems to be a bigger focus on actually using the resources for good solutions.

#### 4.4.3.2 DOCUMENTATION

##### 4.4.3.2.1 INDUSTRY

The first company says that the information about barriers is documented in the drilling program. The second company explains that the information about the barriers is documented in a main register where all information from the risk analyses is gathered. The third company has chosen to implement the barrier strategy in the management system and also has incorporated the barrier strategy in the maintenance program, which also the fourth and fifth company have done.

##### 4.4.3.2.2 DNV GL

Regarding documentation, one of the interviewees says that it would be useful if PSA set requirements for this from the design phase that can follow the equipment to the operational phase. One of the interviewees claims that those companies that have seen the connection between barrier management and the maintenance system, and hence have the documentation regarding barriers there, are the companies that have succeeded with the barrier management.

##### 4.4.3.2.3 PSA

According to PSA, good documentation is necessary. This can be a challenge today since a lot of the equipment is produced abroad and during very short time.

*"It might be hard for the operator to participate in the engineering phase and influence how the barriers are designed"*

#### 4.4.3.3 ASSURING THE STATUS OF THE BARRIERS

##### 4.4.3.3.1 INDUSTRY

The first company speaks in general terms and says that the status of a barrier is assured through operation offshore. It can e.g. be that the mud<sup>1</sup> is tested during the day to make sure that it follows the required specifications. The second company says that they have established assurance activities for all requirements and implemented these activities in the maintenance program.

The third company updates the barrier strategy every 5<sup>th</sup> year if no significant changes occur. The status of the barriers is assured through verification activities. Also the fourth company has their own verification activities and says that the operational and organisational barriers are harder to assure the status of. The fourth and the fifth company have implemented the barrier strategy and assurance activities in the maintenance program together with the performance requirements.

One of the companies believes that using the maintenance system for the technical barriers results in a systematic tool where the function of the barrier is tested. The operational is more day-to-day practice and harder and more complex to monitor and measure. The organisational barriers are not hard to identify, but they can be related to procedures, which make them a bit hard and complex to measure but

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<sup>1</sup> The mud is used to control the pressure in the well to avoid a well kick that can result in a blowout (United states department of labor, n.d.).



easy to practice. The HR section assures the competence of the personnel, i.e. an employee is not sent offshore if it does not have the right competence.

#### 4.4.3.3.2 DNV GL

One of the interviewees at DNV GL argues that those who have implemented the barrier strategy into the maintenance program, has a good overview and the assurance of the status of the barriers is a part of the daily maintenance work. The interviewee mentions a problem with the internal verifications, which is that the person testing the barrier is also the person who is responsible for maintenance. This can be a problem if the verifier finds a problem on e.g. one of 50 gas detectors. The person might then fix the rest of the detectors before testing them, which can cause a misleading result. The assurance of the operational and organisational barriers can be harder to perform, since the requirements can be hard to understand.

#### 4.4.3.3.3 PSA

PSA had no specific comments regarding this topic.

#### 4.4.3.4 RESPONSIBILITY

##### 4.4.3.4.1 INDUSTRY

The first company explains that it is not common to have a person who is explicitly responsible for all of the barriers. Those that have the responsibility for the barrier management are usually the drilling engineer during the planning phase and the drilling leader during the operations on the rig. The third company has divided the responsibility for the barriers between different units that each is responsible for the technical, operational and organisational barriers. Another company has divided the responsibility between the HSE department and the technical department whereas a third company only refers to the technical manager on the rig.

##### 4.4.3.4.2 DNV GL

One of the interviewees explains that the concept of barrier management is good from a life cycle perspective but this requires a specific person to have a holistic view of the barriers. This is not common which might cause a big loss of information on the way, e.g. the information about performance standards that are established during the design phase of the equipment. In those cases where there is one responsible person, the HSE sections are responsible for the barriers, which can be challenging.

*“The HSE department has a supportive role and does not have the technical competence. The barriers are often related to technical issues on the rig which is hard to control from land”*

##### 4.4.3.4.3 PSA

PSA argues that there is a lot of focus on the equipment and that there is a need to understand how the management and facilities are linked. At the facilities it is common with people who have the responsibility for the barriers, e.g. one who has the responsibility for the technical barriers and one that has the responsibility for the operational. The most important thing is to assure that there is a link between the risks and the barriers, something that should be spread from the management to those working closest to the barriers.

#### 4.4.3.5 AWARENESS OF BARRIERS

##### 4.4.3.5.1 INDUSTRY

The interviewee at the first company experiences that the personnel on the rig is aware of some of the barriers and gives the BOP (blowout preventer) as an example, but with other barriers it can vary. The management regularly works with the understanding of risks and barriers among those working on the

rig. However, the interviewee also says that the understanding differs from rig to rig and from leader to leader.

*“Some leaders are very good at working with these kinds of questions but it is hard to know why it differs.”*

The second company has different measures such as observation and reporting to increase the barrier awareness. The third company makes the barrier management public by activating everyone in the process and giving people ownership of their HSE Cases. The company also produces literature and training to increase the understanding. To spread the information in the fourth company, workshops with participants from various areas are arranged. The information is documented in the governing documents and thus available for everyone.

One interviewee thinks that it is hard to actually use the risk assessment and bowtie analysis in the everyday work.

*“It is hard to make sure that the function of the barriers is understood and to use the risk assessment and bowtie analysis in the everyday work.”*

The challenge is also to see how the different barrier elements actually are linked to each other e.g. competence and procedures.

*“It is also hard to make sure that everyone is aware of the performance standards and acceptance criteria”*

To come around this, the company has held courses for personnel regarding barrier management. For new personnel, this course is given within a certain time frame after the first day. The interviewee also thinks that it is hard to understand the risk for how a major accident evolves.

#### 4.4.3.5.2 DNV GL

The interviewee experience that it is a challenge to spread the understanding of what a barrier shall do and what hazards it controls, to the personnel. The second interviewee explains that it can be hard for the companies to see the difference between the barrier management work and the “normal” maintenance work. The companies often argue that they have always done the work that is suggested in the barrier management, but then called it maintenance.

#### 4.4.3.5.3 PSA

Regarding the awareness of barriers, PSA mentions that it is hard to understand how the barriers function together. Good barrier management requires broad knowledge, but the barriers are often viewed isolated, and not how they function together and how this can influence the safety. Regarding how the barriers are understood throughout the organisations, the interviewees think that this is relatively good but that there is room for improvements.

#### 4.4.3.5.4 AUDIT REPORTS

Also many of the audit reports describe that the bowties and risk analyses are not updated (PSA, 2010). Another issue is that it is not described how they should be used offshore. Also, the documentation related to competence assurance needed improvements at some rigs, the maintenance program was insufficient (SCEs were not identified) as well as the participation of employees.

#### 4.4.3.6 ANALYSIS

How the regulations with regards to barrier management are interpreted could affect safety with regards to both personnel and environment. PSA has experienced challenges with how the regulations are implemented by the industry but say that they see improvements.

With regards to the interviews, it seems as all the companies have some kind of strategy and work with barrier management. The main issue is rather how the information about the bowties and risk analyses should be used in the everyday work by those working offshore. The interviewees, as well as the people at DNV GL and PSA mention this, and also the audit reports discuss this. The methods are used to identify the barriers, but in many cases it stops there, i.e. they are not a part of the everyday tasks and activities. The requirement from the authorities (MR, section 5) is that the operator or the party responsible for the operation shall stipulate the strategies and principles that form the basis for design, use and maintenance of barriers to make sure that the barriers' function is safeguarded throughout the offshore or onshore facility's life. Also, personnel shall be aware of what barriers that have been established and which function they are intended to fulfil and also the performance requirements.

The companies try to spread the information and involve the personnel who work in different areas of the organisation. This is good, personal awareness of hazards and communication are factors that influence the safety level (Ismail, Doostdar, & Harun, 2012). DNV GL and PSA argue that using the maintenance program is a winning concept to implement the barrier management and strategies in the daily work. How this is handled today depends on traditions and structures. Many of the interviewees mention that they have implemented the barrier strategy in the maintenance system and that they are satisfied with this. To implement the documents might not be the difficult part, but to actually make use of it to reach a certain level of safety is harder.

During the interview with DNV GL, it was discussed how the responsibility for the barriers should be organised. One of the interviewees thought that it would be good to have one person with the overall responsibility who could follow the documentation of the barriers with requirements from the design until the barrier is exchanged to get a cradle to the grave perspective. This could give a "T" view of the system, i.e. one person organises and is responsible for documentation whilst those working near the barrier have a deeper understanding of the actual task that the barrier has and how this can affect the rest of the facility. The holistic view is important but also the details need to be considered. To make sure that the T-perspective is reached, good communication between those working with the barriers is important. An interviewee from one of the companies experiences that different leaders have different ways of approaching e.g. the spread of information. An impression is that how the holistic view is reached and spread depends both on e.g. guidelines and regulations, but also on the persons who have the actual responsibility together with the tradition and culture in the company.

