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Author: Talar Arif	……Talar Arif………… (Signature Author)

Academic Responsibility: Professor Ove Njå

Supervisors: Ivar Skjeldal and Kjetil Moen, Aker Solutions MMO

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Risk reducing measures in the context of risk management

In quantitative risk analysis for maintenance and modification projects

By

Talar Arif

University of Stavanger
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FACULTY OF SCIENCE AND TECHNOLOGY
Department of Industrial Economics, Risk Management and Planning

"If you can't count it, it doesn't count."
Holsti, 1969 (Holme, Solvang, 2004)

Abstract

Risk analysis in the oil industry is used to identify and address the risks that are involved in a certain situation, on for instance a platform. Risk analyses have a long history in the oil and gas industry, and have been a vital part of the entire lifecycle of any project in this industry.

The content of the risk analysis consists of risk identification and calculation, and recommended risk reducing measures that can be implemented to reduce the risk to ALARP. The purpose of this thesis is to discuss how risk and risk reducing measures are identified and addressed in a risk analysis process. To be able to prepare and deliver a risk analysis, regulations determined by the authorities shall be followed and standards can be used as guidance. This thesis also looks at the regulations and standards that are present in risk analyses and in which way the risk analysis fulfils the criteria.

Literature review, study of three different case studies and informal interviews, have been performed and evaluated to determine how risk and risk reducing measures are identified and addressed in risk analyses. The three case studies use quantitative-, concept- and total risk analysis, in different stages of the life cycle in a platform. The risk analyses for the three case studies have been evaluated and compared, with respect to the regulations and standards. Furthermore, potential improvements have been suggested to implement in a risk analysis. It is evaluated, from the case studies used in this thesis, that risk and risk reducing measures often are based on traditional approaches as well as implemented data from statistics and previous case studies. The underlying understanding regarding risk and risk reducing measures are often not presented in risk analyses nor are the uncertainties and causes of given activities.

Key words:

- Risk
- Risk Acceptance Criteria
- Risk Reducing Measures
- Risk Analysis
- ALARP

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Abbreviations

ALARP	- As Low as Reasonably Practicable
CRA	- Concept Risk Analysis
EERS	- Evacuation, Escape and Rescue Strategy
EPA	- Emergency Preparedness Analysis
ESDV	- Emergency Shut Down Valve
ETA	- Event Tree Analysis
FAR	- Fatal Accident Rate (per 100 mill. hours)
FES	-Fire and Explosion Strategy
HAZID	- Hazard Identification
HSE	- Health, Safety and Environment
ISO	- International Organization for Standardization
MMO	- Maintenance Modifications and Operations
NORSOK	- NOrsk SOkkels Konkurranseposisjon
PLL	- Potential Loss of Lives
PSA	- Petroleum Safety Authority
QRA	- Quantitative Risk Analysis
RAC	- Risk Acceptance Criteria
RBI	- Risk Based Inspection
SLA	- Sleipner A
SLT	- Sleipner T
SSIV	- Subsea Isolation Valve
STAMP	- Systems-Theoretic Accident Model and Processes
TRA	- Total Risk Analysis

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Introduction

Risk is wherever we are; it is present in every activity or event we are a part of. Risk itself is neither bad nor good. It is the measure of deviation that is given from what is expected. The consequences on the other hand, can be bad or good. Risk related to people is the most crucial risk that we can be exposed to, especially in the oil industry. The risk on for instance a platform offshore is high both for personnel, the assets and the environment; the consequences can be fatal. Thus, risk can differ from fire and explosion danger to risk related to getting your finger cut or falling. Risk analysis is the process of dealing with uncertainty and trying to mitigate the consequences of the risk and uncertainty occurring. A risk analysis is often used as a tool for decision making (Aven, Vinnem, 2007). Therefore, identifying and assessing risk is important in order to analyze potential consequences. Risk reducing measures can be determined to mitigate the consequences and reduce the risk involved as low as reasonably practicable.

Risk analysis is used on a daily basis in the oil industry, both offshore and onshore. New platforms, modifications of existing platforms or extensions involve risk that can harm people, assets and the environment. Through preparing a risk analysis, the hazards and risks that are involved are identified and determined. The risk analysis process differs, depending on the operating company as well as on the company preparing the risk analysis, but has to be in relation to the regulations that have been determined by the authorities. Preparing a risk analysis is necessary for determining the risk that is involved through setting risk acceptance criteria to be able to determine risk reducing measures. After the Piper Alpha accident, risk analyses have been applied in specific parts of the design, maintenance and modification processes. Risk analyses have been used as a decision making tool for determining and identifying risk involved in certain activities (Brandsæter, 2002). If a risk analysis had been performed for Piper Alpha, the decision of not installing blast walls between the oil separation units would have been analysed as a high risk decision. A risk analysis would have shown that the probability and consequences would have been very high. As result of implementing risk analysis in the oil industry, better decisions have been made and risks have been identified, addressed and reduced. However, the risk analysis process needs constant improvements regarding risk and risk reducing measures through learning from previous accidents and activities.

The risk analysis process and approach for identifying risk is often based on experience and the process can always be modified and improved depending on the elements that need to be evaluated. The purpose of this thesis is to identify and present how risk and risk reducing measures are identified an addressed in quantitative-, concept- and total risk analysis. Providing a literature review and theoretical background related to risk and risk reducing measures in the oil industry is in place and case studies have been used to help determine the purpose of this thesis. Three different case studies have been used that represent how risk analyses are presented for operating companies in Norway. Through, literature review, comparing and reviewing case studies, a discussion and analysis will be performed to indicate whether the risk and risk reducing measures in a risk analysis comply with the regulations and standards. Regulations have been determined by the Norwegian Petroleum Safety Authority (PSA) which the oil industry shall follow. Standards, as NORSOK- and ISO standards, can contribute as guidance when following regulations; they have also been analyzed with respect to how they are used in risk analysis when identifying risk and risk reducing measures. Therefore, the risk analysis shall contain the requirements that have been determined by the authorities and this thesis will evaluate whether the requirements have been followed in the risk analyses. In addition, research has been performed to determine further potential improvements that can be implemented to ameliorate the process of risk analysis.

Problem statement and research question

The main focus for companies related to the oil industry, and for that matter with other industries as well, is to analyse risk and the consequences related to exposure to a certain risk. Though most companies have defined their views and limits on risk through risk acceptance criteria, risk identification and risk reducing measures also need to be analyzed and determined.

The risk reducing measures will contribute in reducing the risk, and thus the consequences. Through the risk analysis process, risk and risk reducing measures are identified and determined. It is interesting to analyse the risk concept that is used in quantitative risk analysis and how the risk picture and understanding of risk contributes to determining the risk reducing measures. When having the understanding and picture of how risk is defined, the understanding of safety to for instance the personnel or environment can be determined.

The main scope of this thesis is to analyse how risk and risk reducing measures in the context of risk management in quantitative risk analysis has been presented for maintenance and modification projects. The research questions in this thesis can thus be defined as:

"How are 'risk' and 'risk reducing measures' identified and addressed in risk analyses when analyzing case studies based on quantitative-, concept- and total risk analysis?"

"How can the content of a risk analysis be improved with regards to the identification and presentation of 'risk' and 'risk reducing measures'?"

These two research questions are closely linked. The presentation of risk and risk reducing measures will be analysed and addressed and, if possible and if needed, improvement potentials will be introduced to help improve risk analyses. By identifying and answering these questions, the risk analysis process will be much clearer, as well as how risk and risk reducing measures are identified and addressed in risk analysis processes. The risk and risk reducing measures, and how they are identified and determined, will differ depending on the risk analysis. The risk analyses used in this thesis are a related to quantitative-, concept- and total risk analysis of a platform, in the Norwegian Continental Shelf.

When an operating company needs a risk analysis of a platform or of a modification process, other consulting companies specialized in preparing quantitative risk analysis are used. However, the companies that are preparing the risk analyses have their own perception on risk, which they use in accordance with the risk perception from the operating company. This risk perception is then the underlying understanding that is used for the risk analysis. Also, regulations and standards are used in the process of identifying and addressing risk and risk reducing measures. It is fascinating to evaluate how companies use and present the term 'risk' and how it is further used in determining the risk reducing measures for quantitative-, concept- and total risk analysis . This thesis is set to evaluate the risk concept and how it is identified and used when determining and identifying the risk reducing measures. One of the main interests is whether the three risk analyses for the three cases satisfy and comply with the requirements set by the authorities. In addition, the risk analyses are different (quantitative-, concept-, and total risk analysis) and thus have different approaches and are prepared in different stages. It is important to identify their differences and whether they lack information or identification of certain aspects that should be in a risk analysis.

The case studies are:

- **Case 1**: Quantitative Risk Analysis for Gudrun-tie-in to the Sleipner platform
- **Case 2**: Total Risk Analysis for the Sleipner platform
- **Case 3**: Concept Risk Analysis for the installation of pre-compressor on the Troll A platform

Even though these risk analyses types differ in content and usage, the risk perception and the underlying understanding of risk and of the risk reducing measures is the main focus. It is interesting to evaluate how the three case studies identify risk and risk reducing measures, how they address these terms and how they are used. By comparing the three different risk analysis types the result can illustrate the usage of the risk analysis for determining the risk perception as well as determining the risk reducing measures. The three case studies represent typical case studies that are used in Norway by consulting companies that deliver these risk analysis documents to the operating company. Therefore, the result of how risk and risk reducing measures are identified and addressed in these three cases will give an overall indication of how the risk is identified and presented in the oil industry.

To recap; this thesis will study risk analyses with respect to the regulations and standards that shall be fulfilled, to evaluate:

- The risk concept and identification of risk (how is risk understood, analysed and presented in risk analyses)
- The presentation and development of risk reducing measures

Research purpose

The aim for this research is to identify how risk and risk reducing measures are identified in risk analysis processes. Through this research data and documents have been evaluated and analyzed to determine how the terms risk and risk reducing measures for the three case studies have been identified and addressed in the risk analysis.

The three case studies used in this thesis will give an overall illustration of how the term risk is defined in the quantitative-, concept- and total risk analysis that have been used. The term risk, especially in petroleum related activities, is very important to be defined. Through identifying risk and risk reducing measures, the safety of the personnel and the environment can be illustrated. Through risk analysis, risk can be identified, the potential consequences can be evaluated and the priorities for measures and actions can be determined. By determining and identifying risk, the measures can be determined to reduce the consequence of the risk as much as possible. Following a brief introduction on the three case studies, a discussion is performed to obtain total view on how risk and risk reducing measures have been illustrated. The main purpose of the thesis is thus to illustrate how risk analysis uses the terms risk and risk reducing measures in different risk analysis and whether there is potential for improvement.

The Norwegian Petroleum Safety Authority has set regulations that shall be followed in the oil companies. A risk analysis shall go through the regulations and the recommendations to satisfy the authorities and retain their license to operate. Standards are recommended to follow the regulations that are set. Thus, the thesis will also analyse whether the risk analysis comply with the regulations and the standards used. Through complying with the regulations and the standards that are used, this will contribute to the risk analysis for developing the risk concept and identifying risk and risk reduction measures.

The three case studies are used to determine if the approach used in the risk analysis, to identify and address risk and risk reducing measures, is effective. This will be evaluated by determining whether the three risk analysis fulfil the requirements and regulations set by the authorities and how the risk analysis determines and identifies the risks involved in a platform. In addition, theoretical overview has been established to compare the understanding from the literature review with the understanding of the risk analyses. This is done in different stages of a platform live cycle:

- The quantitative risk analysis for Case I has the focus on risk involving an extension of a platform
- The total risk analysis for Case II focus on the risk involved for an (entire) existing platform
- The concept risk analysis for Case III focuses on the risk that is involved when a platform is modified

Limitations of the research

The main limitation regarding this research is associated with the risk analyses that have been used. The analyses are related to three case studies for offshore platforms. The three cases are of quantitative risk analysis methods, but the fact that they differ in being concept-, quantitative- or total risk analysis has not been explained in detail or what they contain. The first case study is a quantitative risk analysis of a tie-in; the second case study is on the total risk analysis of a platform, while the third case study evaluates the concept of a pre-compressor that will be added to a platform. The presentation of risk and risk reducing measures is of main interest, not what type of method was used and why that was used. The main focus is on how the terms risk and risk reducing measures have been identified and further assessed in the three risk analysis that are evaluated for the three case studies. Thus, the thesis is limited to three case studies, more case studies could have been used to stress the risk concept and the identification of risk and risk reduction process.

In addition, the main focus is on risk related to the personnel, not the assets or the environment. The risk analysis contains sub analysis like fire and explosion analysis, escape routes, fatalities etc. to determine the risk involved on the platform. Examples from the risk analyses that are related to risk have been given; these examples are related to the fire and explosion analysis. The examples are restricted and are only given as an indication of how the risk analysis presents risk and risk reducing measures. Since the risk analysis is comprehensive, only very few tables and examples have been used from the documents. Also, the presented regulations, guidelines and standards are limited to the ones that are considered as the most important and relevant ones, related to the risk analyses for the case studies.

No further analysis has been done regarding the cost and benefits of implementing the measures that have been proposed or the benefits of them. Whether the actual risk reducing measures have been implemented (the recommended measures in the risk analysis) for the three cases have not been followed up.

Research approach and Methodology

During the process of writing this thesis, increased interaction between the literature (theory) and case studies established the analyse process of this research to determine the research questions. The relationship and lack of relationship between the interactions create an increase in literature search, while writing the thesis more research and literature had to be collected. By being able to adapt information from different angles, the research question is better approached (Holme, Solvang, 1996).

This thesis is aimed to find how risk and risk reducing measures are identified and addressed in risk analysis. To be able to find out how this is done, case studies have been selected to find how risk and risk reducing measures are presented. The study also includes a literature review of relevant topics that are concerned with the content of the risk analysis. In addition, informal interviews have been conducted with the most important stakeholders to get an overview of how the risk analysis process is prepared and processed.

Literature Review

The first step of starting this thesis was to go through literature that was considered relevant, with emphasis on gaining fundamental understanding of key elements. Through, undertaking a literature review, the definitions and terms that are most relevant have been distinguished, analyzed and presented. Regulations in Norway and standards that are considered relevant have been analyzed and presented to get a better understanding. Furthermore, a course related to regulatory competence for the petroleum industry was attended to get the underlying understanding of Norwegian regulations and relevant standards (RVK, 2012). Through this course the regulations were presented and the most important and relevant regulations for this thesis have been selected and presented in Section 2.

A literature review was also performed to identify potential improvements that can be implemented in risk analyses used in the oil industry in Norway. Most of the literature used, has been selected from the literature used throughout the Masters study that are related to risk. A lot of time has been used on determining the correct literature that should be used for this thesis.

These selected literatures illustrate the most important definitions and terms that will contribute in analyzing the research questions. When having the needed knowledge to understand the terms risk and risk reduction measures, the risk analyses for the case studies can be evaluated. The case studies are very comprehensive and require understanding of risk to be able to analyse the risk analyses.

Interviews

Non-formal interviews and discussions have been performed regarding the content of the risk analyses, with personnel at Aker Solutions. Relevant personnel that are using the risk analyses on a daily basis have been addressed to find out what their perception has been regarding the risk analyses. These conversations and discussions were not formal and thus not used in a large scale throughout the thesis, as this was preferred by the informants. The main focus was to get input on how the risk analysis is addressed and used on a daily basis for the people that use them. They wished to remain anonymous, but gave their perceptions and opinions related to how risk and risk reducing measures are identified and addressed in risk analyses.

In addition, the consulting companies that have prepared the risk analyses of the three case studies have been contacted. Conversations and discussions have been performed to understand the underlying understanding of the process for identifying and addressing risk and risk reducing measures. These informants also wished to remain anonymous. Therefore, their information has been used to the minimum in this thesis. The main purpose of having discussions with key informants that prepare the risk analysis is to find out how the risk analysis process is prepared and further evaluated as well as seeking information on the aspects that the risk analysis is missing or lacking. Through these conversations, the process of preparing and determining a risk analysis was explained. When understanding how the risk analysis is processed, the underlying understanding was established. These companies determine the risk reduction measures together with the operating companies; the informants that were contacted explained how they address risk and risk reduction measures and how they are determined. Since they wanted to remain anonymous, the information that was given, contributed to a better understanding of their processes for determining risk and risk reduction measures.

To get an understanding of how and what the operator company contributed with, in the risk analysis, non formal interviews have been conducted with Informants from the operator company. These Informants were both involved in the risk analysis process of the three case studies used, and with other similar case studies.

Also, non formal interviews have been conducted with the PSA; they also wished to remain anonymous. The interviews were open interviews, where questions were prepared but the interviews were more focus on discussions and conversations, rather than a formal interview. The interviews with the authorities contribute to the thesis, with an other view and conception than the ones from the consulting or operating companies.

Notes were taken from the conversations to further implement in this thesis. A qualitative approach has been used in this thesis to present and give an understanding of risk and risk reduction measures in risk analyses. The link between research questions, collected data (case studies) and research conclusions is the research design used in this thesis (Blaikie, 2009).

By conducting open and non formal interviews (or rather discussions and conversations) the Informants have been able to share more information. They felt comfortable to talk about subjects that they wouldn't have been comfortable talking about if it was a more formal interview, or if they were quoted and referred to. Therefore, the non informal interviews were a conscious decision to let the Informants speak their minds and have as much information as possible to use in this thesis.

Case studies

The most important part of the thesis is the evaluation and analysis of the risk analyses from the three case studies. The case studies that are selected, in agreement with the supervisors, represent risk analyses that are used in the oil industry to determine the risk that is involved. Three cases have been selected to increase the potential for generalisation and to compare them with each other; they contribute as evidence (Yin, 2009). A better understating is then established regarding the risk analyses that are used in the oil industry by these documentations. The three case studies have different approaches and thus differ in content. By evaluating the literature review and the three cases, the research question and purpose was then determined. The following documents were included in the risk analysis for the three cases (the documents where further divided into subdocuments and appendices):

Case study:	Documents:
Quantitative risk analysis- Gudrun tie-in	Concept Risk Analysis of Gudrun tie-in
	HAZID analysis
	Sensitivity Analysis
	Preliminary Design Accidental Loads Specifications
	Accidental Loads
	Risk Assessment
	Emergency Preparedness Analysis
Total Risk Analysis- Sleipner	Summary Report
	Emergency Preparedness Analysis
	Risk Analysis report Sleipner A
	Risk Analysis report Sleipner B
	Risk Analysis report Sleipner R
	Risk Analysis report Sleipner T
Concept Risk Analysis- Troll A Pre-compression	Concept Risk Analysis of Troll A Pre-compression
	HAZID analysis
	Explosion Risk and Fire analysis
	Sensitivity analysis
	Emergency Preparedness Analysis
	Installation Risk Analysis
	Ventilation and Wind analysis

Table 1: Risk Analysis documents

Through analyzing and comparing the case studies, further discussions can be performed and a conclusion is given regarding how the risk and risk reducing measures are identified and addressed. Potential improvements for the risk analyses have been proposed through learning and evaluating the case studies. The theoretical basis establishes the main understanding required to describe and evaluate the risk analyses in the case studies.

All views and opinions throughout this thesis are the responsibility of the author only and do not represent the involved organisations or people interviewed.

Structure of the thesis

The most effective and productive structure for introducing and analyzing this thesis has been evaluated. And the structure that is used in the thesis is used to let the user understand the focus for the research. The structure of the research is divided into the following sections:

Section 1: Theoretical approach
The first section of the thesis is regarding the theoretical background that is necessary to have before analyzing and further evaluating the purpose of this thesis. This section is further divided into two different subsections. The first subsection is regarding the regulations (in Norway) and standards (both Norwegian and international) related to risk in the offshore industry. The most important regulations and standards have been presented. The second subsection is a literature review, which is essential to interpret and perceive the other sections in the thesis. Through the theoretical background the most important terms and definitions have been demonstrated.

