Master's thesis

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Evaluation of Safety Systems at an Unmanned Production Platform

An ALARP-Analysis

Master's thesis in Marin Teknikk
Supervisor: Jan Erik Vinnem
June 2019

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Kunnskap for en bedre verden

Summary

This thesis has evaluated the safety and security systems at an unmanned production platform through an ALARP-analysis. Aker Solutions and Aker BP have developed a concept design for an Unmanned Production Platform (UPP) in the North Sea. The UPP was designed to be visited and entered only to perform maintenance. In total would the UPP be manned 56 days a year. The primary transport and evacuation method is the SOV with the W2W gangway. The UPP has been the basis for the safety and security evaluation.

The PSA requires processes to reduce health, environment and safety risk beyond an estimated minimum level in sofar as this is practicable. These processes are often called ALARP processes. The ALARP principle stipulates that those responsible should reduce risks of death and injury for workers and members of the public to levels that are As Low As Reasonably Practicable.

This thesis has performed a limited QRA and ALARP-analysis. The QRA has focused on explosion, fire, and collision. The ALARP-analysis has analyzed the risk reduction measures of an additional escape chute, a fire retardant lifeboat, additional SSIVs, shutdown of installation before maintenance, the change of SOV positions, and a deluge system. The measures recommended implemented after the analysis are a SSIV at the multiphase riser, a change of SOV position to lay standby at 300 m distance, and to shut down the production and empty the risers before maintenance.

The design had a low risk to personnel, but a greater potential for reducing the risk to assets and the environment. The analysis performed in this thesis were performed with a low sensitivity. The measures where a gross disproportion between cost and benefit were found can safely be disregarded, but all other measures should be analysed with a higher sensitivity to ensure a proportionate cost-benefit ratio.

Sammendrag

Denne oppgaven har vurdert sikkerhetssystemene på en ubemannet produksjonsplattform ved gjennomføring av en ALARP-analyse. Aker Solutions og Aker BP har utviklet et konseptdesign for en ubemannet produksjonsplattform (UPP) i Nordsjøen. UPPen ble designet for å bli besøkt og bemannet kun ved vedlikehold. Totalt ville UPPen bli bemannet 56 dager i året. Den primære transport- og evakueringsmetoden vil være ved SOV med W2W gangbro. UPPen har vært grunnlaget for sikkerhetsevalueringen.

Ptil krever prosesser for å redusere helse-, miljø- og sikkerhetsrisiko utover et minimumsnivå , så langt det er praktisk mulig. Disse prosessene kalles ofte ALARP-prosesser. ALARP-prinsippet fastslår at de ansvarlige skal redusere risikoen for død og skade for arbeidere og medlemmer av offentligheten til nivåer som er så lave som praktisk mulig.

Denne oppgaven har utført en begrenset QRA og ALARP-analyse. QRAen har fokusert på eksplosjon, brann og kollisjon. ALARP-analysen har analysert risikoreduserende tiltak for en ekstra redningsstrømpe, brannhemmende livbåt, flere SSIVer, avstengning av installasjon før vedlikehold, bytte av SOV-posisjon og et brannvannsanlegg. Tiltakene som anbefales etter at analysen er gjennomført, er en SSIV på multifaserøret, en endring av SOV-posisjon til å ligge standby på 300 m avstand, og å stoppe produksjonen og tømme stigerørene før vedlikehold.

Designet hadde liten risiko for personell, men et større potensial for å redusere risikoen for materielle verdier og miljøet. Analysen utført i denne oppgaven ble utført med lav sensitivitet. Tiltakene hvor analysen viste et stort misforhold mellom kost og nytte kan trygt forlates, men alle andre tiltak bør analyseres med høyere sensitivitet for å sikkre en forholdsmessig nytte av kostnaden.

Preface

This master's thesis marks the end of my studies in Marine Technology at the Norwegian University of Science and Technology (NTNU). The thesis is concerned with the safety and security barriers and systems of an Unmanned Production Platform (UPP). Writing this thesis has been a challenging and rewarding experience where I have learned extensively about offshore installations, safety and security barriers and ALARP-analysis.

I would like to thank Linda Fløttum from Aker Solutions and Sissel Eng from Aker BP for help, guidance, and access to necessary data.

A special thanks goes to my supervisor Jan Erik Vinnem, Professor at NNTU, for invaluable help, guidance, and supervision throughout the entire process.

I want to thank all my friends and my office for a memorable time here at NTNU. It would not have been the the same without you. Thank you.

Trondheim, 11.06.2016

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List of Abbreviations

BAT	=	Best Available Technology
CAPEX	=	Capital Expense
CBA	=	Cost Benefit Analysis
CRA	=	Consept Risk Analysis
DNV-RP	=	Det Norske Veritas Recommended Practice
ESDV	=	Emergency Shut Down Valve
F & G	=	Fire and Gas System
FAR	=	Fatal Accident Rate
GNP	=	Gross National Product
HC	=	Hydrocarbons
HSE	=	Health Safety and Environment
ICAF	=	Implied cost of Averting a Fatality
KO drum	=	Knock Out drum
LCC	=	Life Cycle Cost
MTTF	=	Mean Time To Failure
NCS	=	Norwegian Continental Shelf
NORSOK	=	Norwegian Offshore standarisation organisation (>Norsk Sokkels Konkukuranseposisjon =)
NPD	=	Norwegian Petroleum Directorate
NPV	=	Net Present Value
NTS	=	Norwegian Technology Standards Institution
OPEC	=	Organization of the Petroleum Exporting Countries
OPEX	=	Operational Expense
PLL	=	Potential Loss of Life
POB	=	Personnel On Board
PSA	=	Petroleum Safety Authority Norway
QRA	=	Quantitative Risk Assessment
RAC	=	Risk Acceptance Criteria
RRM	=	Risk Reduction Measures
SIL	=	Safety Integrity Level
SOV	=	Service Operation Vessel
SSIV	=	Subsea Intervention Valve
UPP	=	Unmanned Production Platform

Chapter 1

Introduction

1.1 Background

In 1967 was the first oil reservoir on the Norwegian continental shelf (NCS) found by Phillips. In 1969 was the largest offshore oil field on the NCS to date discovered, and the Norwegian oil venture began. In the years to follow several large reservoirs were found on the NCS. The fields were developed together with a connecting infrastructure [29]. In the recent years has there mostly been discovered smaller reservoirs, with exception of Johan Sverdrup. The advancement of technology, oil price, and field size has resulted in a profitable development of smaller reservoirs.

In 2014, the oil price dropped critically. After the entrance of American shale gas at the world market the price control of OPEC was challenged. OPEC answered by producing maximum volumes of oil and gas, in an attempt to squeeze the shale gas producers out of the market. This strategy resulted in a critical decrease of the oil price [5]. Oil and gas production is a large contributor to the Norwegian economy, where the oil industry produce a 17% share of GDP in 2018[30]. If the Norwegian oil industry were to lose its profit it would critically inflict the Norwegian state and welfare.

The enormously sized reservoirs have not been found in the last 20 years on the NCS. In consequence, smaller reservoirs have been developed. When the demand for profit is increasing and the forecast of oil price is decreasing, there are incentives to develop fields with lower Capital Expenses (CAPEX) and Operational Expenses (OPEX). This has been an incentive to create unmanned installations. In addition to reduce the expenses, the safety of the workers can be increased, by removing them from the source of risk at the installation.

The ALARP principle stipulates that those responsible should reduce risks of death and injury for workers and members of the public to levels that are As Low As Reasonably Practicable (ALARP) [15]. The Petroleum Safety Authority Norway (PSA) requires processes to reduce health, environment and safety risk beyond an estimated minimum level insofar as this is practicable. These processes are often called ALARP processes [26]. At an unmanned offshore installation operating at the Norwegian continental shelf the PSA requirements are governing for Health, Safety and Environment (HSE).

1.2 Challenges

A transition from manned to unmanned installations are incentivized by two purposes; reducing the expenses and increasing the personnel safety. To successfully accomplish the transition is challenging. Many of the safety systems at manned installations require high levels of maintenance, which do not comply with a low OPEX. Naturally, the designers seek to reduce the maintenance at unmanned installations, in order to decrease the OPEX. This can be done by completely removing systems, or to choose low maintenance equipment. Several of the safety systems are maintenance requiring in order to keep the Safety Integrity Level (SIL) required at manned installations. The case used in this thesis has removed some of the safety and security systems to decrease the CAPEX and maintenance.

The Norwegian oil and gas venture faces an uncertain future, due to the political climate, with the Paris-agreement [42], Greta Thunbergs fight for stricter political environmental decisions [46], etc. The uncertainty is raising the expectations for profitable and safe extrusion. While the cost must be reduced, it is unacceptable to reduce the safety and security. When at the unmanned installation must the workers be as safe as at an ordinary installation, even with reduced time spent on the installation.

Unmanned offshore installations at the Norwegian continental shelf are both subsea and above surface. The current installations are relatively simple, i.e. wellhead platforms. An unmanned production platform will be significantly more complex. The reduction of cost is one of the main drivers for developing unmanned installations. Using a walk to work-vessel (W2W), instead of a helicopter, can reduce the required support systems at an installation. There are few clear regulations and risk acceptance criteria for the W2W-solution. The facilities regulations §6 opens for simpler solutions than prescribed at complex, manned installations. The solutions must be proven satisfactory through special assessments. A thorough ALARP-analysis can be a part of justifying the risk picture in the new design.

1.3 Scope of work

The purpose of this master thesis is to evaluate the level of safety and security systems and barriers at a unconventional design concept. The main method of evaluation will be an ALARP-analysis. The focus will be on evacuation and escape in case of fire, explosion, collision, and safety during planned and unplanned maintenance. This master thesis will perform a limited Quantitative Risk Assessment (QRA) and ALARP-analysis of an unmanned production platform (UPP) concept developed by Aker Solutions for Aker BP. The QRA is based on the Concept Risk Analysis (CRA) performed by Aker Solutions.

1.4 Structure

This thesis will present an introduction to the necessary theoretical information of risk, ALARP-analysis and QRA. The case is presented in the case study, along with the theory of unmanned production platforms. The limitations and how to analysis is performed will be provided in the method chapter. The theory and method chapters are closely connected, and are best read together. The method chapter will provide a more extensive reasoning for the choices made to obtain the results, as well as the values of repeating parameters. The results are presented in the case study chapters. A discussion of assumptions, results, and limitation will be performed in the discussion chapter and will be the basis for the conclusion.
All abbreviations are listed in Abbreviation List before the start of the Introduction chapter. When a citation is placed after a paragraph, it references the entire paragraph.

Chapter 2

Literature Review

The main literature utilized in this thesis is presented in this chapter. It is evident that the supervisor of this thesis has involvement in the literature presented, and the literature is complementary of each other.

2.1 NORSOK z-013

The NORSOK Z-013N rev.2 *Risk and emergency preparedness analysis*, published in 2001 is developed by NTS with broad industry participation. "The purpose of this NORSOK standard is to establish requirements for effective planning, execution and use of risk and EPA. Also the use of RAC is covered, thus the standard covers some aspects of risk assessment. " [31].

Annex E provides guidelines for cost benefit analysis. The annex provides an ALARP-demonstration for personnel and asset risk. The guidelines for evaluation of costs has been utilized and adjusted to 2019-values.

2.2 Risk Management

Risk Management - With Applications from the Offshore Petroleum Industry by Aven and Vinnem (2007) is about making decisions in the face of risks and uncertainties. Chapter 5 *Applications - Operations Phase* and Appendix B *Example, ALARP Demonstration* have been used in this thesis.

The qualitative analysis and presentation of risk reduction is heavily influenced by these chapters, as well as the evaluation of the analysis results.

2.3 Offshore Risk Assessment

Offshore Risk Assessment - Principles, Modelling and Applications of QRA Studies by Vinnem (2014) has been important when performing the QRA study. It has been the theoretical basis for the QRA, and the risk values derived form the QRA.

Chapter 3

Theory

3.1 Risk

Risk is the likelihood of a given consequence [41]. It is calculated by multiplying the possibility of the event with the consequence of the event, as seen in equation 3.1[45].

$$Risk = Probability\,(p) \cdot Consequence\,(c) \tag{3.1}$$

There are three dimensions of risk, Personnel risk, Environmental risk, and Asset risk [45].

The framework regulations §11 *Risk reduction principles* requires: "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." [26]

The definition of risk is further: "Risk means the consequences of the activities, with associated uncertainty. The term 'consequences' is here used as a collective term for all potential consequences of the activities." [26]

3.1.1 PLL

Potential Loss of Life (PLL) is the fatality risk assessment, where PLL is calculated as

$$PLL = \sum_{n}\sum_{j}(f_{nj} \cdot c_{nj}) \tag{3.2}$$

[45]

where:

f_{nj}	=	annual frequency of accident scenario (event tree terminal event) n with personnel consequence j
c_{nj}	=	expected number of fatalities for accident scenario (event tree terminal event) n with personnel consequence j
N	=	total number of accident scenario (event tree terminal event) in all event trees
J	=	total of personnel consequence types, usually immediate, escape, evacuation and rescue fatalities.

[45][1]

3.1.2 FAR

Fatal Accident Rate (FAR) is the individual risk. The FAR value is the number of fatalities in a group per 100 million exposed hours. FAR is expressed as:

$$FAR = \frac{PLL \cdot 10^8}{Exposed\ hours} = \frac{PLL \cdot 10^8}{POB_{av} \cdot 8760} \tag{3.3}$$

[45]

where:
POB_{av} = average number of manning level [45][2]

3.1.3 Ship collision

The frequency of collision upon arrival is assessed with following equation from DNV-RP 107:

$$F_{Collision\,(approaching\ supply\ vessel)} = N \cdot P_1 \cdot P_2 \cdot P_3 \tag{3.4}$$

where:

N	=	Number of visiting vessels per year
P_1	=	Probability of being on collision course (per visit)
P_2	=	Probability of loss of control onboard the vessel when on collision course
P_3	=	Probability of failure to warn/divert a vessel approaching on collision course

[7]

3.2 ALARP

A continuous risk evaluation of offshore installations are a requirement[26]. The ALARP analysis is one method to perform an evaluation of the risk below the acceptance criteria. All risks exceeding the acceptance criteria require immediate risk reducing measures (RRM). In these cases the ALARP-analysis will give insight on the most effective RRMs.

The goal of the ALARP-analysis is to have all risk reduced to a negligible level. If the cost of the risk reducing measure is grossly disproportionate with the risk reduction

[1] p.27
[2] p.29

will a not negligible risk be accepted, as long as it is under the acceptance criteria. Risk aversion and qualitative aspects are contributing to the evaluation of the risk reduction [31]. The NORSOK Standard Z-013N rev.2 demonstrates the ALARP analysis as seen in figure 3.1.

The QRA is the basis for the ALARP-analysis. All risks in unacceptable regions must be reduced before the ALARP-analysis take place.

When the acceptance criteria are met, there is still a requirement to continue reducing the risk 'to the extent possible'[26]. All RRMs which are not grossly disproportionate of the risk reduction should be implemented. In the Norwegian rules and regulations there are no lower limit of risk reduction. This lower limit is an outcome of every evaluation where the cost will be to high for a possible reduction.