The importance of having someone who is responsible for the barriers was also discussed with the PSA. PSA argues that the documentation might be even more important today since a lot of the engineering of the equipment is done abroad. Due to this, it can be hard for the operator to participate in the engineering phase and influence how the barriers are designed. This is also a reason for why it could be of importance to have a specific person who is responsible for the barriers, to make sure that information is not lost on the way. As mentioned, those implementing the barrier strategy with the maintenance system seem to manage the barrier most successful. However, these personnel are mainly not working with HSE, which the barrier management is a part of (PSA, 2013b). There needs to be a bridge between the HSE and the maintenance personnel, which might be a challenge to build since the maintenance personnel work offshore and the HSE personnel work onshore. How the responsibility affects the work with the environment was not discussed, but the overall safety might be affected if issues fall between the chairs due to unclear role of responsibility.

The interviewees explain that the requirements are met through the use of various standards. Only one of the companies said that they use company specific requirements since they have a lot of experience within the company that they want to use. The company specific requirements are used since they are more stringent than those in the standards suggested by the PSA. The companies that do not use their own requirements argue that this is due to the fact that it requires time and resources that is more efficient to use on other measures to increase safety. Also, the companies think that it is better to focus on being updated on the regulations that PSA issues. Especially the requirements for the technical barriers have

clear requirements, however, the requirements with regards to operational and organisational barriers can be harder to interpret and meet.

The interviewees at PSA also mention that the technical solutions can be good, but they can still cause accidents if the dependencies among barrier functions are not examined properly. The regulations require that there shall be sufficient independence between the barriers, if more than one is needed. PSA states that generally, the operators are good at assuring this for a certain barrier function. The problem though, which is related to the challenge to spread information about the link between a barrier and the associated risk, is that the barriers are viewed isolated. This can cause problems if a barrier is impaired since this can decrease the safety level in a certain area.

#### 4.4.4 ENVIRONMENTAL BARRIERS

##### 4.4.4.1 INDUSTRY

Regarding the environmental barriers, many of the interviewees argue that the safety barriers used to mitigate and prevent major accidents also hold for environmental consequences. Even though there is not a specific focus, the interviewees state that the environmental aspect definitely is taken into consideration.

The first company says that the major accidents with environmental consequences also can have severe consequences on assets and personnel and that it is hard to find events that only have an environmental consequence. The interviewee mentions that safety critical elements are listed in the maintenance programs but says that the regulations regarding environmental barriers are unclear.

*“There have been discussions regarding the environmental critical elements but it is not clear in the legislation if they should be identified or not.”*

The interviewee mentions that since PSA describes barriers on a general level they do not leave out anything and it lies on each player to decide how to comply with the regulations.

*“If also the environmental critical elements were to be identified it might mean that there would be additional equipment to be classified as critical and that there could be another focus and reasoning about the environmental elements.”*

Hence, identifying the environmental barriers would maybe not make a very big difference in practice, but rather in people’s heads. With regards to environmental risk acceptance criteria, the interviewee explains that there are no criteria set but that the operator applies to the Ministry of Climate and Environment for use and discharge of chemicals. The interviewee refers to section 29, MR with regards to the volume that needs to be reported in contrast to another company that describes that a SINTEF report is used to decide the acceptance criteria.

Another company is of a different opinion. The interviewee argues that there already exist specific barriers that only hold for environmental risks and says that everyone on the rig is familiar with the different barriers and their function. The interviewee also states that the requirements regarding the environment are clear in the legislation.

The fourth company says that the focus is not on an environmental barrier, but rather on the consequence if a barrier would fail. The interviewee mentions, as many of the other interviewees, that there exist barriers or equipment that is mainly for environmental consequences. However, they are not classified as barriers and the likelihood for the event they are preventing might be higher but the consequences lower. The issue with the environmental barriers rather is how to decide the environmental risk acceptance criteria.

*“The legislation is clear, the challenge is to decide the acceptance criteria for environmental issues since the criteria must be set with regards to the specific site.”*

This company also operates in the Barents Sea which is an area with a very sensitive environment. The interviewee thinks that the requirements regarding what is allowed to “do” to the environment is the same in all areas, but since some are more sensitive than others there might be a need for extra guidelines about how to make sure that the regulations are followed.

The interviewee at the fifth company states that all scenarios that are related to potential discharge are a part of the barriers. The performance standards will cover more than one major accident since a certain hazard can arise from different types of failures or accidents. E.g. a fire can happen both due to a ship collision and a helicopter accident and hence, active fire fighting will be an activity for different accident scenarios.

#### 4.4.4.2 DNV GL

Only one of the consultants at DNV GL had thoughts about how the work with environmental barriers, within drilling, is done. The interviewee thinks that most of the barriers have a split function and hold for both safety and environment and that there might be barriers that have some kind of conflict between environment and safety. The Macondo accident is mentioned as an example where the crew had closed the diverter line. The diverter was closed, i.e. that the hydrocarbons could not escape to the environment and hence reached the platform where they caused an explosion. The interviewee says that the event with worst consequences can be analysed in a quantitative risk assessment and if a certain activity for the environment will increase the risk for safety, some kind of ALARP investigation needs to be done. In the HAZID and QRA, hazards and risks are identified and from these the barriers are planned.

#### 4.4.4.3 PSA

Also the interviewees from PSA state that those hazards that involve consequences on the environment usually also involve the aspect of safety for humans. PSA does not specifically treat environment as its own area, but it is integrated in the work with safety and major accidents. The interviewees argue that it is important with good solutions and design and that this will protect both people and the environment. It is also mentioned that it is the ministry of Climate and Environment that has the main responsibility but that there is cooperation between the authorities since the legislations align. The interviewees think that too much focus on the environment can result in that the safety for human life is threatened.

*“Saving life is always the highest priority and there should be other solutions to take care of the environment”*

An example of what could happen if trying to decrease the consequences on the environment when there is a major accident can be not to release the hydrocarbons to sea through the diverter line which instead then might cause major consequences to the personnel. However, the focus on environment is increasing and might put more stringent technical requirements on the equipment.

#### 4.4.4.4 AUDIT REPORTS

With regards to acute spills to the environment, result from the audits was e.g. that only one barrier was used against discharges to the sea from the tank with drilling fluids, which makes the system vulnerable and increases the likelihood of a discharge (PSA, 2013c; PSA, 2012b). Another aspect that was brought up in several audits was that the evaluation of the risk to avoid acute releases was insufficient. Also, the environmental management systems at some rigs did not fulfil the requirements in the regulations, which meant that there was no systematic overview regarding the barriers preventing acute spills.

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· The diverter line is put on top of the wellhead and is used to lead the hydrocarbons away from the platform in case of a well-kick. The hydrocarbons then reach the environment instead of the platform (Drillingformulas).

#### 4.4.4.5 ANALYSIS

All of the interviewees, including DNV GL and the PSA, argue that the safety of the environment is taken into consideration through the safety barriers. One of the companies says that the scenarios related to potential discharge are a part of the barrier analysis, and thus includes environment in the safety concept but does not mean that the barriers are divided between environment and safety. The identification of the barriers is done with help from the hazard identification and risk assessment. The focus is on the hazard itself and not which type of barrier (environment or safety) that is needed to limit potential consequences. Also Hauge et al (2011) argue that the same barriers that protect the environment from acute releases to sea also protect personnel against hazardous events.

Some of the interviewees said that the equipment used to protect the environment might not always be considered as barriers. If there would be a legal requirement to identify the environmental critical events, equipment that is not considered critical today actually could be identified as critical with respect to the environment. Since most of the companies that were interviewed use barriers to prevent major accidents, the identification of an environmental barrier might be affected of what is considered an environmental major accident. Hence, it should be clear for the companies what serious harm to the environment is.

When discussing the environmental barriers, the site-specific aspect, as discussed in section 4.4.1.4 was central. A part of identifying and deciding requirements for the barriers is to define the overall risk acceptance criteria and break them down to performance requirements for the individual barrier. Hauge et al (2011) discuss the guidelines in e.g. standards with regards to environmental risk acceptance criteria and mention ways of measuring the effect on the environment, e.g. restitution time. According to Hauge et al (2011) most of the operators seem to use these guidelines (even though only one operator actually described this in the interviews). However, the examples used in the guidelines seem to be applied directly in practice and hence, the criteria are not site specific. The restitution time can be difficult to estimate and hard to comprehend and also hard to use when deciding the requirements for technical equipment. The point is, that if the environmental risk acceptance criteria are not adequately set, the barriers that will prevent from major accidents might not have the relevant requirements.

What also is mentioned by Hauge et al (2011) is that the environmental risk assessments mainly focus on consequence reducing measures and not the frequency reducing measures. The frequency reducing barriers are traditionally mainly focusing on personnel safety. This was also discussed with people working with environmental risk analyses at DNV GL. Within the Norwegian oil and gas industry, there seems to be a tradition and culture with regards to personnel safety<sup>17</sup>, which might be why the focus is not as big on environmental safety with regards to barriers. In practice, the requirement to also identify the environmental barriers might not mean that a lot of extra barriers would need to be maintained. One of the interviewees rather thinks that there would be a psychological change and people would be aware of the environmental aspect, both for frequency and consequence reducing barriers.