Section 2: Case study
The case studies have been analyzed to determine the risk identification process and how risk is addressed. Three case studies have been presented and analyzed in this section. The three case studies are introduced with the main focus being on risk and risk reducing measures, examples from the fire- and explosion analysis have been used to illustrate how risk is being introduced and used in the three risk analyses.

Section 3: Discussion
The third section goes through the three case studies that have been presented and discusses them. The relationship and differences between the three cases are analysed and discussed against each other, based on the risk presentation of the risk analyses, to determine improvement potentials. This has been done with focus on the theoretical background and regulations and standards.

Section 4: Conclusion
A conclusion is given to complete and understand how risk and risk reducing measures are identified and handled in quantitative-, concept- and total risk analysis.

Section 1: Theoretical approach

The first section of this thesis presents the theoretical background that provides the most relevant terms and definitions for this thesis. The theoretical approach has been divided into two subsections to distinguish between two major views that are critical in this thesis.

The first subsection is regarding the regulations, recommendations and standards that are used in the Norwegian petroleum industry. The regulations shall be followed and the standards are recommendations that are given to be able to follow the regulations. The most relevant regulations that are related to risk and risk reducing measures have been presented. In addition, the standards that are recommended by the authorities and the standards that are used in the three risk analyses have been introduced and explained. The main reason for selecting the presented standards is that these standards represent how risk and risk reducing measures should be used.

The second subsection presents the literature review that is selected in order to understand and analyze the risk identification process and evaluate how the risk reducing measures are identified and addressed in the case studies. The most important and relevant terms and definitions have been selected and demonstrated. These particular terms and definitions have been selected in order to understand and interpret the risk analysis for the case studies that are used in this thesis.

”**Research without theory is blind, and theory without research is empty”**
(Bourdieu and Wacquant, 1992)

1.1 Regulations and Standards

Working in the petroleum industry means working in a high risk environment. The high risk involved can for instance be due to hazards regarding oil/gas pressure and temperature for the produced fluids. Therefore, Health, Safety and the Environment (HSE) are factors that need to be taken into consideration in analysis and preparations to avoid unwanted situations. The laws, thus the regulations in the petroleum industry context, have been presented to protect and secure the people involved and safeguard the material assets for the community. Therefore, regulations and standards have been established to ensure a safe working environment. All regulations must be read and understood as consistent regulations and in the context of the governing laws. In addition, the authorities recommend the use of norms that are outlined in the guidelines; this also includes the use of standards. These recommended standards ensure that the intensions of the regulatory requirements are being followed (RVK, 2012). The Norwegian Petroleum Safety Authority (PSA) is responsible for ensuring and controlling submission and obedience with the regulations.

The regulatory- and standardization levels in the regulations can be placed in the Figure 1:

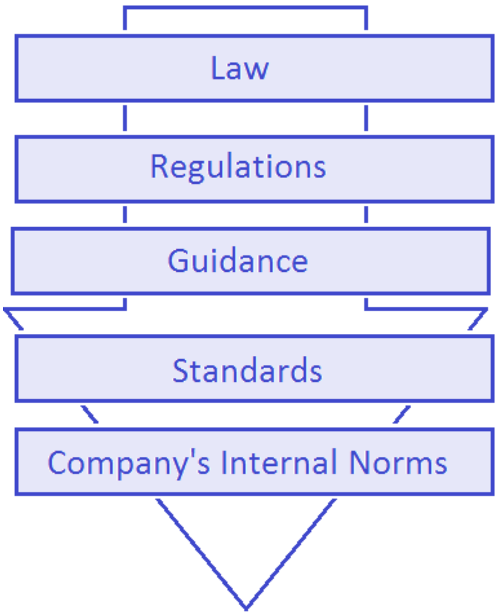

Figure 1: Regulations and standards (RVK, 2012)

The Framework regulations (2001) are used to determine goals that are the superior quantities that the oil companies have set for themselves in correspondence with the regulations. Risk and risk reducing measures have to be identified and determined to keep the risk as low as reasonably practicable. These risk reducing measures and the identification of risk needs theoretical concepts to prepare a risk analysis of for instance a platform or a modification of a platform.

The coherence between the regulations, theoretical concepts, risk (reducing measures) and the superior goals can be illustrated through Figure 2:

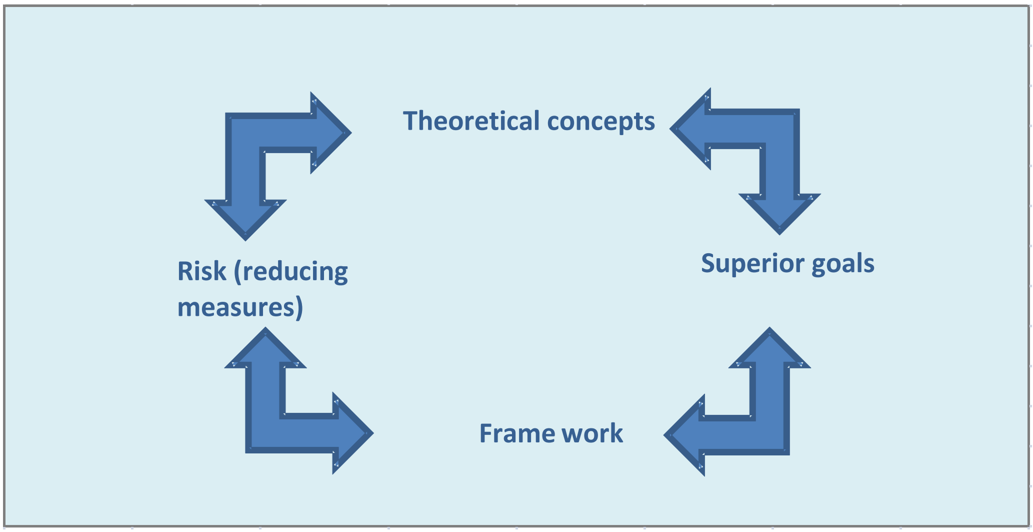

Figure 2: Coherence with regulations (Aven et al., 2004)

Management of risk and safety regarding the offshore industry has two main elements; superior goals and risk reducing measures (Aven et al., 2004). The superior goals are concerned with the visions and goals that need to be determined depending on the surroundings, available elements, economy, experience, etc. Most of the oil companies strive to achieve the ultimate goal zero, where no harm is done to the people or the environment before- during- and after production. To be able to achieve the determined visions and goals, measures need to be determined and implemented.

The measures in the context of this thesis are the risk reducing measures that need to be identified and determined to reduce the risk as low as reasonably practicable. In addition to superior goals and risk reducing measures, theoretical concepts and frame conditions need to be taken under consideration. Through theoretical concepts, the understanding regarding superior goals and risk reducing measures can be established. A theoretical concept is needed to understand the risk concept and establish the underlying understanding before starting the risk analysis process. When the underlying understanding is established, the risk acceptance criteria and the risk reducing measures can be determined and further analyzed. The framework is dependent on the resources available, the situation and risk management approach. In the oil industry, the regulations set by the PSA are important frameworks that shall be followed (Aven et al., 2004).

1.1.1 Norwegian Regulations

In Norway the regulations are set by the Petroleum Safety Authority (PSA), these regulations related to health, safety and the environment in the petroleum activities and at onshore facilities are divided into the following sections:

- The Framework Regulations
- The Management Regulations
- Technical and Operational Regulations
- The Facilities Regulations
- The Activities Regulations

The Framework Regulations (2001) contribute to a basis of the coordinated regulations and supervision offshore and some specific onshore facilities, regarding health, safety and environment. They demonstrate the fundamental requirements for how to manage activities in the oil industry (RVK, 2012).

Framework Regulations (2001) § 11, is the section regarding the risk reducing principles. It states that the "*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."*

Risk shall be reduced, also in the early stages when choosing the technical, operational and organisational solutions. The potential harm to individuals has to be analysed and reduced to offer the best possible results provided that the costs are not unbalanced with regards to the risk reduction that will be achieved. Risk reducing measures have to be presented to reduce the risk as much as possible. The measures and solutions that will reduce the uncertainty towards the health and safety of the personnel shall be chosen. In addition, the elements that contribute to harm to people, assets or the environment shall be replaced with elements that will have less potential of harm.

The health, safety and security of the people involved on a platform are the most crucial aspects that need to be taken into consideration. Framework Regulations (2001) §11 illustrates that, when identifying risk and risk reducing measures in the context of quantitative risk analysis, the health, safety and security of the personnel has to be the highest priority. The Guidelines of § 11 from the Framework Regulations (2001) further address general risk reducing principles, for instance:

- ALARP principle (As Low As Reasonably Practicable): the risk shall be further reduced beyond the minimum level that follows from the regulations.
- BAT principle (Best Available Technology): the party responsible shall use a basis for its planning and operations the technology and methods that the best and most effective results
- Pre cautionary principle: clarify a principle that is recognized (inter)nationally in the area of HSE
- Substitution principle: alternative solutions shall be chosen that do not entail the relevant risk factor

These Guidelines can be implemented in the risk analysis to indicate the use of the risk reducing principles.

Regulations related to management and the duty to provide information in the petroleum activities and at certain onshore facilities (2010) state that risk reducing from § 11 shall be selected by the responsible parties. Management Regulation (2010) § 9 demonstrates the acceptance criteria for major accidents and environmental risk. The acceptance criteria shall be set for the people that are involved both offshore and onshore. In particularly, acceptance criteria shall be set for the people that are exposed to a particular and/or higher risk depending on the area they work at. Acceptance criteria shall also be determined for loss of main safety functions and damage to the environment or third party. By setting these acceptance criteria the risk identification process has to be determined in advance, before the risk analysis process. Furthermore, they are important with regards to the risk acceptance criteria that are determined before specifying the risk reducing measures. A risk analysis should contain risk acceptance criteria to illustrate the criteria that are distinguished with respect to the risk involved. When the criteria have been distinguished, the risk reducing measures can be specified.

The risk analysis shall have a clear purpose, also the conditions, structure, building and the limitations that form the basis of the risk analysis. The risk analysis shall be presented in a balanced and comprehensive matter for the target group. This indicates that the "*responsible party shall carry out risk analyses that provide a balanced and most comprehensive possible picture of the risk associated with the activities. The analyses shall be appropriate as regards providing support for decisions related to the upcoming operation or phase*".

Facilities Regulations (2010) § 7, which is related to the Main Safety Functions, states that the main safety functions shall be defined for each facility to ensure that the safety of the personnel is guaranteed. The main safety functions shall be maintained to prevent escalation of accident situations and protect the rooms and areas that are most exposed.

The risk acceptance criteria have to be determined for the main safety functions in addition to acceptance criteria for personnel or the environment. Accidents and hazards may occur even if the regulations and recommended actions are undertaken; therefore emergency preparedness analysis shall be carried out. The emergency preparedness analysis is a part of the risk analysis where major risk factors are evaluated. Risk analysis shall be accomplished to identify and determine the contributions to major accidents and the uncertainty involved. Necessary assessments shall be carried out for sensitivity and uncertainty analysis. Thus, the risk analysis shall (Management Regulations, 2010, § 17):

a) identify hazard and accident situations,
b) identify initiating incidents and ascertain the causes of such incidents,
c) analyse accident sequences and potential consequences, and
d) identify and analyse risk-reducing measures

1.1.2 Norwegian Technology Standards

The Norwegian petroleum industry has developed the NORSOK (NOrsk SOkkels Konkurranseposisjon) standards to ensure adequate safety, value adding and cost effectiveness for existing and future petroleum industry developments. NORSOK standards have been published by the Norwegian Technology Standards Institution (NTS) which covers both technical and operational matters regarding safety in the petroleum industry (NORSOK Z013, 2010). Most of the NORSOK standards have been recommended to follow by the PSA. Therefore, understanding and exercising these standards can be an advantage to use when following the regulations. The risk analysis used in this thesis shall follow the regulations, but should also include the standards that are recommended.

NORSOK Z-013

NORSOK Z-013 (2010) has been developed to establish requirements for effective planning, execution and use of risk and emergency preparedness analysis as well as the use of risk acceptance criteria. This standard has been recommended to be used by the PSA when determining risk- and emergency preparedness analysis. NORSOK Z013 (2010) has also been used for the risk analyses of the case studies used in this thesis. NORSOK Z-013 (2010) is based on the following elements:

- Establishment of risk acceptance criteria prior to execution of risk analysis
- The relation between risk and EPA, especially the integration of the two types of analysis into one overall analysis process
- Planning and execution of analyses
- Further requirements to use of risk and EPA for different activities and life cycle phases
- Establishment of requirements based on risk and EPA

Thus, this standard has been used and referred to throughout the risk analysis for the case studies. The main purpose for the standards is to illustrate the recommended actions that need to be analyzed in a risk analysis.

This standard overlaps and meets the regulations set by the PSA, due to the fact that risk and emergency preparedness plans are in focus. When determining the risk analysis, these factors should be presented.

1.1.3 International Standards

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. The preparations of these standards are carried out through the ISO technical committees. International organizations, governmental and non- governmental, in cooperation with ISO, work on these standards (ISO 13702, 1999). As for the NORSOK standards, the ISO standards are recommended to follow in the risk analysis process. ISO standards have been used in the risk analyses of the three cases. The two ISO standards that have been presented below have been used for the risk control and mitigation of fires and explosions. In addition, the guidelines and tools presented in the last ISO standard have been used to identify hazards or identify risks.

International Standard 13702

ISO 1372 (1999), Petroleum and natural gas industries – Control and mitigation of fires and explosions on offshore production installations- Requirements and guidelines, has been developed to assist in the development of new and existing installations; the standard should only be used where it is reasonably practical to do so. This International Standard describes the objectives, requirements and guidelines for the control and mitigation of fires and explosions on offshore installations. The principal objectives are the safety of the personnel, the protection of the environment and assets and the minimization of financial consequences of fires and explosions. Controlling and mitigating fires and explosions are important factors that should be presented and evaluated in a risk analysis. The risk that is involved should then be identified and presented as well as the risk reducing measures. The safety of the personnel is the most important objective that this ISO standard represents, as in the regulations set by the PSA, and this should also be the case for the risk analysis.

International Standard 17776

ISO 17776 (2002) is from the British Standard Petroleum and natural gas industries, offshore production installations, and is used as Guidelines on tools and techniques for hazard identification and risk assessment. This international standard has been developed to assist with managing hazard identification and analysing risk. Oil and gas exploration and production activities can involve hazards that need to be identified as well as the consequences of the hazards. This standard complements the regulations by describing several tools and techniques that can be used to identify and manage hazards and risks. Hazard identification and risk analysis can be managed by identifying the hazards, assessing the risks involved and reducing or eliminating risk. Identifying potential hazards should be part of a risk analysis to determine the risk involved in the potential hazards. The risk and the risk reducing measures have to be presented to assess the risk. The risk reducing measures will then contribute to reducing or even eliminating the risk that is involved for the potential hazards that are identified.

1.2 Literature review

Through understanding definitions and terms, the analysis of case studies can be carried out. A theoretical background will illustrate the most important definitions in order to understand the case studies that are presented and then the discussion that is given. By having the right theoretical background the understanding of this thesis will also become easier. The terms and definitions that are explained in this section are the ones that are considered most relevant and important for understanding the concept behind the case studies and their risk analysis.

To analyse the risk that is involved in for instance a case study, different risk analysis methods can be used. In this case quantitative-, concept- and total risk analysis have been used in the different case studies to analyze the risk that is involved when a tie-in to a platform is considered or when a pre-compressor is to be installed. To be able to determine the risk that is involved in the different case studies, risk acceptance criteria are set to determine the acceptable risk, therefore risk acceptance criteria are important to determine. When the risk has been identified through a hazards and risk identification process, the risk reducing measures can be determined to distinguish the measures that can be implemented to reduce the risk as low as reasonably practicable.

The most important definitions have been further described in the subsections of Section 1.2, containing:

- 1.2.1 Risk
- 1.2.2 Risk Analysis
- 1.2.3 Risk Acceptance Criteria
- 1.2.4 Risk Reducing Measures
- 1.2.5 The ALARP principle

1.2.1 Risk

In the oil industry risk is presented in different ways for systems, both offshore and onshore. Standards and regulations are given to reduce risk and minimize the possibility of an occurrence that was not intended. They are for instance available in the NORSOK standards where operational and technical safety issues are handled. The operator and service companies shall have an effective process of evaluating and managing elements as health, safety, environment and risk (ISO 13702, 1999).

Risk, as a definition, refers to uncertainty about and severity of the consequences of an activity with respect to something that human's value (Aven, Renn, 2010). The term risk can be seen as the "absence of safety" and is used as a goal for setting the safety levels (TRA Sleipner, 2004). Safety can be defined as the absence of unwanted and destructive events. High risk is being perceived as an unknown event and vice versa. Risk is thus a product of the consequences of the unwanted events towards personnel, assets and the environment, as well as the probability that these events may occur.

NORSOK standard Z-013 (2010) defines risk as the combination of the probability of occurrence of harm and the severity of that harm. Risk may be expressed qualitatively as well as quantitatively where the probability of occurrence is set between 0 and 1 or as a frequency, with the inverse of time as dimension. Whereas, ISO standard 13702 (1999) explains risk as the combination of the chance that a specified undesired event occurs and that the severity of the consequences of that event are taken into consideration.

Regulations set by the PSA Norway (Framework Regulations, 2001) also define risk, in the area of health, safety and working environment, as a combination of probability and consequence. Risk shall be reduced as much as possible. The solutions for reducing risk and the barriers that have the highest risk reducing purpose shall be chosen.

To be able to set and prepare a risk analysis process, the risk picture develops the scope of the analysis. It shall include a clear description of the objective and scope of the analysis as well as of the methodology that is set to be used in the analysis (NORSOK Z013, 2010). The presentation of the risk picture should include the ranking of risk contributors, potential risk reducing measures, assumptions, premises etc. Moreover, risk can be expressed in different ways, but the most general way of expressing risk is (Aven et al., 2004):

"*the uncertainty regarding what the outcome/ consequences are of a given activity*"

Since risk can be defined in different ways, it is necessary to understand and create an understanding of risk related to a certain activity. In addition, the risk definition should be expressed in a risk analysis to ensure that the reader of the risk analysis understands the meaning of risk that is further used.

Risk involved in a particular situation can be calculated and the consequences can be determined for the people that might be involved. Thus, when risk is related to the loss of lives that are involved, the Fatal Accident Rate (FAR) value can be implemented to determine the risk picture. The FAR value expresses the number of fatalities per 100 million exposed hours for a defined group of personnel or activities, which often is used as a risk criterion (NORSOK Z013, 2010). FAR values should be used since operating companies have a demand for maximum annual frequencies related to personnel risk. These frequencies are the alleged main safety functions (Aven, Vinnem, 2007).