Grossly disproportionate refers primarily to the cost of implementation vs the gain in risk reduction. The risk reduction refers to the legal impairment of life and limbs of personnel and civilians, loss or impairment of assets, environmental damages, and loss of reputation. This is evaluated both quantitatively and qualitatively.

The NORSOK Standard Z-013N stipulates that high quality RRMs may be implemented without a Cost Benefit Analysis (CBA) and for RRMs not immediately implemented a CBA should be performed. All RRMs without a improprotion between cost and benefits should be implemented. The CBA has quantitative and qualitative aspects, as not all aspects are easily quantifiable. If the RRM has an disproportionate CBA, the risk aversion and quality aspects must be considered strong enough for implementation. If not, the RRM can be rejected. [31]

3.2.1 CBA

A Cost Benefit Analysis (CBA) consists of both quantitative and qualitative parts. The quantitative cost is considered in a life cycle perspective, LCC.

$$LCC = \sum_{n=1}^{N} 1,0p^{-n}[\sum_{j=1}^{3} \Delta C_{nj} \cdot V_j(C) - RC_n - IC_n] > 0 \tag{3.5}$$

[31]

where

LCC	=	Life cycle cost (Net Present Value) for a particular risk reduction measure from year 0 until year 'N'
N	=	Last year of field life time
$1,0p^{-n}$	=	Depreciation factor for year 'n', based upon interest 'p' %
ΔC_{nj}	=	difference in expected accident consequence in year n, risk dimension j j = 1 dimension: risk to personnel j = 2 dimension: risk to environment j = 3 dimension: risk to assets
$V_j(C)$	=	valuation of risk dimension j as a function of the accident consequence C
RC_n	=	running costs (operating, maintenance, etc.) in year n
IC_n	=	investment costs in year n

A positive LCC is a clear indication of a economical benefit from implementing the RRM.

The risk dimensions personnel, environment, and material value may be challenging to evaluate. For personnel evaluation are there two alternative expressions:

- Assess cost of human life.
- Assess willingness to pay for averting a statistical fatality.

Valuation of the environmental risk may consist of:

- Clean up cost.
- Cost of lost oil.
- Compensation to the fishing and fish farming industries, local communities, etc. for loss of income due to environmental damage.

The valuation of the asset risk consist of two parts:

- Cost of replacement of structures and equipment due to material damage.
- Value of production loss/deferred production.

The quantitative benefit is generally expressed as:

$$\Delta C_{nj} = \sum_{i01}^{I} [f_{nij}^{i} \cdot C_{nij}^{i} - f_{nij}^{rrm} \cdot C_{nij}^{rrm}] \tag{3.6}$$

[31]

where

ΔC_{nj}	=	difference in expected accident consequence in year n, risk dimension j for 'I' number of accident scenarios (total number of end events for all event trees)
f_{nij}	=	accident frequency in year n, scenario i, risk dimension j (superscript 'i' denotes initial condition, whereas superscript 'rrm' denotes condition after RRM)
C_{nij}	=	accident consequence in year n, scenario i, risk dimension j

[31]

ICAF

Implied Cost of Averting a Fatality (ICAF) "is the cost of a risk reduction measure divided by the reduction in Potential Loss of Life that it provides over its lifetime. " [41]

$$ICAF = \frac{Cost\,of\,measure}{Reduction\,in\,PLL} \tag{3.7}$$

[41]

3.2.2 Qualitative analysis

The non-quantifiable parts of the CBA must be considered with respect to implementation of the RRM. These aspects will differ from company to company, and be weighted differently. Aspects for a qualitative analysis may be

- Perceived risk from personnel and the public [38]
- Risk to environment, including the uniqueness of the site [9]
- Risk related to installation [38]

Aven and Vinnem [4] argues the qualitative analysis should be approached through:

Good Practice
Good engineering and procedural practices for common situations. It may include solutions, which have not been incorporated into design standards but have been found to be successful in the field.

Codes and Standards
Codes and Standards often provide an appropriate solution for well understood hazards and situations. They embody the lessons learnt.

Engineering Judgment
Sound application of engineering and scientific principles and methods to control a situation. It includes a subjective experienced-based 'feel' for what is acceptable. It is particularly useful for filtering out extremes - situations that are clearly inappropriate - to allow more rigorous analysis of less clear situations.

Stakeholder Consultation
Consultation with stakeholders - workforce, safety representatives, supervisors, managers, and regulators - is an important part of the ALARP judgement, particularly if the views, concerns and perceptions of these groups are not aligned.

Tiered Challenge
A team of operations and specialist staff works together down the hierarchy, identifying all the possible control options in each category. The team starts with the highest one and challenges why it cannot be applied. If the case is made and it is agreed not to apply a control, the team moves on to the next one down. The range of the team ensures a widely thought out solution.

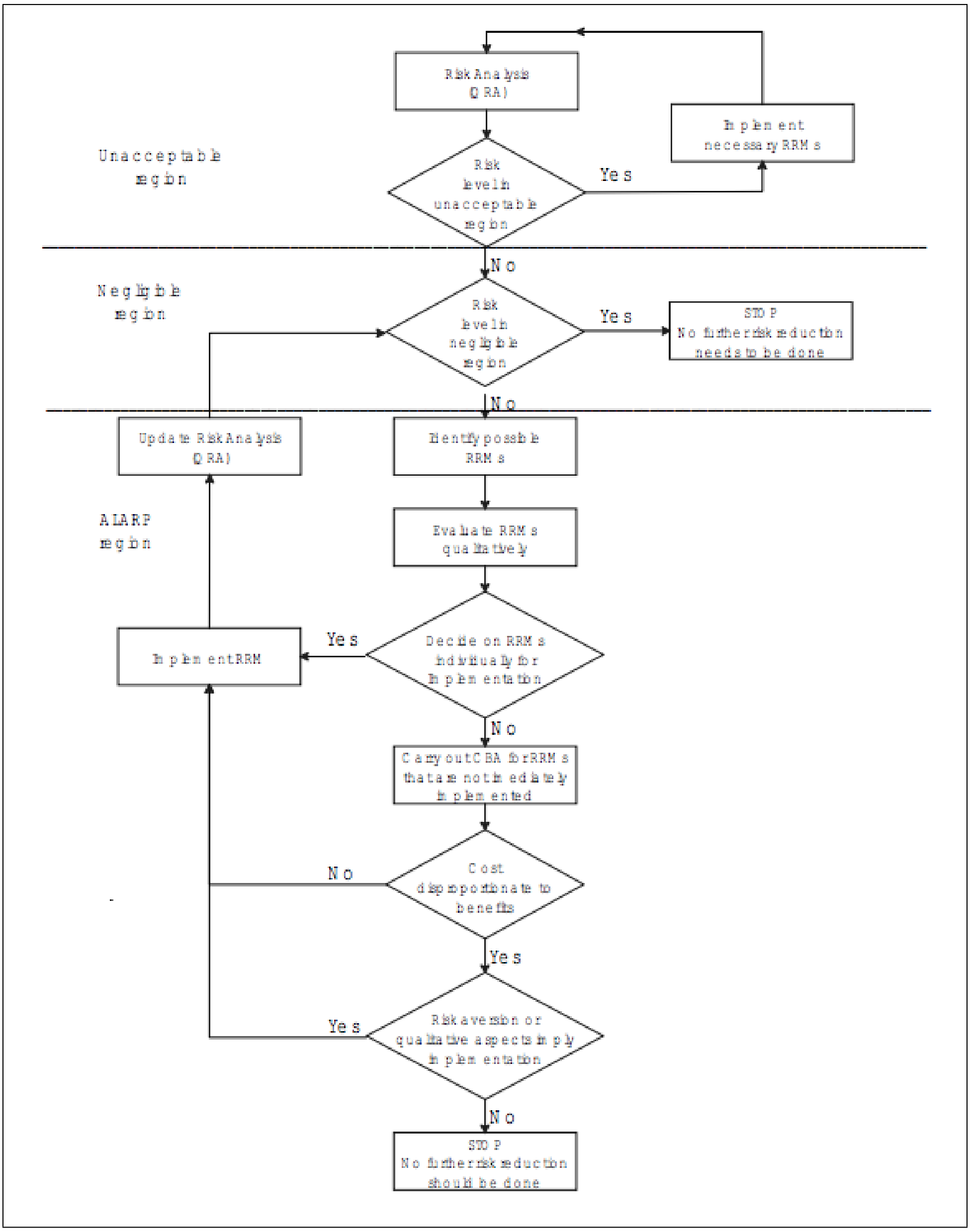

Figure 3.1: ALARP-demonstration regarding personnel risk from NORSOK Z-013N [31]

Chapter 4

Method

The ALARP-analysis is constructed as advised in NORSOK Z-013 Rev.2, and Risk Management written by Terje Aven and Jan Erik Vinnem. It is not an analysis in the full extent, and is based on a concept, not a fully developed design. This chapter will describe how the theory of the ALARP-analysis has been applied. The assumptions and reasoning for general values and important evaluation methods are presented here.

4.1 ALARP-analysis

Based on the QRA the analysis of the risk reduction will begin. A description of all risk reducing proposals must be performed. This includes the risk of personnel, environment, and assets. Negligible risk need not to be assessed. Due to lack of time there will be risks not assessed in this thesis.

4.1.1 CBA

When computing the LCC,

$$LCC = \sum_{n=1}^{N} 1,0p^{-n}[\sum_{j=1}^{3} \Delta C_{nj} \cdot V_j(C) - RC_n - IC_n] > 0 \qquad (4.1)$$

it is assumed

- the field life time, N, is 20 years.
- 7% internal interest rate, p. [4]

Evaluation of environment

Valuation of the environmental damages are easier to estimate than the willingness to avert environmental damage. *Norsk olje og gass* refers to the operators in assessing this willingness, as there is no set acceptance criteria for this. The criteria at NCS is to reduce risk according to the ALARP-principle. [8] An operator can chose not to evaluate the willingness of avoiding environmental spills, but rather focus at the cost of a spill.

Natur og ungdom has the zero emissions principle approach, and therefor no economical valuation of the willingness to avoid environmental damage. *Natur og ungdom's* stand is that there is no cost to large to avoid environmental damage from oil and gas spills. [9]

The approach to validate the risk reduction of environmental damage is severely split, and will have an impact on the outcome of the ALARP-analysis in all RRM's. This thesis will be performed with the assumption of a willingness to avoid environmental damage for 1,5 million NOK per ton. After the oil spill from Exxon Valdez in Prince Williams Sound in 1989 the cost of cleaning, compensating, fines, etc. 1 440 000 NOK (1997-value) per ton [31]. Adjusted to 2018 value would the cost have been 2 233 000 NOK per ton [40]. It is reasonable to believe the fines, compensation and clean-up costs will be higher in 2019 and in the future for the North Sea, than in the Exxon Valdez case. An event leading to a large oil or gas spill will cause not only a loss of oil and gas, but also a loss in possible production while the installation is being repaired and a loss in reputation. These factors are difficult to quantify, but have great implications. The value of avoiding a spill is therefor increased with a factor of 7,5 from the case of Exxon Valdez case. Reduction of the risk of environmental spills will also reduce the risk of small scale, long term spills which have an impact on all the same factors. However, this potential benefit will not be considered in this analysis.

Valuation of life offshore

The value of an offshore life is set to 300 mill NOK [18].

Valuation of Assets

The assets are valuated according to the cost of the entire installation. In case of an explosion or a fire it is assumed most of the installation will be damaged due to lack of fire fighting systems.

Cost of production delay

There are different costs connected to different consequences. Most of the costs are independent of time, with the exception of inflation and change in social and political valuation. The cost of lost income however, is dependant on both time and case. A delay in production will be accounted as a cost. The installation will still have running costs, and the maintenance is required even when no income is generated. Plenty of operators have loans with interest, where the time until the loan is paid down will increase.

The cost of a production delay is dependent on each installation and is based on the decisions made by the operator. If the delay occur at a time of low prices, and the company has a low loan or interest, and the production is extended to a time with high prices, may the delay result in a financial gain. This will be assumed not to be the case in this thesis. For the purpose of this thesis, a delay in production is estimated to a loss of 2.16 million NOK per day. This is based on an field estimate of 0.5 billion barrels sold at minimum price of 35 $ per barrel over 20 years. The lost income will be higher at peak production, but this is disregarded for the purpose of simplifying the analysis. The more critical loss of income at startup is disregarded as well.

ICAF

The Implied Cost of Averting a Fatality (ICAF) include the investment cost (IC), the running cost (RC), the loss of material value, and the reduction in PLL in the computation.

$$ICAF = \frac{IC + RC - loss\,of\,material}{Reduction\,in\,PLL} \tag{4.2}$$

The Irish Commission for Energy Regulation (CER) published a guidance document in 2013 as part of the Petroleum Safety Framework. In this guidance document are they advising implementation of RRMs when the ICAF is below the defined ICAF of €2 400 000 at 2013 prices [41]. This will equal to € 2 514 000 in 2019 prices, which corresponds to 25 000 000 NOK. If the ICAF is higher than defined ICAf the measure can be considered grossly disproportionate with respect to the CBA. The CER is an Irish commission, and grossly disproportionate can be interpreted differently in Norway. The guideline from the CER is therefore considered as an input to a possible limit of grossly disproportionate.

Presentation of CBA

The CBA for each RRM analysed in this thesis is represented with the use of the same tables as used in chapter 5.4 in Risk Management by Aven and Vinnem [4]. The tables present an overview of key parameters for decision alternatives, expected cost parameters, and cost parameters. In RRMs where the Annual impairment frequency is unobtainable, or sufficient information is not provided, it will not be included in the tables. This thesis present the cost parameters with use of LCC and not NEt Present Value (NPV), as the computations mainly follow the NORSOK Z-013 rev.2 standard.

4.1.2 Qualitative Analysis

In the qualitative analysis are the approaches recommended in Risk Management [4] used as far as possible. The Good Practice through consideration of the requirements and practices from manned installations. Codes and Standards are used, such as NORSOK S-003, NORSOK Z-013, Commission for Energy Regulations ALARP Demonstration Guidance Document, etc. The Engineering Judgment is performed with input from supervisor Jan Erik Vinnem, Aker BP, and Aker Solutions. Stakeholders Consultation are mainly represented through the workers union representatives and interest organisations. A Tiered Challenge is not performed in lack of a team of qualified staff.

4.2 QRA

The QRA focuses on explosions, fires, and collisions. Explosion and fire risk is calculated with use of event trees. The fire event trees are in the classical horizontal form, with visual lines to follow the calculation of risk. The explosion risk calculation is performed horizontally. The base case QRA is the QRA for the West position of the SOV. The PLL value is computed as in equation 6.2. The FAR value is computed from the PLL, where average annual manning is 20 pax exposed over 616 hours, and the FAR value is computed as

$$FAR = \frac{PLL \cdot 10^8}{20 \cdot 616} \tag{4.3}$$

When considering the SWAT FAR value the average manning is 10.

The collision QRA was well covered in the CRA from Aker Solutions. The experience from offshore installations in the North Sea is that visiting supply vessels dominate the collision frequency. The collision QRA is based on the frequency of Collision from visiting vessels on arrival, Collision upon entering safety zone and manoeuvring the vessel into operating position, and Collision from operating position. [2]

4.3 Available data

The UPP concept was studied as part of a concept evaluation phase, where several concepts were studied for a possible field development. A partial, quantitative analysis was performed as required in this concept development phase, and the data has been made available for this thesis.