During the interview with PSA, the interviewees said that if there is too much focus on the environment, this could mean that human life is threatened. The interviewees state that if there is a conflict between environment and safety for personnel, it could be confusing which category to prioritise. However, this is regulated in the guidelines to section 1, FrR, where it says that the consideration for human life and health shall prevail. It is realistic that this clarification is done. However, it might be an idea to actually highlight the environmental aspect more since the fact that human life shall prevail might be an excuse to not take care of the environment properly. It is easy to "blame" the protection of humans, instead of working actively to decrease the effects on the environment and at the same time keep a high safety level also for personnel.

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<sup>17</sup>Senior consultant Valentin Vandenbussche and engineer Zhanar Yessekeyeva, DNV GL, interview 2/3 2014

#### 4.4.5 THE LEGISLATION

The experience of the regulations from PSA differs between the interviewees. Some think that it works very well while others find it confusing.

The interviewee from the first company mainly mentions the legislation with relation to the emergency preparedness and thinks that this part of the legislation is very clear. The second company does not mention many disadvantages or advantages with the legislation. The major part of the legislation that is mentioned is how a major accident is defined which was discussed above.

It is mentioned during one of the interviews that PSA's strategy (regarding barriers) is open to interpretation. The company needs to interpret the strategies but in the way that PSA expects. PSA often does not give a lot away but leave it to the companies to demonstrate that they satisfy the regulations. The interviewees think that this is sometimes frustrating but it forces the players to think about what they actually are doing rather than just tick-in-a-box.

The interviewee from the fourth company believes that the expectations from the regulations are clear. The company fulfils the requirements through the development of the entire process with help from the requirements and with the experience within the company and also as a joint project with people from different disciplines. The interviewee is aware of the EU directive and some of the performance standards that are used are adopted from here. The company has compared different requirements and used the one that gives the best result.

The fifth company experiences that the regulations regarding barriers work well. The approach that PSA has is good, the company needs to show that they have control and the way that PSA suggests the companies to do barrier management is experienced as logical and rational. What is most important is that the company itself needs to understand what it is that they are supposed to do, which might not be achieved through a higher level of details. The interviewee has an example of how the regulations have developed and describes an old requirement regarding fire protection. The regulation regarding fire protection used to be a certain capacity that was not based on a certain case which could mean that the required capacity would not be enough. Today, the regulations say that the fire protection should be "enough", which means that the company itself needs to figure out the capacity they actually need. The interviewee thinks that this gives more meaning to the work and safety than a detailed requirement.

##### 4.4.5.1 DNV GL

The consultants at DNV GL experience that some of the companies that need to comply with the regulations do not fully understand what they are supposed to do and why. Especially the definition of a major accident is hard to interpret but the specific section that handles barriers is OK. Also, the organisational aspect is hard to understand and the interviewee thinks that this should be removed from the regulations.

##### 4.4.5.2 PSA

PSA understands that there sometimes can be some confusion with respect to the legislation and the sections that handles barriers and safety systems. The sections that regulate the safety systems are a part of an older regulation and are left since many of the operators are used to this expression.

##### 4.4.5.3 ANALYSIS

Most of the interviewees experience that PSA's regulations work fine. One of the interviewees argues that the regulations are open for interpretation, but that it is better to have the performance-based regulations instead of just following a list of requirements. With this system it is necessary to see and understand both details and the big picture and show PSA that the company has the right level of safety. Another interviewee thinks that the expectations in the regulations are clear. The part that can be unclear is how the environmental barriers should be handled and what the requirements are. It seems as many of the

companies are aware of the performance-based requirements that PSA set, but the issue is rather how the requirements shall be met. To help, several standards are referred to in the guidelines to the regulations and PSA states that if these are used, the correct level of safety shall be met. During a short review of the standards, it was seen that many of them refer to safety for human lives, environment and assets. However, the amount of standards is extensive and there was no time to go through all of them in detail, i.e. there might be more standards than NORSOK S-003 that focus on the safety of the environment.

The interviewees from PSA explain that it is the Environment Agency that is responsible for the environment; however, with regards to the barriers, PSA has the supervisory role. As mentioned, the requirements with regards to the environment are also part of PSAs regulations and hence lie under the responsibility of PSA.

#### 4.4.6 EMERGENCY PREPAREDNESS

A part of the interview guide also handles emergency preparedness and how the regulations are applied within this area. Due to limitation of time during the interviews, the emergency preparedness was not prioritised and the interviews with PSA and company number 4 did not touch upon this area.

The first company thinks that the regulations are very clear and mentions requirements regarding analysis and acceptance criteria. The plan is based on a risk assessment and the identified hazards and accident situations are used to dimension the plan. On the rig there are exercises once a week. Every second week the exercise is based on a specific situation and the other week a drill that aims to practice on mobilisation is performed.

The second company has more of a coordinating role in the emergency preparedness since it does not perform any operations (petroleum company) itself. A bridging document is conducted by the company to coordinate the preparedness plan at the drilling rig with the third party.

The third company explains that third party mainly does the spill response and the task for the company is hence to inform the third party about what happened. Training is done with drills and exercises, which are scenario based. There is a contingency plan that explains how and what to do and that there should be response for each scenario that is identified.

The interviewee from the fourth company also describes weekly exercises. The emergency plan is developed in advance and possible situations and scenarios are described. There are, at least four times per year, joint big scale exercises where helicopters and hospital are involved. The operator plans the bigger exercises with people specialised in the area. The plan is spread through the drilling and the scenario for the exercise is described in advance and sent out to the personnel. There is also documentation that is available for everyone and lessons that are learned are registered.

##### 4.4.6.1 DNV GL

The consultants at DNV GL explained that the emergency preparedness plan is based on the identified hazards.

*“The training does not focus on understanding the risks, escalation of an accident or if more than one thing happens at the time. The exercises are not realistic”*

Information of what shall be done if something happens is described on pictures in the facility. Opposite to the other interviewees, one of the consultants does not experience that the legislation in this area is very good. Many of those working have different experience. DNV did a test where they asked 12 different people how they would do during a certain scenario and received 12 different answers.



#### 4.4.6.2 AUDIT REPORTS

The audit reports conclude that knowledge with regards to the preparedness plan is not sufficient offshore and that the information and knowledge had not been transferred to the preparedness organisation (PSA. 2013d). Also, the participation of employees was insufficient and the information from the risk analyses was not spread and used for the planning.

#### 4.4.6.3 ANALYSIS

A lot of analysis could be done regarding emergency preparedness. Due to the restriction of time, this area has not been the main focus but is mentioned since it has a clear link to barriers with regards to major accidents. The preparedness itself could be seen as a barrier to limit the consequences of an accident, and with regards to the environment, focus is on preventing the spread of hydrocarbons after a release (Hauge et al, 2011). The authorities responsible to manage and coordinate the activities are the Ministry of Fisheries and Coastal Affairs and the Norwegian Coastal Administration and not PSA (Norwegian Petroleum Directorate, 2013). Often, a third party is responsible for reducing the effects of an oil spill and hence the communication between the operator and the third party is of importance.

The interviewees answered that the third party participates in the emergency preparedness exercises and that they have drills and trainings every week. The impression was that the companies, at least in theory, are well prepared. However, one of the interviewees from DNV GL had an objection with regards to the exercises. It was meant that the exercises are not enough scenario based, meaning that the people on the rigs only get to practice on what to do after a certain alarm is activated. The interviewee argued that it might be more important to be able to react to a certain kind of hazard.

Training is important since untrained personnel might be hurt, of course, but also that the situation can be worsened (Coppola, 2011). With regards to drills, most people know how to act since this has been practiced since the childhood. To be as efficient as possible they should mimic real-life situations. How this is conducted at the rigs could not be fully mapped during the interviews, but according to the answers, the exercises consist of both drills and scenario-based trainings.

The audit reports mention issues with the emergency plan itself and spreading this to the personnel. This was however not brought up during the interviews, which rather might be a result of the method (further discussed in section 5.9). Also, the information from the audit reports does not give the same picture as the interviews.

## 5 DISCUSSION

In this chapter, recommendations with regards to barrier management and environmental barriers are discussed and summarised. The chapter also includes a discussion about the method used to answer the research questions. The structure of the discussion is the same as in the results and analysis chapter.

### 5.1 MAJOR ACCIDENT

#### 5.1.1 DEVELOP GUIDELINES AND RECOMMENDED PRACTICE FOR THE DEFINITION OF MAJOR ACCIDENTS

In discussions about barriers and environmental impact, with both interviewees and personnel at DNV GL, the definition of a major accident has been central. The greatest concern seems to be the difficulty to decide what a major accident actually is and what “serious harm” to the environment means. As mentioned several times; what can be regarded as a major environmental accident at one site, does not mean that the same applies at a different site (Hauge et al, 2011).