The Table below gives an indication of FAR values that have been observed for other activities as well as the oil industry (TRA Sleipner, 2004):

Professions/ Activities	**FAR value**
Helicopter flying	740
Diving	320
Flying	56
Car passenger	29
Motorcycle	28
Oil industry	19
Travelling by train	5

Table 2: Observed FAR values (TRA Sleipner, 2004)

The Potential Loss of Life (PLL) is used to identify the potential risk level for the personnel in a specific area or for a field. The PLL value, for a specified area, expresses how many persons are expected to die in a year as a consequence of an accident in the area (TRA Sleipner, 2004). However, the PLL value is dependent on how often the accident occurs and how many lives are exposed or lost. PLL should be used as a criterion for installations that are unmanned or for groups that normally are not exposed to risk. The loss of lives in for instance the installation or modification phases can be taken into consideration when determining the risk reducing measures. Therefore, the PLL and the FAR values are an essential part of the risk analysis process and are used in the case studies that have been selected for this thesis. The relation between FAR and PLL used in the case studies is expressed as (TRA Sleipner, 2004):

$$FAR = \frac{PLL * 10^8}{N * T}$$

Where:
N= Number of personnel working in that area
T= Average number of working hours a years
10^8= Number of hours exposed

Risk can be graphically illustrated with the help of a risk matrix. The arrangement of accident probability and corresponding consequence in a matrix may be a suitable expression of risk in cases where many accidental events are involved or where single value calculation is difficult (NORSOK Z013, 2010). The matrix is separated into three regions, which can be expressed both quantitatively and qualitatively:

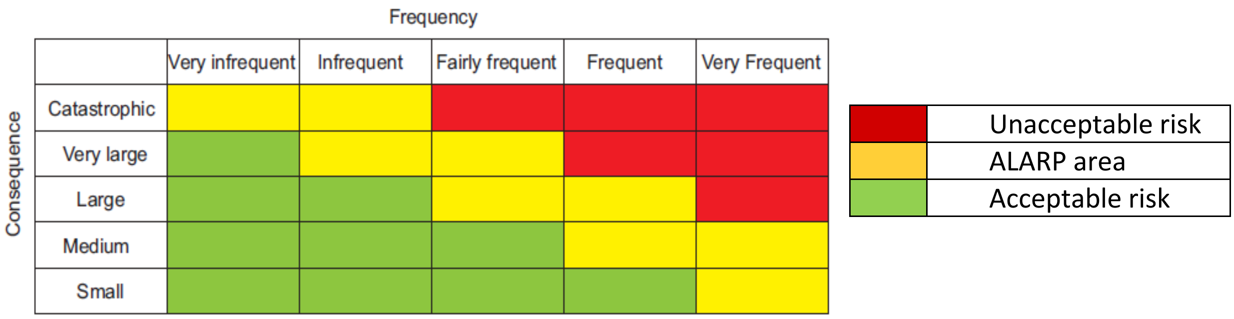

Figure 3: Risk Matrix (NORSOK Z013, 2010)

The area that is set as the "ALARP" region is between acceptable and unacceptable risk, where evaluations have to be carried out in order to determine whether further risk reduction is required or whether more detailed studies should be conducted. This area can be seen as "risk reducing needed area" or the ALARP area, since the risk should be as low as reasonably practicable. Including a risk matrix is important to enable ranking of risk and the consequence and frequency involved. It also reflects where risk reducing measures are needed; also after the risk reducing measures are implemented, further risk can be determined again with help of the risk matrix (NORSOK Z013, 2010).

1.2.2 Risk Analysis

Through risk analysis the nature and the quantity of risk related to an activity is expressed. Usually a risk analysis is a methodology that uses analytical methods in a systematic approach to determine risk. This approach can be improved over time through learning from previous activities or analyses (NORSOK Z013, 2010). The most important aspect of the risk analysis is the identification of consistent hazards. Through the identification process of hazards and the scope of the hazards, the risk involved can be determined. When the risk involved has been identified and determined, the cause and consequence analysis can start. The causes of the hazards are then being evaluated as well as the consequences of the hazards occurring. Throughout the entire risk analysis process, the risk description plays a crucial part. When the risk has been identified, the risk acceptance criteria can be set and the risk reducing measures can be determined. The risk assessments process can be illustrated by for instance using an event tree, as has been done in the case studies used for this thesis. Thus, a risk analysis specifies the main elements and risk involved in a certain situation or event and determines the uncertainties when evaluating probabilities for (un) desired outcomes. Consequently, the risk picture is produced (Pham, 2011).

The term Quantitative Risk Assessment/Analysis (QRA) refers to assessing the frequency of an event and its measurable consequences like fatalities, damages, etc. When identifying a hazard, frequency (probability) and consequence of the event, are used in risk analysis (Smith, 2011). A QRA systemises the present state of knowledge including the uncertainties about the phenomena, processes, activities and systems involved are being analysed. It identifies the possible hazards and threats as well as their causes and consequences to determine whether the risk is tolerable or acceptable, choosing the most effective and efficient risk policy. This can be the risk reducing measures. Aven (2011) discusses that to model systemic accidents it is necessary to go beyond causal chains and describe systems performance as a whole, where the steps and stages on the way to an accident are seen as parts of the whole.

Even though QRA are often used in the oil industry for determining the risk and hazards involved in a given situation, QRA has also receiver strong criticism due to the fact that uncertainties often are underestimated. In addition, using QRA when there isn't enough knowledge regarding probabilities and consequences the QRA can be misleading (Pham, 2011). As Aven (2011) discusses, the QRA should not be eliminated when knowledge is lacking, but rather improved.

NORSOK Z013 states that a QRA should include several elements (NORSOK Z013, 2010):

Requirements regarding the content of the risk analysis:
1) identify hazardous situations and potential accidental events;
2) identify initiating events and describe their potential causes;
3) analyse accidental sequences and their potential consequences;
4) identify and asses risk reducing measures;
5)provide a overall picture of risk, presented in a way suitable for the various target groups;

Table 3: Content of the risk analysis (NORSOK Z013, 2010)

NORSOK Z013 states that the QRA should include process accidents, storage accidents, blowouts, etc. in the process of analysing the initial events when identifying potential hazards (NORSOK Z013, 2010). The standard sets requirement that analysis of the following shall, as a minimum, be included if the hazard is relevant according to the objective:

Requirements regarding quantitative analysis:
1) process accidents;
2) risers/landfall and pipeline accidents;
3) storage accidents (liquid and gas);
4) loading/offloading accidents;
5) blowouts and well releases;
6) accidents in utility systems, e.g. leaks of chemicals, fires, explosion of transformers etc.;
7) accidents caused by external impact and environmental loads, e.g. collision, falling/ swinging loads, helicopter crash, earthquake, waves;
8) structural failure (including gross errors);
9) loss of stability and/or buoyancy (including failure of marine systems).

Table 4: Requirements regarding quantitative analysis (NORSOK Z013, 2010)

The Concept Risk Analysis (CRA) addresses a certain concept in a risk analysis; this can for instance be a in modification phase or a replacement phase on a platform. The CRA should include the identification of the hazards, their causes and their consequences, in order to demonstrate and determine the risks involved in a concept phase. The main purpose of a CRA is the comparisons of alternatives and an assessment of compliance of the overall risk acceptance criteria that often are determined in the TRA. Moreover, the risk reducing measures should be evaluated and determined to get the risk as low as reasonably practicable. The CRA is often undertaken when the decision has been made to proceed in installing for instance a new pre-compressor on a platform (NORSOK Z013, 1998).

The Total Risk Analysis (TRA) often illustrates the entire frame or all the design change analysis, regarding for instance a platform, often in the project phase. The main purpose of the TRA is the verification of for instance a design, for determining compliance with the pre-determined risk acceptance criteria. It provides the overall assumptions for a safe operation. The TRA should also include the identification of the hazards, their causes and their consequences, in order to demonstrate and determine the risks involved in a concept phase. Throughout the lifecycle of for instance a platform, TRA updates need to be undertaken to update when modifications have been made, new installations have been made, experience etc (NORSOK Z013, 1998). These updates in the TRA can be demonstrated in for instance quantitative risk analysis or concept risk analysis.

Thus, the risk analysis and the risk analysis process can be summarized as an accumulation of numerous activities and evaluations that have been performed with regards to risk, to implement and maintain any support that is needed in a decision making stage.

A risk analysis can consist of several different sections; including hazard identifications, explosions and fire analysis, ALARP evaluations and emergency preparedness analysis. The hazards identification, sensitivity analysis and emergency preparedness analysis were addressed as the most crucial parts of the risk analysis process for the case studies used in this thesis, to analyze how risk and risk reducing measures are identified and addressed.

Hazard identification

Defining hazards is crucial, especially on an oil platform, but the methodology and analysis is the most important part. The term hazard can be defined as the potential harm resulting in injuries to humans, damaging the environment or property, or a combination of these factors (ISO 17776, 2002). It is the source of physical damage that can convert into damage to people and the environment. Risk identifies the uncertainty and possibility of this damage as well consequences. Hazard Identification (HAZID) and risk assessment is crucial with respect to the risk identification that is needed to identify the risks involved. HAZID, as a technique is used to identify the considerable hazards correlated with the activity under consideration. HAZID and risk assessment has therefore been divided into identifying the hazards, assessing the risk involved and identifying the elimination or reducing of the risk involved (ISO 17776, 2002).

After the hazard analysis, the cause should be evaluated to find the probability and risk involved of the hazard occurring. In order to identify the hazards and risk involved, the following approaches can be used (ISO 17776, 2002):

- Experience
- Checklists
- Standards
- Structured review techniques

Sensitivity Analysis

Another crucial part of a risk analysis is the sensitivity analysis. The sensitivities analysis evaluates how the calculated risk changes, due to the changes in the information that the analysis is based on (Aven, 2008). The sensitivity analysis illustrates the effect and risk of changes made on for instance a platform. In addition, the sensitivity analysis should include the evaluations of effect that changes/modifications have on the risk reducing measures. This can be related to changes that influence the risk related to manning on a platform, leak frequencies, environmental vulnerability, and potential accidents etc. This indicates that the analysis results are depending on different types of conditions and evaluations. In a modification project several sensitive elements may be evaluated. The sensitivity analysis should include the identification of the most important aspects and assumptions, in addition to the evaluation of their effects and the effects of the potential risk reducing measures (NORSOK Z013, 2010). Through, among others, the sensitivity analysis the risk involved and the risk picture can be established. The sensitivity analysis is set as a requirement in NORSOK Z13 (2010) for establishing a part of the risk picture.

Emergency Preparedness Analysis

The Emergency Preparedness Analysis (EPA) is an analysis which includes establishment of the defined situations of hazards and accidents, including major dimensioning accidental events, establishment of performance standards for emergency preparedness and their fulfilment and identification of emergency preparedness measures (NORSOK Z013, 2010). EPA identifies the danger- and accident situations that are essential to establish an emergency preparedness plan for. NORSOK Z013 (2010) states risk and emergency preparedness can be used as a basis for decision making, in different types of activities and different life cycle phases. The emergency preparedness is often based on the visions, goals and principles of the operator company. The EPA is also based on the risks and the risk acceptance criteria in a certain activity. Through an EPA the hazards are identified and an analysis is performed related to the potential initiating events and their consequences, to establish a risk picture and thus an important part of a risk analysis. The EPA should for instance include escape routes, safe areas, consequences for manning or pollution etc. (NORSOK Z013, 2010).

1.2.3 Risk Acceptance Criteria

To set the limits and criteria for which risk level that can be accepted, Risk Acceptance Criteria (RAC) is established. The criteria for the accepted risk level should be determined before the risk analysis process starts. The acceptable criteria are set through quantitative and qualitative measuring criteria for the company (NORSOK Z013, 2010). The importance of RAC can be stressed due to the fact that before the risk analysis can begin, the accepted criteria should be determined. Through this criteria, that is set to be the accepted risk that can be involved in a given situation, the risk definition can be explained in for instance a case study. The main purpose of RAC is to keep the risk related to certain activities at a level that is considered acceptable and should be as low as possible (Aven et al., 2004).

By determining the RAC before starting any risk analysis process, an average risk determination is made so that the acceptable criteria for the personnel and for the most exposed group complement each other (Managing Regulations, 2010). The determined goals that are further set should then not exceed these accepted criteria. Barriers shall be set to reduce the probability of failures and hazard and accident situations developing, as well as limiting possible harm and disadvantages, to manage health, safety and the environment. These solutions and barriers, which have the greatest risk reducing effects, shall be chosen based on evaluations (Management Regulations, 2010). The RAC are used to provide support in the decision making processes. They should be formulated based on the damage potential and activity level represented by a certain activity.

RAC sets the total risk level which is defined as tolerable, with respect to a specified period of time or phase of the activity. The RAC represents a reference for the estimation of the need of risk reducing measures; therefore the RAC should be available foregoing the start of the risk analysis (Aven, Vinnem and Vollen, 2006). Most of the accepted criteria regarding risk involved are set determined by the operator company that is involved. The RAC should reflect the safety purposes and the particularities of the process that is evaluated (NORSOK Z013, 2010). When the RAC have been determined, the risk analysis process can start and the risk reducing measures can be established for risk that is involved in each particular case.

NORSOK Z013 (2010) states that the RAC should include the regulations that control safety and the environmental aspects of the activities, as well as the ALARP principle (see Section 1.2.4). In addition, the RAC should recognize norms for the activity that is given and a criterion regarding the risk level of similar industries. The main safety functions should also be defined for each facility involved. Further documentation of the RAC used is necessary to be used in the current or future risk analysis processes.

1.2.4 As Low As Reasonably Practicable

ALARP in general

The ALARP (As Low As Reasonably Practicable) principle is a principle that states that risk should be reduced as low as reasonably practicable (Aven et al., 2004). The perception is that all reasonable measures will be taken in respect to risk that can consist in the so called tolerable area. This is done by reducing them moreover until the cost of further risk reducing is roughly excessive to the benefits that can be made. In any case, it is necessary to demonstrate the application of good practice (Smith, 2011). The Guidelines of § 11 from the Framework Regulations (2001) further address general risk reducing principles by for instance using the ALARP principle. The ALARP principle is important, when determining the RAC and risk reducing measures, to reduce the risk beyond the minimum level that follows from the regulations. The risk reducing measures in the three cases used for this thesis are referred to as ALARP measures.

Figure 4 illustrates the ALARP principle for risk management process:

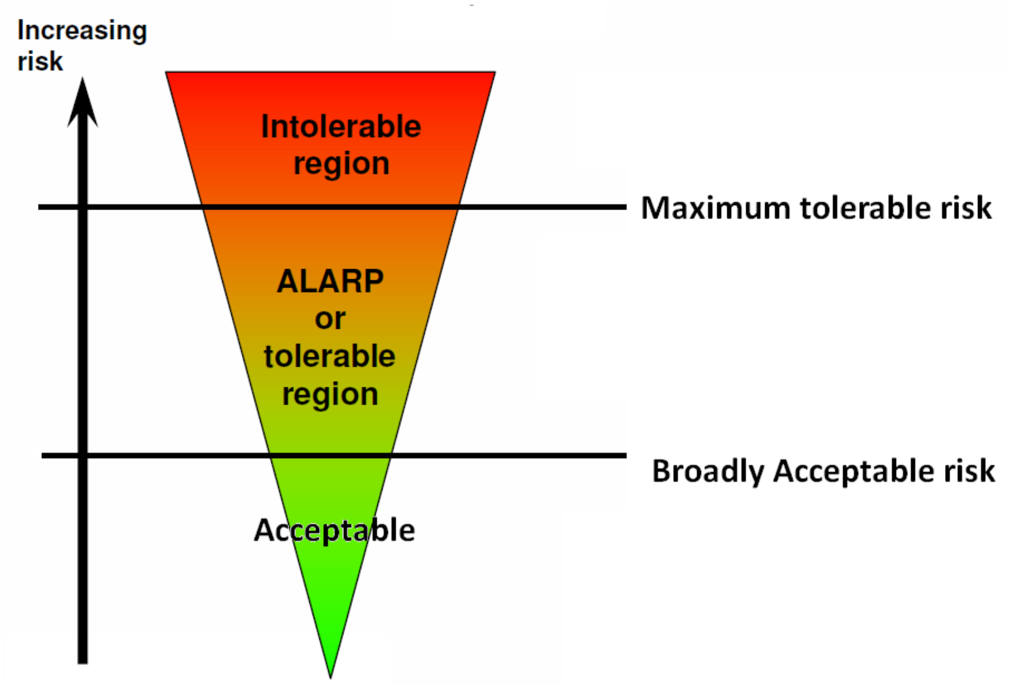

Figure 4: The ALARP principle (Smith, 2011)

As the ALARP principle states, a risk reducing measure should be implemented provided it cannot be demonstrated that the costs are excessive related to the gains obtained. Thus, when the ALARP principle is applied, three regions are taken into consideration:

1. the risk is so low that it is considered **negligible**
2. an intermediate level where the **ALARP** principle applies
3. the risk is so high that it is **intolerable**

In most cases, risk is found to be in region 2 and the ALARP principle can then be applied. Therefore a committed inquiry to detect any potential risk reducing measures should be applied, as well as an evaluation of them to be able to identify the ones that should be implemented (Aven, 2011).

In the risk analysis of one of the case studies used for in this thesis, the ALARP measures are expressed quantitatively in the following matter (QRA Gudrun tie-in, 2009):

$$T_{breakeven} = \frac{PLL_m}{PLL_b - PLL_a}$$

Where:

PLL_m = additional PLL under the installation phase

PLL_a = PLL after the modification

PLL_b= PLL before the modification

$T_{break\ even}$ = the number of years before the risk reducing measure compensate for the increase risk during the installation phase

This formula is used to see if the risk reducing in the operational phase is bigger than the risk increase during the installation of the measure.

ALARP in Norway

Framework Regulations (2001) § 11, state that the ALARP principle should be implemented to reduce the risk with respect to health, safety and the environment; it states that the risk shall be further reduced to the extent possible.

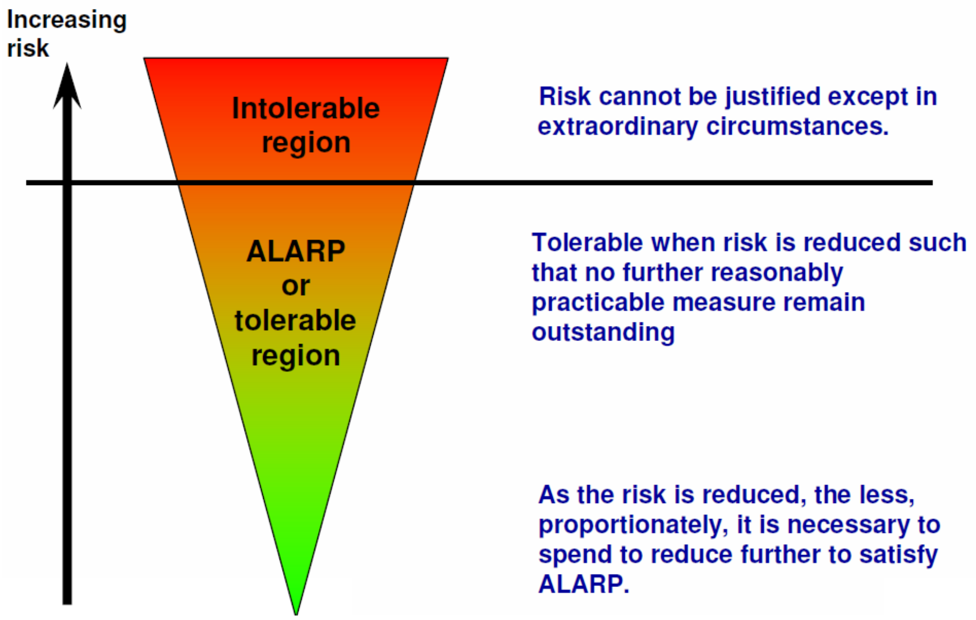

Figure 5: The ALARP principle in Norway (NORSOK Z013, 2010)

The ALARP area is the entire part under the accepted limit for risk, without any lower region (Preventor, 2006). An ALARP demonstration process identifies the potential risk reducing measures, evaluates those measures to be able to make decisions and document the accepted and rejected risk reducing measures (NORSOK Z013, 2010).

1.2.5 Risk reducing measures

Risk reducing measures are set to reduce or mitigate the risk in a certain activity or situation. This can include safe solutions and consequence reducing measures as well as emergency preparedness measures (HSE, 2006). The risk reducing measures should take into account the reliability and the vulnerability of the risk reducing measures and the possibility of documenting and calibrating the evaluated measures of risk reduction (NORSOK Z013, 2010). The measures that are set to reduce the risk that is involved in each case are an important aspect of the risk analysis process to prevent, optimize or mitigate the effect of for instance an accident. Through determining the risk reducing measures, the risk involved could be reduced to as low as reasonably practicable (the ALARP principle). In the process of setting risk reducing measures, expert judgement and experience can be used to determine the measures. It is important to recognize the conditions that can demand change from previously used practices, codes and standards. Risk estimation can accommodate in the decision making process assuming that the acceptance criteria are determined. Applying safer designs and guaranteeing integrity of the assets are measures that should be processed wherever attainable. This is also the case for emergency response measures (ISO 13702, 1999).