Chapter 5

Case study

5.1 Environment

The case is positioned in the North Sea. There are currently no installations at the location of this case, but several installations in the proximity. There is an estimated distance of 150 km to the nearest shore. This thesis will use Sleipner A as a reference installation for the environment, as it is representative and has public records. The lowest temperature at Sleipner A in 2018-2019 was 0,0°, with a normal temperature above 4,0°[21]. The wind at Sleipner A in the years 2009-2017 is illustrated by the windrose in figure 5.1.

The North Sea is one of Norway's most intensively utilized sea areas, and one of the worlds most trafficked. The North Sea is the main contributor to the wealth creation from oil and gas in Norway, as well as an important ocean for fishing. [22]

The Norwegian Continental Shelf (NCS) is the sea area out to 200 NM from the main land, Svaldbar, and Jan Mayen. In the areas where the 200 NM are in conflict with other countries 200 NM is the border defined by the median line principle. [12]

The NCS is regulated by the Norwegian Petroleum Directorate (NPD) and the Petroleum Safety Authority Norway (PSA). The NPD regulates the explorations, development and operations, etc. [32], while the PSA regulates the HSE. A governing principle at the NCS is that the company is responsible for the safety and security regarding their installations and operations. The companies are required to ensure their HSE-responsibility through risk analysis, risk acceptance criteria, risk assessments, risk management and - reduction, including ALARP-analysis. In the cases where a specific criteria is set by the government, this is viewed as a minimum requirement, and must be further assessed by the company. The Norwegian government has set as a goal that "the Norwegian petroleum sector shall be a world leader for health, safety and the environment" [11]. [11]

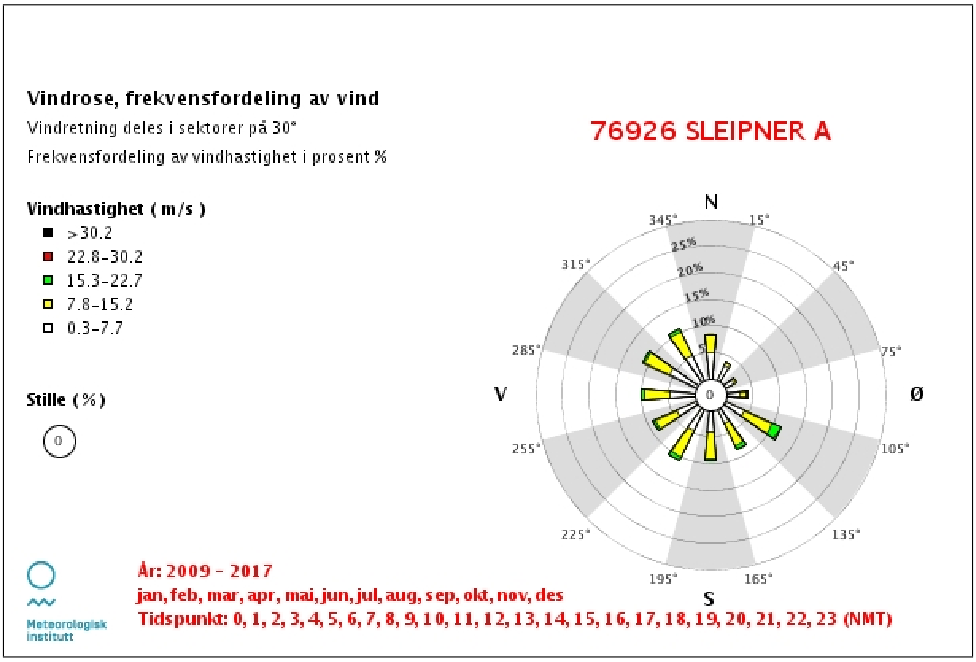

Figure 5.1: Wind at Sleipner A 2009-2017 [28]

The PSA has framework regulations regarding management, facilities, activities, technical and operations, working environment, prohibition against anchoring and fishing, and the working staff [33]. Regulation of the Norwegian offshore industry is heavily based upon previous accidents [11]. When a company is introducing new technology the existing regulations will no longer be adequate, and it is the company's responsibility to document for the PSA an adequate level of safety and security to obtain permission to use new technology. Since the 26th of April 2019 the use of SOV as living quarters for simple installation included in the framework regulation, §[27]. The technical requirements of the SOV is implemented in the facilities regulations.

5.2 UPP

This thesis will analyse a concept design of an Unmanned Production Platform (UPP). The UPP is not designed to be manned, and the control room is moved ashore. The only time there will be personnel at the installation is during maintenance. It is scheduled for 48 days of planned maintenance and eight days of unscheduled maintenance per year. In total there will be personnel at installation 56 days per year. The planned maintenance will be carried out in campaigns of 12 days each. The unplanned maintenance is estimated to have a duration of one day each [2][1]. In this thesis there is assumed to

[1] p.23

be no night shifts, 12 hour work days including 1 hour break at the SOV. The installation contains personnel for 616 hours per year, which corresponds to 7,03% of the year. It is further assumed that the work crew at the installation will consist of 20 persons, based on the capacity of the SOV used at the Tambar installation [1].

To decrease the need of maintenance it is crucial to have reliable equipment with a high Mean Time To Failure (MTTF). The maintenance strategy is based on the plug-and-play method of installation. This requires pre-planning of all repairs, as the whole module is replaced, and the whole module must be brought to the installation. This thesis will not regard the events where there is a redundancy of critical modules to avoid down-time due to waiting on repair.

The UPP has three decks with production and a W2W deck. The intermediate deck and the cellar deck have separated the utility area from the process area with an enforced wall. The wall can withstand an overpressure of 0.7 barg from the process area. The weather deck can withstand 0.7 barg overpressure from above and below, and the cellar deck can withstand 0.7 barg overpressure from above.

The decks are 40.7m x 34.0 m and the deck height is 6 m. The utility area is enclosed, and the electrical and instrumental areas are mechanically ventilated, whereas the rest of the installation is naturally ventilated. The absence of walls around the process area provides ventilation. The cellar deck is located 25.5m above the waterline. At the east and west side stairs are connecting all decks, and the SOV access platform. The west side is the muster area and contains an escape chute with an accompanying liferaft.

The UPP is headed 30°west. The UPP receives unstabilized oil from three wellhead platforms, all with gas lift. The risers are located in the middle of the jacket. Evacuation from the UPP is primariy by SOV, secondary by helicopter pick-up, and tertiary by escape chute.

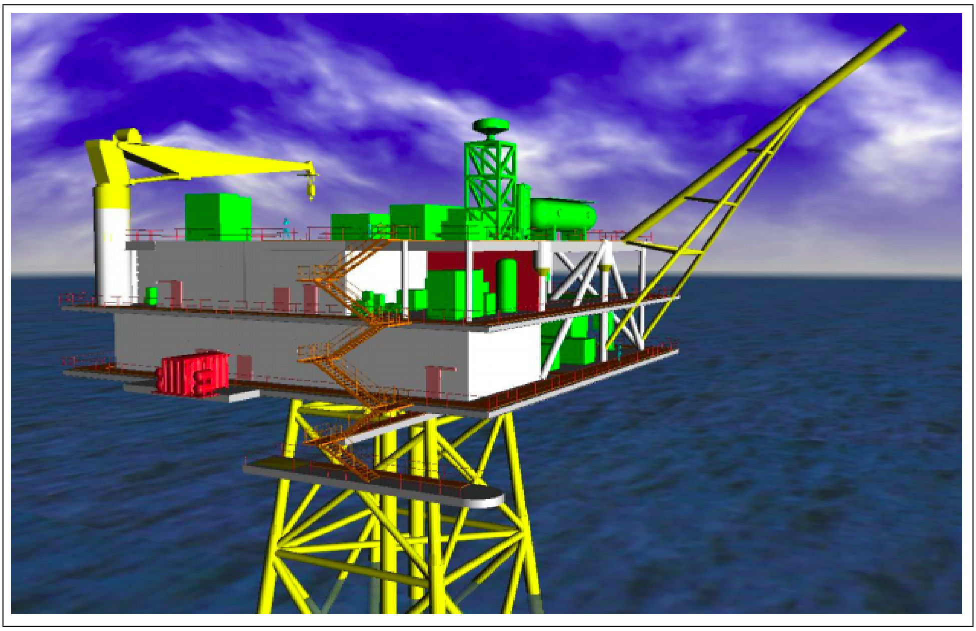

Figure 5.2: Overview of the UPP looking from South-West [3]

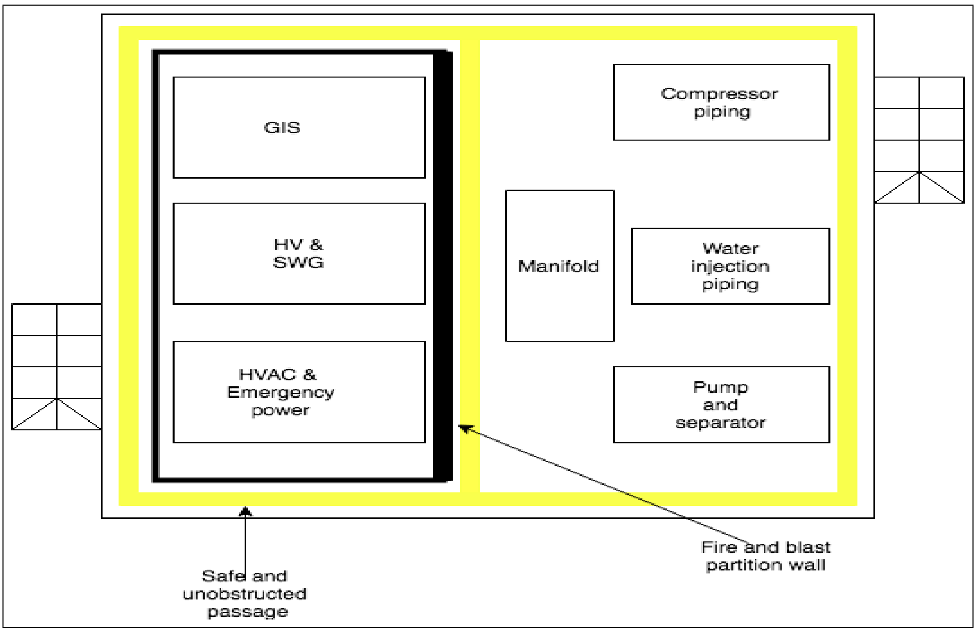

Figure 5.3: A schematic illustration of the lower decks layout and systems.

5.2.1 Safety and security systems

SSIV

The UPP is designed with SSIV at one of two gas-lift risers, the oil risers, and the gas export pipeline.

F&G

The UPP is planned to have sufficient fire, gas, heat, and smoke detectors. There is no firewater system provided.

Flare System

The UPP has a conventional flare system with a KO drum designed for 15 bar.

Drain

An open drain system is assumed in order to reduce the consequences of an oil leak. The drain is routed to the sea, and terminated below seaa level.

Fire and blast protection

There are no safe area at the installation. The wall between the process and utility are is reinforced to withstand explosions with 0.7 barg overpressure, as well as fire. The cellar deck is enforced to withstand the same explosions without harm to the W2W deck.

Evacuation

Primary mean of evacuation is the SOV, secondary is helicopter pick-up, tertiary by escape chute with life raft.

5.3 SOV

The SOV expected to be used in transport of personnel and equipment has a displacement of maximum 10 000 tonnes [2]. This thesis further assume the use of a SOV similar to the SOV used at Tambar.

The SOV will be purpose built accommodation vessel with a fully integrated W2W gangway. The marine crew will consist of 21, including 8 in catering crew. There will be single cabins for the installation crew of 20. "The vessel has a robust and relatively simple system comprising of two main shaft driven controllable pitch propellers with high lift rudders. Island Diligence has two forward and two aft tunnel thrusters and a drop down azimuth forward. The vessel will operate in the Bus-tie Open mode for DP2 operations" [1]. Material will be transferred from the SOV to the installation by crane. [1]

5.4 W2W

The Walk to Work (W2W) system is a transfer system of personnel. A gangway is extended from the SOV to the installation, and the crew can walk on to the installation. The gangway is operated with a joystick by an operator in the tower, and after connection a motion compensation system that monitors the ships movements. The gangway connects to the installation at a designated H-beam, where it maintains a constant pressure.

The intended use of the W2W is to connect with the installation when the crew is transferring, and disconnect when the crew has transferred. The SOV will stay at a distance of 20 m from the installation. When using a SOV for transport of personnel there is no longer a requirement for shelter as with helicopter transport. The SOV will be the installations safe zone, shelter and break room. It is intended that the crew only works at the installation, and returns to the SOV via W2W for breaks, eating, sleeping, etc. [2]

The limitations due to significant wave height, H_s, is set by the suppliers. The limitation depends on the gangway and the ship it is installed at. Some operators choose to restrict the H_s limitation even further. Kongsberg Maritime and Zbridge have set the operational limit to $H_s < 3.5m$ [16] [47]. The system is also limited by requirements of visibility to the installation, wind, height of connection point, etc.

Figure 5.4: Illustration of a W2W gangway [43]

5.5 SWAT

The SWAT-team concept is to use a smaller crew to perform short term operations. These crews will not be utilised for planned maintenance, but rather in unscheduled situations requiring manual intervention. The SWAT-team will be trained to perform the operation on shore or at another operation and will have a shorter planned time of operation than a normal crew. The pre-training, single focus, and short operation allows the acceptance criteria for FAR-values to be higher. It is assumed that the SWAT-crew will consist of a maximum of 10 persons. It is further assumed a distribution equal to normal manning at the installation after arrival.

5.6 Acceptance criteria

The Norwegian government represented by PSA requires that the operator and the party responsible for operating a mobile facility, shall set risk acceptance criteria (RAC) for major accident risk and for environmental risk associated with acute pollution. This is specified in the Management's Regulations §9 [34]. The study report had performed an interpretation of the operators RAC, and the proposed risk acceptance criteria in the study was a FAR less than 10 for all 1^{st} party personnel, and a FAR less than 20 for SWAT teams and well intervention teams. For the loss of main safety functions the criteria is f< $1.0E-4$ per year per load category.

Chapter 6

QRA of Case study

The QRA is performed with limitations. The assessment focuses mostly on the personnel risks to serve as a contributor to the ALARP-analysis. The QRA in this thesis builds on the information presented in the CRA from Aker Solutions. This QRA is focused on explosion, fire, and collision. In general has conservative values been chosen to result in a conservative QRA. In an early design phase there are unknown factors, as the design is not as detailed as with finished designs. This limits the extensiveness of the QRA further.

Based on the PLL values from each scenario the FAR value was computed. Aker Solutions had not computed PLL or FAR values, and there are therefor no computations for comparison for this thesis.

6.1 Assumptions

It is assumed a normal manning of 20 persons, and a SWAT manning of 10 persons. The distrubution is as follows:

Deck	Normal manning	SWAT manning
Weather deck	4	2
Intermediate deck, process area	4	2
Intermediate deck, utility area	4	2
Cellar deck, process area	4	2
Cellar deck, utility area	4	2

Table 6.1: Distribution of manning at different areas.