Some of the interviewees explain that the definition of a major accident includes the quantification of the number of fatalities to five. To have some kind of similar approach to the environmental effects would at a first thought be convenient. But since the effects on the environment differ depending on site, it would be hard to find a just number. A more realistic measure might be to make sure that the operator has a methodology to decide what a major accident is, that takes aspects as e.g. restitution time into consideration. The thesis has not studied how this is done today in detail, but after discussions with employees at DNV GL, it seems as the methodology differs between the operators. An example is the risk matrix that many operators seem to use to decide the level of environmental risk. Some companies only use the amount of released oil, while other companies use the restitution time to decide how the area will be affected. Using only the released volume of oil as a measure of consequence, might not indicate how the area is affected, since the same volume of released oil will have different consequences in different areas.

The idea with PSA’s regulations is to engage the operators to the safety work, and having clear and specific methods might counteract this. However, to facilitate the companies’ work, an idea could be to review the methods used by the operators and establish a document with recommended practices, maybe as a recommended standard that is used in other areas. Some of the interviewees expressed that the environmental risk acceptance criteria are hard to identify and decide, and if a guideline to identify the major accidents was accessible, the process might be enhanced. The importance of knowing how to make the site specific analyses increases as the petroleum activities move north to the Arctic waters. The ecosystems in the Arctic waters are very sensitive and a spill that is categorised as harmless on the NCS, might have consequences of another magnitude in the Arctic (Sjøgren, 2014).

#### 5.1.2 EXTEND THE ACCIDENT MODELS

Another aspect that was thought of after the review of the regulations was how the Norwegian Petroleum industry views accidents. PSA uses the energy-barrier concept for all types of accidents, both major and smaller. However, this model might not be suitable for all types of accidents since they usually origin from different event sequences. A smaller accident, e.g. that an employee hits the head in the roof, may be possible to explain quite clear; there was no sign that the roof was low or the employee did not wear a helmet. The accident can be prevented e.g. if it is assured that the employees wear helmets or through a warning sign. The safety culture might play an important role as well, that the employee did not wear a helmet from the beginning might be due to organisational aspects, but the specific accident can be prevented through the use of a certain barrier. With major accidents, the case seems to be different. Investigations after major accidents, e.g. the Macondo accident and the accident in Texas City, argue that it is not possible to find a specific reason to why the accidents happened. It is rather a result of complex technology and organisations together with coupled systems (PSA, 2011). The development of complex technology goes faster than our understanding of how the complex systems work and fail (Dekker, 2011), which is a reason to why accident models that take the complexity into account also have been established.

To emphasise that the major accidents have complex underlying causes, might increase the understanding of how the origin of these accidents differ from e.g. occupational accidents. Research argues that the systemic accident models provide a deeper understanding of how the complex systems behave and contribute to an event (Underwood & Waterson, 2013). Underwood & Waterson (2013) state that if the systemic accident models were used, the safety recommendations would be more effective. However, challenges with the models might be usability, and some practitioners claim that the systemic models are too complex and that the models they use today work well. Since major accidents seldom happen, it might be hard to see a clear link between how the model affects the level of safety. However, the model might affect how the preventive work is done, e.g. if the focus is on viewing technical barriers isolated or to give a holistic understanding of the interactions between different systems. Highlighting that major accidents arise from complex conditions and interactions between components, rather than from failure of the components themselves, might increase the understanding of the barriers' roles to prevent major accidents, the difference between major and smaller accidents, and the awareness of how different components interact. This could hopefully lead to increased understanding of the risks and increased level of safety.

## 5.2 THE DEFINITION OF A BARRIER

### 5.2.1 CLARIFY THE MEANING OF THE CLASSIFICATION OF BARRIERS

All interviewees were clear about the basic concept of a barrier and that its purpose is to prevent or limit consequences of a hazard. The issue was rather the confusion regarding operational and organisational barriers. In PSA's regulations, it is not possible to find a definition of what these types of barriers include and the regulations are quite open to interpretation. It was clear that some companies interpret that e.g. the organisational barriers are the management systems while other companies say that the employee is the barrier. Sklet (2006) argues that the function that a barrier is intended to have needs to be clear and related to a specific hazard. A safety management system describes how the organisation shall work to achieve its objectives and rather has an overall focus compared to e.g. the BOP which function is to prevent a blowout. Most of the interviewees agreed on that the operational barriers are the specific tasks that need to be fulfilled to ensure safe operations; the issue rather seems to be how to monitor and verify that the barrier works as intended. Hence, a recommendation is that clear definitions of operational and organisational barriers are established and that the requirements with respect to reliability, robustness etc. are clarified. A clarification of the concepts might also facilitate the assurance of the status of the three types of barriers, which seems to be a challenge today.

As some of the interviewees mention, the organisational barrier can be management systems and policies. Hollnagel (2006) describes this as incorporeal barriers that need to be interpreted and analysed by an intelligent agent, i.e. a human. PSA, on the other hand, argues that the organisational barriers are the personnel that work close to the barrier. The organisational factors are important, whether or not they are considered as barriers. These factors are the foundation of the safety culture, which plays an important role to achieve a satisfactory level of safety (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007). An efficient way of implementing them into the organisation could be to categorise them as barriers, since barriers might be considered a concrete measure to prevent accidents. A challenge related to this, could be how to actually make them a part of the daily operations and assure that the personnel are aware of them. For successful implementation, the management needs to take responsibility through commitment and good examples. Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás (2007) argue that the management plays an important role to assure that the personnel working near the barrier actually is aware of the function of the equipment. However, maybe it is not necessary to include the aspects such as management systems in the barrier concept, but see it as an additional aspect that is just as important as the barrier concept to achieve safe solutions and still make sure that the management also prioritise this aspect.

One aspect that the author reflected upon during the interview with PSA was that the interviewees referred to good technical solutions as the best way to prevent accidents. Good technical solutions might be useful to prevent some of the hazards introduced by a weak organisation, but due to the complexity, the organisational factors are also important to prevent major accidents. It seems as it is unclear also to PSA what the organisational barriers actually are and there might be a risk of neglecting the aspect, which might increase the likelihood of a major accident. Also, to increase the number of barriers can result in a more complex system which can increase the likelihood of an accident (Rosness, et al., 2010).

### 5.2.2 PREPARE FOR THE UNPREDICTABLE

Sklet (2006) argues, as mentioned, that the barrier's function needs to be clear and related to a specific hazard. But since the major accidents arise from complex situations and are more or less not possible to predict, it could be efficient to also prepare for the unpredictable. Also, if the barriers need to relate to a specific hazard and not all hazards are possible to identify, there might not be explicit measures to prevent the unpredictable, which might be a disadvantage with the barrier model. Resilience engineering is a concept which idea is that the system can adjust its function either prior to, during, or following changes and disturbances and hence continues to function during both expected and unexpected conditions (Hollnagel, Tveiten, & Albrechtsen, 2010). Since the cause of the accident might be unknown, the hazard that the barrier prevents and protects might not be identified. However, the barrier still plays an important role in the proactive work since it is used both to prevent and protect a target. Barriers are only one part of the resilience engineering, but it could be wise to actually consider also this way of thinking of accidents and widen the perspective and possibilities of the barriers. The technical development is very fast which requires also development of accident models to describe and prevent the new threats.

If a barrier relates to a specific hazard, it might be easier to explain why a certain barrier is needed and why it actually is a barrier. This might be one of the major disadvantages with the resilience engineering concept. It is hard to grasp and measure and might require re-organisation of the companies' procedures. However, the resilience engineering might be necessary as the complexity increases and a start might just be to be aware of the concept and implement it where it is possible. Changing procedures and parts of the traditions probably require both time and economical resources and it might hence be too late to introduce a new way of thinking when problems already are starting to be visible.

### 5.2.3 HARMONISE THE PLAYERS' DEFINITIONS

Something that relates to what should be considered as a barrier is how the barrier concept is linked to a major accident. In this thesis, the focus has been on major accidents. This is mainly how DNV GL works with barriers and it is also how many of the drilling companies work. However, the section in PSA's regulations that regulates the barriers, does not explicitly mention major accidents. Some of the companies said that they use the concept for all types of accidents, and not only the major accidents. Using the barrier concept to identify the equipment that is critical to major accidents can help the companies to prioritise the maintenance work and increase the level of safety. DNV GL and PSA seem to have different views of barriers and their relation to major accidents. However, the standards that are referred to in the guidelines clearly point to barriers aimed at major accidents<sup>18</sup>. Aven (2012) emphasise that it is common with different definitions with regards to terminology within risk management. The differences can cause confusion which can result in that risks are missed or overlooked, which is a reason to why common definitions is recommended. Aven also argues that the lack of a common language causes chaos and makes the communication harder.