The general order of determining risk reducing measures is to prevent, detect, control, mitigate and emergency response (ISO 17776, 2002). This means that the probability of occurrence should be reduced, limit the extent and duration of the hazardous event as well as reducing the consequences related to a certain activity. By following this order, or even using these aspects, when determining the risk reducing measures, the general requirements for determining the measures will be satisfied. Thus, the risk reducing measures that are determined should include the aspects of preventing, detecting, controlling and/or mitigating the risk involved, as well as setting up an emergency response plan. The technical possibility of setting risk reducing measures will influence the measure that will be selected to reduce the risk involved; in addition the costs for implementing the measures plays a crucial role. The energy needed to implement the measure with respect to cost, time and difficulties involved when implementing, and recourses, etc. should be deliberated against the benefits that can be obtained when implementing the measures. However, the risk involved for implementing the measures as well as the degree of uncertainties associated with the risk should be evaluated (ISO 17776, 2002).

ISO 13702 (1999) states that the risk reducing measures should include:

Risk Reducing Measures:
a) Measures set to prevent incidents and thus to reduce the probability of them existing
b) Measures set to control incidents to restricting the magnitude and length of the incident
c) Measures set to mitigate the impact, thus establishing the measures to reduce the impact of the consequences

Table 5: Risk Reducing Measures (ISO 13702, 1999)

NORSOK Z013 (2010) states that the identification of potential risk reducing measures shall be performed throughout and as part of any risk assessment process, in the following way:

Identifying Risk Reducing Measures:
a) Separate assessments with the purpose of identifying possible risk reducing measures and evaluating their effect shall be performed as a part of the risk assessment process;
b) The assessment shall seek to identify measures with the following priority:
1) Measures that provide inherently safer design; 2) Measures that reduce the possibility of accidental events occurring; 3) Measures that reduce the consequences if accidental events should occur.
c) Evaluation of possible risk reducing measures should be based on
1) Qualitative assessments, i.e. reflecting inherent safety principles, best available technology, cautionary principles, 2) Quantitative or qualitative analysis of cost, benefit, and other effects of the relevant measures, i.e. reputation, robustness, effectiveness, maintenance and operational effects.
d) The identification and evaluation of risk reducing measures shall be documented. It shall include a description of the risk reducing process that has been followed, as well as the results of the risk reducing process;
e) Documentation of the risk reducing assessment shall include
1) Overview of the elements in the risk reducing assessment, 2) Overview of the involved parties in the assessment, 3) Documentation of the identified measures and their effect on the risk, supporting analyses and evaluations.

Table 6: Potential Risk Reducing Measures (NORSOK Z013, 2010).

The risk reducing measures should be evaluated and documented to ensure that everyone involved has the updated measures and can use it in every stage of the installation; this can involve strategies regarding design, fire, explosion, escape routes etc. (ISO 13702, 1999). When evaluating these strategies elements need to be taken into consideration related to risk, and for instance the nature of the fire and explosion, the environment, the flammable materials and the amount of it, etc. The measures should control or decrease uncertain events in the installation layout, the emergency shutdown systems, emergency power systems, fire and gas systems by controlling ignition, spills, escape routes and setting active/passive fire protection systems. Inspection, testing and maintenance are needed to be able to manage the systems (ISO 13702, 1999).

Measures to recover from incidents need be provided based on risk analysis and should be developed taking into account possible failures of the control and mitigation measures. The risk reducing measures are based on the results of the evaluation, detailed health, safety and environmental objectives and functional requirements that should be set at appropriate levels (ISO 17776, 2002).

Section 2: Case studies

This second section of this thesis presents the case studies that are used. Three case studies have been selected that are relevant for determining how risk and risk reducing measures are identified and addressed. These case studies represent risk analysis that are often used in the Norwegian oil industry and thus will give a good indication of how the standard is. The case studies have been shortly presented and the most important aspects have been illustrated. Evaluations and analysis have been performed for each of the risk analysis related to the three different case studies.

Case 1 presents a quantitative risk analysis of the Gudrun tie-in to the Sleipner platform. The most important aspects and elements of the risk analysis have been selected, presented and analyzed. Including risk acceptance criteria, risk reducing measures, risk analysis and hazards identification.

Case 2 has been selected due to the fact that it is a total risk analysis of a platform, namely the Sleipner platform. The most essential elements of the total risk analysis have been presented and analysed in Section 2.2.

The last and third case is a concept risk analysis regarding pre-compressors for Troll. Also here, the most important parts of the risk analysis have been presented and analyzed.

The different risk analysis types (quantitative-, total-, and concept-) demonstrate how the risk analysis is presented and used. Through analyzing and comparing the three case studies a picture will be illustrated regarding the identification of risk and risk reducing measures. These case studies represent current changes that are made or are planned for the near future, thus are relevant for the risk analyses that are currently carried out.

2.1 Case I: Gudrun tie-in to Sleipner A

The first Case study is related to the Gudrun tie-in to Sleipner. A quantitative risk analysis has been performed and this subsection will illustrate the content. The most important aspects of the risk analysis, that contribute to identifying risk and risk reducing measures, have been illustrated.

2.1.1 System description

The Gudrun field is located approximately 55 km north of Sleipner A (SLA). The water depth is circa 109 m. The Gudrun field has been developed by a processing platform with water removal and a jacket substructure. Oil and gas from Gudrun will supply to Sleipner in two pipelines (QRA Gudrun tie-in, 2009):

- The rich gas pipeline: the rich gas is routed to an existing inlet separator at Sleipner A. The gas from this separator will be routed to Sleipner T for CO_2 removal.
- The oil pipeline is tied in upstream of the third stage separator at Sleipner A. The oil is then mixed with the Sleipner oil and the condensate from the Gudrun gas pipeline; into the third stage separator and afterwards in the oil export system.

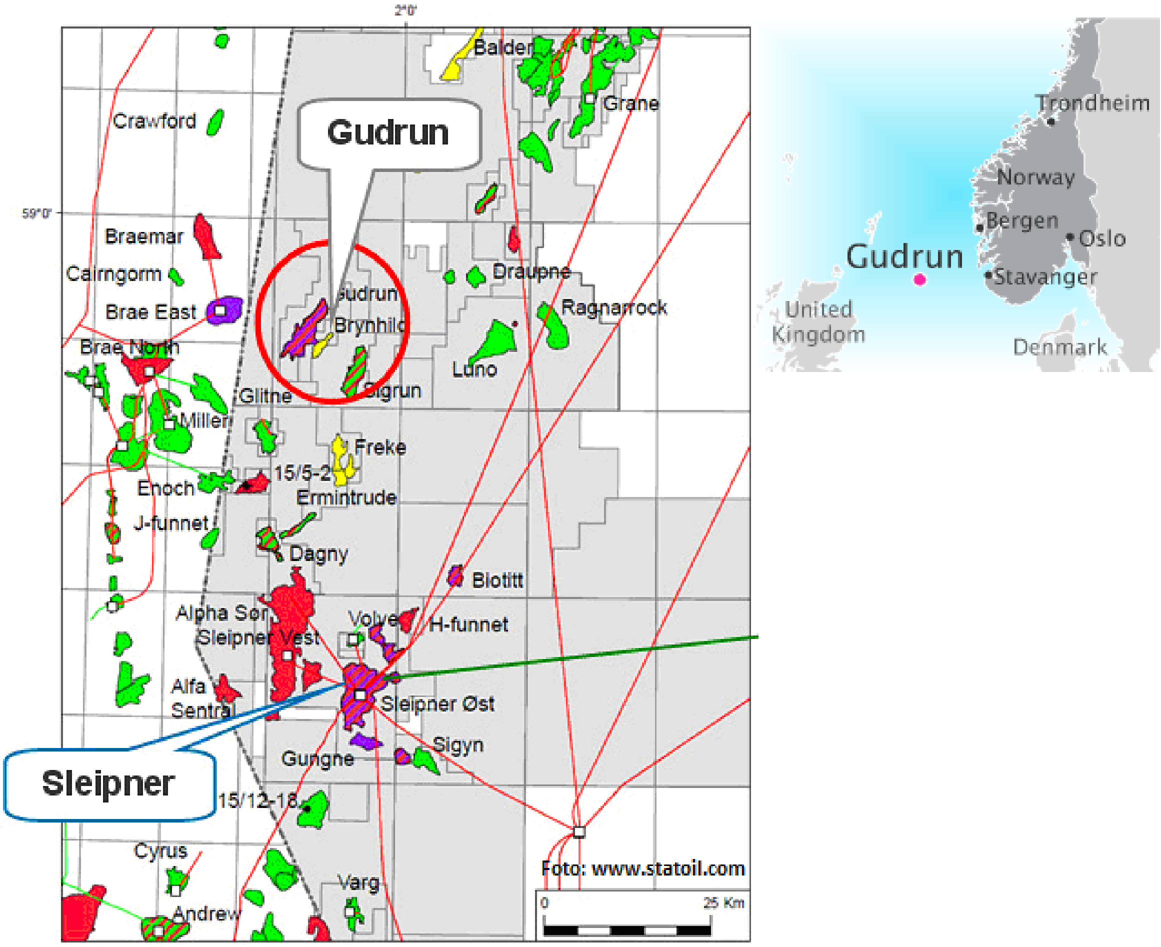

Figure 6: Sleipner map (QRA Gudrun tie-in, 2009)

2.1.2 Risk Analysis

A Quantitative Risk Analysis (QRA) has been performed for the tie-in of Gudrun to the Sleipner A platform. The QRA of the modifications on Sleipner related to the tie-in are performed to identify any risk aspects that might influence the risk perception on Sleipner A and Sleipner T (SLT), performed in 2009. A lot of the information used for the tie-in is related to the TRA for Sleipner, which is Case Study II (Section 2.2).

Risk has been presented through the following technical analyses that have been performed as part of the risk analysis (QRA Gudrun tie-in, 2009):

- HAZID analysis
- Sensitivity Analysis
- Preliminary Design Accidental Loads Specifications
- Risk Assessment
- Explosion Analysis

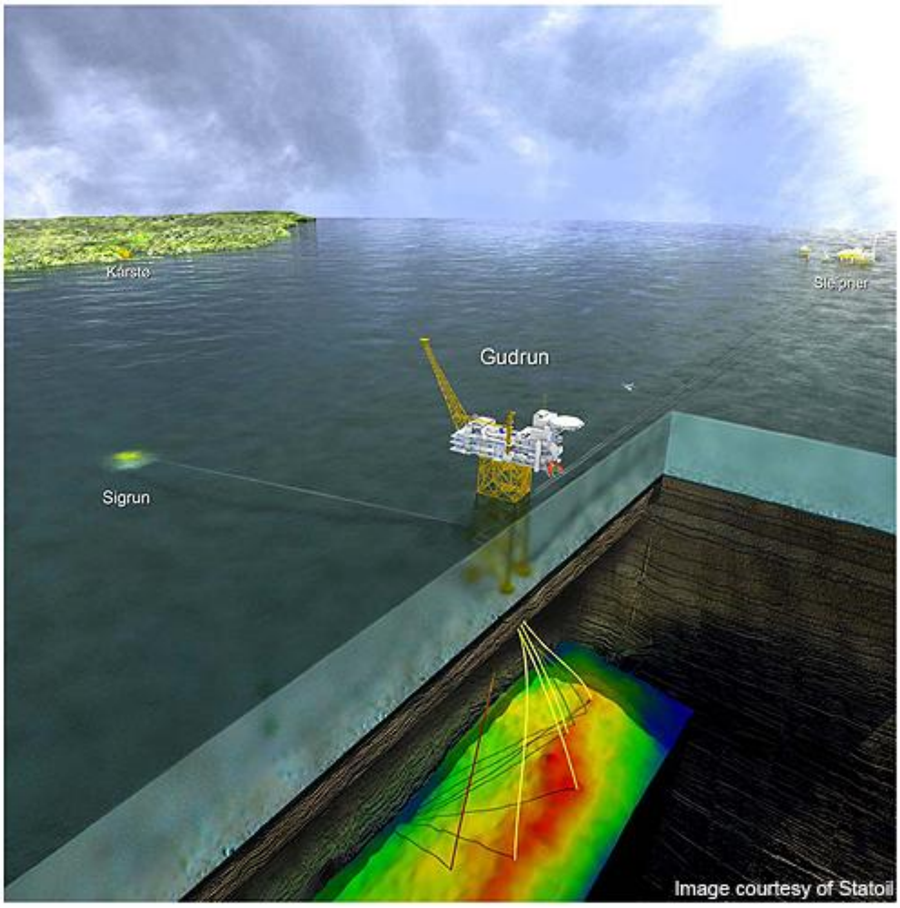

Figure 7: Gudrun tie-in to Sleipner A (QRA Gudrun tie-in, 2009)

Through the modifications of the Gudrun platform being tied-in to the Sleipner platform, a risk analysis has been performed to view any risk factors that can be related to SLA and SLT.

The analysis indicates that the total risk results for SLA will increase in the installation phase of the Gudrun tie-in (QRA Gudrun tie-in, 2009). This increase is due to the fact that the manning onboard will increase due to the tie-in, as well as increased probability for ignition.

Nevertheless, the explosion risk will increase due to the increased equipment density. Potential accidental types have been determined as well as their risk and their FAR values. The values are based on previous case studies and statistics. Figure 8 illustrates the average FAR contributions per accident type (ERA Gudrun tie-in, 2009):

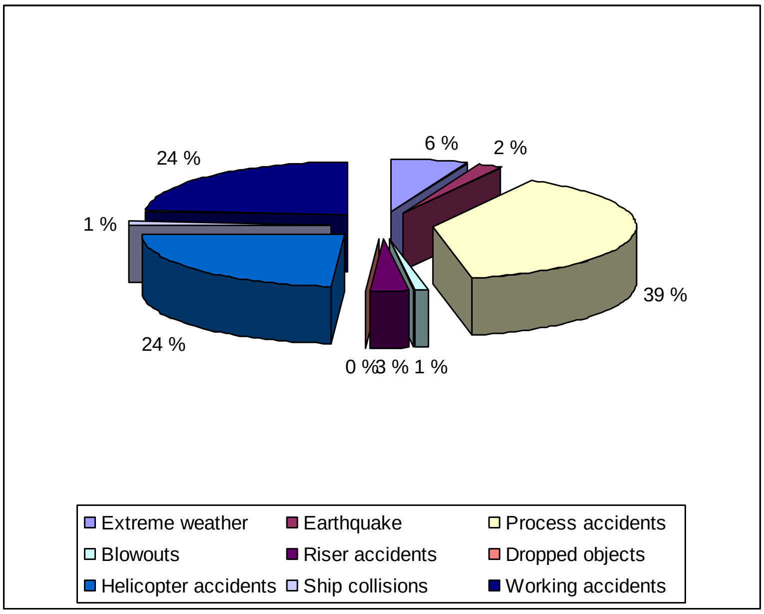

Figure 8: Average FAR Contributions per Accident type (ERA Gudrun tie-in, 2009)

Figure 8 indicates that the highest average FAR contributor is related to process accidents, but also working accidents and helicopter accidents. The risk involved when processing, working or transportation by a helicopter is thus high. The risk has been further evaluated with regards to the tie-in and risk reducing measures have been recommended based on the tie-in process to SLA and on previous tie-in cases. Hazardous situations and potential accidental events have been analyzed and their consequences have been calculated in the QRA. The requirements with regards to NORSOK Z013 (2010) have been evaluated in the risk analysis (ERA Gudrun tie-in, 2009). The risk analysis also evaluates specific elements that contribute to increasing the risk, for instance:

- Field FAR

The field FAR for the Sleipner field will increase due to Gudrun tie-in. This indicates an increase of 0.04 with is lower than the acceptance criterion that is set to a maximum increase in field FAR of 0.1 (QRA Gudrun tie-in, 2009). Risk reducing measures should be implemented to reduce the FAR value and thus the risk as low as reasonably practicable.

- Personnel Group FAR

It is assumed that the FAR for most exposed groups will increase linearly with FAR for SLA. The Personnel Group FAR of less than 25 is set by the operator company. The FAR for the most exposed personnel group will have a small increase due to the tie-in, but still be under the accepted criteria for FAR. This increase can be due to the fact that more personnel will be needed for the tie-in. Risk reducing measures should be discussed with regards to risk involved for the personnel.

- Loss of main safety functions
Increase in impairment frequencies for the main safety functions on SLA due to the Gudrun tie-in for process explosions will increase. The frequencies for escalation and escape routes will also increase due to the additional equipments (QRA Gudrun tie-in, 2009). This sets the impairment frequency per year for the total including Gudrun tie-in and the escalation and the escape routes values above 1.0E-04, which is the requirement, set in NORSOK Z-013 (2010). The NORSOK standard has been used to evaluate the routes availability for loss of main safety functions. Further risk reducing measures should be implemented to reduce the risk involved.

- Potential Loss of Life
The Potential Loss of Life (PLL) is increasing due to the increased manning in the process modules. The total PLL for the Gudrun tie-in is higher than the total PLL for TRA. Risk reducing measures should be discussed and implemented to decrease the PLL and decrease the risk as low as reasonably practicable (QRA Gudrun tie-in, 2009).

2.1.3 Risk Calculation and Risk Acceptance Criteria

The risk calculation is performed by using the information available from the total risk analysis document of the Sleipner field, to build a standalone risk model for Gudrun Tie-in. The expected risk increase from Gudrun tie-in has been measured against risk acceptance criteria that are specified for the Gudrun project.

The acceptance criteria are set as following (QRA Gudrun tie-in, 2009):

- **Overall personnel risk**: The project shall not increase the FAR value on the Sleipner field. This means that the project shall not increase the FAR value on the Sleipner field with more than **0.1**. If it does increase, it should be compensated for, by implementing risk reducing measures in other areas of the field to bring the FAR value down again.
- **Loss of main safety functions**: the project shall not increase the risk loss of main safety functions on SLA and SLT to more than **20%** above the existing level before the project. Otherwise, risk reducing measures should be implemented in other areas of SLA and SLT to bring the increase in risk down again.
- **Personnel risk, most exposed group**: The FAR value for the most exposed group shall be below the value that has been given by the operator company.

The Risk Acceptance Criteria (RAC) have been determined before the risk analysis process had started (by the operating company). These acceptance criteria are then further used in the risk analysis process, changes to the accepted criteria cannot be made (QRA Gudrun tie-in, 2009). These risk acceptance criteria, illustrate that the overall personnel risk shall not increase the FAR value from the Sleipner field. Nevertheless if this does happen, risk reducing measures should be implemented to set the risk as low as reasonably possible, which in this case indicates below the FAR value.

The loss of the main safety functions also need to have accepted criteria to ensure that the risk involved doesn't pass the risk loss of main safety functions on SLA and SLT. The personnel that are most exposed to explosion, fire, pressure, heat, etc. also play a crucial role when it comes to risk and the risk involved with certain activities. Risk acceptance criteria are thus set for the most exposed group to ensure that the FAR value remain below the accepted limit. This is applicable for the installation and design phase of the project. The RAC have not been further compared with risk levels of similar industries, as required by NORSOK Z013 (2010). Nevertheless, risk acceptance criteria have been set for personnel and loss of main safety functions.

Damage to third party has not been included in this QRA (but in other internal evaluations performed by the operator company). The risk analysis shows that the RAC that are defined in the project are fulfilled. Nevertheless, it is suggested that even if the acceptance criteria are fulfilled, the potential for further reducing the risk related to the Gudrun tie-in should be considered. Thus, the risk reducing measures should contribute in further reducing the risk as low as reasonably possible.