6.2 Fire

The QRA for fire concerns the events where equipment or hydrocarbons (HC) ignites and burns. The only equipment included in the QRA are pumps. Other ignition sources are neglected in this QRA. Fires started by or causing explosions are regarded in the explosion section of the QRA. The frequency of internal ignition of a pump is computed as

$$Frequency\ of\ Internal\ ignition = Short\ circuiting\ of\ switch \cdot internal\ leak \tag{6.1}$$

The short circuiting of switches and internal leak frequencies were gathered from a generic data set [6]. If the pump is close enough to other equipment is the probability of spreading set to 5%. If it is far away from other equipment is the probability of spreading 0%. Besides the pumps are the events of major and medium leaks of oil and gas analysed. Small oil and gas leaks are neglected, as the fire will be insignificant if there is only a fire, and in case of an explosion is the event computed in the explosion QRA. In the event where a leak is spreading due to explosion is the PLL value not included in the sum, as it is already computed in the explosion QRA. The fire QRA can be found in appendix 9.8. The highest PLL occurs due to internal ignition with a possibility of utility and process fire impairing the escape routes, and a possibility of process fire escalation. The PLL values ranges from $1.11 \cdot 10^{-3}$ to $8.73 \cdot 10^{-6}$ depending on the size and medium of the leak. Major oil leak is the contributor to the highest fire risk with a PLL of $1.11 \cdot 10^{-3}$.

6.3 Explosions

The QRA for explosions was based upon the Explosion overpressure at utility vs frequency for hydrocarbon events inside process area at UPP from the CRA [2][1]. The explosions where divided in small, medium, and large, and caused by oil or gas. The limit of small explosions were up to 0,2 barg, medium explosions were 0,2-0,6 barg, and large explosions were 0,6-1,2 barg. The highest PLL values are listed in Table 6.2. The exceedance frequency of the largest value is the representing frequency.

Immediate fatalities are fatalities cased by the explosion directly, by overpressure or fragments from the explosion. Everyone in the area at the deck where the explosion takes place are regarded as immediate fatalities. To reduce these fatalities must the explosion frequency be reduced.

Evacuation fatalities are the fatalities in the areas exposed to the explosion, e.g. at the deck above, below, or in the utility area. These are fatalities due to fragments from the explosion. Medium explosions are assumed to break the deck between cellar and intermediate deck. Large explosions are assumed to break the fire and blast wall and cause fatalities in the utility area as well. The evacuation fatalities are assumed to only reach one deck up and/or down, and the utility. It is assumed 0 evacuation fatalities

[1] p.41

after small explosions, 4 evacuation fatalities after medium explosions, and 4-12 evacuation fatalities after large explosions.

Escape fatalities are fatalities occurring due to the following fire, or destruction of possible escape means or the ability to reach the escape means, such as the W2W deck and escape chute.

Impairment of load bearing structure may occur in two cases. These two cases are medium and large explosion of liquids at cellar deck. If the oil overflows the flow boundary and spills into the sea there will be flammable liquids around the platform legs, and the SOV. Both cases have a possibility of igniting a fire after the explosion. This fire may spread to the oil at the sea surface and start a fire at sea. This fire will expose the SOV and depending on the wind make evacuation from the platform by SOV unfeasible. Evacuation by life raft will also be unfeasible in this scenario. A sufficiently large fire at sea can threaten the integrity of the main load bearing structure, and thereby impair a main safety function. It is assumed that oil spill to the sea will only occur for large liquid leaks at cellar and lower decks. The CRA have calculated a leak frequency based on the systems and equipment located per area defined in the layout drawings. A large leak is a leak above 10 kg/s and 80 mm. The annual process leak frequency for large liquid leaks at cellar and lower deck is 7E-03 [2][2]. A large explosion may cause damage to walls, to the degree that the main load bearing is impaired. The probability of impairments of main load bearing structure is set to 0.05-0.07 for medium and large explosions. The probability of impairment of main load bearing structure is assumed 0 for small explosions.

Placement	Type of leak	Size of leak	PLL value
Intermediate deck	Liquid	Large	$9,00 \cdot 10^{-6}$
Cellar deck	Liquid with posibility of fire at sea	Medium	$8,14 \cdot 10^{-6}$
Intermediate deck	Liquid	Medium	$7,87 \cdot 10^{-6}$
Cellar deck	Liquid	Medium	$7,87 \cdot 10^{-6}$
Intermediate deck	Liquid	Small	$7,03 \cdot 10^{-6}$
Cellar deck	Liquid	Small	$7,03 \cdot 10^{-6}$

Table 6.2: The explosion scenarios with the highest PLL values.

6.3.1 Assumptions

As there are no leak sources of significant size in the utility area, it can be assumed that there will be no explosions in the utility area. In the case that there is enough gas for an explosion in the utility area the amount of gas in other areas would mean a much greater probability of an explosion occurring there first, that explosions in the utility area can be neglected in the QRA.

The SOV will not be affected by the explosions, as the decks are all at a higher elevation than the SOV. The only exception is in case of a fire at sea.

[2] p.31-32

Large explosion at cellar deck, with a following fire will be critical for an evacuation when the SOV is positioned at the east side. The survivors at the installation will not be able to enter the SOV. They will still be able to use the escape chute at the west side and be picked up by the SOV when at sea. If there is a fire at sea, evacuation can only be performed by helicopter. It is further assumed pilots are not willing to fly to burning installations.

6.4 Collisions

The QRA of Collisons can be found in Appendix 9.9. The collision upon arrival is computed from equation 3.1.3. It is assumed that the SOV sails outside of the Safe Zone each night and the number of visiting vessels are therefore the number of days with maintenance. DNV-RP 107 recommends P_2=$2.7 \cdot 10^{-6}$[7][3]. The CRA has argued that P_1 and P_3 is assigned values of 0.1. "Normally, P_1 and P_3, are assigned low values in order to reflect modern navigation systems and procedures in order to warn/divert a vessel approaching on collision course. However, since experience indicate that estimated collision frequencies may be estimated on the non-conservative side, o.1 is applied as probability of being on collision course, while no reduction is applied to reflect probability of warn/divert a vessel on collision course. Instead, a speed reduction down to 3 m/s is judged for 70% of the collisions to reflect reduction of peed upon maintaining control over the vessel. "[2]

"For loss of position upon maneuvering into position and in in operating position the suggested frequencies derived from experience in the north sea is applied:
Probability of drift-off: $2{\cdot}10^{-5}$ *per hour*
Probability of drive-off: $1{\cdot}10^{-5}$ *per hour*
If conservatively applying one hour for vessel repositioning from safety zone to operating position next to the installation, a potential collision frequency of $3{\cdot}10^{-5}$ per visit results. " [2]

The annual collision frequency is computed as the sum of frequency of Collision upon arrival per year, probability of Drift-off per year, probability of Drive-off per year, and frequency of Collision when repositioning per year.

The Annual impairment of main safety function "main load bearing capacity" is $1.10{\cdot}10^{-5}$ per year. The installation is designed in accordance with NORSOK N-003. Head-on collisions at 3 m/s, sideways and stern collisions at 2 m/s corresponds to 50 MJ, 28 MJ and 22 MJ impact of collision energy. The Ship collision impact energy - Exceedance curve establishes a yearly frequency of $1.10{\cdot}10^{-5}$ for collisions with impact energy above 50 MJ. [2]

[3] p.28

Collision upon arrival $[/yr]$	Probability of drift-off $[/yr]$	Probability of drive-off $[/yr]$	Collision frequency when repositioning $[/yr]$	Annual collision frequency $[/yr]$
$1.51 \cdot 10^{-6}$	$1.23 \cdot 10^{-2}$	$6.16 \cdot 10^{-3}$	$1.68 \cdot 10^{-3}$	$2.02 \cdot 10^{-2}$

Table 6.3: Collision frequencies and probabilities.

The QRA of the Case Study is combined with the QRA basis for the CBA of SOV positions in the appendix. The west position is to be read as the QRA of the case study.

6.5 FAR values

The FAR values computed in the QRA are found by use of equation 3.3. It is the summarized PLL value from each main category that is used as the PLL value. The manning is 20 persons with normal manning, and 10 persons with the use of SWAT-teams. The yearly exposed hours are 616 hours. Collisions are not represented in the FAR value tables, as it is assumed no fatalities caused by collisions.

Case / Main category	SOV at West position	SOV at East position	SOV at 300m distance
Explosion	0,805	0,811	0,802
Fire	0,191	0,191	0,191
Collision	-	-	-

Table 6.4: FAR values with normal manning

Case / Main category	SOV at West position	SOV at East position	SOV at 300m distance
Explosion	0,729	0,838	0,729
Fire	0,191	0,191	0,191
Collision	-	-	-

Table 6.5: FAR values with SWAT manning

Chapter 7

ALARP-analysis of Case Study

7.1 Risk Reducing Measures

Based on the QRA, it is clear that all FAR values are well within in the accepted area. The ALARP-analysis will focus on the scenarios with the largest risks, and the design-deviations from standard practice.

To reduce the explosion risk it is natural to start with the leak frequency of liquid leaks at intermediate and cellar deck. Large explosions at intermediate deck cause the greatest potential loss of life, and an enhancement of the protective walls, floor, or ceiling may reduce the risk. Installation of SSIV valves at the mulitphase pipe can reduce the risk of liquid leaks.

Leaks from risers and defaults in equipment may cause fires at the installation. This will cause extensive material damage, loss of life, and possible spills and pollution. A deluge system will reduce the duration of the fires, and thus reduce the damage. A fire retardant lifeboat can reduce the potential fatalities during evacuation, especially in the event of a fire at sea.

A thorough shutdown of the installation before personnel enters and start working will reduce the frequency of fire and explosions during maintenance. Events caused by human errors will be reduced, as well as the probability of unwanted events occurring during manning of the installation.

The annual collision frequency is high. It is not compensated for the difference in collision impact. The annual impairment frequency for collisions over 50 MJ is $1.15 \cdot 10^{-5}$ [2]. The critical collisions may be reasonable low and lives are not at high risk, but a change of SOV position might reduce the collision frequency. A lower collision frequency will reduce the material damages, and possibly reduce fatalities. Other RRMs to reduce the collision risk is to improve the operational procedures and improve the reliability of the SOV, but this is outside the scope of this thesis.

7.1.1 Additional escape chute

To escape the installation there are three possibilities in the design. The primary escape is by SOV, secondary is by helicopter pick-up, and tertiary is via escape chute with rafts. In the event of a explosion with a following fire may the escape be faster with an extra escape chute.

This escape chute will only be favourable in the days with wind from the North to East sector. This is statistically happening 34 days a year. The probability of an event with fire which unables other other evacuation means occurring at a day with favourable wind for an escape chute at the east side is very small. It is most likely that explosions will take place in the process area, which increase the possibility of destroying the escape chute. In events where both the escape chute at east and west side will be possible to use, there will not be an alternative to use both as the mustering area will be at the west side.

The Additional escape chute will not be further assessed as there events where an additional escape chute will be beneficial are so few that it will be grossly disproportional to install it.

7.1.2 Fire retardant lifeboat

In the events of explosion with fire at sea it is assumed 20 fatalities, which includes all the personnel at the installation. It is assumed that neither the SOV or a helicopter are willing to approach a burning installation while there is a fire at sea. It is also assumed that the life raft will be useless as it is not fire resistant. Fatalities can be reduced by replacing the escape chute and life raft with a fire retardant lifeboat.

7.1.3 Additional SSIV

A Sub Sea Isolation Valve (SSIV) can reduce the leak duration of the pipe where it is installed. This will in turn reduce the risk of explosion and fire. A SSIV can reduce the risk to personnel, environment and assets. Most of the risers are equipped with SSIV, but the multiphase and one gas-lift are not. Including a SSIV on either of them will reduce the leak duration.

7.1.4 Cold installation during maintenance

Shut down of the installation during maintenance will reduce the probability of explosions and fires. If there is no oil or gas being processed or pumped into the installation the probability of leaks to ignite are significantly reduced. The risk reduction of production stop and production stop with emptying of the risers will be analysed. A shutdown of the installation will result in a delay in income from production. As the risers must be emptied as well the delay in production will be further increased. It is assumed it will take 24 hours to shut down and empty the installation, and 24 hours to return to full production. This results in 80 days per year without production.

7.1.5 Change of SOV position

The SOV is designed to stay at 20 m distance upwind of the installation, primarily at west side of the installation. The RRM proposed is to have the SOV is at standby at 300 m from the installation and only approaches it further to connect with the installation for transfer of crew. This will reduce the risk of drive-off, drift-off and the SOV can chose the best position for pick-up and drop-off before every landing. The second RRM is to position the SOV at the east side.

7.1.6 Deluge system

The UPP is designed without any firewater. A deluge system reduces the heat load of a fire, and thus reducing the evacuation fatalities as well as the material damages. A deluge system sprays water from all nozzles after the fore is detected and the deluge valve is opened. The deluge valve can be remotely closed after the fire is extinguished. The Deluge system require a pressurisation and a sprinkler pump, nozzles, fire detection control panels, compressed air supply, feed and intermediate tanks, and piping connecting the system. [23]

7.2 Fire retardant lifeboat

A fire retardant lifeboat instead of a life raft will provide the equal opportunities for evacuation as the escape chute with life raft, but can also provide a safe escape during fire at sea. The fire retardant lifeboat is a lifeboat with a fire retardant shell.

PSA requires that lifeboats at NCS are can free fall in The facilities regulation §44 [25]. The price of a freefall lifeboat is 13.3 million NOK [19]. The escape chute and life raft costs seven million NOK [10]. The additional cost of the fire resistance shell is set to 10 million NOK.

The yearly preventive maintenance requirements of an escape chute are 45 hour. This is distributed with 33 hours every year and 30 hours of winch and wire change every fourth year. For a lifeboat is the yearly maintenance requirement 107 hours every year, and the davit requires an additional 5 hours. Both the escape chute and the lifeboat have monthly inspections at manned installations. [10] The requirements are yearly certification and testing. With a leasing agreement with the provider will the maintenance requirements not increase and can be adjusted to the maintenance campaigns. [13] It is assumed a cost of 2000 NOK per hour of maintenance. This includes man hours, equipment and spare parts. The true cost is most likely higher. The cost of transport is not included, as this is assumed equal for both cases. In addition to the included preventive maintenance is the corrective maintenance. This is excluded from the analysis.

The change from Escape chute with life raft to a fire retardant lifeboat will only affect the risk to personnel, as the measure is a defence barrier concerning human lives only.

7.2.1 Cost Benefit Analysis

Alternative	FAR	PLL $[/yr]$	ΔPLL $[/yr]$
Escape chute and life raft	0.805	$9.92 \cdot 10^{-7}$	
Fire retardant lifeboat	0.802	$9.88 \cdot 10^{-7}$	$4 \cdot 10^{-7}$

Table 7.1: Overview of key risk parameters for the fire retardant lifeboat alternative

Alternative	Investment cost $[millNOK]$	Annual operating cost $[millNOK]$
Escape chute and life raft	7	0.09
Fire retardant lifeboat	23	0.21

Table 7.2: Overview of expected key risk and cost parameters for the fire retardant lifeboat alternative

Alternative	LCC (20 yrs) $[millNOK]$	ΔPLL $[/yr]$	ICAF $\frac{E(Cost)}{E(savedlives)}$ $[millNOK]$
Escape chute and life raft	-7.5	-	N/A
Fire retardant lifeboat	-21.7	$4 \cdot 10^{-7}$	$3.16 \cdot 10^{6}$

Table 7.3: Overview of key risk and cost parameters for the fire retardant lifeboat alternative

The reduction in PLL when installing a fire retardant lifeboat instead of an escape chute is very small. This results in a high ICAF for the RRM. In this case is the cost of a statistical saved life more than 3 billion NOK. The CER recommend implementation of a RRM if the ICAF is less than 25 million NOK, or the LCC is positive. In this case is neither of CER's quantitative recommendations fulfilled. The LCC cost increase from an escape chute to a fire retardant lifeboat is 16.3 million NOK. Both measures, the escape chute and the lifeboat, costs quite a lot. However is it not an option to have neither. The cost of changing to a fire retardant lifeboat can be concluded to be economically disproportionate with the benefit.