Maybe the most important aspect is that there is no clear distinction between major and smaller accidents, as discussed above. The different accident types need to be treated differently and since PSA's regulations build the foundation, the risk of misunderstanding and misinterpretations should be reduced as much as possible. The need to separate major and smaller accidents, or process and occupational accidents, was

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<sup>18</sup> Head of Section Asset Risk Management Atle Stokke, DNV GL, 23/4 2013

discovered e.g. after the incident in Texas City (Allars, 2007). The different types of accidents need to be managed differently since they have different origins.

#### 5.2.4 RESTRUCTURE THE REGULATIONS

After working with the regulations during the thesis period, the author's impression is that the structure of the regulations is a little unclear. The sections that cover barriers are spread throughout the four regulations (FrR, MR, FR, AR) and the cross-references confuse the user. E.g., in section 5, MR, which is the main section with regards to barriers, there is no reference to the sections that cover e.g. physical barriers or the BOP. This could make it hard to actually know what is included in the barrier concept and also to see the overall picture, which is something that PSA emphasise and tries to help the industry with through the document for barrier management. To go through the regulations and make clear cross-references would probably facilitate the work for those who need to comply with the regulations.

As mentioned, the regulations stipulate that human life always prevails if there is a conflict between e.g. environment and human life. This is of course realistic, but it might lead to a negligent attitude towards the environment. It might mean that it is possible to defend a leak or spill with the argument that it was necessary in order to avoid increased risk to humans. This might delay the development of structured work with environmental barriers since the awareness might not be as raised as necessary. To come around this might not be possible only through a changed legislation. It is probably necessary to actually raise the question and have a discussion within the industry so that both authorities and operators have a common understanding how this should be interpreted.

The document "Principles for barrier management in the petroleum industry" (PSA, 2013b) published by PSA is experienced as hard to understand with regards to the terminology. The document should be easy to understand for everyone who uses it. Luko (2013) states that if the terminology is unclear, information can be misunderstood or interpreted in a way that was not intended. Hence, a recommendation is to go through also this document and clarify the concepts and highlight the most important parts.

### 5.3 BARRIER MANAGEMENT IN PRACTICE

Both DNV GL and PSA believe that those who have managed to implement the barrier management and barrier strategy with the maintenance systems have come far. If the barrier management is a part of the maintenance system, the barriers will be a part of the daily operations.

#### 5.3.1 AWARENESS INCREASING ACTIVITIES

The main challenge seems to be how to use the risk analyses in the daily work. Those working onshore seem to have a bigger insight to why certain tasks shall be done with regards to the barriers. A strong commitment from the management onshore might be the first step to barrier management, but since the operational phase is the main part of the process, commitment offshore is also important to efficiently operationalise barrier management. Fernández-Muñiz et al (2007) states that the commitment from the management is as important as the commitment from those working near the barriers. The idea is that the personnel working close to the barriers shall understand that the malfunctioning of a certain barrier correlates to an increased risk for a major accident. To spread the information about barrier management, many companies organise workshops and compile literature. It was not discussed during the interviews how this is followed up, but a recommendation is to ensure that the information that has been gained is regularly updated. Activities to ensure this could be organised on a regular basis as a mandatory part of the employment. Implementing activities that shall be performed might be a way to change or develop the mind-set of people. The focus needs to be on both the preventive and the protecting aspects of barrier management.

### 5.3.2 CLEAR RESPONSIBILITY

During the interviews, it was discussed how the companies have organised the responsibility of the barriers. The interviewee at DNV GL claimed that it is necessary to have one person who can follow the barriers through the lifetime, and not different responsible persons in different stages. Lack of clear roles of responsibility have been discovered to be contributing factors to major accidents and an example is an accident with a Pan Am flight in 1972 (Rhona et al, 2008). Due to the lack of clear areas of responsibility, the captain, first officer and flight engineer were all involved in trying to solve the airplane's problem, such that none of them was monitoring the flight. Hence, clear responsibility for the barriers seems to be important to increase the level of safety. If good communication is assured between the sections responsible for barrier management, both the technical aspects that the technical manager (or managers) has and the overall perspective that the HSE personnel have, could give a "T"-picture of the barriers. Clear documentation of the responsibilities could make it easier to get an overview for the person who has the head responsibility. Hence, to make sure that the roles of responsibility are clear can be an important factor to ensure good barrier management.

## 5.4 ENVIRONMENTAL BARRIERS

### 5.4.1 ESTABLISH A RECOMMENDED PRACTICE FOR ENVIRONMENTAL BARRIERS

One of the reasons for the topic for the thesis is the EU directive that was reviewed in section 4.2. The EU directive focuses on major accidents and differs between safety and environmental critical elements. PSA's regulations aim to decrease the risks on health, safety and environment in the Norwegian petroleum industry. Hence, the environmental aspect should be considered as much as the health and safety, both with regards to major and smaller accidents. The regulations stipulate that the barriers can *also* be used to prevent or limit spills, which might be confusing; should the equipment that prevent and limit spills also be treated as barriers? Since the EU directive, that requires the operators to identify the environmental critical elements, has been issued, it can be imagined that the requirements on environmental measures will increase, and hence the requirements for environmental barriers. The industry should be prepared for this and one measure could be to develop procedures for the identification of the environmental barriers and critical elements. In UK, the department of energy and climate change (DECC) has established a guideline to help players to identify ECEs, which could be done by Norwegian authorities as well. This type of recommended practice or guideline should include the procedures of the identification of hazards, which is related to the definition of a major accident. Further, it could be important to focus on how to decide the requirements with regards to the site-specific conditions. It already exist methods for this but according to Hauge et al (2011) the examples in the guideline are implemented immediately by the operator, which means that it is not site specific. With regards to the safety equipment, the SIL method could be developed to include a method for EIL, environmental integrity level. In this method, it could also be useful to include how the maintenance should be structured for the equipment to give a holistic view. Hence, the methods that exist today should be clarified and gathered to make it easy for the operator to see the red thread between hazard identification, risk assessment, barrier identification and barrier management with regards to environmental barriers.

During the interviews, all companies said that the safety barriers also protect the environment, and the impression is that the environmental aspect with regards to major accidents is not considered explicitly. The review of the regulations gave the impression that the sections about environmental barriers are unclear to some extent and due to this and the result from the interviews, clarification seems to be necessary to enhance the work. An issue when assuming that the safety barriers also protect the environment is that the performance requirements (qualities of barriers in section 3.4.4) for safety equipment might not be suitable for the protection of the environment (Hauge et al 2011). Even if the actual barrier protects the environment, the requirements with regards to e.g. reliability might differ. Hence, also this aspect should be included in a best practice since this seems to be important so that the level of safety (both for environment and personnel) is as high as possible. In a sensitive area, it could be

imagined that the requirements for the environment would be more stringent than those for safety. If not being aware of this, the safety for the environment could be adventured.

To identify also the environmental barriers/ECEs would probably not mean that much extra work. Many of the barriers apply to both safety for personnel and environment and due to this, the number of barriers would probably not increase that much. Even if the barriers would be the same for both safety and environment, the awareness (as discussed above) would probably increase and then maybe the risk picture would be widened.

#### 5.4.2 ENCOURAGE MANAGEMENT TO INCREASE ENVIRONMENTAL AWARENESS

It seems, as the general tradition in the industry is to focus on safety for personnel and not as much on the environment. Some of the companies only referred to a blowout when discussing major accidents with environmental consequences, while other companies said that they also include e.g. ship collision and loss of stability. It does not seem as there is a common approach to the major accidents and different companies use barriers to different scenarios. It seems as the identification of environmental barriers depends on the culture in the company, which may also affect the general level of safety. To increase the awareness of environmental barriers, activities such as seminars could be arranged with managers in the industry. Kaplan and Mikes (2012) argue that the insight to the risk management, also from the management is vital to assure good risk management. One incentive to raise the environmental awareness is the trend of moving the activities north, where the prerequisites for the environment are different, compared to the southern parts of the NCS.

It should be noted that since the companies that participated in the interview study are drilling companies, safety and environmental issues are closely linked since the main hazard would be a blow out<sup>19</sup>. A blow out might cause both injury/death and discharges to the environment. For other operations, e.g. subsea production and loading and offloading specific environmental barriers might be more relevant. However, the interviewees seemed to have different views of what constitutes an environmental barrier which might be a reason to try to raise the awareness even more.

### 5.5 THE LEGISLATION

The issues with regards to the legislation have been discussed above. The main issue that was identified is the rather unstructured regulations, where it can be hard to find the necessary requirements and how they are related to each other.

### 5.6 EMERGENCY PREPAREDNESS

#### 5.6.1 ASSURE THAT THE DRILLS AND EXERCISES ARE BASED ON REALISTIC SCENARIOS

The response to an emergency is important, both with regards to personnel and the environment. To get an impression of how this works in reality was hard through interviews. At least in theory, the companies seem to be well prepared. However, DNV GL thought that the drills and exercise lack relation to realistic scenarios, which could be an area of improvement.