2.1.4 Hazard identification

The Hazard Identification (HAZID) is a crucial part of the risk analysis process; it identifies the hazards that are involved in certain activities or events. Thus, through HAZID, risk is identified. Risk analysis presents the main features of field development and the critical areas that can be in conflict with RAC (HAZID Gudrun tie-in, 2009). Figure 9 illustrates how the risk analysis process is used to identify potential hazards:

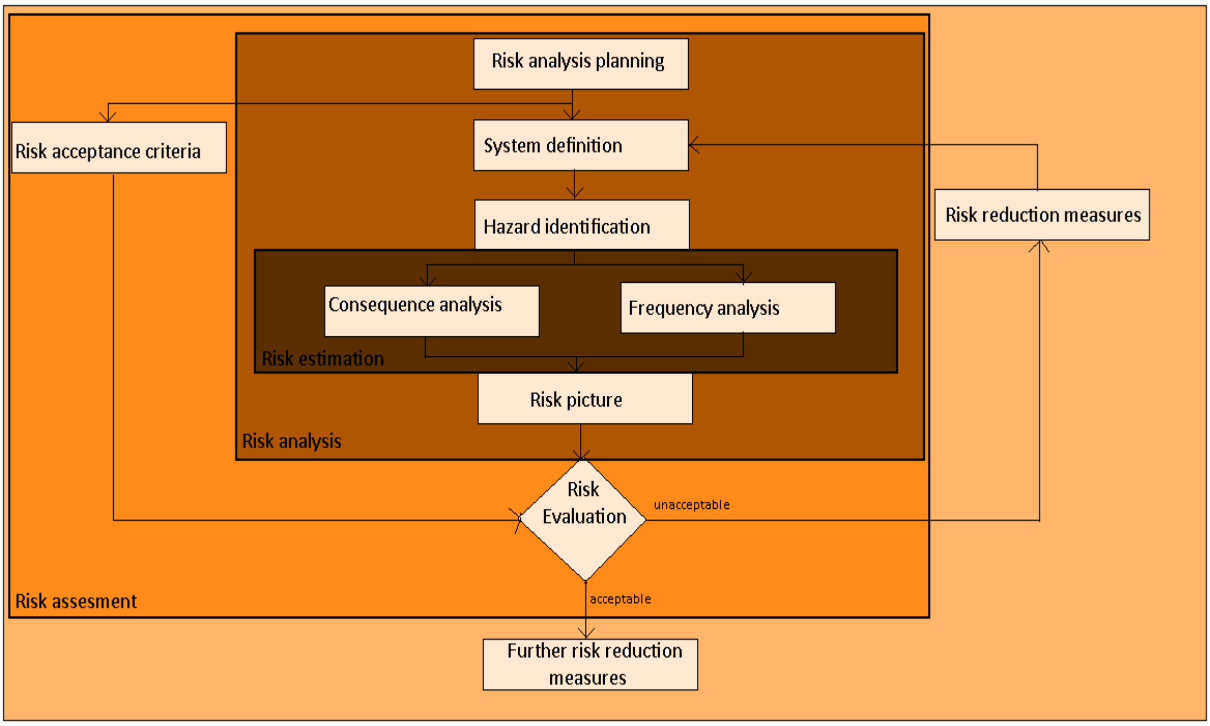

Figure 9: Risk analysis process (HAZID Gudrun tie-in, 2009)

This risk analysis process starts with the planning phase, where risk acceptance criteria are determined, the systems are defined and the hazards are identified. Through evaluating consequence- and frequency analysis, the risk picture will be formed and the risk evaluations can start. From the risk analysis and evaluations, the risks and hazards involved will be identified and addressed, and by determining risk reducing measures the risk should to be reduced as low as reasonably practicable.

The HAZID of Gudrun tie-in was limited to the modifications of topside of SLA (related to the pipeline, risers etc.). The modifications at SLT and risks during the installation period were not covered in the HAZID analysis. Through the HAZID analysis the risks have been classified in critical and non-critical hazards for subsequent analysis (HAZID Gudrun tie-in, 2009). The HAZID analysis has been performed throughout 5 meetings with the stakeholders in the operating and contractor companies. Governing documents from the operator company and documents related to SLA and Gudrun have been used in addition to previous created HAZID analysis used for other tie-in modifications. Most of the information is based on the RAC, previously created HAZID analysis and risk analysis.

For the Gudrun tie-in to Sleipner field, a total of 21 risk factors are identified and evaluated (HAZID Gudrun tie-in, 2009). The risk factors indicate the elements that can contribute to risk increase. The ranking of the risk factors where ranked from 1 to 5, using a computerised tool for risk assessment, where:

Number	Rank
1	Unacceptable
2	Poor
3	Acceptable
4	Good
5	Perfect

Table 7: Risk factors rankings (HAZID Gudrun tie-in, 2009)

The risk factors indicate the elements or events that contribute in increased risk, so the lower the ranking of the risk factors, the higher the risk is. The building blocks indicate the changes that will occur due to the tie-in and the ranking/score of the risk involved will then be given. Comments and actions are given (where needed) to implement for instance risk reducing measures or further evaluations. The summary of the risk factors contains the following 2 factors that are related to fire and explosion exposure:

Building block	Risk factor	Score	Comments	Action
Modifications, extension of existing plant	Fire/Explosion exposure of main support structure	3	Existing segments will not be significantly affected	Needs “guideline evaluation”
Riser inside concrete shaft	Fire	1	The design load of J-tubes is important and should be verified	Needs separate “explosion study”

Table 8: Example of Risk factors (HAZID Gudrun tie-in, 2009)

These so-called actions are then further discussed with the operator company to determine further actions, if any. In the HAZID analysis of Gudrun tie-in (2009), it is also stated that introduction of more equipment in an area will result in more frequent fires, longer fire durations or explosion probabilities. Therefore, hazards have been identified and risk reducing measures have been determined and actions are set.

One of the important hazards identified is the risk factor “Fire” (see Table 8). For this risk factor, is it stated that the riser will not be exposed to fires on the sea surface, but rather inside the shaft where the riser will sustain a short lasting fire. With 2 or more gas risers the internal explosion risk is a major concern. Elimination of ignition sources or inserting of the shaft atmosphere can be implemented as risk reducing measures. Thus, through the HAZID process, risk is analyzed and identified for different activities. Since this process is done through a computerised tool, the information available is restricted and no further explanations have been given with regards to the different risk factors (HAZID Gudrun tie-in, 2009).

In addition to the hazard identifications, sensitivity analysis also plays a crucial role in the quantitative risk analysis. The sensitivity analysis include contributes to the hazard identification process and thus the process of identifying risk and the vulnerable activities involved (Sensitivities Gudrun tie-in, 2009).

The sensitivity analysis presents the measures that can be taken to reduce the risk of hazards and/or given sensitivities. The following measures are presented in the sensitivity analysis (Sensitivities Gudrun tie-in, 2009):

- Subsea Isolation Valves
There will be added SubSea Isolation Valves (SSIVs) to the two new pipelines. The main effect of SSIV is the significant reducing in leak and fire duration. In addition, SSIV reduces fire durations and thus minimize the material damages in case of a fire scenario, both economical, health, safety and environmentally wise.

-Emergency Shutdown Valves
Emergency Shutdown Valves (ESDV) can be placed on the upstream bridge over to SLT, but this will result in an increase of the leak rate but a reducing of the fire durations. Further analysis is needed should this valve be placed there.

- Fire walls
There has been build a new balcony outside a part of the Gudrun platform. As a result, the fire walls towards the neighbouring modules are planned to be extended, but the effect of shorter fire walls on ventilation is small. Furthermore, the effect on explosion loads is small related to the base case modification.

- Increased explosion risk
Simulations of the balcony on D22 showed that the explosion frequency increased with 10% due to reduced ventilation.

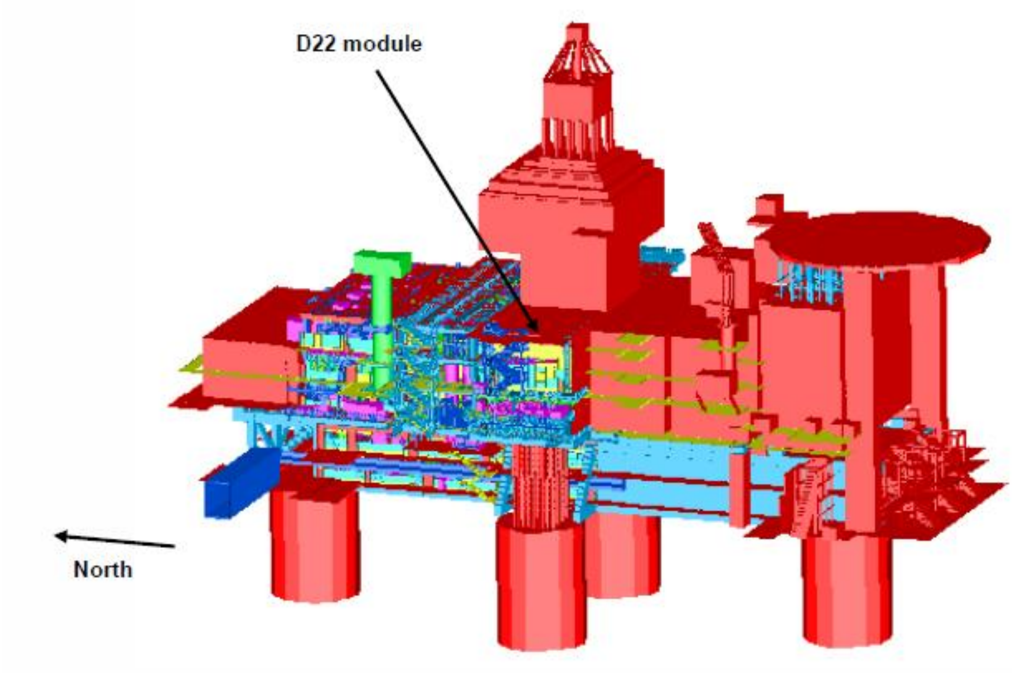

Figure 10: Geometric model of the SLA platform (TRA Sleipner, 2004)

The consequences of an explosion are 100% fatalities in the module and 50% in the neighbouring modules (Sensitivities Gudrun tie-in, 2009). These explosions may lead to damage or loss to the main safety functions, which are escalation and escape routes. If the explosion frequency increases with 10% the risk results will still be below the acceptance criteria. The field FAR criterion of maximum increase of 0.1 is barely fulfilled, with an increase of 0.09. Risk reducing measures have been proposed to reduce the risk involved for the planned modifications on D22 (TRA Sleipner, 2004).

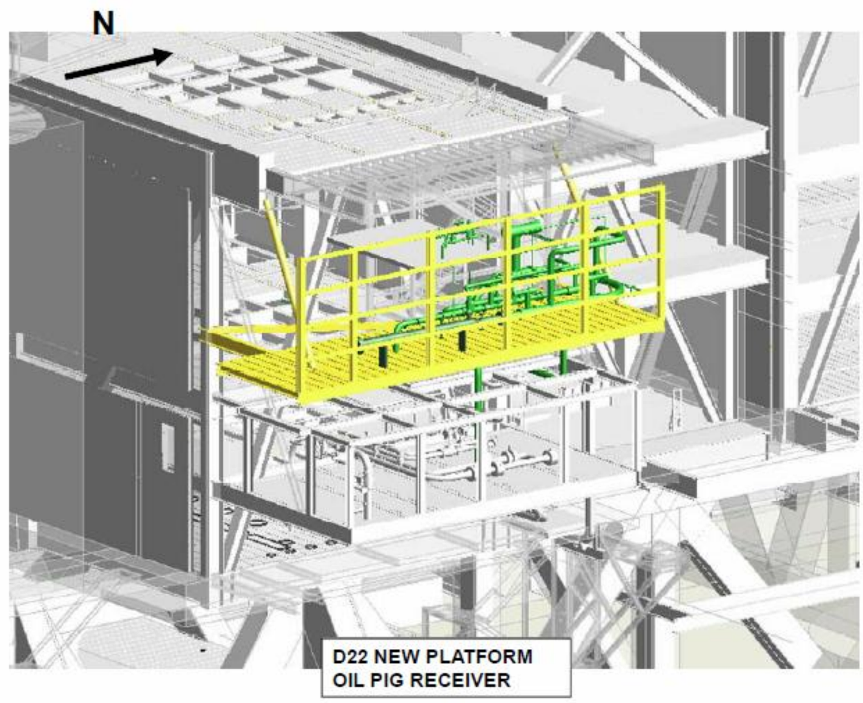

Figure 11: Planned modification on D22 (TRA Sleipner, 2004)

The consequences related to the sensitivity analysis are based on previous experience and previous case studies. Several calculations have been illustrated in the sensitivity analysis illustrating what the risks are (in different areas) and which measures should be carried out, based on the ALARP principle. FAR and PLL values have been used to illustrate the effects of the risk reducing measures. For instance leak frequencies and their consequences have been calculated to demonstrate the importance of implementing the risk reducing measures to reduce the risk as low as reasonably practicable.

2.1.5 Risk reducing measures

Risk reducing measures have been addressed as ALARP measures to indicate that the ALARP principle is used when the risk reducing measures have been determined. However, no further explanation has been given regarding the ALARP principle (QRA Gudrun tie-in, 2009).

It can be noted from the risk analysis that one ALARP measure could lead to increased risk in the installation phase, namely the removal of equipment for the inactive wells at SLA. The risk involved for having the equipments available for the inactive wells was not acceptable and risk reducing measures were suggested. The removal of the equipment for the inactive wells also involves risk. It is recommended by the company that has created the risk analysis that the operator carries out further risk calculations (QRA Gudrun tie-in, 2009).

To get an overview over all the hazards and sensitivities that are present when carrying out the tie-in, a sensitivity analysis has been performed to view the sensitivities and the risks involved. This sensitivity analysis for the Gudrun tie-in to Sleipner shows among others, that the following ALARP measures have been recommended to prevent any increase in the risk involved (Sensitivities Gudrun tie-in, 2009):

Recommended ALARP measures
SubSea Isolation Valves (SSIVs) have been evaluated as a risk reducing measure, due to the fact that they contribute to significant reducing of leak and fire durations in case of riser/pipeline accidents.
Avoiding flanges upstream the riser Emergency Shutdown Valves (ESDVs) has been evaluated; the risk contribution is not significant, but ESDV is recommended as a risk reducing measure.
It is also recommended that guideline evaluations should be carried out to determine dimensioning of fire durations to determine the overall risk picture
A leak occurring on the balcony may spread more easily to the areas below if the balcony deck is grated instead of plated. Therefore a plated deck has been evaluated and recommended as a suitable solution.
A relocation of the metering package is recommended even if it will have small impact on the personnel risk level and the frequencies for impairment of the main safety functions on SLA. However, relocation of the metering package will have a positive effect by reducing the impairment frequency of the escape route over to SLR
The removal of equipment for the inactive wells at SLA can lead to a significant reduction on explosion loads in the module and thus as a risk reducing measure.

Table 9: Recommended ALARP measures (Sensitivities Gudrun tie-in, 2009)

The ALARP measures have been determined through the HAZID process that has been performed with help of relevant personnel, as well as experienced personnel. In addition, best practices and previous studies and experience has been implemented to complete the risk analysis and determine risk reducing measures. These recommendations will then be further discussed and approved by the operator company before any measures can be taken. The risk reducing measures are explained as in the Table above, no further information has been given with regards to whom, at what time and how the risk reducing measures should be implemented (Sensitivities Gudrun tie-in, 2009).

The risk reducing measures have been determined to contribute in preventing and controlling incidents and thus reducing the probability of them. However, the probabilities have not been illustrated in the QRA. The consequences of the risk reducing measures have been calculated in the QRA for the risk reducing measures. For instance for the risk reducing measure related to implementing new SSIVs;

1. In General (the description on what the SSIV is and what effect it will have on the new pipelines)
2. Risk and Risk calculations; leak frequencies have been calculated/ simulated based on having the SSIV and not implementing the SSIV
3. Consequence calculations have been performed as well as comparing the situation without implementing the SSIVs. The consequences have been discussed for the personnel, main safety functions and accident potentials when having the SSIVs and without the SSIVs
4. Conclusion is given and arguments have been given with regards to implementing the SSIVs. The main effect of the SSIV is the reduction potential it has on leak/ fire durations. Hence the consequences of the scenarios are minimized with the SSIVs, thus the risk is reduced.

The risk analysis has this structure for all the risk reducing measures (risk identification, risk reducing measure, consequence and conclusion). The results of the risk reducing measures do not further explain how the risk reducing measures have been identified. In addition, statistics have not been taken into consideration to illustrate the importance of the risk reducing measure. In addition, no alternatives have been given to the risk reducing measures that are recommended. The operator company is further in charge of selecting the risk reducing measures and implementing them.

2.2 Case II: Sleipner field

The second Case study is related to the Total Risk Analysis (TRA) that has been performed for the Sleipner field. This subsection will discuss all the elements of the TRA that contribute in identifying risk and risk reducing measures.

Risk and risk reducing measures have been presented and analyzed to give an indication of how risk and risk reducing measures have been identified and addressed.

2.2.1 System description

The Sleipner field started its production in 1993. The field initially consisted of Sleipner A, Sleipner R (SLR) and the flare platform; these three plants got the name Sleipner East. In 1996 the production started in Sleipner West as well, which consisted of the installations Sleipner B and Sleipner T. Sleipner T is connected to Sleipner A through a bridge. Sleipner B is an unmanned wellhead platform controlled from Sleipner A (TRA Sleipner, 2004).

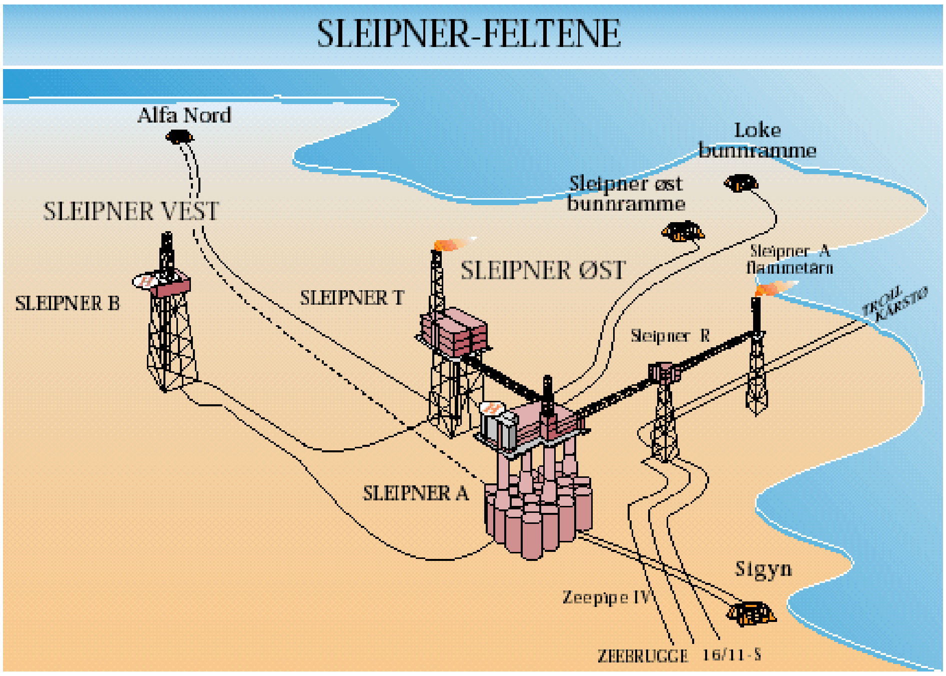

Figure 12: Sleipner A platform (TRA Sleipner, 2004)

2.2.2 Risk Analysis

The second case will thus be regarding the Sleipner field. A risk- and emergency analysis has been performed for the Sleipner installations from September 2002 until June 2004. The most important parameters that are taken into consideration are the fire and explosion barriers, escape routes, the technical demand for the safety systems as well as the design of the emergency preparedness elements. The main purpose for the total risk analysis that is used was to update the risk picture that was portrayed from 1995 until 1999. Focus was set on the physical and operational changes that had been performed on the field. The analysis covers the entire Sleipner field with the assumption that the surrounding plats and fields like Alfa North, the Sleipner West compression and Ormen Lange are installed and functioning (TRA Sleipner, 2004).

The total risk analysis is used as a tool to support and handle risk that is connected to running a business. It's a systematic method for identifying the main contributions to the risk level, as well as knowledge needed to start the risk reducing measures identification to reduce the risk. In the total risk analysis it is stated that identifying unwanted events and possible dangers should be performed by experienced personnel who have the knowledge on the actual activities. Considering the frequencies, it should be done on a global level by collected historical data combined with data collected from experience and activity levels of the analysed field (TRA Sleipner, 2004).