Viking Equipment state the procurement cost of an escape chute with life raft for 20 persons at 100 kg is 1.35 mill NOK. The escape chute has a 30 month service interval, and an annual check. [20] The Viking solution will decrease the RC with 50% and decrease the IC, which will make the transition to fire retardant lifeboat even less economically beneficial.

7.2.2 Qualitative Analysis

NORSOK S-001 chapter 22.4.2 and the Facility regulation §44 requires permanent installations in NCS to have both a lifeboat and an escape chute with a life raft. There shall be lifeboats for 100% of POB and one additional lifeboat to compensate for unavailability, and life raft with minimum capacity of the largest lifeboat [39]. As the maximum assumed POB are 20 persons, there will be needed two lifeboat and one life raft to fulfill the standards requirement. Fulfilling standards is an argument in favor of installing a RRM. However do the standard state that for a Normally not manned installation simpler evacuation means may be acceptable and shall be evaluated and described in the safety strategy. This is in accordance with §6 in the Facilities regulations, stating that 'simpler solutions can be chosen for simpler facilities than those prescribed, provided these solutions can be proven satisfactory through special assessments' [24].

To deviate from normal safety equipment will increase the perceived risk. The workers union are not guaranteed to agree with the reduction of safety equipment.

A fire retardant lifeboat decrease the personnel risk, but only in the event of a oil leak with fire at sea and at the installation. The lifeboat will not influence the risk to the environment or the assets. The risk decrease by use of fire retardant lifeboat is very small.

The fire retardant lifeboat require more than the double amount of maintenance as the escape chute [10]. This is not complying with the main objective of the design, which is to keep the OPEX and maintenance as low as possible. Installation of a fire retardant lifeboat does not solve the fire and explosion problem, and is a very expensive defensive barrier[4][1]. To replace the escape chute with a fire retardant lifeboat with the only arguments being a very small risk reduction is not recommended.

7.3 Additional SSIV

Installing a SSIV at a pipe will reduce the leak duration. A SSIV will limit the inventory that can be released from a riser leak, to the inventory between the topside riser Emergency Shut Down Valve (ESDV) to the SSIV. The two pipes without a SSIV are the multiphase pipe and one gas lift pipe. It is assumed the gas-lift pipe does not have a check valve. A SSIV has a procurement cost of 60 million NOK, and the installation cost will be in addition. There is normally not performed any maintenance at a SSIV. Testing

[1] p.185

of the functionality of the SSIV will be performed at certain intervals. This cost is not included in this analysis.

A highly conservative approach is chosen when assessing the benefit of a SSIV. It is assumed a decrease in leak duration and explosion frequency of 90% by installation of a SSIV. The leak frequency impacts the difference in environmental risk, and the explosion frequency impacts the difference in personnel and material risk. If the analysis implies implementation with these assumptions the sensitivity of the analysis can be increased. To differentiate between the gas-lift and the mulitphase is the multiphase assumed to be oil.

The SSIV will only affect the explosion part of the QRA, as there is assumed no fire in the risers without explosion. As the SSIV will reduce the leak frequency it will have impact on risk of personnel, environment, and materials. When assessing the change of risk to personnel is the explosion frequency adjusted to manned hours used. For the change in risk to the environment is the change in leak frequencies used. For the change in risk to the materials is the explosion frequency for the entire year used.

7.3.1 Cost Benefit Analysis

Alternative	FAR	PLL $[/yr]$	Δ PLL $[/yr]$	Δ Leak frequency
Base case	0.805	$9.92 \cdot 10^{-5}$		
Gas-lift SSIV	0.339	$5.74 \cdot 10^{-5}$	$4.18 \cdot 10^{-5}$	0.228
Multiphase SSIV	0.446	$4.42 \cdot 10^{-5}$	$5.05 \cdot 10^{-5}$	0.219

Table 7.4: Overview of key risk parameters for the SSIV alternatives

Alternative	Investment cost $[millNOK]$	Annual operating cost $[millNOK]$
Base case	0	0
Gas-lift SSIV	60	N/A
Multiphase SSIV	60	N/A

Table 7.5: Overview of expected key risk and cost parameters for the SSIV alternatives, change in risk for personnel and environment is presented.

Alternative	LCC (20 yrs) $[millNOK]$	ΔPLL $[/yr]$	ICAF $\frac{E(Cost)}{E(savedlives)}$ $[millNOK]$
Base case	-		
Gas-lift SSIV	-3.74	$4.18 \cdot 10^{-5}$	$3.58 \cdot 10^{4}$
Multiphase SSIV	4.06	$5.05 \cdot 10^{-5}$	$5.15 \cdot 10^{4}$

Table 7.6: Overview of key risk and cost parameters for the SSIV alternatives

The reduction in PLL value is very low so the ICAF is very high. The ICAF become far above 25 millions, and there is no basis for implementation of SSIVs to save lives. The Multiphase SSIV is analysed to have a large enough benefit for the environment and installation assets to gain a positive LCC. With the positive LCC it is economically beneficial to implement the SSIV.

The CBA is performed with a very low sensitivity. A 90% reduction in leak duration and explosion frequency and the assumption of complete destruction of the installation if an event occur are both contributing to an over-estimated benefit of the SSIV. Installation cost and the cost of function control are not included in the CBA. These costs will decrease the LCC.

A more sensitive CBA should be performed before implementation purely based on the CBA.

7.3.2 Qualitative Analysis

The SSIV is only effective until failure. Repair of SSIVs are not performed. The SSIVs failure mode is to fail to launch, which leaves it in open position. It is no cost related to the failure of a SSIV. The effect of the SSIV is not guaranteed to last in the lifetime of the installation.

The SSIV valve have a insignificant impact on the PLL. It is not prominent equipment for risk reduction, and the perceived risk of leaks in the riser are relatively low.

It is not required by rules or regulations to have SSIV at pipes or risers. Several installations has chosen not to install any SSIVs, such as Balder [35] and Luno II [17]. At present, there is not an established good practice of using SSIVs at NCS for normally unmanned installations.

The SSIV can reduce the spill during incidents, and environmental organisations such as *Natur og Ungdom* want every measure to reduce the risk of environmental damage implemented [9]. The SSIV can reduce both the environmental damage and reduce the asset damage.

7.4 Cold installation during maintenance

7.4.1 Cost Benefit Analysis

It is assumed a risk reduction of risk to personnel and assets, but no risk reduction to the environment when shutting down the installation. It is assumed a 100% risk reduction to explosion risk when the riser and installation is shut down and emptied before maintenance. Due to emptying of the risers, it is assumed a decrease in fire with 90%. A installation where the production is only shut down, without emptying of the pipes, is it assumed no difference in the explosion risk and a 90% fire risk reduction. The annual loss of income is computed with a oil barrel price of 35$, as it is the lowest price the installation need to be profitable for.

Alternative	PLL $[/yr]$	Δ PLL $[/yr]$
Base case	$2.13{\cdot}10^{-3}$	
Production shutdown and empty pipes	$2.03{\cdot}10^{-4}$	$1.93{\cdot}10^{-3}$
Production shutdown	$3.03{\cdot}10^{-4}$	$1.83{\cdot}10^{-3}$

Table 7.7: Overview of key risk parameters for the maintenance status alternatives

Alternative	Investment cost $[millNOK]$	Annual loss of income $[millNOK]$
Base case	0	0
Production shutdown and empty pipes	0	1 730
Production shutdown	0	1 210

Table 7.8: Overview of expected key risk and cost parameters for the maintenance status alternatives.

Alternative	LCC (20 yrs) $[millNOK]$	ΔPLL $[/yr]$	ICAF $\frac{E(Cost)}{E(savedlives)}$ $[millNOK]$
Base case	-		
Production shutdown and empty pipes	$-1.82 \cdot 10^{-4}$	$1.93 \cdot 10^{-3}$	$4.72 \cdot 10^{5}$
Production shutdown	$-1.27 \cdot 10^{-4}$	$1.83 \cdot 10^{-3}$	$3.47 \cdot 10^{5}$

Table 7.9: Overview of key risk and cost parameters for the maintenance status alternatives

The base case with full production at all time is unrealistic. There will be need for maintenance where at least part of the production need to be shut down. There is nearly 2‰ reduction in PLL when the production is shut down and the pipes are emptied. The PLL is 0.1‰ higher when the pipes are still full during production shutdown. The risk reduction is small comparing production shutdown with production shutdown and emptying of the pipes. However, the loss of income is more than 500 million NOK higher when the pipes are emptied.

The CBA is performed with the minimum price of oil barrels for a installation to be profitable. A realistic oil barrel price is higher, and at the time this thesis is written is the price of an oil barrel at 50$ and rising. A higher price per barrel results in a higher loss of income, but also a higher ability to handle the loss of income.

The CBA does not give reason to implement more than minimum reduction of production during maintenance, as it will result in a economical loss and risk reduction is too small compared to the loss.

7.4.2 Qualitative Analysis

All maintenance will be well planned ahead of personnel entering the installation. The work flow and work permits will be well planned and extensive. The necessary precautions will still be well planned and the risk of continued production will be evaluated before every entrance of personnel. At manned installations the production is continuous with personnel on board, and the HSE regulations can be complied with production during maintenance.

The consequences of a human error during maintenance is much lower for the personnel with a full shutdown and emptying. The consequences for the environment and assets caused by human error are not necessarily reduced to an equal degree. The errors will be discovered at a later time, but will still have a consequence.

Assumed the same safety and security procedures are followed as during maintenance at manned installations there will be no need to implement a full production shutdown before every maintenance.

7.5 Change of SOV position

The SOV can stay at three different positions during manning at the UPP. The planned main location of the SOV is the west side of the platform. In conditions where the west side is unfavorable the east side can be used. An alternative SOV position is at a safe distance of 300 m.

West position

The west position is the base case in this comparison. This is the position the design has preferred. The west position is upwind or in sidewind most of the year. Only 7% of the year is the west position in downwind. The installation is designed to improve the safety when the SOV is at this position. Safety and security is increased at this position because the utility area is between the W2W and the process area, it is safe to evacuate to the W2W from all decks even after an explosion in the process area, gas and flames will blow away from the SOV 20% of the year, and the risk of a drive-off causing collision is minimal. Since the SOV often is at upwind will the frequency of drift-off increase.

East position

The east position of the SOV is at the downwind side of the installation 20% of the year. The downwind position reduces the frequency of collision due to drift-off and make maneuvering easier in situations with high wind speed, but allowable H_S. In case of a fire in the risers or process area is this position not favorable, as the prevailing wind direction will place this landing point where the flames are blowing. If the wind blows from another direction will the landing point still be close to the fire in the process area or demand the crew to cross the process area to escape. In case of explosion will the escape route to the east W2W position be partly or fully impaired and the SOV be damaged due to the proximity of the explosion. This is unfavourable.

300 m distance

To limit the possibility of drift-off or drive-off can the SOV stay at a safe distance at - 300m. By positioning the SOV at this distance can the weather make drift-off unlikely, and the crew will have time to react in case of drive-off. The only close installation is the Frigg Gamma Delta (FGD) wellhead, which is ~ 200 m away. The SOV can assess the conditions of the UPP and the weather before every landing with the W2W-bridge. The connection time will be longer as the conditions and weather must be assessed, and it is a longer drive from waiting position to the UPP. The SOV will not be a source of ignition in case of gas leaks. The SOV will have an increase in the number of approaches to the installation, which will increase the collision frequency, and the evacuation time of the installation will increase as the SOV must react to an event and will have increased time to connect to the installation.

Assumptions To compare the collision frequencies between the west position and 300 m distance position is it assumed the SOV arrives at the installation 4 times a day, to drop off crew in the morning, pick up and drop off crew for lunch and to pick up the crew in the evening. This results in a four times higher frequency of collision upon arrival for the SOV position of 300m distance. This is a minimum increase in the approaches to the installation, as the SOV is serving the crew with all facilities, such as WC and break room. To comply with the assumption that crew on the installation is actively working and for all other purposed is at the SOV, the SOV need to connect with the installation much more often then four times a day. It is further assumed that each arrival and connection last one hour.

The hourly probability of drift-off and drive-off is assumed equal for upwind and downwind positions.

7.5.1 Cost Benefit Analysis

Alternative	Annual impairment frequency (main load bearing capacity)	FAR	PLL $[/yr]$	Δ PLL $[/yr]$
West Position	$1.10 \cdot 10^{-5}$	0.805	$9.92 \cdot 10^{-5}$	
East Position	$1.10 \cdot 10^{-5}$	0.811	$9.99 \cdot 10^{-5}$	$-7.63 \cdot 10^{-7}$
300 m distance	$1.10 \cdot 10^{-5}$	0.802	$9.88 \cdot 10^{-5}$	$4.07 \cdot 10^{-7}$

Table 7.10: Overview of key risk parameters for the position alternatives

The annual impairment frequency of the "main load bearing capacity" is equal for all positions as the ship is the same and the installation is design to withhold head on collisions of 50 MJ after recommendations from NORSOK N-003. [2]

Alternative	Investment cost $[millNOK]$	Annual operating cost $[millNOK]$
West Position	0	0
East Position	0	0
300 m distance	0	0

Table 7.11: Overview of expected key risk and cost parameters for the position alternatives.

There are no cost difference in the different positions, as the decision is mainly operational.

Alternative	LCC (20 yrs) $[millNOK]$	ΔPLL $[/yr]$	Δ Collision freq. $[/yr]$	ICAF $\frac{E(Cost)}{E(savedlives)}$ $[millNOK]$
West Position	-			
East Position	-0.0024	$-7.63 \cdot 10^{-7}$	0	0
300 m distance	0.0012	$4.07 \cdot 10^{-7}$	0.011755	0

Table 7.12: Overview of key risk and cost parameters for the position alternatives

As there are no cost of changing the design the ICAF is zero for all positions.

It is clear that the position should not be changed to the east position, as it will decrease the safety and security of the personnel. This is caused by the design of the utility and process area. Collision frequency is equal for east and west There is a small positive effect of having the SOV lay standby at 300m. This is mainly caused by the opportunity to evacuate the personnel by choosing the most favourable position with every event. The increased time of evacuation is not accounted for in this thesis. It is also noted a greater collision risk due to increased arrivals from a distance.

7.5.2 Qualitative Analysis

The most used position to connect the SOV to the installation is downwind. This practice create less critical situations in case of DP failure and drift-off. To use a upwind position must the captain of the SOV agree.

At Oseberg H is the SOV and W2W gangway continuously connected as long as there are personnel at the installation [37]. This is a more secure way of ensuring to ability of evacuation, compared with a SOV at 300 m.

PSA is developing regulations for use of SOV and W2W. When Aker BP wanted to use W2W at Tambar requested PSA the company to obtain consent before using the W2W vessel for accommodation [36].