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## 5.7 THE EU DIRECTIVE

The aim with the analysis of the EU directive was to understand the requirements for barriers (SCEs/ECEs) that will be necessary for member states to comply with. Some of the companies that operate on the NCS also operate on e.g. UK waters and hence have to comply with both UK regulations and Norwegian regulations. The differences are not that big, the highlighted differences are that the directive only focuses on major accidents, the requirement of a major hazard report and the focus on ECEs and a recommendation regards to the directive is to increase the focus on environmental barriers on the NCS. The impression from both PSA and the companies is that the focus on the environment increases in the drilling industry, which is why it might be an idea to start working with these questions to be prepared if there would be a change in the legislation.

## 5.8 SUMMARY

As discussed, it seems as the environmental barriers to some extent can be overlooked in the Norwegian drilling industry. Reasons for this might be culture and traditions and also how the regulations are organised. The EU directive that has been studied can be used as an input to how the environmental barriers can be handled and maybe one of the most important aspects is to actually illuminate the environmental barriers to make sure that they are considered in the same way as the barriers for personnel safety.

Environmental awareness seems to be increasing in general in the society today. The Macondo accident caused severe damage to the coastal and marine environment and the climate discussions are constantly present. Hence, the importance of the environmental aspect is not only relevant for the Norwegian petroleum industry. It also holds for other industries, and, of course, the rest of the petroleum industry.

The focus on environment makes the users of the produced services demand more and more. The focus on the environment is not only important to actually reduce the impact, it is also important when maintaining and building a company's trademark. With regards to major accidents within the oil and gas industry, the focus after the Macondo accident was equally divided between the loss of human lives and the environmental impacts and BP's trademark was severely hurt (Vidal, 2011).

Hence, it might be an idea for also other industries to also classify their safety not only with regards to personnel safety but also with respect to the environment. The sooner the work is started, the better the industries are prepared if something goes wrong. Also, the resilience engineering might be wise to consider since the development of technology is fast and increases the complexity and coupling, making it difficult to predict what can go wrong in the interaction between the components and organisations.



## 5.9 THE METHOD

To highlight the potential sources of errors that the choice of method can cause, a discussion regarding the collection of data and analysis of the same follows below.

Two methods were used for the thesis; literature study and interviews. The literature study was done both to deepen the knowledge about barriers and to collect data for the review of PSA's regulations and the EU directive. With regards to barriers in general, there is no common terminology and mainly Hollnagel (2006) was used as reference. Using several sources would of course widen the perspective further, but since the literature that was found was cited in other reviewed documents, this was considered a valid and trustworthy reference that could be used as a foundation for the theory. Another reason why Hollnagel was used is because the work describes barriers on a general basis independent of industry. Other sources were mainly focusing on barriers to protect human life in the oil and gas industry. Since the environment and human life might be necessary to protect differently, the general source was considered as more relevant.

To collect data for the comparison of PSA's regulations and the EU directive, the documents were reviewed with help from specific questions. The questions were established with help from personnel at DNV GL who have several years of experience from working with regulations. To ensure that the author had understood the purpose with the regulations and that no misinterpretations had been done, DNV GL personnel reviewed the result. Due to time limitations, only certain parts of the regulations have been studied. The focus has only been on how environmental barriers and SCE/ECE are handled in the different regulations. Hence, there might be other parts that differ that might be important to take into consideration before stating that there are no significant differences.

Using interviews as scientific method might not always be uncontroversial. Researchers that are critical argue that the result can only be used as preparation for further research and that the method lacks objectivity (Kvale, 1997). However, the interviews make it possible for the researcher to make a deeper analysis of the opinion of the interviewees, which is not possible if a quantitative method such as survey is used. The benefit with a quantitative method could be that it is possible to make a statistical analysis of the result, but for the topic of the thesis it was valuable to be able to ask attendant questions to clarify the answers. Another benefit with the interviews is that nuances of the interviewee's answer can be noticed, something that is not possible during a survey.

To keep track of the subjects during the interviews, an interview guide was established. The interview guide was based on the requirements from PSA's regulations, conversations with employees at DNV GL and relevant literature. It can be concluded that not all of the questions were suitable for the interview and some aspects may be better described if studied in practice. Topics that include how the work with e.g. barrier management is conducted and how the work is documented could be answered in more detail if e.g. documents were analysed. To be able to compensate for this in some extent, audit reports from PSA were used. The results from the audits are based on interviews, site visits and analysis of documentation. This data collection is more extensive and requires more resources, with regards to e.g. time, which is a reason to why the interviews yet were chosen as method. Also, due to time restrictions during the interviews, not all questions were always answered. During the interview with PSA, the emergency preparedness part was not discussed at all. Since all interviews with DNV GL and the companies had been performed before the interview with PSA, the author had got an opportunity to form an opinion of the topics that were most relevant to discuss. The fact that there was not enough time to discuss emergency preparedness is reflected in the result and analysis, presented in section 4.4.

When using interviews as the research method, it should not be denied that the answers can be misinterpreted by the interviewer. During the interviews, only the author was present. To avoid that information was missed; the interviews were recorded and transcribed. To make sure that the answers were understood as the interviewee intended, the transcription was sent to the interviewee who could

make comments and clarify questions. To help the author to stay neutral and not ask leading questions, the interview guide was carefully constructed and followed. However, since semi-structured interviews were held, the attendant questions could be of a more spontaneous character and sometimes the interview was rather a discussion between the author and the interviewee. The conversational nature of some of the interviews might have coloured the interviewees' answers, even though the author tried to be as neutral as possible. The interviewee hopefully noticed misinterpretations when the transcription was reviewed.

In total, 10 people were interviewed. It would have been interesting to interview as many as possible to get an even broader view of the topic, but due to time limitations quality was prioritised over quantity. Kvale (1997) states that the answer to the question "how many interviewees do I need", is "interview as many as you need to get your answer". This has mainly been restricted by the time and to try to make the picture as wide as possible, people from oil and drilling companies, PSA and DNV GL have been interviewed. Even if the interviewees represent different parts of the industry, a specific person might have their own opinion and interpretation of a certain subject and asking the same question to another person in the same organisation could give a different answer. The result should be used with caution since it is possible that aspects and opinions might have been missed due to the number of interviewees. Another aspect with regards to the interviewees, is that all of the interviewees were experienced and had several years of experience. This was a requirement that was set to find people with as much knowledge as possible. A challenge with this might be that they are "stuck" in their way of working and do not consider new ideas as maybe someone with less experience would do. If the number of interviewees would have been larger and if there would have been more time, it would have been interesting to also interview those with less experience to also investigate if this would result in a different view.



## 6 CONCLUSION

In this chapter, the conclusions made from the result and analysis are presented. Each research question is presented together with a summary of the results related to the question.

### 6.1 ANSWERING THE RESEARCH QUESTIONS

#### 6.1.1 WHAT DO THE NORWEGIAN REGULATIONS, ISSUED BY THE PETROLEUM SAFETY AUTHORITY, REQUIRE REGARDING ENVIRONMENTAL BARRIERS TO PREVENT MAJOR ACCIDENTS?

To begin with, PSA's regulations do not differ between barriers to prevent smaller or major accidents. The barriers are defined as measures to prevent or limit consequences of hazards and accident situations. Since PSA's regulations have the purpose to promote high standards for health, safety and the environment, the requirements for environmental barriers are the same as for barriers that are used to protect human life. Requirements are e.g. that the barriers shall be independent of each other when more than one barrier is necessary, the personnel shall be aware of what barriers that have been established, which function they intend to fulfil and what the performance requirements are. The regulations also stipulate that the barriers can be technical, operational or organisational and that strategies and principles to maintain the function of the barrier during its lifetime shall be established. An issue with the regulations is that the information about barriers is spread through the different sections without clear cross-references, which might make it hard to see the connections between the sections that regulate barriers.

An issue when deciding the performance requirements for a barrier supposed to protect the environment is to decide the acceptable risk level that shall be ensured by the barrier(s). With regards to personnel safety, the same requirements can be used independent of the site where the activities take place. For the environmental barriers, the requirements depend on the site where the activities take place. This is mentioned in the regulations but how it should be done does not seem to be clear to the drilling companies, which might adventure the safety for the environment.

To fulfil the requirements, PSA refers to standards such as NORSOK and ISO. The number of standards that are referred to is extensive and it has not been possible to go through all of them in detail. A quick review was done and as the PSA regulations, the standards intend to safeguard life, environment and assets. Only one standard, NORSOK S-003 Environmental Care, handles requirements with regards to the environment.

#### 6.1.2 HOW IS THIS INTERPRETED AND APPLIED BY THE INDUSTRY?

Barriers are mainly regulated in section 5, MR, which says that strategies and policies shall be stipulated and that the personnel shall be aware of the barriers and the function they intend to fulfil. The implementation of the regulations regarding barriers has been done differently within the industry and PSA has conducted a document with guidelines to barrier management. All companies that were interviewed said that they have a barrier strategy and barrier management. The challenge seems to be to ensure that the information from the risk analyses is spread to those working near the barriers.