The risk analysis method used is illustrated in Figure 13:

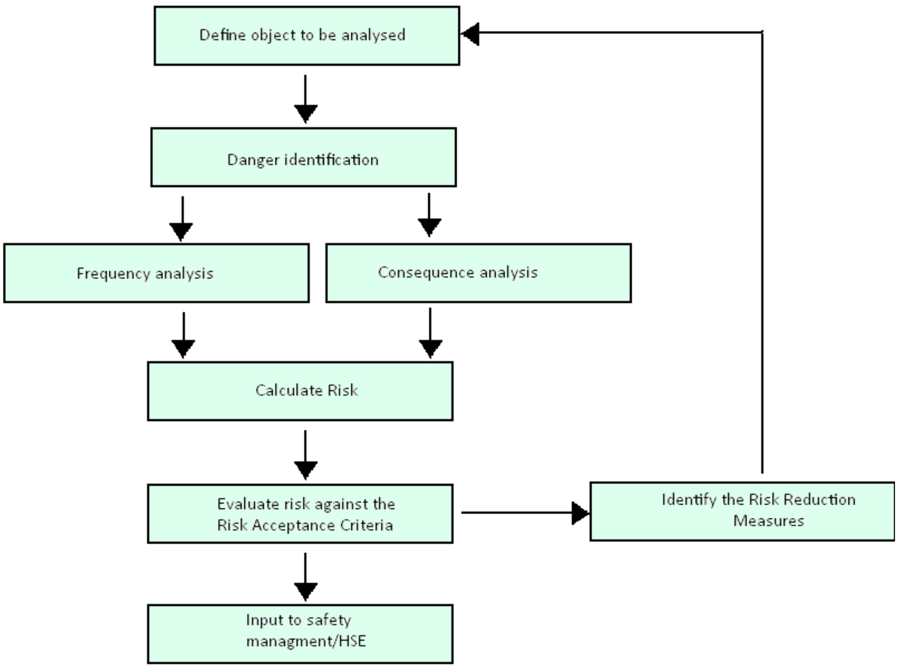

Figure 13: Risk analysis method for Case II (TRA Sleipner, 2004)

An event tree analysis has been used to set the probability for certain events occurring. The Risk Based Inspection (RBI) inspects for instance oil pipelines and suggests inspection intervals or other measures according to the risk level it was initially set to. These recommendations and measures are further used in the TRA for Sleipner.

2.2.3 Risk Calculation and Risk Acceptance Criteria

The RAC used in the TRA for Sleipner are determined by the operator in charge, before the risk analysis process was started. The acceptance criteria for managing health, safety and environment state that the following, regarding the risk that is considered acceptable for the Sleipner field (TRA Sleipner, 2004):

- **The overall personnel:** the average individual risk, expressed in FAR must meet the criteria set by the operator company. The same elements have been taken into consideration for the PLL value. The average should be calculated for all the personnel on the installation with an average period of one year.
- **Loss of main safety functions:** The risk of material losses is also taken into consideration, thus the material losses contribute to the economical losses. The acceptance criteria chosen should give the most optimal economical solution. Hence, risk reducing measures are taken when the reduction in expected loss is greater than the cost of the measure. The acceptance criteria have also taken into consideration the risk of damage to the environment.
- **Personnel risk, most exposed group:** the FAR for the most exposed group is set to by the operator company. This is for the entire Sleipner field.

In many cases, it should be possible to achieve a lower risk level than the ones set by the acceptance criteria. Alternative solutions and risk reducing measures should be mapped and implemented when the beneficial value is considered greater that the disadvantages, even if the risk level satisfies the minimum requirements. These risk acceptance criteria contribute in setting a limit to the risk that is considered acceptable (TRA Sleipner, 2004).

The RAC values had been divided into two groups:

1. Acceptance criteria that have been determined by the operator company before the risk analysis process has started. These RAC values are more general and illustrate the RAC with respect to health, safety, security and the environment. The risk related to personnel and fatalities has been determined with FAR values, the ALARP principle has been used to indicate that the risk reducing measures should be able to achieve a lower risk level. Risk shall be defined for personnel, main safety functions and for the environment.
2. Acceptance criteria have also been determined that are specified to the Sleipner field. The RAC from the operator company have been used to determine the RAC that are specified for the Sleipner field. This is thus an addition to the RAC that have been determined by the operator company (point one). In the Sleipner specific RAC the acceptance criteria with regards to PLL and FAR that are connected to SLA and SLB. RAC have also been identified for third party and different areas of the Sleipner field.

This subdivision of RAC values set by the operator company in general and RAC values determined for a specific field make the risk analysis and the RAC more clearly. Through this process of explaining and using more time to clarify the RAC, the risk analysis becomes much more understandable and better defined. The demonstration and explanation process of how the risk analysis has been performed and how the operator- and consulting company view the different values as risk, RAC, risk reducing measures, ALARP etc., interprets and illustrates their understanding and their values.

2.2.4 Hazard identification

The TRA of Sleipner A has an own document regarding the term risk, called Risk analysis which clarifies the explanation of the term risk. This document explains why the risk analysis has been performed, with the help of experienced personnel, statistics, preciously created risk analysis, internal documents from the operator company and from the consulting companies.

Through explaining important terms as risk, an indication is given of how the term is further used in the risk analysis and how they have defined risk. For the TRA risk has been defined as probability multiplied by consequence, which is a rather simplified version of the definition. This has been further evaluated in the TRA with the help of a system description, hazards identifications and consequence modelling. In the TRA, the RAC, risk reducing measures, the ALARP principle and other important definitions have been explained in their own chapters. Through explaining the content and the definitions used in the TRA, the risk analysis becomes much more understandable. The user that is reading the TRA gets a better understanding of how the consulting companies have performed the TRA and how they have defined and identified risk and risk reducing measures. The definition risk has been explained as an expression of "absence of safety". This is then used as a goal when determining the safety level of certain activities. It is further explained that the main perspective of the risk analysis is to identify the potential dangerous and unwanted events, asses the frequency/probability of occurrence (how often can this event occur?) and survey the consequences of the identified events.

The identification of unwanted events often is determined within a group of experienced personnel, while the frequency of occurrence is based on statistics and how often the event has occurred in the past. After the frequency and the consequences have been determined, the next step is to evaluate whether the risk is acceptable or not with the help of RAC. This process is also carried out by a group of experienced personnel. The risk that is involved for personnel is identified using FAR and PLL values. Risk reducing measures, in accordance with the ALARP principle, are then identified and determined also with the help of experienced personnel. The evaluation for the frequencies of loss in the head safety functions has been analysed in the technical report. The main safety functions that are evaluated include (TRA Sleipner, 2004):

- Preventing escalation
- Structural integrity
- Protection of critical areas
- Protection of safe areas
- Maintaining escape routes

The report concludes that SLA and SLT have high frequencies for escalating from the existing area to a new area related to fire and explosions scenarios. For SLR the frequency for loss of the main safety functions is related to the blow down functions due to fires. The frequencies for loss of the main safety functions are compared for SLA, SLT and SLR for fires, explosions, falling loads that can lead to fires, helicopter accidents, ship accidents, working accidents, extreme weather and earthquakes etc.
The highest frequencies are related to loss of modules and decks; no cost benefit analysis of the measures has been performed to reduce the frequencies. However, hazard identifications and sensitivity analysis indicate where the potential risks are, and then risk reducing measures can be determined to reduce the risk as low as reasonably practicable (TRA Sleipner, 2004).

The risk analysis has primarily been used for the establishment of the scenario descriptions and to describe the defined hazards and accidents. Updating the risk analysis has been done in parallel with the work of the EPA. Through the risk analysis, the EPA has received input to the scope and description of the defined situations and scenarios. Furthermore, the EPA retrieves information from the risk analysis to identify which events are set as main designs for the emergency response (frequency, consequence). The EPA will set the standards for how each defined hazard and accident should be handled (TRA Sleipner, 2004).

HAZID has been used to determine the hazards- and accident activities or events, which further have been evaluated in the potential accidents analysis. The hazards that have been identified are divided into more general accidents that can occur (like fire, explosions, leaks, dropped objects etc.) and the accidents that are Sleipner specific. For the latent, the hazards have been defined with regards to the emergency preparedness, for instance:

- Personnel accidents
- Lost of control functions
- Acute emission of harmful substances
- Fire, explosion, leaks with regards to specific areas on the Sleipner field

Through this hazards and accident identification analysis, the risk has been illustrated for different activities in different areas. Where the risk was considered not acceptable, risk reducing measures were considered and determined by the operator and consulting company.

The TRA of Sleipner also illustrates the risk that is considered acceptable with help of the FAR. This has been illustrated for:

- The operator company: the FAR values have been calculated based on statistics from the operator company
- Other operator companies in the Norwegian continental shelf: the FAR values have been illustrated for the Norwegian continental shelf (no further explanation was given to where this information was taken from)
- The Sleipner field: the FAR values have been demonstrated for the Sleipner field with regards to hazard- and accident identification. In addition, the FAR values have been compared to FAR values that had been determined through the last TRA, which was performed in 1999. It is indicated that the risk is reduced due to updates and modifications that have been performed throughout the last years as well as increase in knowledge that has been implemented through new equipments (new types of ventilations, risers, new tools for explosion simulations etc.)

2.2.5 Risk reducing measures

In addition to setting the acceptance criteria, the TRA should include evaluation of the ALARP process. Based on the calculated risk level on the Sleipner field, which is above the accepted criteria, the Sleipner operations should address alternative solutions and potential risk reducing measures. Hence, the best measure should be implemented when the benefit is set to be greater than the loss or the advantage bigger than the disadvantage. The TRA gives some concrete actions and measures that are recommended, but states that other measures can be taken beyond the given examples. However, these 'other' actions or measures have not been identified (TRA Sleipner, 2004).

For instance, replacement of the flange connection with compact flanges to reduce leak frequencies in the leak source, since compact flanges have been used in the past with less leak rates than the traditional flange connection. This measurement can reduce the risk regarding the personnel as well as reducing the frequency for loss of the main safety functions. When improving the ventilations in an area where hydrocarbon leaks can occur, the best measure is undertaken to reduce the ignition probability. This measurement has been implemented in different areas in SLA and SLT. Again, this measurement can reduce the risk regarding the personnel as well as reducing the frequency for loss of the main safety functions. Other measures are also given to reduce the ignition probability.

It is recommended in the TRA that there are minimal personnel in a process area. To reduce risk, the average personnel in a process area should thus be reduced. This will directly affect the risk regarding the personnel. Risk reducing measures (in the TRA addressed as ALARP measures) have been suggested by evaluating the potential risks involved through hazards identification and sensitivity analysis, with the usage of the ALARP principle.

As in Case 1, the ALARP measures have been determined through the HAZID process that has been performed with help of relevant personnel, as well as experienced personnel. Also best practices and previous studies and experience have been implemented to complete the risk analysis and determine risk reducing measures. These recommendations will then be further discussed and approved by the operator company before any measures can be taken. FAR values have been determined in the HAZID, whenever the FAR values were considered high or close to the accepted limit/ criteria, risk reducing measures had been proposed. Some of the risks reducing measures included (TRA Sleipner, 2004):

- Reduction of leak rate: by for instance implementing compact flange or replacements of the traditional flange connections. The reduction of leak rate will be an effective measure for reducing the personnel risk and reduce the rate of loss of the main safety functions.
- Reducing the ignition probability: improving the ventilations, reducing the personnel working in the warmer areas and increased segmentation of large process segments.
- Reducing the staffing/personnel: the reduction in risk (measured in FAR) can be obtained by reducing the manning in particular areas.
- Accidents at work: the measured FAR value is based on the average events that occur on the Norwegian Continental Shelf.
- Reducing the rate for loss of main safety functions: most of the risk related has been obtained from other studies (for instance the Ormen Lange studies) and measures had been suggested based on that (related to construction, modifications, implementations, new equipments, tools etc.)

2.3 Case III: Troll A – Pre Compression

The third and last case study presents the Concept Risk Analysis (CRA) for the installation of pre-compressors, at the Troll A platform. This is a modification risk analysis, which will evaluate the risk involved in modifying the Troll A platform. The CRA has been presented and analyzed to determine the risk and risk reducing identification for this concept risk analysis.

2.3.1 System description

The Troll A platform is placed 80 km north-west of Bergen, Norway. The Troll A platform produces oil and exports gas from Troll B and C platforms to Kollsnes.

The main process of Troll A, was originally designed with gas/ liquid separation only, as the Troll East reservoir pressure was high enough to export the gas/ liquid to Kollsnes without gas compression (CRA Troll A, 2011). As gas is produced, the Troll East reservoir pressure is continuously reduced. Therefore, modifications should be made in the main topside process to maintain the export rate. These modifications are (CRA Troll A, 2011):

Year	Modification
2005	Two pre-compressors with electrical drive system were included
2011	Installation of a third export line to Kollsnes in order to lower the gas export pressure
2015	It is planned to install two new pre-compressors with electrical drive system
2024	Planned tie-in of Troll West Gas Province

Table 10: Modifications in Troll A (CRA Troll A, 2011)

The overview of the pre-compression (in M11- Compressors 3&4) project is illustrated in Figure 14:

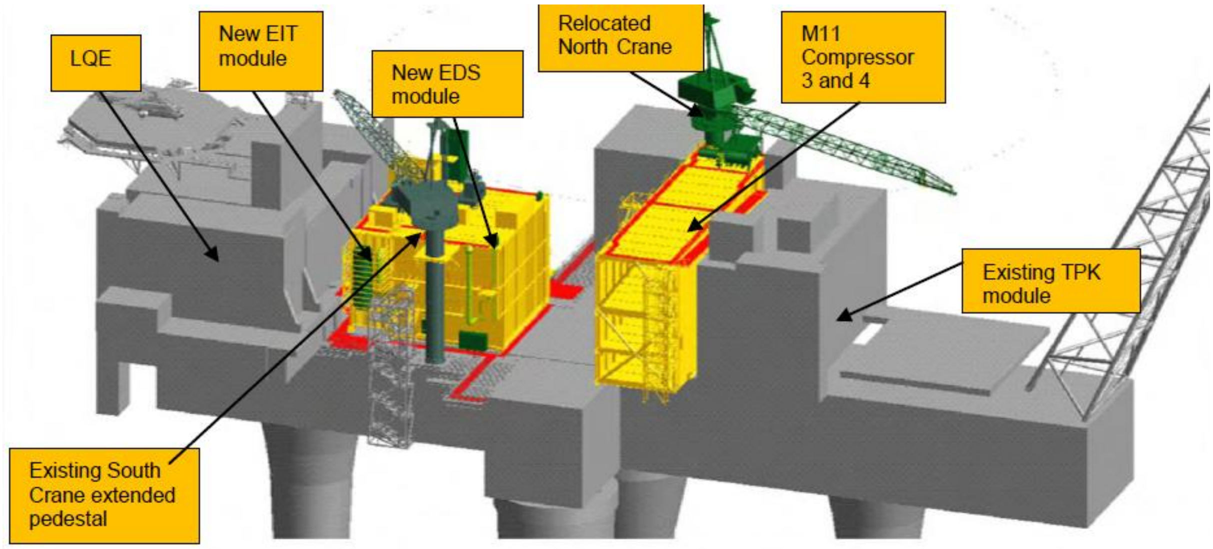

Figure 14: Troll A Pre-Compressor overview (CRA Troll A, 2011)

2.3.2 Risk Analysis

The third Case will thus be regarding the concept of an installation of pre-compressors of the Troll A platform. The concept risk analysis is of the modifications on the Troll A platform and has been performed to identify any risk that might contribute to changing the risk perception of the Troll A platform. The analysis was performed in 2011 (CRA Troll A, 2011).

The risk increase that might occur has been measured against the operators risk acceptance criteria, as described in Section 2.3.3. The technical report contains the following technical notes, as part of the Concept Risk Analysis (CRA Troll A, 2011):

- HAZID
- Explosion and Fire Analysis
- Ventilation, Wind Analysis
- ALARP evaluations
- Risk Reducing Measures
- Emergency Preparedness Analysis
- Risk Analysis

Figure 14: Troll A platform (CRA Troll A, 2011)

The risk analysis has been performed in accordance with the internal documents and standards from the operating company in addition to NORSOK Z013 (2010). The risk analysis reflects the changes to personnel and loss of main safety functions expressed using FAR and PLL values. The risk analysis is then further used to update the TRA for Troll A. Where needed, existing data and results from the existing TRA for Troll A have been used for calculating certain events. The major risks involved with installation of the pre-compression are changes in process accidents, changes in explosion risk and dropped objects; most of this data is taken from the existing TRA for Troll A (CRA Troll A, 2011).

In the risk analysis process Event Tree Analysis (ETA) has been used to calculate the leak frequencies (which have been set as the top events) that can occur due to ignition, strong explosions, blowout failures, fire water failure and escalation to equipment within an area. Thus, the ETA results in different end events, for instance (CRA Troll A, 2011):

- Un-ignited leaks
- Local fire due to external to internal ignition
- Strong explosions due to external or internal ignition

The consequences of the fire and explosion scenarios are further described with respect to the PLL values and the impairment with the loss of the main safety functions. The PLL is calculated based on the probability of fatalities in the area multiplied with the average manning in the area.

The pre-compression project gives small increase in risk for the most exposed personnel group, but the risk for this group is still well below the tolerance criterion. The risk also increases in the installation phase due to the increased manning on the platform. Nevertheless, the FAR values still remain under the tolerance criterion (CRA Troll A, 2011).

The analysis related to the loss of the main safety functions summarizes that the frequency of impairment of main safety functions due to fire and explosions are relatively high. ALARP measures should be taken to protect the loss of the main safety functions like escape ways.

The risk analysis process identifies all the hazards and risks that might occur and risk reducing measures are then presented to reduce the risk to as low as reasonably practicable. Risk is the main focus and has been implemented in every aspect of the analysis. The risks involved in for instance collisions, explosions or dropped objects have been explained and the results have been compared with the risk acceptance criteria. Where needed, risk reducing measures have been suggested to keep the risk as low as reasonably practicable.

For this case study, additional analysis and reports had been implemented in the risk analysis for instance reports regarding meetings between stakeholders, methodology, quality analysis and project management. This additional information was given shortly, in a separate chapter that was regarding the methodology used in the risk analysis, including information regarding kick off meetings, presentation meetings, weekly status reports etc (CRA Troll A, 2011, Appendix A). A document created internally for the operating company contains all the information regarding meetings and methodology used.

2.3.3 Risk Calculation and Risk Acceptance Criteria

The risk calculation is performed by using the information available from the CRA document to build a standalone risk model for the Troll A pre-compressor. The expected risk increase from the pre-compression has been measured against risk acceptance criteria that are specified for the project.

The acceptance criteria have been determined by the operator company and are set as following (CRA Troll A, 2011):

- **Individual Personnel Risk (FAR):** the overall FAR value for the personnel at the Troll A platform shall meet the criterion that has been determined by the operator company (which is the maximum value for the FAR).
- **Loss of main safety functions**: the probability of loss for defined main safety functions shall be lower than 10^{-4} per year per safety function. This is set per accident type as; fires, explosions, collisions, dropped objects and environmental loads.
- **Personnel group**: The FAR for all personnel groups shall meet the criteria of FAR below the value of 25.

These risk acceptance criteria indicate that the risk should not be higher than the criterion that has been determined as acceptable. The risk acceptance criteria have been further used in the analysis for the results of the event trees that have been used to calculate risk. The values and results from the analysis have been compared to the risk acceptance criteria throughout the analysis to ensure that the results are in compliance with the acceptance criteria. If the results are high or higher than the determined RAC values, risk reducing measures have been recommended to keep the risk as low as reasonably practicable.

The RAC values for the personnel risk has been divided into overall FAR, area FAR and personnel group FAR; the risk acceptance criteria have been set with regards to FAR values. This has been done in cooperation between the operating company and the contracting company that is preparing the risk analysis.