7.6 Deluge system

The deluge system is assumed to cover utility and process area at intermediate and cellar deck. The deluge system will set off automatically in the event of a pressure drop in the fire main and fire and gas detection. This is conservatively assumed to cause a 90% reduction in fire events, a 100% reduction in escape fatalities due to explosions, and 90% reduction in explosion frequency.

It is assumed each sprinkler has an effective reach of 2 m in diameter. This corresponds to 42 sprinklers evenly distributed in the utility area and 91 sprinklers in the process area. With 133 sprinklers at each deck will there be a total of 266 sprinklers at the installation. In addition is it assumed 700 m piping and one salt water pump and one air compressor. Each valve is assumed one trim package, which include valves, piping, drain, emergency release, etc. [44]. The cost of the deluge valves and piping is 7.3 million NOK, and the cost of two fire water pumps, Framo A60 with 500m^3/h is 22 million NOK each[14]. The procurement cost of the Deluge system is 51.3 million NOK. The maintenance is assumed equal to the escape system, at 107 hours per year.

7.6.1 Cost Benefit Analysis

Alternative	PLL $[/yr]$	ΔPLL $[/yr]$
Base case	$2.13{\cdot}10^{-3}$	
Deluge System	$2.09{\cdot}10^{-4}$	$1.92{\cdot}10^{-3}$

Table 7.13: Overview of key risk parameters for the Deluge alternative

Alternative	Investment cost $[millNOK]$	Annual operating cost $[millNOK]$
Base case	-	-
Deluge system	51.3	0.21

Table 7.14: Overview of expected key risk and cost parameters for the Deluge alternative

Alternative	LCC (20 yrs) $[millNOK]$	ΔPLL $[/yr]$	ICAF $\frac{E(Cost)}{E(savedlives)}$ $[millNOK]$
Base case	-	-	N/A
Deluge System	5.87	$1.92 \cdot 10^{-3}$	$-3.66 \cdot 10^{3}$

Table 7.15: Overview of key risk and cost parameters for the Deluge alternative

The ICAF is negative due to the large economical gain from avoiding destruction of the installation. This is due to the assumption the Deluge systems ability to extinguish fires. When the economical gain from reducing damage to the installation is neglected the ICAF is 1.39 billion NOK. The LCC positive with 81.2 million NOK over 20 years.

This indicates that a Deluge system should be implemented to reduce the cost of asset damage in case of fire or explosion.

The CBA does not include the cost and damage the Deluge system causes when it is set off. It is possible that the deluge system sets off due to false gas alarms, or leaks or fires that would not be critical. This will cause more damage than gain, but are not included.

The CBA should be performed with a higher sensitivity and more detailed operation cost.

7.6.2 Qualitative Analysis

Per June 2019 there are no unmanned production platforms in operation at NCS. It is not established a Good Practice regarding building and operation of unmanned process platforms. Manned platforms has firewater systems.

The facilities regulation §36 require Firewater supply at all installations with accommodation. This is not required at unmanned installations. To design the UPP is not a break of Good Practice, Codes or Standards, as this do not currently exists.

Firewater reduces the damage caused by fire. With firewater installed will communication and critical control systems have a higher operability. this will increase the control of the installation after a fire or explosion event. Extensive knowledge of the current state of the installation after an event will increase the safety when reentering the installation to repair. A longer operability of the control systems will decrease the environmental damage and secure the installation before reentering.

7.7 Recommendation of implementation

7.7.1 Recommended systems

This thesis recommend implementation of a SSIV at the multiphase riser, to change the SOV position to standby at 300 m distance, and to perform maintenance at a cold installation with empty pipes.

The Deluge System, the SSIV at the multiphase riser, and the SOV at 300m all had positive LCC in the cost benefit analysis. A positive LCC implicates a positive result of the implementation in the lifespan of 20 years.

Shutdown of the installation during maintenance, Cold Installation, had the largest risk reduction of the RRMs. The cost of production shutdown is so high due to the loss of income, so the CBA does not indicate implementation.

Implementation of the SSIV will reduce the risk reduction of the Deluge System, and it is not given that both systems will have a positive LCC is both are implemented. The Deluge system has a much higher maintenance need and cost than the SSIV. A governing principle in the design is to reduce the maintenance as far as possible. The Deluge system is not complying with this. Both RRMs should be analysed with a higher sensitivity of effect and pricing. Based on the analysis performed is implementation of a

SSIV is rather recommended, even with the large difference in the LCC. This is to comply with the low maintenance principle. The personnel risk is only slightly reduced in both cases and the environmental risk is reduced with the SSIV.

With compliance from the SOV crew and the work crew is the SOV position at 300 m distance a recommended risk reduction measure. The frequency of collision upon arrival is likely to be larger, due to an increase in arrivals. All other collision frequencies are being reduced with the SOV at a distance. The most critical aspect of the SOV at 300 m distance is the increased evacuation time. However will the SOV be able to position itself at best as possible and thus be able to stay connected longer after an incident ha occurred.

Shutdown and emptying of the pipes before maintenance, a cold installation, is recommended. A full shut down before every maintenance will result in a delay in income of at least 1.7 billion NOK every year. This is less than 30% of the income generated of the installation every year even with production shutdown. A cold installation will reduce the consequences of human error. Given the implementation of SSIV and SOV at 300 m, and the lack of firewater and fire retardantlifeboat at the installation is the cold installation a measure that will decrease the need for rapid, fire retardantevacuation.

7.7.2 Cost of implementation

The investment cost of the recommended RRMs are at least 60 million NOK. In addition are the costs of planning, installing, and adjustment made to improve the design with the new measures. The yearly operation and maintenance cost are mainly consisting of the loss of income due to shutdown and inspection of the SSIV valve. The delay of income due to shutdown is minimum 1.7 billion NOK.

7.7.3 Risk reduction after implementation

The implementation of SSIV at the multiphase riser, SOV at standby at 300 m and a full shutdown of the installation before maintenance reduces the risk for personnel, environment and assets. The environment risk is reduced with 20%, and the PLL and asset risk is reduced with $1.98 \cdot 10^{-3}$.

Chapter 8

Discussion

8.1 QRA

The QRA is based on a concept design and the Concept Risk Analysis (CRA) performed by Aker Solutions. The level of detail in the design result in an uncertainty of the risk in the QRA.

8.1.1 Extensiveness

The QRA is limited to explosions, fire, and collision. Marine hazards and other hazards such as falling objects are not analyzed. The QRA is focusing on the risks determined by design and do not concern the operational procedures. The exception is the preferred position of the SOV, which is determined by both design and operational procedures. In opposition to the formal and extensive approach of assessing all the main safety functions with the QRA is this QRA very limited. This has possibly limited the Risk Identification process. The RRMs analyzed are quantitatively analyzed with regard to fire, explosion and collision. A more extensive QRA would provide a more extensive quantitative assessment.

The explosion QRA cover the sizes and types of explosions and the explosion frequency is based on the exceedance frequency computed by Aker Solutions. It is limited by the assumption of an equal distribution of the crew around the installation, which does not account for larger groups of personnel in extensive maintenance tasks.

The collision QRA is performed as in Aker Solutions CRA. It is assumed no lives are lost due to collision.

The fire QRA is analysing the events where medium and major leaks cause fires, but not an explosion. Small leaks are not included in the QRA for fires. Small leaks should have been included for a better QRA, as these leaks are more likely to be able to cause fires without explosions.

The pumps are the only equipment assumed to self-ignite.

If the fire QRA had been performed more extensively and with a higher sensitivity, the CBA based upon the QRA would be improved. However, the explosion QRA has a much higher impact of the potential loss of life. The consequence for the risk to personnel is not severely affected by the limited fire QRA.

8.1.2 Impact of assumptions

This thesis has assumed a 20-year lifespan for the installation. The installation is designed for a 30-year lifespan. This will increase the ICAF for the RRMs, as the installation cost is distributed over fewer years.

The running cost (RC) is generally assumed low. In the analysis of some RRMs is the RC neglected, as it is very low or non-existent. The SSIV is an example where the RC is neglected. The assumption of 2000 NOK per hour is too low, as it includes the equipment for repair and in the case of deluge systems also includes transport to the installation.

Throughout the thesis, assumptions are there made. All of these assumptions are having an impact at the results and sensitivity of the analysis. The assumptions are consistently made to increase the benefit of the RRMs. This is done to rather overestimate the benefit of a measure, than underestimate the risk. When the analysis concludes with an unfavorable RRM will the conclusion stay as unfavorable even with a higher sensitivity. The beneficial RRMS should be reevaluated with a higher sensitivity to cost and effect. The qualitative analysis will not be affected by the sensitivity of the CBA.

8.1.3 Conservatism

The QRA is conservative in regard to fatalities. Personnel in an area exposed to explosions or fires are never expected to survive. It is never assumed any survivors due to human intervention, skill, or luck.

In estimation of the probability of an event, the conservative approach is used. The probability of a fire at sea after a large or medium oil leak with explosion is assumed to be 50%. This is a conservative estimation, as there are many factors and barrier failures that must be aligned to have a fire at sea. The conservatism of high probabilities of events will provide a safety to not underestimate risks.

8.2 ALARP

8.2.1 Limitations

The analysis has not focused on loss of main safety functions, and this is a weakness. The reduction of PLL and environmental risk has been governing in the analysis.

A consequence of not focusing at the main safety functions is the lack of comparing

RRMs solving the same problem. This results in a lack of alternatives, and a limited analysis. For example is only the risk reduction of a deluge system analyzed, but not compared to other firewater solutions. This provides a narrower basis for the decision of implementations.

The risk increase due to installation or maintenance is not evaluated. The risk increase during temporary work is significantly less than the risk decrease of implementation of a RRM over 20 years; however will the risk reduction be overestimated.

The cost of installation and planning before installation is not included in the analysis. There is an example from the industry where the total cost of installing lifeboats where more than three times higher than the procurement cost [19]. As this thesis analyses a concept in the design phase the cost of planning and the cost and risk of installation will be necessary costs and risks included in the cost of designing and building the installation, and should not affect the ALARP-analysis.

8.2.2 Conservatism

The analysis is performed with conservative values and assumptions. When the RRM is assumed to reduce a frequency, they are assumed to reduce the fire, explosion, and leak frequency with 90%. With empty pipes are the explosion frequency assumed to be reduced with 100%. A fire reduction of 90% is in this analysis regarding both reduction of frequency of fires and the consequence of the fire.

The fatalities are also conservatively estimated. This result in a conservative risk picture, and risk aversion governing the analysis.

The willingness to avoid statistical fatalities and environmental damage are estimated very conservatively. This is due to an increased skepticism of the oil and gas industry, and to avoid underestimating the value of a life, the environment, and the consequences of the loss of reputation in these events. The evaluation of assets are conservatively estimated to the price of a new installation.

The drift-off / drive-off frequencies are only valid for an upwind position, but has been applied for all positions in the analysis. The analysis should be performed with a higher sensitivity. However, the drive-off / drift-off frequencies are not crucial in the outcome of the collision analysis.

8.2.3 Recommendations

The recommendations of implementing a SSIV, change of SOV position, and maintenance at a cold installation are based on both quantitative and qualitative analysis. The recommendations are made based on the analysis performed. The sensitivity of these analyses are low, and should be improved. For the RRMs not recommend it is not necessary to perform more sensitive analysis, as they are not quantitative or qualitative beneficial.

Similar solutions for the risk reductions can be analyzed, such as a less extensive fire water system. This will provide better recommendation of the implementation of risk reducing measures.

8.2.4 Results

The PLL and FAR value of the installation was low before the analysis took place. This has resulted in a high ICAF value for all RRMs. The economically beneficial measures are mainly due to reduction in environment and asset risk.

The conservatism of the analysis and of the assumptions made in the analysis provides a certainty of the gross disproportion of the discarded measures. This only applies for the measures discarded based on the CBA. An inexperienced person performs the qualitative analysis, and more experienced persons can draw other conclusions. The measures where a beneficial CBA was concluded are uncertain and analyses that are more sensitive may not result in beneficial CBAs. The assumptions regarding the reduction in asset risk are so conservative that for the measures where the asset risk is governing the CBA may result in grossly disproportionate results with a higher sensitivity.

Chapter 9

Conclusion and further work

9.1 Conclusion

The analysis shows a small potential for reduction of risk to personnel, and a greater potential for risk reduction to assets and environment.

The recommended implementation of a SSIV at the multiphase riser and change of SOV position to 300 m distance will be beneficial while reducing risk for personnel, environment, and assets. Shutting down the production and emptying the risers for a cold installation before maintenance is recommended based on the qualitative analysis to reduce the risk for personnel and assets.

The other risk reducing measures analysed in this thesis, an additional Selantic, a deluge system, and a SSIV at the Gas-Lift, are not recommended implemented due to having a grossly disproportionate cost-benefit relation.

The analysis is conservative and performed with a low sensitivity. The rejected risk reducing measures are certainly grossly disproportionate. The recommended measures need to be analysed with a higher sensitivity before implementation.

The UPP analysed has a reasonably low personnel risk. The risk regarding environment and assets has potential for reduction. A thourough ALARP-analysis should have been performed to reduce the environmental and asset risk before construction of the UPP.

9.2 Further Work

The analysis of the safety and security systems and barriers of the UPP have potential for extensions, with regard to both RRMs analysed and the sensitivity. These analyzes should focus on the loss of main safety functions and compare measures which reduce the risk of losing the main safety functions. The W2W solution is a relatively new system, and should be further analysed.

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[46] Jonathan Watts. Greta Thunberg, schoolgirl climate change warrior: âĂŸSome people can let things go. I canâĂŹtâĂŹ | Environment | The Guardian, 3 2019.

[47] Zbridge. Zbridge.