As mentioned, the barriers are by PSA classified as technical, operational and organisational. All interviewees (drilling companies, DNV GL and PSA) agree that the technical requirements are easy to interpret and comply with. The issue seems to be the definitions of operational and organisational barriers. Some interviewees believe that it is hard to set the requirements for these types of barriers while others argue that it works well. The confusion that some of the interviewees experience might lead to that the requirements are not met, both for safety and environmental barriers.

It was emphasised by both DNV GL and PSA that the companies that have combined the documentation about the barriers and implemented the barrier strategy with the maintenance program, are able to maintain the barriers as intended by PSA. Good documentation is also important during the engineering and design phase since a lot of the equipment is produced abroad, which makes it hard for the operator to

participate. This relates to the importance of having a specific person who is responsible for barriers, to enhance the contact with the designer of the equipment to make sure that e.g. the technical requirements are met. The responsibility for the barriers seems to differ between the different companies. In some companies the HSE department is responsible, in some the technical department is responsible and in some the responsibility is shared between the two departments. PSA and DNV GL argue that it is of relevance to have clear roles of responsibility to assure good barrier management.

The drilling companies seem to interpret the regulations regarding environmental barriers differently. Some companies explain that consideration is taken to specific environmental barriers and some say that the safety barriers cover the environmental aspect. The regulations do not mention environmental barriers explicitly and it is up to the operator itself to ensure that the level of safety, both for personnel and environment, is sufficient.

#### 6.1.2.1 ARE THERE SPECIFIC ENVIRONMENTAL MEASURES, OR ARE THE SAME BARRIERS THAT ARE USED FOR SAFETY ALSO USED FOR ENVIRONMENT RELATED ACCIDENTS?

The result from the interviews is that almost all companies assume that the barriers protecting personnel also apply to the protection of the environment. Depending on how a barrier is defined, i.e. if it is only used for major accidents or also for smaller accidents, the range of the barriers will differ. An issue is that it can be hard to decide what a major accident is, with regards to the environment. It does not seem as there is a common view of what types of hazards that shall be included which might lead to that environmental barriers are to some extent overlooked. However, for drilling activities, the main hazard (blow out) that is relevant for environmental risks also protects personnel, which might be why other hazards seldom were mentioned. The case might be different if focusing on e.g. production activities.

#### 6.1.2.2 DO THE OPERATORS HAVE ADDITIONAL REQUIREMENTS WITHIN THEIR ORGANISATION?

The impression is that only a few companies have internal requirements. Those that have established their own requirements base it on experience within the company and do it to assure that PSA's requirements are met. The companies that do not establish their own requirements argue that they instead focus on the standards that PSA recommend, to make sure that no parts are missed.

#### 6.1.3 WHAT DOES THE NEW EU DIRECTIVE 2013/30/EU ON SAFETY AND OFFSHORE INSTALLATIONS SAY, IN RELATION TO THE NORWEGIAN REGULATIONS?

When reviewing the EU directive, focus was made on how the SCE and ECE are described and what requirements that are stipulated. Hence, other aspects that are not related to barriers might differ and affect the safety level, both for personnel and the environment.

##### 6.1.3.1 DO THEY ALIGN OR IS THERE A GAP?

Three major differences between the regulations were identified:

- The EU directive explicitly focus and mentions ECE and major environmental consequences
- The EU directive only applies to major accidents whereas PSA's regulations apply to all types of accidents
- The EU directive requires the operator to produce a major accident report where the operator shows that measures have been taken, both with regards to safety (personnel) and environmental consequences

The main difference is that the EU directive explicitly mentions ECEs, which is not as clear in PSA's regulations. The ECEs mainly focus on the technical aspect and not on operational and organisational factors as the barrier concept does. Also, the EU directive only refers to major accidents, while PSA's regulations also refer to smaller accidents. The smaller accidents might be regulated in other EU directives, but this has not been studied. The major accident report can be compared to the work with barrier management, but the requirements for the content is more specified than the requirements for barrier

management in PSA's regulations. PSA's requirements can instead be found in e.g. guidelines and standards that are referred to in the regulations.

#### 6.1.3.2 COULD THE EU DIRECTIVE FACILITATE THE IDENTIFICATION OF ENVIRONMENTAL BARRIERS AND HENCE INCREASE THE LEVEL OF SAFETY WITHIN THE INDUSTRY?

The impression is that the EU directive can help to highlight the environmental aspect related to petroleum activities and major accidents. The impression is not that the Norwegian regulation in itself lacks requirements for the environmental barriers, but that it is rather the tradition and cultures that influence how the barriers are identified. The barrier terminology was introduced in 2001 and during the latest years the focus has increased. Since major accidents seldom happen, it can be hard to actually understand how a certain measure decreases the risk of an accident. If the focus is equally on the environmental aspect and the personnel, the holistic view of which consequences that a failure of a barrier can lead to might increase.

## 6.2 SUMMARY OF RECOMMENDATIONS

In section 5, the recommendations, based on the data analysis, was discussed. This section summarises the conclusions that were discussed in section 5.

- Develop a recommended practice to identify major accidents with regards to the environment
- Extend the accident models to include systemic models
- Clarify the meaning of the classifications of barriers
- Include resilience engineering as a strategy to decrease the risk of major accidents
- Harmonise the players definition of barriers
- Restructure the sections in the regulations that regulate barriers and clarify the requirements
- Organise awareness increasing activities to increase the understanding of barrier management
- Clarify the responsibility for the barriers
- Establish a recommended practice for environmental barriers
- Encourage management to increase the awareness of environmental aspects
- Assure that the drills and exercises are based on realistic scenarios

## 6.3 FURTHER WORK

It seems, as the research about environmental barriers is included in the general safety aspect, the thesis's results indicate that there are areas that need to be further investigated:

- Continue the research with companies that work with production since these activities might be associated with different types of environmental risks than the drilling activities
- Investigate how the performance requirements for safety (personnel) align with performance requirements for the environment
- Investigate in more detail if the specific focus on ECEs in the EU directive could decrease risk related to environmental damage if implemented on the NCS.

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# APPENDIX 1

## INTERVIEW STUDY, DRILLING COMPANIES AND DNV GL

### INTRODUCTION

*Thank you for participating in the interview study regarding barrier management and environmental barriers in practice as a part of my master thesis. I will talk to people in the drilling industry, personnel at DNV GL and personnel at PSA in order to gather information about how PSA's regulations are understood and implemented in practice.*

*The interview will take about one hour and is semi-structured, meaning that the questions are fairly open, which gives you the opportunity to express your thoughts and experiences. The interview will be recorded so that I can focus on the conversation and also have the chance to make a fair analysis. The answers will be transcribed and sent to you, to give you the opportunity to read and comment what we talked about. The answers will be used anonymously and only used for this thesis.*

*Do you have any questions before we start?*

### MAJOR ACCIDENTS

*What:* how does the operator define the concept major accident?

*Why:* also major accidents is an expression that is mentioned frequently in the regulations. To have a common language when working with risk is important to make it easier to work towards common goals, and to set clear goals (Luko, 2013). If PSA and the operator define major accidents in different ways, it can result in different ways of interpreting the concept and thus working towards different goals.

*How:*

- How is the concept major accident defined in your company?
- How do you experience that the definition works? Is it known within all layers in the company?
- Do you think there is a need for clarification of the definition?
- How do you think that the definition affects the preventive work with major accidents and limitations of the consequences of the same?

## MEANING OF THE CONCEPT BARRIER

*What:* what does the concept mean and how is it interpreted and defined within the organisation?

*Why:* barriers are used as an expression in the regulations and it has been discovered by PSA that there is a problem regarding implementation of the barrier requirements in the industry (Midttun, 2013a). To facilitate this, it is important the relevant terminology is fully understood. When working with risk, a common language is important to be able to e.g. formulate clear goals (Luko, 2013).

*How:*

- How do you define the concept barrier in your company?
- Why using this definition (possible answers company requirement, compliance with PSA etc.)?
- How do you experience that the definition works? Does it cover all aspects of barriers, e.g. both technical and organizational elements? Is it known and understood throughout the organisation?
- How do you think the definition affects the work with barriers? (Barrier management?)
- Do you think there is a need for clarification of the definition?
  - If yes, why? What is missing/unclear?

## WORKING WITH BARRIERS

*What:* how does the operator work with barriers to prevent major accidents?

*Why:* the requirement for working with barriers can be found in PSAs regulations. As mentioned, the concept can be found at several places in the regulations and the subject area of the question is hence important to create a picture of how the industry works with the concept and if this correlates to the regulations. This question is central to answer the thesis's research questions.