The risk that can be involved is then identified with the help of a systematic HAZID analysis. The HAZID report has been used as the first step to identifying potential accidental events, both for the operational and installation phase. As a part of identifying hazards and thus risks, barrier elements have been identified. After the barriers have been determined the risk reducing measures that can be implemented are discussed. Based on the hazard identification, event trees and statistical data or previous experience have been used to calculate the risk involved. Several tools (from the operating company and from the company preparing the risk analysis) have been used to calculate the effects of identified accidents or hazards.

2.3.4 Hazard identification

The Hazard identification methodology for the CRA for Troll A is the same as the one used for the QRA of the Gudrun tie-in (see Figure 9). The analysis follows the requirements determined by the operating company's guidelines for concept risk analyses for major modifications.

The HAZID was used to identify possible hazards due to the new pre-compressors. The HAZID includes a rough classification into critical and non-critical hazards for subsequent analysis. In addition, the HAZID suits as a familiarization to the project with identification of design basis for the project and subjects that should be focused in the preparation for operation. The HAZID was used to identify hazards related to (CRA Troll A, 2011):

- Personnel injury (fatalities)
- Pollution to the environment
- Major asset damage
- Undesired operational problems

The HAZID check list contains (CRA Troll A, 2011):

- Technical safety (leak/ignition sources, explosion venting, dropped objects etc.)
- Working environment (fall/ height differences, hot/cold surfaces etc.)
- Environmental (biological hazards, ergonomic hazards, toxic substances etc.)

The identified hazards were then classified into the following four categories (CRA Troll A, 2011):

Risk classification	Description
1	The area (room, system) does not give any safety concerns (e.g. does not contain any potential hazardous substances)
2	The area (room, system) introduces safety concerns, but the risk factor is known to be small from other similar concepts
3	The area (room, system) contains hazardous substances and/or introduces other safety concerns. The risk factor shall be quantified in QRA
4	The area (room, system) contains hazardous substance or the arrangement produces safety concerns, which are unique, special to this concept. New risk estimates are required to conclude an acceptability

Table 11: Risk Classifications (CRA Troll A, 2011)

An Emergency Preparedness Analysis (EPA) has been reported in accordance with the standard presented in NORSOK Z013 (2010). The Troll A pre-compression project will to some degree affect the emergency preparedness at Troll A (CRA Troll A, 2011):

- For the operational phase some of the scenarios will be changed, due to new equipment and modules, while for the installation phase the manning level and new activities (lifting, demolition, etc.) will affect the dimensioning of the emergency preparedness. Based on this, several actions are suggested for the operational and installation phase.
- For the installation phase, the main reason for the increase in risk is the increased manning and the changed manning distribution, where more people will be working closer to areas with higher risks. Solutions to reduce the risk are given.

To carry out the EPA, the following activities were evaluated (CRA Troll A, 2011):

- Familiarization with TRA and emergency preparedness requirements at Troll A
- Evaluation of the effect of the CRA results including HAZID and installation risk analysis for the both operational and installation phase
- Evaluation of the effect of the CRA results including HAZID and installation risk analysis on the requirements to emergency preparedness dimensioning for both the operational and installation phase
- Conclusions and suggestions to further actions to secure the required level of emergency preparedness at Troll A

The EPA included the risks involved with regards to explosions, leakages, dropped objects, collision etc. The EPA for the pre-compression has been further implemented in the updated TRA of Troll A. Table 11 gives an indication of how comprehensive the EPA was carried out:

Operational Phase
Must make sure that alarm signals are audible and visible in the new modules
Must give training/information to relevant personnel about the new modules to reduce risk
Verify that no escape route is affected by the new equipment and that all areas, including new modules, have two escape ways. This is to reduce the risk.
Installation Phase
It must be verified that the installation of the pre-compression equipment do not interfere with the possibilities to notify all personnel
Make sure that all personnel onboard have the necessary training regarding emergency preparedness
Must evaluate having temporary firewater cannons or other solutions to reduce the risk
Establish bridging emergency preparedness document for the lifting vessels
Must make sure that there are enough first aid personnel onboard, even in the periods with the highest manning

Table 12: EPA (CRA Troll A, 2011)

2.3.5 Risk reducing measures

The risk reducing measures for this case study have also been referred to as ALARP measures, as in Case 1 and 2. The process of determining risk reducing measures identifies the primary contributors to risk changes and proposes adequate risk reducing measures. The ALARP measures have been determined through best practice, experience and simulations that can contribute in determining the risks that are involved in specific scenarios.

The following sensitivity cases for ALARP evaluations are analysed (CRA Troll A, 2011):

- Changes in risks due to no fire wall between tow modules (M11 and TPK): no fire wall increases the risk for the personnel and further evaluations were performed
- Changes in risks from M11 due to extra fire protection and escape probabilities from crane: the risk picture for Troll A does not change significantly due to the crane
- Risk changes from M11 due to inclusion of weather cladding on the module: the changes increase the NORSOK requirements and further analysis were performed

The ALARP evaluations have been performed with the help of Event Tree calculations for (CRA Troll A, 2011)

- Internal and External Fire probabilities
- Strong explosions
- Blow down failure and Firewater failure
- Escalation to other equipment due to fire

These ALARP measures have been determined through the HAZID process that has been performed with help of relevant personnel, as well as experienced personnel. Best practices and previous studies and experience have been implemented to complete the risk analysis and determine risk reducing measures. These recommendations will then be further discussed and approved by the operator company before any measures can be taken.

The risk reducing measures were determined through workshops with key personnel from the stakeholders involved where the following was covered:

Operational phase
Reduction of leak frequency (M11)
Reduction of ignition probability (segment size, blow down, detection, electrical equipment etc.)
Limit consequences of explosions (reinforcements, pressure relief, deluge)
Limit consequences of fires (process equipment, fire fighting equipment, escape routes etc.)
Installation phase
With regards to the operational phases
Reduction in manning
Optimize manning distribution
Demolition of fire/blast wall
Other issues (Lifting activities, Supply vessels etc)

Table 13: Risk reducing measures (CRA Troll A, 2011)

The results from the risk reducing measures workshop include a total number of 19 identified areas where measures have been discussed, where 5 are for the installation phase and 14 for the operational phase. It also indicates who is responsible (all contractors) for follow up of the risk reducing measures and it is stressed that it is necessary to document what further is done and how the measures are implemented. The following Table illustrates how the risk reducing measures have been presented in the risk analysis:

Phase	Cue word	Hazard identification	Measures	Responsible	Due date
Installation	Blast wall	fire wall will be removed some time in advance of module installation. The risk for escalation to adjacent area in case of well accidents (leaks/blowouts) is close to accept criterion	-Limit well operation when demolition has started -Postpone demolition of the firewall as long as possible -Consider H0 instead of A60 for EIT module -Temporary fire/blast wall (not the best solution as it will require additional construction activities, and the supports for the temporary wall will be in conflict with well intervention activities)	Contractor	(Not given)
Installation	Manning in a certain area	High risk for personnel during construction. Exposed to process accidents and accidents due to well leaks.	Reduce manning -Limit scope/period for installation -Supports can be fitted during shutdown -Hot work during shutdown. Limit habitat welding during operation	Contractor	(Not given)
Installation	Manning distribution	Exposure of personnel. The main reason for the increase in risk level during installation is the increased manning in combination of changes in the manning distribution. I.e. more persons in high risk areas, or in vicinity of high risk areas.	-Risk levels are still within risk acceptance criterion (info) -The correct manning level is not yet established, and ALARP measures for manning and manning distribution shall followed up later in the project		(Not given)
Operational	Fire protection	Active fire protection is suggested. Extent of passive fire protection is needed Active systems are: -Deluge -Fire protection in compressor house -Dedicated deluge coverage for critical equipment	Carry out fire integrity study. Assess results in combination with results from fire risk analysis	Contractor	(Not given)

Table 14: Risk reducing measures (CRA Troll A, 2011)

The measures are based on both qualitative and quantitative research meaning (CRA Troll A, 2011):

- Qualitative research: contacted stakeholders, meetings, discussions etc. to gather information
- Quantitative research: statistics and previous cases have been used to compare and collect information; all the input values have been included in the risk analysis.

Section 3: Discussion

This Section will contain further analysis and discussion regarding the case studies presented in the previous Section.

The main purpose of this Section is to evaluate how the risk is identified and addressed in the context of risk analyses, that is for the quantitative-, concept- and total risk analysis. In addition, the same will be done for risk reducing measures to present how they are identified and addressed.

In Norway, the risk analysis process is required to follow the Norwegian regulations and the standards that are recommended. Therefore, the compliance with the regulations plays a crucial part in the risk analysis and is also evaluated. How much of the regulations and standards have been taken into consideration and how far have operator and consulting companies stretched themselves to reduce the risk to ALARP?

Finally, a more general and potential improvement approach has been given to how the content of the risk analysis can be improved. This discussion is based on the three case studies and the views of the author of this thesis with regards to improvement potentials.

3.1 Case studies

3.1.1 Regulations and Standards

The regulations set by the authorities are a tripartite collaboration between the authorities, employers and the employees. These Norwegian regulations shall be applied and implemented in the petroleum industry. The Norwegian PSA's viewpoints focus on quality, learning, competence and preventing, with the main focus being on risk (RVK, 2012). The requirements set by the authorities have been analyzed in the risk analysis of the three cases. The main focus has been on harm and danger to people, and the risk analyses have been used to evaluate how the regulations and standards have been implemented in the three case studies.

All three cases provide an overview of the acceptance criteria that is set by the operator and further applied in the risk analysis, with the main focus being personnel and assets. This is a requirement from the authorities as described in § 9 of the Management Regulations (2010). The RAC have been implemented with help of FAR values. The most exposed group of personnel has also been evaluated and acceptance criteria are set for them as well. The main safety functions are defined and further analyzed to ensure the safety of the personnel. Personnel working in and outside immediate accident area have been evaluated to ensure the escape routes and plans. For the quantitative risk analysis for Gudrun tie-in, the total risk analysis of Sleipner A and the concept risk analysis for the pre-compression of Troll A, an EPA was presented in the risk analysis. Thus, the RAC fulfill the requirements that are given by the authorities. No further documentation or explanation was given regarding the accepted criteria and how or why they are defined as accepted criteria. This is not a requirement from the authorities, but to implement the underlying understanding of the accepted criteria can contribute in making the risk analysis more understandable. In addition, the RAC have been determined by the operating companies, but it would have been useful to involve and compare the accepted criteria with criteria that have been accepted for other similar activities/platforms or even with other operating companies. Through comparing RAC, the understanding of why a particular criterion is set as acceptable can be illustrated in a risk analysis.

The risk analyses of all three cases provide a picture and overview of the risk associated with the different activities that are presented. The risk analyses provide support for decisions related to the upcoming events, as the Gudrun tie-in to Sleipner and the adding of the pre-compressors on Troll A platform. The risk involved for the risk related activities and events has been presented in the risk analysis for personnel and assets, as required in the Framework Regulations (2001) §11. This has been satisfied with the use of analysis regarding hazard identifications, sensitivity analysis and analysis regarding accident situations. Potential hazards and incidents have been identified and their consequences have been presented in the risk analyses for all three cases. The documentation part regarding potential incidents and their consequences could be improved with regards to how the risk analysis process reaches decisions regarding incidents and how their consequences could be. Furthermore, risk reducing measures have been proposed to reduce the risk as much as possible. The combination of harm and the degree of severity of the harm in the form of fatalities, personnel injuries and other health hazards has been measured and assessed in the risk analysis.

In the Guidelines of the Framework Regulations (2001), general principles have been presented regarding risk reducing principles. The ALARP principle has mainly been used in the three cases. The other principles (BAT-, Precautionary- and substitution principle) have also been used, but have not been given the same attention as the ALARP principle. The Best Available Technology (BAT) principle has been applied to some extent when determining the risk reducing measures, in very few elements of the three cases. The pre cautionary- and substitution principle haven't been implemented, except briefly in Case II. But as the Informants from the consulting companies preparing the risk analysis, have discussed with each other and myself, the pre cautionary- and substitution principle has been implemented implicitly. However, the pre cautionary- and substitution principle should be more visible in the risk analysis by for instance implementing a section in the risk analysis regarding the alternative solutions or measures that can be implemented. The risk analysis should argument and discusses the limitations that are in the risk analysis. These limitations can be regarding information available, limited overview of risk reducing measures or lack of similar cases that the risk analysis can be compared to etc. The Guidelines (Framework Regulations, 2001) that are recommended regarding principles that could be implemented when determining the risk reducing measures, should be taken into account. If one of the principles, which have been suggested by the authorities, hasn't been used, then the risk analysis should inform about that.

The solutions and barriers, which have the greatest risk-reducing effect, have been chosen based on an individual level as well as an overall evaluation related to risk. To be able to accomplish the requirements and acceptance criteria for accidents in the regulations, NORSOK Z013 (2010) is recommended to be followed. As NORSOK standard Z013 states, in similarity with Section 17 of the Management Regulations (2010), the risk analysis should include identification of hazardous situations and potential accidental events. The identification of hazardous situations and potential accidental events has been included in the risk analysis. However, the causes of potential events and accidents haven't been further evaluated, but the consequences and the risk reducing measures have been assessed in some degree. The requirements regarding the potential accidents in the quantitative risk analysis have been fulfilled and a document regarding analyses of accidents is created. The different types of accidents, e.g. process accidents, fire, explosion, failure etc., have been analyzed in all three cases. Nevertheless, the content of the analysis is not as comprehensive as it could have been, i.e. the documentation regarding the causes of accidents and the consequences should be implemented in the risk analysis. Also, even thought the risk analysis documents differ in having focus on a concept (as a tie-in to a platform or adding a pre-compressor) or total platform, all possible and different accident scenarios have to be evaluated, as stated in NORSOK Z013 (2010). The identification of the accidents should be detailed and precise to avoid confusion, moreover to satisfy the standards that are recommended. This is done in all three case studies; potential accidents and unwanted activities have been illustrated in the risk analysis, but again, the underlying understanding regarding for instance causes and why these activities have been selected in the risk analysis, should also be presented.

The strategies recommended in ISO 13702 (1999) related to FES and EERS have been used in some extend, in all three cases. Lastly, the requirements set by the authorities have been satisfied. In addition, the internal requirements of the operator have been met, since the operator was involved in parts of the analysis process. The RAC have been pre-defined by the operating company and the ALARP principle has been used to determine the risk reducing measures as well as using the BAT in some degree. The solutions and measures are selected with respect to safety standards. However, operating and consulting companies should stretch themselves to go beyond the requirements that are set as minimum requirements. This can be done by, for instance following NORSOK or ISO standards in the fullest degree possible. By going beyond the minimum requirements, the operating companies and consulting companies will push themselves to get better, have more knowledge and improve their potentials with respect to HSE.

3.1.2 Risk

The first Case is regarding the QRA of the Gudrun tie-in to Sleipner A. When a tie-in is planned for a platform the risk involved will increase due to the extra manning involved in the process. Throughout the risk analysis document, the risk concept is presented and used. Hazardous situations have been identified and potential accidental event have been presented with the use of event trees. However, the risk perception and understanding from the consulting company that has prepared the risk analysis, is not presented as a definition to make the risk presentation complete. The quantitative risk analysis starts with the Hazard Identification document where the potential risks have been identified and presented. The Potential Loss of Live (PLL) values and the Fatal Accident Rate (FAR) are calculated and evaluated for the potential hazards and risk related scenarios. The reasons for any increase in risk due to the tie-in have been presented and comparisons have been made with the Sleipner A to obtain an overview over the risk concept. The effect of the increase in risk has been evaluated and the consequences and the results are presented.

The TRA of the Sleipner field (Case study II) has been performed by another consulting company than the one that performed Case I and III. The entire TRA was in Norwegian, as opposed to Case I and III that were presented in English. Furthermore, the degree of presentation of risk and risk identification differs from the other two. Before the analysis started, the concept and definition of risk and risk analysis was described and evaluated. This gives an overview of how risk is presented and identified throughout the rest of the analysis. The risk analysis process has been explained in detail, to ensure that the reader understands the process of identifying and calculating risk that is involved in the different events that may occur. In addition, to assure that risk and the risk definition is understood, all the additional definitions have been explained like the risk reducing measures, risk levels, risk contribution, FAR, PLL etc. The RAC are then listed in accordance with the risk picture that was described and the risk that is accepted for the personnel, loss of safety functions and risk for harming the environment.

The CRA for the installation of the pre-compressors for Troll A (Case study III) introduces the risk definition in the different risk analysis stages. The same risk analysis methodology is used as the one from Case I (see Figure 9). Risk as a definition is not introduced as in Case II, but rather used throughout the hazard identification process. The RAC, which are determined by the operating company, have been introduced for individual personnel risk, overall personnel risk and the loss of main safety functions. The RAC have been presented through FAR values. The risk assessment is based on the results from the HAZID that was carried out for operational phases. The identification of risk changes due to the pre-compression, the risk related to the changes has been calculated in different accident scenarios. The risk contributions from the various process segments are estimated by using event tree models. The event trees present different top events that result in numerous consequences. The results of the event tree analysis summarize the risk picture on a format that is required for comparison of the risk acceptance criteria. The main risk factors were risk for personnel and the impairment of the main safety functions; they have been calculated with FAR values and PLL.

There are HAZID workshops to identify and address the risks for the three cases, in addition the experience of senior consultants and previous case studies are used. Hence, a group of experts is put together that are familiar with the integrity and equipments that is used, to find the HAZIDs. It is important to stress that HAZIDs should not be the same, time after time, which often is the case. New techniques and updated methods should be used to identify other potential hazards. Even before starting the risk analysis process, qualitative analysis can be taken into consideration to discuss the potential hazards that can be involved. Risk and hazard identification is based on assessments and understanding of people that are involved in the risk analysis process and all stakeholders should therefore be involved.

Risk, as described in Section 2, can be expressed as "*the uncertainty regarding what the outcome/ consequences are of a given activity*" (Aven et al., 2004). Since, Case 1 and 2 haven't expressed their definition of risk, the risk definition is difficult to capture from the risk analysis. The reader of the risk analysis then has to create his/her own understanding of risk. The expression from Section 2 is related to uncertainty that can be linked to the outcome of a given activity. Therefore, it is crucial to demonstrate this uncertainty. The uncertainty related to personnel, main safety functions or to the environment. Often, in the oil industry and in risk analysis, risk is presented as probability multiplied with the consequence. This definition and presentation of risk is then quite simplified. As Aven et al. (2004) presents risk related to uncertainty and consequence of a given activity, the understanding of risk will give a better understanding of risk and the uncertainties that are involved with risk. However, uncertainty revolved around not being able to predict, with reasonable certainty, what the outcome of an activity, event or measure will be (Aven et al., 2004). Often the probabilities are based on statistics and tools that are used to calculate the risk levels. Therefore, including the uncertainties related to given activities allows the risk analysis process to dive deeper into the understanding, the causes and the consequences of a certain event or activity. Accurate risk estimation cannot be measures, it is therefore important to involve all uncertainties that can be involved in unwanted activities. Therefore, the importance of definitions like risk should be stressed in a risk analysis. This clarifies for the stakeholders the underlying understanding of the risk concept that has been used when preparing and processing a risk analysis. The concept of risk and the risks that are involved in different parts of the life cycle of a platform needs to be described in such a way that everyone can read it. The description of risk and risks involved should be such that everyone reading the risk analysis should understand it. The calculations that are done represent how high the involved risk is and the risk analysis concludes based on the numbers that the risk is high (or low), thus are very quantitatively.

It is important for both the operator and consulting company to have the same understanding of criteria for what is expected from the risk analysis and what the risk analysis should include. Since different consulting companies have different approaches to present risk and risk reducing measures (Case I and II vs. Case III), the underlying understand of risk has to be established before starting the risk analysis process. This can be beneficial for all stakeholders involved and is helpful in the decision making process. Therefore, the risk analysis should start in an early phase of the life cycle so that the risk analysis can contribute as a decision tool. It would be inconvenient if the risk analysis was created in after the decision making process or as only a part of compliance to regulations and rules.