Appendix

9.3 Explosion frequencies

Local overpressure at utility vs frequencies for hydrocarbon events inside process area, CRA p. 41
Barrier towards Utility area

Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	1,05E-05	3,87E-06	2,67E-06	1,97E-06	1,55E-06	1,27E-06	1,12E-06
Weather deck liquid							
Local overpressure	0	0,2					
Exceedance frequency	3,51E-07	1,19E-07					
Weather deck gas							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	3,16E-06	1,05E-06	4,92E-07	2,81E-07	1,76E-07	1,19E-07	7,03E-08
Lower deck gas							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	2,67E-06	1,27E-06	9,14E-07	6,68E-07	5,62E-07	4,78E-07	4,08E-07
Lower decks liquid							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	4,78E-06	1,76E-06	1,27E-06	9,84E-07	7,73E-07	6,33E-07	5,62E-07

Unscaled frequencies [/year]
Local overpressure at utility vs frequencies for hydrocarbon events inside process area, CRA p. 41
Barrier towards Utility area

Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	1,50E-04	5,50E-05	3,80E-05	2,80E-05	2,20E-05	1,80E-05	1,60E-05
Weather deck liquid							
Local overpressure	0	0,2					
Exceedance frequency	5,00E-06	1,70E-06					
Weather deck gas							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	4,50E-05	1,50E-05	7,00E-06	4,00E-06	2,50E-06	1,70E-06	1,00E-06
Lower deck gas							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	3,80E-05	1,80E-05	1,30E-05	9,50E-06	8,00E-06	6,80E-06	5,80E-06
Lower decks liquid							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency	6,80E-05	2,50E-05	1,80E-05	1,40E-05	1,10E-05	9,00E-06	8,00E-06

Local overpressure at utility vs frequencies for hydrocarbon events inside process area

Adjusted for a 90% reduction of leak frequency 0,1

Barrier towards Utility area

Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency		3,87E-07		1,97E-07			1,12E-07
Weather deck liquid							
Local overpressure	0	**0,2**					

Exceedance frequency		**1,19E-08**					
Weather deck gas							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**1,05E-07**		2,81E-08			7,03E-09
Lower deck gas							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**1,27E-07**		6,68E-08			4,08E-08
Lower decks liquid							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**1,76E-07**		9,84E-08			5,62E-08

Local overpressure at utility vs frequencies for hydrocarbon events inside process area

		Adjusted for a 90% reduction of leak frequency				0,1	
Barrier towards Utility area							
Local overpressure	0	0,2	0,4	0,6	0,8	1	1,2
Exceedance frequency		5,50E-06	3,80E-06	2,80E-06	2,20E-06	1,80E-06	1,60E-06
Weather deck liquid							
Local overpressure	0	**0,2**					
Exceedance frequency		**1,70E-07**					
Weather deck gas							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**1,50E-06**	**7,00E-07**	**4,00E-07**	**2,50E-07**	**1,70E-07**	**1,00E-07**
Lower deck gas							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**1,80E-06**	**1,30E-06**	**9,50E-07**	**8,00E-07**	**6,80E-07**	**5,80E-07**
Lower decks liquid							
Local overpressure	0	**0,2**	0,4	0,6	0,8	1	1,2
Exceedance frequency		**2,50E-06**	**1,80E-06**	**1,40E-06**	**1,10E-06**	**9,00E-07**	**8,00E-07**

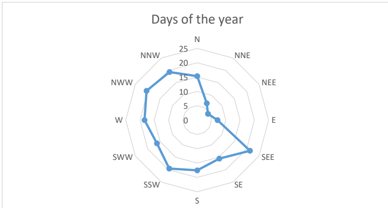
9.4 Wind distributions

Wind direction 30° differance	Sleipner A		Mean wind	Days of the year
N	8,4		4,2	15,33
NNE	3,7		1,85	6,7525
NEE	2,4		1,2	4,38
E	3,9		1,95	7,1175
SEE	11,7		5,85	21,3525
SE	8,5		4,25	15,5125
S	9,6		4,8	17,52
SSW	10,7		5,35	19,5275
SWW	8,9		4,45	16,2425
W	10,1		5,05	18,4325
NWW	11,2		5,6	20,44
NNW	10,6		5,3	19,345
	99,7		49,85	181,9525

	SOV west		**SOV east**	
	Wind that	Cumulative distribution	Wind that	Cumulative distribution
	S	4,8	N	4,2
	SSW	5,35	NNE	1,85
	SWW	4,45	NEE	1,2
	W	5,05	E	1,95
Sum		**19,65**		**9,2**
			71,15	28,85

	Vind fra S & V	Vind fra N&Ø	Vind fra andre retninger
i prosent	0,1965	0,092	0,7115
days	71,7225	33,58	259,6975

Wind direction 30° differance	Days of the year
N	15,33
NNE	6,7525
NEE	4,38
E	7,1175
SEE	21,3525
SE	15,5125
S	17,52
SSW	19,5275
SWW	16,2425
W	18,4325
NWW	20,44
NNW	19,345



9.5 Production Income

Average income			
Assumed reserves at field	5,00E+08	barrels	Source: Lorentzen e.24
Minimum price per barrel	50	dollar	
Min. field income	2,50E+10	dollar	
Min. field income	2,25E+11	NOK	
Daily income at peak prodution	3,08E+07	NOK	

Minimum required income assumption		
Assumed reserves at field	5,00E+08	barrels
Price per barrel	35	dollar
Min. field income	1,75E+10	dollar
Min. field income	1,575E+11	NOK
Daily income at peak prodution	2,16E+07	NOK

9.6 QRA Explosion & SOV Positions

Personell on decks		**Use of SOV**						
Weather deck:	4	Planned mai	48			48		
Intermediate deck, process area:	4	Critical corre	8			8		
Intermediate deck, utility area:	4							
Cellar deck, process area:	4		**Manning**	**Days/ year**	**Hour/ per day**	**Hours/ year**	kilde: CRA p. 23	
Cellar deck, utility area:	4		Planned maintenance	48	11	528		
			Unplanned	8	11	88		0,076712
Assumed Explosionloads from process area and we	0,7 barg		Total	56		616		0,07028

Position	**frequency [/year]**	**West**	**East**	**300 m**
Case				
Evacuation due to explosion weather deck, gas				
Explosion size		Small	small	Small
Exceedence frequency		1,05E-06	1,05E-06	1,05E-06
Imediate fatalities		4	4	4
Probability of following fire		0	0	0
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**4,22E-06**	**4,22E-06**	**4,22E-06**
FAR	**(PLL*10^8)/manning***	**0,034227**	**0,034227**	**0,034227**
Evacuation due to explosion weather deck, gas				
Explosion size		Medium	Medium	Medium
Exceedence frequency		2,811E-07	2,81E-07	2,81E-07

Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**1,12E-06**	**1,12E-06**	**1,12E-06**
Evacuation due to explosion weather deck, gas			
Explosion size	Large	Large	Large
Exceedence frequency	7,03E-08	7,03E-08	7,03E-08
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	No	No	No
Impact on SOV	No	No	No
PLL	**5,62E-07**	**5,62E-07**	**5,62E-07**
Evacuation due to explosion weather deck, liquid			
Explosion size	Small	small	Small
Exceedence frequency	1,19E-07	1,19E-07	1,19E-07
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0

Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**4,779E-07**	**4,78E-07**	**4,78E-07**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Small	Small	Small
Exceedence frequency	1,27E-06	1,27E-06	1,27E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,06E-06**	**5,06E-06**	**5,06E-06**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Medium	Medium	Medium
Exceedence frequency	6,677E-07	6,68E-07	6,68E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**5,34E-06**	**5,34E-06**	**5,34E-06**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Large	Large	Large
Exceedence frequency	4,076E-07	4,08E-07	4,08E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	yes	yes	yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	12	12	12
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	No	No
PLL	**6,522E-06**	**6,52E-06**	**6,52E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Small	Small	Small
Exceedence frequency	1,757E-06	1,76E-06	1,76E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	no	no	no
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**7,03E-06**	**7,03E-06**	**7,03E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4

Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**7,87E-06**	**7,87E-06**	**7,87E-06**
Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,62E-07	5,62E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	12	12	12
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	No	No
PLL	**9,00E-06**	**9,00E-06**	**9,00E-06**
Evacuation due to explosion on cellar deck, process area, gas			
Explosion size	Small	Small	Small
Exceedence frequency	1,27E-06	1,27E-06	1,27E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0

Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,06E-06**	**5,06E-06**	**5,06E-06**
Evacuation due to explosion on cellar deck, process area, gas			
Explosion size	Medium	Medium	Medium
Exceedence frequency	6,677E-07	6,68E-07	6,68E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	NO	NO	NO
Impairment of escape	No	No	No
Impairment of main load bearing structure	No	No	No
Impact on SOV	No	yes	No
PLL	**5,34E-06**	**5,34E-06**	**5,34E-06**
Evacuation due to explosion on cellar deck, process area, gas			
Explosion size	Large	Large	Large
Exceedence frequency	4,076E-07	4,08E-07	4,1E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	8	8	8
Impact on evacuation	Yes	Yes	Yes
Impairment of escape	No	0,092	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	yes	No
PLL	**4,891E-06**	**5,19E-06**	**4,89E-06**

Evacuation due to explosion on cellar deck, process area, Liquid			
Explosion size	Small	Small	Small
Exceedence frequency	1,76E-06	1,76E-06	1,76E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**7,03E-06**	**7,03E-06**	**7,03E-06**

Evacuation due to explosion on cellar deck, process area, Liquid			
Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**7,87E-06**	**7,87E-06**	**7,87E-06**
FAR			

Evacuation due to explosion on cellar deck, process area, Liquid			
Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,62E-07	5,62E-07
Imediate fatalities	4	4	4

Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	8	8	8
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**6,75E-06**	**6,75E-06**	**6,75E-06**

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea			
Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Escape fatalities	12	12	0
Tail wind	0,092	0,1965	
Probability of fire at sea given an exploson with a following fire	0,5	0,5	0,5
Impact on evacuation	0,007	1	0,007
Impairment of escape	2,263E-08	4,83E-08	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**8,14E-06**	**8,45E-06**	**7,87E-06**
FAR			

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea			
Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,62E-07	5,62E-07
Immediate fatalities	4	4	4
Probability of following fire	1	1	1

Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	8	8	8
Escape fatalities	6	6	6
Tail wind	0,092	0,1965	0,092
Probability of fire at sea given an exploson with a following fire	0,5	0,5	0,5
Impact on evacuation	0,007	1	0,007
Impairment of escape	2,263E-08	4,83E-08	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**6,88E-06**	**7,04E-06**	**6,75E-06**
SUM PLL	**9,92E-05**	**9,99E-05**	**9,88E-05**
FAR **(PLL*10^8)/manning***	**0,8049036**	**0,811094**	**0,801597**
		-7,63E-07	4,07E-07

Key parameters for the explosion analysis, CRA p.40			**Explosion size**	
Leak size	**Lower decl**	**Weather deck**	Size	Local overpressure at utility
Congested and/or confined region available for explosive cloud formation	(25x24x12=	(36x34x7= 8568 m3)	small	0,2
Maximum cloud size for worst case combination of wind direction and leak direction, equivalent stoichiometric cloud size	3500 m3	1500 m3	medium	0,6
Expected maxmum overpressure upon ignition of a 1000 m3 stoichiometric cloud size	1,6 barg	1,3 barg	large	1,2

9.7 QRA Explosion & SOV Positions for SWAT-team

Position	West	East	100 m
Case			
Evacuation due to explosion weather deck, gas			
Explosion size	Small	small	Small
Exceedence frequency	0,00000	0,00000	0,00000
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**2,11E-06**	**2,108E-06**	**2,11E-06**
Evacuation due to explosion weather deck, gas			
Explosion size	Medium	Medium	Medium
Exceedence frequency	2,81E-07	2,811E-07	2,81E-07
Imediate fatalities	2	2	2
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,62E-07**	**5,622E-07**	**5,62E-07**
Evacuation due to explosion weather deck, gas			
Explosion size	Large	Large	Large
Exceedence frequency	0,000000	7,028E-08	7,03E-08
Imediate fatalities	2	2	2
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	2	2	2
Impact on evacuation	No	No	No
Impairment of escape			
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**2,81E-07**	**2,811E-07**	**2,81E-07**
Evacuation due to explosion weather deck, liquid			
Explosion size	Small	small	Small
Exceedence frequency	0,00000	0,00000	0,00000
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No

Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**2,39E-07**	**2,39E-07**	**2,39E-07**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Small	Small	Small
Exceedence frequency	2,67E-06	2,671E-06	2,67E-06
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,34E-06**	**5,341E-06**	**5,34E-06**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Medium	Medium	Medium
Exceedence frequency	6,68E-07	6,677E-07	6,68E-07
Imediate fatalities	2	2	2
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	2	2	2
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**2,67E-06**	**2,671E-06**	**2,67E-06**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Large	Large	Large
Exceedence frequency	4,08E-07	4,076E-07	4,08E-07
Imediate fatalities	2	2	2
Probability of following fire	1	1	1
Explosion reaching utility area	yes	yes	yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	6	6	6
Impact on evacuation	?	?	?
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**3,26E-06**	**3,261E-06**	**3,26E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Small	Small	Small
Exceedence frequency	1,76E-06	1,757E-06	1,76E-06
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	no	no	no
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**3,51E-06**	**3,514E-06**	**3,51E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,839E-07	9,84E-07
Imediate fatalities	2	2	2
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	2	2	2
Impact on evacuation	?	?	?
Impairment of escape	?	?	?
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**3,94E-06**	**3,936E-06**	**3,94E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,622E-07	5,62E-07
Imediate fatalities	2	2	2
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	6	6	6
Impact on evacuation	?	?	?
Impairment of escape	?	?	?
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**4,5E-06**	**4,498E-06**	**4,5E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Small	Small	Small
Exceedence frequency	1,27E-06	1,265E-06	1,27E-06
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0

Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**2,53E-06**	**2,53E-06**	**2,53E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Medium	Medium	Medium
Exceedence frequency	6,68E-07	6,677E-07	6,68E-07
Imediate fatalities	2	2	2
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	2	2	2
Impact on evacuation	?	?	?
Impairment of escape	?	?	?
Impairment of main load bearing structure			
Impact on SOV	No	yes	No
PLL	**2,67E-06**	**2,671E-06**	**2,67E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Large	Large	Large
Exceedence frequency	4,08E-07	4,076E-07	4,08E-07
Imediate fatalities	2	2	2
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	?	?	?
Impairment of escape	?	?	?
Impairment of main load bearing structure			
Impact on SOV	No	yes	No
PLL	**2,45E-06**	**2,446E-06**	**2,45E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Small	Small	Small
Exceedence frequency	1,76E-06	1,757E-06	1,76E-06
Imediate fatalities	2	2	2
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**3,51E-06**	**3,514E-06**	**3,51E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Medium	Medium	Medium

Exceedence frequency	9,84E-07	9,839E-07	9,84E-07
Imediate fatalities	2	2	2
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	2	2	2
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**3,94E-06**	**3,936E-06**	**3,94E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,622E-07	5,62E-07
Imediate fatalities	2	2	2
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	16	4
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**3,37E-06**	**1,012E-05**	**3,37E-06**

SUM PLL	**4,49E-05**	**5,163E-05**	**4,49E-05**
FAR	**0,72858**	**0,8381061**	**0,72858**

9.8 QRA Fire

Major gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of escaperoutes		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00 No				K1	H1	3,09E-04	0	0	0	0	0	0	0	0	0	0,00E+00
	9,833E-01 No				1,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		0,00E+00 yes	1,00E+00 No		0,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				1,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
3,14E-04			0,00E+00 Yes	0,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
			8,53E-01 No		9,50E-01 No	K6	H6	4,25E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,27E-05
	1,67E-02 yes				5,00E-02 Yes	K7	H7	2,24E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	6,71E-07
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	7,71E-07	0	0	0	1	0	0	1	4	0	Is already a
								3,14E-04										
															PLL			1,34E-05

Medium gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00 No				K1	H1	2,11E-04	0	0	0	0	0	0	0	0	0	0,00E+00
	9,833E-01 No				1,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		0,00E+00 yes	1,00E+00 No		0,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				1,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
2,15E-04			0,00E+00 Yes	0,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
			8,53E-01 No		9,50E-01 No	K6	H6	2,91E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,73E-06
	1,67E-02 yes				5,00E-02 Yes	K7	H7	1,53E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,59E-07
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	5,28E-07	0	0	0	1	0	0	1	4	0	Is already a
								2,15E-04										

PLL 9,19E-06

Major oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00 No				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
	0,000E+00 No				0,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		1,00E+00 yes	0,00E+00 No		1,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				0,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00 Yes	1,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
4,55E-04					9,50E-01 No	K6	H6	3,69E-04	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,11E-03
	1,00E+00 yes		8,53E-01 No		5,00E-02 Yes	K7	H7	1,94E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	5,82E-05
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	6,69E-05	0	0	0	1	0	0	1	4	0	Is already a
								4,55E-04										