*How:*

- How is barrier management executed
  - How are relevant barriers and associated requirements identified during design?
  - Who is responsible for this?
    - How are the requirements for the barriers decided?
    - What level of detail is there?
    - Are they followed up? How?
    - How do you assure independence between the barriers?
- How is the work with barriers documented?
  - How often is it updated?
  - What is included?
  - How is the status of the barrier assured?
    - Day to day?
    - Verification audits (how often? Independent verifier?)
- Who is responsible for the barriers?
  - How is this made clear for everyone within the company?
- How is the awareness of the barrier spread?
  - Is the communication done regularly or at certain stages of the life cycle (start up e.g.)?

## ENVIRONMENTAL AND SAFETY BARRIERS

*What:* has the operator a specific working procedure for environmental barriers or is this combined with the one for safety barriers (if there is a procedure?)?

*Why:* the industry asks for methods to handle environmental critical elements in their equipment<sup>20</sup>. Due to this, it is of interest to investigate how this is handled today and if there is a need for a clearer legislation. The EU Directive 2013/30/EU explicitly mentions environmental critical elements and aims to increase the safety for the environment in the European oil and gas industry, which could be a complement to the existing regulations.

*How:*

- Have you defined any major accident scenarios with only environmental consequences?
- Do you differ between environmental and safety barriers?
  - If yes: how do you identify the different barriers?
  - If no: why?
    - Is there an interest in doing it?
    - Is it because of unclear legislation?
    - Is it because of lack of knowledge?
- How are the acceptance criteria for major accidents decided, with regard to environmental impact?

## EMERGENCY PREPAREDNESS

*What:* how do the operator prepare for major accidents, is the legislation enough to prepare for major accidents and is the information spread through the organisation?

*Why:* knowing what do to and how to act if a major accident occurs is important to minimise the consequences. PSAs regulations contain requirements for this and the subject is investigated to see if the legislation is clear enough. The preparedness plan is an organisational barrier used to minimise the consequences of a major accident, which is why this question is important for the thesis.

*How:*

- How is the emergency preparedness plan established (regarding major accidents with environmental consequences)?
  - Who conducts it?
  - What is it based on?
  - What does it cover?
  - How often is it updated?
- How do you ensure cooperation with other operators?
  - How do you communicate?
- How do you select the emergency preparedness organisation?
- How is the emergency preparedness plan spread through the organisation?
  - Do you think everyone is aware of it and its content?

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<sup>20</sup> Personal communication, Ellen Ombler consultant DNV GL, 2014-02-17.



## LEGISLATION

*What:* is the legislation, regarding barriers, sufficient for the operator? Is there a need for further guidelines?

*Why:* to create a picture regarding how the industry considers that the legislation is clear enough or if it needs to be clarified, this question is relevant. The question intends to investigate if the legislation provides the necessary support and guidance that it aims to do. The answer will, as when interviewing, probably give a highly subjective view of the question, but it is based on the experience of the interviewee and is thus regarded important to answer the research questions of the thesis. Uncertainties in the legislation can make the operator unsecure, which can impair the risk management work (Ödlund, 2010). The question can also give an indication of whether the EU directive could fill the, by the operator, identified gap.

*How:*

- How do you ensure that you fulfill the requirements regarding barriers in the management regulations (PSA) and
- Are the company specific requirements related to barrier and major accident management that goes beyond the PSA/NMD requirements
  - Why/why not?
- Do you consider the legislation to be clear and easy to interpret?
  - If no, which areas should be clarified and why?
- Which role in the company is responsible for being up to date on rules and regulations related to major accident/barrier management

Thank you for your time, is there anything you would like to add?

## APPENDIX 2

### INTERVIEW STUDY, PSA

#### INTRODUCTION

*Thank you for participating in the interview study regarding barrier management and environmental barriers in practice as a part of my master thesis. I will talk to people in the drilling industry, personnel at DNV GL and personnel at PSA in order to gather information about how PSA's regulations are understood and implemented in practice.*

*The interview will take about one hour and is semi-structured, meaning that the questions are fairly open, which gives you the opportunity to express your thoughts and experiences. The interview will be recorded so that I can focus on the conversation and also have the chance to make a fair analysis. The answers will be transcribed and sent to you, to give you the opportunity to read and comment what we talked about. The answers will be used anonymously and only used for this thesis.*

*Do you have any questions before we start?*

#### MAJOR ACCIDENTS

*What:* what are PSAs thoughts about the definition of a major accident?

*Why:* the definition of a major accident will affect how an operator works with barriers against major accidents. The concept is mentioned frequently in the regulations and formulating requirements to the operators to control the risk of major accident is one of PSAs most important tasks. Also, having a common language when working with risks is important to make it easier to work towards common goals (Luko, 2013). If PSA and the operator define a major accident differently, it might result in different ways of interpreting the concept and thus working towards different goals.

*How:*

- Which definition should be used when working with major accidents?
- What are your thoughts about the definition?
  - How should the consequences be quantified?
  - What are your thoughts about mentioning something about complexity as an underlying reason? (In the definition to emphasize the reason and thus understanding of major accidents)
- What is your experience from how it works in practice?

## MEANING OF THE CONCEPT BARRIER

*What:* what is PSAs view of barriers to prevent and mitigate major accidents?

*Why:* barriers is one of PSAs focus areas this year and failure of these is a frequent cause of undesirable incidents in the petroleum sector (PSA, 2013a). PSA (2013a) also says that the players have implemented the requirements differently and that the industry must comply with the requirements in the management regulations. Again, a common language is important to make sure that everyone works in the same direction (Luko, 2013). This question is also important to understand PSAs intentions with the regulations regarding barriers.

*How:*

- How do you define barriers?
  - In the regulations you also mention safety systems, what is the difference? Why do you differ?
  - How would you define technical, operational and organizational barriers?
  - Do you differ between environmental and safety barriers? Or do you think it would be necessary?
  - What is included in the expression safety? (i.e. is safety only human life or is it also environment (and asset)?)
  - How do you experience that this works in practice?

## WORKING WITH BARRIERS

*What:* how does PSA experience that the industry works with barriers and how does PSA want the industry to actually work?

*Why:* This question will be asked to understand how PSA experiences what is lacking from the industry and what needs to be improved. The question will hopefully clarify further what PSA actually wants to achieve with the regulations. It will also give further input to the thesis and information that can be used when comparing the result from the interviews with operators with what is meant with the regulations.

*How:*

- What do you want to achieve with the barrier management and barrier strategy concept? Why was it established from the very beginning?
- How do you experience that the industry handles barriers and barrier management?
  - Is the concept understood throughout the companies, on all levels?
    - Why, why not?
    - What can be done differently, with regards to both PSA and the industry?
    - Does it differ between the companies?
    - Is there a difference between drilling and production companies?
- How do you experience that the document “Principles for barrier management in the petroleum industry” is used and understood by the operators?
  - Are you planning for a new version?

## ENVIRONMENTAL AND SAFETY BARRIERS

*What:* what expectations does PSA have on operators regarding barriers against environmental consequences?

*Why:* the thesis focuses on the requirements for environmental barriers in the context of major accidents. Since the industry has asked for methods to handle environmental critical elements<sup>21</sup>, it is of interest to know what PSA thinks about this and how they consider the regulations and guidelines to cover the environmental aspect.

*How:*

- How do you experience that the industry works with environmental barriers?
  - Do you include environmental barriers in the concept safety? Or is a barrier a barrier? (And not categorized)
- How do you experience that the industry focuses and is aware of potential environmental consequences (from major accidents)?
  - How does it affect the preventive work?
  - What do they put in the word safety? (Human life? Environment? Asset?)
- Which sections and standards are most important to fulfil the environmental requirements?
- How do you think a major accident with environmental consequences should be defined?
- Do you believe that there is a need for extra guidance regarding environmental barriers?

## LEGISLATION

*What:* are there any parts of the legislation, with respect to barriers and especially environmental barriers that is experienced as difficult by the industry? Also, what thoughts do they have regarding the Arctic and the legislation related to that? This topic also covers questions about the EU Directive 2013/30/EU and if PSA has considered to implement it?

*Why:* it is of interest to know how PSA experiences that the legislation regarding barriers is implemented in the industry. This gives a further view of potential gaps between PSAs intentions with legislation and the work that is done in reality. Since the industry is moving north, it is of interest to know if PSA has any thoughts the current legislation and if e.g. further guidelines will be necessary. The thesis also includes a comparison of the EU Directive 2013/30/EU and the Norwegian legislation, which is why questions about PSAs thoughts about the Directive are asked.

*How:*

- Are there any parts of the legislation that you experience harder for the industry to comply with?
  - Which and why?
- During audits, what seems to be the biggest concern?
  - Is it changing? Developing? (A greater understanding developed in the industry?)
  - Why do you think this is the biggest problem?
- What are your thoughts about the EU Directive 2013/30/EU about offshore safety?
  - In the EU Directive, environmental critical elements are mentioned explicitly, have you thought about implementing it?
    - Why/why not? (Implementing)
- What are your thoughts regarding the exploration of the Arctic?
  - What are the major challenges?
  - How can the current legislation handle this? Is there a need for further guidelines?

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<sup>21</sup> Personal communication, Ellen Ombler consultant at DNV GL, 2014-02-17.