Risk is thus identified through evaluating the risk involved in a certain activity based on previous experience and case studies. Through the hazard identification process, all the hazards that can contribute to risk are identified. When the hazard, and thus the risk, is considered high and over the accepted criteria, risk reducing measures are determined. Nevertheless, the statistics and previous case studies have not been mentioned in the risk analyses. This information can be added to the risk analysis (as an appendix) to ensure that the readers understand the process that has been used. In addition, no comparisons have been documented through the risk analysis regarding similar operations, activities or modifications in similar platforms or situations in the Norwegian Continental Shelf. Nevertheless, examples and analysis from other industries, like the air line industry, can be used to learn from.

It is crucial to define the focus related to the reactions and understanding of the people that are being exposed to a certain risk situation. These are the personnel are exposed to the risk scenarios identified in the risk analyses. While experts like to rely on statistics and available technical data, the people exposed are not as comfortable with previous data that is taken into new risk analysis. Their perceptions might be based on other values and philosophies and their own experience. Personnel working in areas that have higher occurrence values related to hazards and risks are more exposed, and may thus react differently. This indicates that a (quantitative) risk analysis is not enough. A more comprehensive qualitative risk analysis should play a bigger role in the risk analysis performed for the oil industry in Norway. Especially in the early stages of the risk analysis, due to the fact that qualitative risk analysis includes different methods and views that can reflect differently on a risk analysis. The quantitative risk analysis focuses more on the statistics and calculations that result in numbers and more statistics. If for instance, the RAC limit is set to 10 and the calculations show that they are less than 10, doesn't mean that the activity is as safe. The understanding and perception of that certain activity might be much broader when consulted with the personnel working onsite; they may have other perceptions both on the causes and on the consequences related to given activities (Aven, Vinnem and Vollen, 2006).

3.1.3 Risk reducing measures

The risk reducing measures have been presented as ALARP measures indicating that the risk should be reduced to as low as reasonably practicable, in all three cases. The ALARP principle has been used as a method and tool for reducing the risk as low as reasonably possible, by the consulting companies that prepare and use the risk analysis. After the ALARP process has been evaluated the chosen measures are discussed. In for instance Case I, ALARP evaluations have been carried out to demonstrate the effect of new installations, relocating equipment, removing equipment, etc. Aker Solutions MMO evaluates the results from the safety evaluations in their formal ALARP evaluations process which also includes cost aspects. The measures are presented and the consequences of implementing the measures have been calculated in relation to the risk involved for the personnel, main safety functions and the potential for major accidents. Afterwards a short conclusion is given on how high the risk is when implementing the ALARP measures. The recommended measures will then be further evaluated and implemented by the operator company, meaning that the operator company will be in charge of selecting and implementing risk reducing measures. The informant from the operating company, discussed that the measures selected by the operating company can differ from the measures that have been suggested by the consulting company in the risk analysis. The risk analysis only works as a suggestion, the decision making lies in the hands of the operating company. This process of determining and selecting risk reducing measures should be done in cooperation with the consulting companies, based on the regulations. But in Norway, the operating company is not required to do so. The same process has been used for Case III.

Case II starts with presenting the defined danger- and accident situations. The EPA evaluates these situations in relations with the risk involved. Hence, the risk results are discussed and the FAR values have been calculated for each danger- and accident situation. The results are further compared with the other Sleipner platforms i.e. SLT and SLR. The FAR values for the personnel involved in the different locations on the platform and the loss of main safety functions are further analyzed to set the recommended measures to reduce the consequences. Based on the calculated risk levels for the Sleipner field the risk reducing measures are presented. The Sleipner operations are examined to determine the alternative risk reducing measures; in the TRA alternatives have been suggested. This is very positive and will contribute more as a decision making tool for the operating company, then having only one risk reducing measures and no further alternatives. In addition, the implementation process for implementing the recommended risk reducing measures have been estimated (provided that the benefits are considered to be greater that the disadvantages). The risk reducing measures have been evaluated for situations of fire, explosions, dropped objects etc, with respect to the ALARP principle. Risk analysis doesn't always have enough emphasises and focus on the uncertainties that may occur from implementing the recommended risk reducing measures. The uncertainties with both risk and risk reducing measures should be involved in risk analysis (Aven, Vinnem, 2007). However, this has not been the case for the case studies used for this analysis.

In Case I and III, alternative risk reducing measures have not been given; only one risk reducing measure for each potential unwanted event or activity. Giving alternative risk reducing measures (if possible), can establish a list of most prioritized measures that the operating company can consider. Also, a panel of experts should evaluate the recommended measures to determine the consequences of the recommended measures. This evaluation and discussion should be documented for further analysis and to be able to use it in other cases as well as documenting which measures have been implemented. These measures are often determined by experts that have used the same measures before. Often the encouragement from operator companies is lacking on reducing the risk even more and using other (new) tools and methods to determine new measures. Risk reducing measures are often based on traditions (Preventor, 2010).

Since the risk reducing measures often are based on statistics and previously determined measures, the focus is often on the major events and activities that can contribute to risk and measures to reduce the risk. These major activities often include accidents that are related to fire, explosions, leaks etc., these hazards are obviously of importance. However, the smaller incidents, accidents and the working environment could also be taken into consideration. This can be achieved by implementing a more qualitative analysis to include all the aspects that can contribute to risk related to for instance the personnel. The most comprehensive approach is to create a checklist of elements that should be included in a risk analysis (Pham, 2011). This document can be implemented and updated throughout every risk analysis process. In addition, changes and new implementations to the list can be updated. Thus, the risk analysis process becomes more clearly.

Through having an overview, new measures should be considered instead of always relying on the traditional measures. The group of experts that are determining these risk reducing measures should contain a well put together group with both experts from the operator side as well as from the consulting company's side. Alternative approaches and methods are not taken into considerations and the risk reducing measures often imply the same measure implementation. Different expertise should be involved in the process of determining measures to find the best suitable measure in addition to finding alternatives. Focus should be more given on finding measures that are best for the personnel related to health, safety and the environment, considering the fact that the financial and time consuming aspects should not be a limitation.

The determination process of risk reducing measures also includes determining the consequences of these measures. As in the case studies used for this thesis, most of the risk analyses do contain a separate part that is concerned with the consequences of the risk reducing process. However, this part of the risk analysis can be improved by implementing aspects as how the risk reducing measures contribute in reducing the consequences as well as how risk will be reduced after the measures have been implementing, i.e. a table that contains information regarding (NORSOK Z013, 2010):

- The suggested risk reducing measure to reduce risk in a given situation or activity
- The new risk picture that initiates that the risk is reduced based on the recommended risk reducing measure
- The alternative approaches/measures that can be taken to reduce the risk
- And with time, who should implement the risk reducing measure (responsibility) and the follow up program regarding whether the risk reducing measure has been implemented, by who, when and how the risk has been reduced

The key aspect with regards to risk, risk acceptance criteria and risk reducing measures, and for that matter other aspects of a risk analysis, is the *documentation* that enables understanding and support in the decision making processes. Documentation is important both before starting the risk analysis process, during the risk analysis process and after the risk analysis process, which enables a procedure for how the risk analysis process is.

3.2 Improvement potentials

Through reading and analyzing the three case studies, an understanding was built on how a risk analysis is demonstrated in the oil industry. Even though the risk analyses differ in being quantitative, total- or concept risk analysis, the risk identification was rather similar (especially Case I and III). Most of the knowledge used in the risk analysis is based on experience, models and statistics. In this subsection a more general overview is given of the improvements that can be considered in a risk analysis;

- Go beyond the minimum requirements: first of all, the risk analyses used in the three cases indicate that the regulations and standards have been used and followed. However, the operating and consulting companies should try and push the requirements that are set as minimum requirements. For instance, by implementing and having more focus on the ALARP principle to reduce the risk as low as reasonably practicable.

- Documentation: evidently, the criteria from the PSA shall be followed, but also the internal criteria that the operating company has, needs to be up to date and followed, as well as documented. Thus, documentation is a very important part of any process, especially the underlying attention and approach that was undertaken before starting the risk analysis process (the base case). Better documentation is also necessary during and after the risk analysis process including (Pham, 2011):
  - the identification of RAC and of the risk reducing measures both quantitatively and qualitatively
  - evaluate the risk reducing measures individually before implementation
  - cost benefit analysis for the risk reducing measures
  - risks involved after the risk reducing have been implemented and
  - how will the risk be reduced if the recommended risk reducing measures should be implemented

- Follow up documentation: with regards to what risk reducing measures have been selected to implement, by whom, when, how etc., should be included in the risk analysis. The documentations can be set together to get an overview of what has been done.

- Cost effective measures: by being oriented to meet the pre-determined RAC, the cost effective solutions and measures might be prioritized and other important aspects, like the environment can become second priority. Acceptability of operations with respect to environment risk is more seen as a political process and the acceptance criteria are not as important as they should be. Often the pre-defined criteria are used for driving the decision making process. However, through replacing this approach with an other approach that highlights risk characteristics and evaluations, the risk analysis will include more focus on the drive for risk reducing measures and the balance between costs and benefits. The regulations from the Norwegian PSA underline the risk reducing principles, but the focus hasn’t been as much as wanted from the oil industry (Aven, Vinnem, 2007).

- Not relying on old cases: to be able to accomplish the demand and acceptance criteria, NORSOK Z-013 (2010) can be used as a guideline. NORSOK Z-013 states that the FAR value for personnel on the installation should be less than 10. Therefore, the traditional approach can not be used as the only approach for every element in the risk analysis; other (updated) approaches, technology or tools should be considered. When the RAC have been determined, the risk analysis process can start with the risk identifications and the risk reducing measures. The knowledge that is required to prepare and create a risk analysis has to be improved and investigated before the risk analysis process can start. The experience based approach is often used in the oil industry, as well as previously created risk analyses are often used. Risk reducing measures should be implemented as new single cases, instead of using a large amount of information based on previous cases (Preventor, 2006). This should be implemented with the principle that sets the intolerable risk and a limit to the risk that can be negligible, which sets the interval in between the ALARP area (Aven, Vinnem, 2007).

- Involve stakeholders: Often the involvement of the personnel is not taken into the risk analysis process. The employers that are working on the platform itself know the risks involved. Therefore, the participation of the on-site personnel is crucial to include all the aspects that are required to complete a risk analysis. Thus, when every given scenario is identified and every possible risk is identified, the risk analysis process will then be more thorough and the risk that is involved can be reduced with risk reducing measures that can be implemented. Thus, the risk reducing measures are then based on the risks that have been identified by including the personnel. The personnel can be from the operator company or from the contracting companies that are working or have worked on the platforms. Through involvement of different personnel with various experiences the risk identification picture can be improved and optional risk reducing measures can de recommended and implemented (Hansson, 2003). When risk has to be managed and analyzed the biggest focus is obviously on the health and safety of the personnel, therefore involving the personnel before starting any quantitative risk analysis might complement if not complete the risk analysis process (Pham, 2011).

- Making risk analyses understandable: The risk analysis process has potential for improvements and through implementing improvements along the risk analysis processes, the content of a risk analysis can be more understandable for all stakeholders involved. A risk analysis should include a solid scientific basis that determines how the risk analysis process is evaluated. Through this scientific basis the process can be clarified, and all readers of the risk analysis will be able to understand the process (Aven, 2011). Often simplicity is the key. After talking to some of the informants, it became clear that the risk analysis not always is as clear as they would have liked. The risk analysis that is presented is often read by others, for instance contractors that are given the task to for instance further evaluate the ALARP values. Therefore, the risk analysis should be readable for all the stakeholders that are involved, especially the authorities (Aven, 2012). This is not always the case and risk analyses are found hard to understand (Preventor, 2010). The ALARP is an important part of a risk analysis. Aven and Vinnem (2007) believe that the authorities should be more closely involved in the ALARP processes and how they are used in the oil industry.

- Uncertainty: is often a word that is not used in risk analyses. However, the interpretations and the measurements of identified hazards, risk calculations, fire and explosion simulations etc. should document which uncertainties that are taken into account and used in the risk analysis. This is also the case for the probabilities of the risks involved (Pham, 2011). In the three cases studies that are used in this thesis, the uncertainties, probabilities and risks are not further evaluated or explained. When for instance, it is given that a possibility might occur for an explosion, further explanations and assumptions are not given. The probability and uncertainties that are involved can be explained to make it clearer. However, this does mean that the risk analysis in itself will be more thorough; simplicity in presentation of risk can be used to make the material better understandable. The uncertainty that might be involved should be further discussed and assessed to complete the risk analysis. When a reader of the risk analysis is not satisfied with the risk analysis and feels information is missing it means that the risk analysis has potential for improvements. To be able to include these elements in a risk analysis, the analysts should have the right background within risk and uncertainty involved with risk. As pointed out by Aven (Pham, 2011), risk analysts often have a "poor background". The right education and training is thus required to communicate the risk picture and the uncertainties involved, to create a judgment (Preventor, 2006). This indicates that the risk picture should be extended with regards to implementing all risk analysis methods that can be used. The Sensitivity analyses that are presented in the three case studies do not contain diverse uncertainty analysis. The Sensitivity analysis can raise the awareness regarding the uncertainties, and not restrict to the average analysis that can be made on the probabilities involves.

- Inform about the limitations: in the decision making process, it is important to use the risk analysis, but it is also important to inform that the risk analysis is based on assumptions that can be uncertain or limited. This information can then be taken into consideration when using the risk analysis as a tool in the decision making process. This understanding, that uncertainty is still available, is crucial to have in the risk analysis process.

- Updating tools and knowledge: the assumptions that are made in the more traditional risk analysis methods cannot be used on these new more complex systems. Therefore, not all factors that might contribute to risk can be determined and thus further evaluated. The contribution to for instance human errors can be difficult to be modeled when the complexity of the system and the risks involved are uncertain. For instance, the STAMP (Systems-Theoretic Accident Model and Processes) model is an accident model that is argued by Leveson (2004) for safety engineering and risk management. System theory is a beneficial when analyzing potential accidents, where accidents occur from failure and insufficient interactions among systems are not fully handled by the control system. Expertise plays a major role when determining both risk and risk reducing measures. The right timing, with regards to starting the risk analysis process early in the design or modification process, plays a big part in how effective the risk analysis can be. Often the risk analysis is prepared during or even after certain events (for instance modifications) have taken place (Kristensen, 2012). The expertise and right timing on starting the risk analysis process can determine the effectiveness and knowledge needed to prepare a satisfying risk analysis that is understood by all the stakeholders involved (Leveson, 2004).

- Not limiting the risk acceptance criteria: as required from the Norwegian PSA, the risk reducing measures should be determined before starting the risk analysis. As Aven (Pham, 2011) argues, is t necessary to specify these strong limitations and accepted criteria? Through setting limits to what is accepted, the company is restricted from obtaining the desired and maybe best suitable results. This might result in weak limits that have been determined, and further used in the risk analysis process. Thus, the RAC are concentrated on obtaining the minimum safety standards that has been accepted, not giving opportunities for improving and reducing the risk when possible.

- Human aspects that contribute to accidents: risk analyses don't focus as much on the qualitative side. Nevertheless this element and other elements are important to include in a risk analysis or in a risk analysis process, like:
  - Safety Management, to create safety culture and order
  - Acceptable Risk with the criteria that is assumed acceptable and its margin
  - Risk Matrix for including the probabilities and consequences before and after an potential event or accident occurs
  - Incident investigation reports from incidents in that area or with that element that contributes to risk
  - Uncertainty and Reliability analysis, also focus on humans and human-errors that can contribute to risk

- Risk analysis as a decision tool: operator companies have to be cautious, to not interpret risk analysis as evidence of no need for change or further evaluate where needed. But implementing change can be challenging for people and companies are often comfortable with the approaches that they are taking and have been taken in the past (Aven, Vinnem, 2007). Therefore, the risk analysis needs to be used as a decision making tool that needs constant updating and new expertise. In addition, risk analysis should not be used as validation of activities that already have been implemented before the risk analysis has started. The risk analysis should be ready and used as a decision making tool before starting activities like maintenance and modifications.

- Underlying understanding of risk reducing measures: that are determined need to be more detailed, meaning that the evaluations that are taken for determining the risk reducing measures should also be included. The steps that are undertaken to determine the risk reducing measures can be both qualitative and quantitative. In the three cases the recommended risk reducing measures are presented, but the underlying understanding of how they reached their conclusions is lacking. Through explaining and documenting this, the risk analysis can illustrate the underlying strategies that are undertaken, in order to improve where needed. Often experience and previously used measures are being used to determine these risk reducing measures; it is up to the operator company to further implement the risk reducing measures. An evaluation process of the recommended risk reducing measures should be carried out (and documented) by for instance using the cost- benefit matrix where the relationship between the costs and the benefits are illustrated as recommended in NORSOK Z013 (2010). This is a very comprehensive process that should be discussed with the operating company. When the processed and risk analysis methods are used, and their underlying understanding are documented, it will make it more understandable when a new risk analysis is prepared. Since the PSA doesn't give any specific demands regarding how to accomplish for instance Framework Regulation (2001) § 9 regarding the risk reducing measures, the operating company should at least have a process for determining the RAC and risk reducing measures. As Aven (Pham, 2011) points out, the validation of risk analysis methods is a crucial but complex issue. To deliver the results in a adequate and trustworthy manner to the operating company (and other stakeholders), it is crucial to advert the minds and process that lies underneath the risk management and risk results in that are presented in the risk analysis. The clarity on the consultants that are preparing the risk analysis and how the group is put together also plays a significant role.

- Ordering the risk reducing measures: as described in the literature review, the risk reducing measures should be ordered with regards to alternatives, prioritizations and the impact of the risk reducing measures. Meaning whether their impact is to prevent, control or mitigate the effects of an accident or activity (ISO 13702, 1999).

- Through combining the qualitative- and quantitative risk analysis, the risk analysis will become complete, valid and more reliable (Holme, Solvang, 2004). And, even though the companies preparing the risk analysis are trying to improve and implement new aspects to the risk analysis process they have been using the last couple of years, no changes have been made (informs the Informant from one of the consulting companies preparing the risk analysis); hence, the risk analysis has remained the same.

Section 4: Conclusion

Regulations have been determined by the authorities and they shall be followed. The case studies fulfill the requirements that are given in the regulations. Also, standards have been used as guidance to fulfilling the regulations. Since risk cannot be eliminated it has to be managed, through determining risk acceptance criteria before starting the risk reducing process, where the accepted limits are determined. Through hazards identification the risks can be identified, this identification process is determined by what normally is a group of experienced consultants. The risk analysis simplifies risk to probability and consequence; the causes and uncertainties related to risk have not been implemented nor documented in the risk analysis. The risk acceptance criteria should be used with care, fulfilling the limits or criteria does not indicate that the risks are accepted. The underlying understanding of the accepted criteria should also be implemented and documented in the risk analysis to demonstrate the awareness with regards to risk.

The industry and technology is changing therefore, risk cannot be identified and limited to traditional methods and techniques. Hence, changes with regards to implementing new methods and techniques for identifying risk and risk reducing measures in the risk analysis process are difficult to adapt. Stakeholders and companies that are involved in preparing the risk analysis should go beyond the minimum regulations, to reduce the risk to ALARP. From the case studies used in this thesis it can be concluded that the risk analyses don’t go beyond the minimum requirements that are determined by the authorities.

The risk analysis only displays the findings, calculation and their conclusions, without demonstrating the underlying understanding of what risk is and what contributes to that risk. Even though the ALARP principle has been used when determining the risk reducing measures, no further explanations have been given in the risk analyses regarding the basis and underlying understanding, that have contributed in identifying risk and risk reducing measures. The risk analyses are based on experts, previous case studies and statistics, i.e. the risk analysis is restricted to the expertise that is available for a given risk analysis. Through a qualitative risk analysis, a more comprehensive risk picture can be established, taking into account underlying factors influencing risk by including several important personnel and stakeholders.

Thus, further development and more comprehensive documentation related to the identification of risk and risk reducing measures should be improved, as well as the focus on risk related to HSE should be increased.

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