PLL 1,16E-03

Medium oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00 No				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
	0,000E+00 No				0,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		1,00E+00 yes	0,00E+00 No		1,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				0,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00 Yes	1,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
3,30E-04					9,50E-01 No	K6	H6	2,67E-04	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,02E-04
	1,00E+00 yes		8,53E-01 No		5,00E-02 Yes	K7	H7	1,41E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,22E-05
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	4,85E-05	0	0	0	1	0	0	1	4	0	Is already a
								3,30E-04										

PLL 8,44E-04

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of W2W landing/SOV fire	Impairment of Main load bearing strucutre - fire	Imideate fatalities	Evacuation fatalities	PLL
Pump, cooling-, Water injection, vent, and scrubber								
		0						
		Yes				0	0	0,00E+00
4	1,1409E-09							
		No						
		1		0	0	0	0	0
				PLL				0

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of W2W landing/SOV fire	Impairment of Main load bearing strucutre - fire	Immideate fatalities	Evacuation fatalities	PLL
Pump, oil export			Prosess fire					
		9,50E-01	0	0,2	0,05	0	0	0,00E+00
		No						
1	1,1409E-09	5,00E-02	0,75	0,2	0,05	4	0	2,28E-10
		Yes						
				PLL				2,28E-10

SUM PLL of Fire 2,03E-03
FAR 16,48881657

9.9 QRA Collision

	West	East	300 m
Collision upon arrival Frequency per year	1,51E-06	1,51E-06	6,05E-06
Probability of drift-off per hour	2,00E-05	2,00E-05	2,00E-05
Probability of drift-off per year	1,23E-02	1,23E-02	4,48E-03
Probability of drive-off per hour	1,00E-05	1,00E-05	1,00E-05
Probability of drive-off per year	6,16E-03	6,16E-03	2,24E-03
Collision frequency when repositioning per visit	3,00E-05	3,00E-05	3,00E-05
Collision frequency when repositioning per year	1,68E-03	1,68E-03	1,68E-03
Annual impairment of main safety function "main load bearing capacity"	1,10E-05	1,10E-05	1,10E-05
Annual collision frequency per year	2,02E-02	2,02E-02	8,41E-03
		0	0,011755

Vissting vessels per year	N	56	assuming the SOV sails outside of safe zone every night. Assuming the SOV at 300m "arrives" at the installation 4 times a day. Drop off, lunch pic up and drop off and pick up.
Probability of being on collision course	P_1	0,1	
Probability of loss of control onboard the vessel when on collision course	P_2	2,70E-06	
Probability of failure to warn/divert a vessel approaching on collision course	P_3	0,1	
Hours of yearly maintenance		616	
Connections with W2W - yearly		224	4 times a day during maintenance. Assuming every connection last one hour

9.10 Fire retardant lifeboat

9.10.1 Explosion with Fire retardant lifeboat

Position	frequency [/year]	West	East	300 m
Case				
Evacuation due to explosion weather deck, gas				
Explosion size		Small	small	Small
Exceedence frequency		0,00000	0,00000	0,00000
Imediate fatalities		4	4	4
Probability of following fire		0	0	0
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**4,22E-06**	**4,22E-06**	**4,22E-06**
FAR	**(PLL*10^8)/manning***	**0,034227**	**0,034227**	**0,034227**
Evacuation due to explosion weather deck, gas				
Explosion size		Medium	Medium	Medium
Exceedence frequency		2,811E-07	2,81E-07	2,81E-07
Imediate fatalities		4	4	4
Probability of following fire		0,5	0,5	0,5
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**1,12E-06**	**1,12E-06**	**1,12E-06**
Evacuation due to explosion weather deck, gas				
Explosion size		Large	Large	Large
Exceedence frequency		7,03E-08	7,03E-08	7,03E-08
Imediate fatalities		4	4	4
Probability of following fire		1	1	1
Explosion reaching utility area		Yes	Yes	Yes
Explosion reaching other decks		Yes	Yes	Yes
Evacuation fatalities		4	4	4
Impact on evacuation		No	No	No
Impairment of escape		No	No	No
Impairment of main load bearing structure		No	No	No
Impact on SOV		No	No	No
PLL		**5,62E-07**	**5,62E-07**	**5,62E-07**
Evacuation due to explosion weather deck, liquid				
Explosion size		Small	small	Small
Exceedence frequency		1,19E-07	1,19E-07	1,19E-07
Imediate fatalities		4	4	4
Probability of following fire		0	0	0
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**4,779E-07**	**4,78E-07**	**4,78E-07**
Evacuation due to explosion on intermediate deck, process area, gas				
Explosion size		Small	Small	Small
Exceedence frequency		1,27E-06	1,27E-06	1,27E-06
Imediate fatalities		4	4	4
Probability of following fire		0	0	0
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**5,06E-06**	**5,06E-06**	**5,06E-06**
Evacuation due to explosion on intermediate deck, process area, gas				
Explosion size		Medium	Medium	Medium
Exceedence frequency		6,677E-07	6,68E-07	6,68E-07
Imediate fatalities		4	4	4
Probability of following fire		0,5	0,5	0,5
Explosion reaching utility area		No	No	No
Explosion reaching other decks		yes	yes	yes
Evacuation fatalities		4	4	4

Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**5,34E-06**	**5,34E-06**	**5,34E-06**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Large	Large	Large
Exceedence frequency	4,076E-07	4,08E-07	4,08E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	yes	yes	yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	12	12	12
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	No	No
PLL	**6,522E-06**	**6,52E-06**	**6,52E-06**

Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Small	Small	Small
Exceedence frequency	1,757E-06	1,76E-06	1,76E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	no	no	no
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**7,03E-06**	**7,03E-06**	**7,03E-06**

Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**7,87E-06**	**7,87E-06**	**7,87E-06**

Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,62E-07	5,62E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	12	12	12
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	No	No
PLL	**9,00E-06**	**9,00E-06**	**9,00E-06**

Evacuation due to explosion on cellar deck, process area, gas			
Explosion size	Small	Small	Small
Exceedence frequency	1,27E-06	1,27E-06	1,27E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,06E-06**	**5,06E-06**	**5,06E-06**

Evacuation due to explosion on cellar deck, process area, gas			
Explosion size	Medium	Medium	Medium
Exceedence frequency	6,677E-07	6,68E-07	6,68E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5

Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	NO	NO	NO
Impairment of escape	No	No	No
Impairment of main load bearing structure	No	No	No
Impact on SOV	No	yes	No
PLL	**5,34E-06**	**5,34E-06**	**5,34E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Large	Large	Large
Exceedence frequency	4,076E-07	4,08E-07	4,1E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	8	8	8
Impact on evacuation	Yes	Yes	Yes
Impairment of escape	No	0,092	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	yes	No
PLL	**4,891E-06**	**5,19E-06**	**4,89E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Small	Small	Small
Exceedence frequency	1,76E-06	1,76E-06	1,76E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**7,03E-06**	**7,03E-06**	**7,03E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**7,87E-06**	**7,87E-06**	**7,87E-06**
FAR			

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Large	Large	Large
Exceedence frequency	5,62E-07	5,62E-07	5,62E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	8	8	8
Impact on evacuation	0,007	1	0,007
Impairment of escape	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0
PLL	**6,75E-06**	**6,75E-06**	**6,75E-06**

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea

Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Escape fatalities	0	0	0
Tail wind	0,092	0,1965	
Probability of fire at sea given an exploson with a following fire	0,5	0,5	0,5
Impact on evacuation	0,007	1	0,007
Impairment of escape	2,263E-08	4,83E-08	0
Impairment of main load bearing structure	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0

PLL		**7,87E-06**	**7,87E-06**	**7,87E-06**
FAR				
Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea				
Explosion size		Large	Large	Large
Exceedence frequency		5,62E-07	5,62E-07	5,62E-07
Imediate fatalities		4	4	4
Probability of following fire		1	1	1
Explosion reaching utility area		Yes	Yes	Yes
Explosion reaching other decks		Yes	Yes	Yes
Evacuation fatalities		8	8	8
Escape fatalities		0	0	0
Tail wind		0,092	0,1965	0,092
Probability of fire at sea given an exploson with a following fire		0,5	0,5	0,5
Impact on evacuation		0,007	1	0,007
Impairment of escape		2,263E-08	4,83E-08	0
Impairment of main load bearing structure		0,007	0,007	0,007
Impact on SOV		0,007	0,007	0
PLL		**6,75E-06**	**6,75E-06**	**6,75E-06**
SUM PLL		**9,88E-05**	**9,91E-05**	**9,88E-05**
FAR	**(PLL*10^8)/manning***	**0,8015973**	**0,804032**	**0,801597**

9.10.2 CBA of Fire retardant lifeboat

LCC of fire resistant lifeboat

	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,934579439	0,873438728	0,816298	0,762895	0,712986179	0,666342	0,62275	0,5820091	0,543933743	0,508349	0,475093	0,444012	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	23000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000
	Risk differences							Risk differences over 20 years													
	Difference in r	Valuation	Diff. environm	Valuation	Diff. asset	Valuation			Difference i	Valuation	Diff. envirc	Valuation	Diff. asset	Valuation							
Diff in PLL	(PLL_explosion	value of life offshore						Diff in PLL	(PLL_explos	value of life offshore											
	4E-07	300000000	0		0				8,00E-06	300000000	0		0								
Diff in FAR	3,31E-03	300000000						Diff in FAR	0,07	300000000											
Diff in PLL	DeltaC_n1	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Diff in FAR	DeltaC_n1	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890	991890
PLL	LCC_yearly	-21695214,95	-186811,0752	-174590	-163168	-152493,484	-142517	-133194	-124480,1	-116336,5489	-108726	-101613	-94965,3	-88752,6	-82946,4	-77520	-72448,6	-67708,9	-63279,4	-59139,6	-55270,7
	LCC	-2,38E+07																			
FAR	LCC_yearly	-2,06E+07	818316,0101	805596,2	714748,9	703638,9307	624289,4	614585,5	545278,51	536802,7712	476267,4	468864,3	415990,4	409524,3	363342,1	357694,4	317357,1	312424,1	277191,9	272883,3	242110,2
	LCC	-1,13E+07																			

LCC of escapechute

	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0p^-n	0,934579439	0,873438728	0,816298	0,762895	0,712986179	0,666342	0,62275	0,5820091	0,543933743	0,508349	0,475093	0,444012	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	7000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000	90000
	Risk differences																				
	Difference in r	Valuation	Diff. environm	Valuation	Diff. asset	Valuation															
	(PLL_explosion	value of life offshore																			
Diff in PLL	0	300000000	0		0																
Diff in FAR	0,00E+00	300000000																			
Diff in PLL	DeltaC_n1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	LCC_yearly	-6626168,224	-78609,48554	-73466,8	-68660,6	-64168,7562	-59970,8	-56047,5	-52380,82	-48954,03683	-45751,4	-42758,4	-39961,1	-37346,8	-34903,6	-32620,1	-30486,1	-28491,7	-26627,8	-24885,7	-23257,7
	LCC	-7,50E+06																			

Cost difference of change from selantic to fire resistant lifeboat

LCC -1,63E+07 NOK

Will cost 16,3 million NOK more with a fire resistant lieboat.

This assumes equal installation cost of lifeboat and selantic.

Delta PLL over 20 years	8E-06
Invest cost	23000000
O&M cost over 20 years	2267119

Cost per avoided loss of 3,15839E+12 The total cost of an avoided loss of life is 3,16 trillions NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	200000	186915,8879	174687,7457	163259,6	152579	142597,2359	133268,4	124549,9	116401,82	108786,7485	101669,9	95018,56	88802,39	82992,89	77563,45	72489,2	67746,92	63314,88	59172,78	55301,67

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9.11 Additional SSIV

9.11.1 Explosion with additional SSIVs

Event trees	frequency [/year]	Base case	SSIV at gas-lift	SSIV at Multiphase	SSIV at gas-lift while manned	SSIV at multiphase while manned
Evacuation due to explosion weather deck, gas						
Explosion size		Small	small	Small	small	Small
Exceedence frequency		1,50E-05	1,50E-06	1,50E-05	1,05E-07	1,05E-06
Imediate fatalities		4	4	4	4	4
Probability of following fire		0	0	0	0	0
Explosion reaching utility area		No	No	No	No	No
Explosion reaching other decks		No	No	No	No	No
Evacuation fatalities		0	0	0	0	0
Impact on evacuation		0	0	0	0	0
Impairment of escape		0	0	0	0	0
Impairment of main load bearing structure		0	0	0	0	0
Impact on SOV		0	0	0	0	0
PLL		**6,00E-05**	**6,00E-06**	**6,00E-05**	**4,22E-07**	**4,22E-06**
FAR	**(PLL*10^8)**	**0,487013**	**0,048701**	**0,487013**	**0,003422704**	**0,034227039**
Evacuation due to explosion weather deck, gas						
Explosion size		Medium	Medium	Medium	Medium	Medium
Exceedence frequency		4,00E-06	4,00E-07	4,00E-06	2,81E-08	2,81E-07
Imediate fatalities		4	4	4	4	4
Probability of following fire		0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area		No	No	No	No	No
Explosion reaching other decks		No	No	No	No	No
Evacuation fatalities		0	0	0	0	0
Impact on evacuation		0	0	0	0	0
Impairment of escape		0	0	0	0	0
Impairment of main load bearing structure		0	0	0	0	0
Impact on SOV		0	0	0	0	0
PLL		**1,60E-05**	**1,60E-06**	**1,60E-05**	**1,12E-07**	**1,12E-06**
Evacuation due to explosion weather deck, gas						
Explosion size		Large	Large	Large	Large	Large
Exceedence frequency		1,00E-06	1,00E-07	1,00E-06	7,03E-09	7,03E-08
Imediate fatalities		4	4	4	4	4
Probability of following fire		1	1	1	1	1
Explosion reaching utility area		Yes	Yes	Yes	Yes	Yes
Explosion reaching other decks		Yes	Yes	Yes	Yes	Yes
Evacuation fatalities		4	4	4	4	4
Impact on evacuation		No	No	No	No	No
Impairment of escape		No	No	No	No	No
Impairment of main load bearing structure		No	No	No	No	No
Impact on SOV		No	No	No	No	No
PLL		**8,00E-06**	**8,00E-07**	**8,00E-06**	**5,62E-08**	**5,62E-07**
Evacuation due to explosion weather deck, liquid						
Explosion size		Small	small	Small	small	Small
Exceedence frequency		1,70E-06	1,70E-06	1,70E-07	1,19E-07	1,19E-08
Imediate fatalities		4	4	4	4	4
Probability of following fire		0	0	0	0	0
Explosion reaching utility area		No	No	No	No	No
Explosion reaching other decks		No	No	No	No	No
Evacuation fatalities		0	0	0	0	0
Impact on evacuation		0	0	0	0	0
Impairment of escape		0	0	0	0	0
Impairment of main load bearing structure		0	0	0	0	0
Impact on SOV		0	0	0	0	0
PLL		**0,0000068**	**6,8E-06**	**6,8E-07**	**4,77901E-07**	**4,77901E-08**
Evacuation due to explosion on intermediate deck, process area, gas						
Explosion size		Small	Small	Small	Small	Small
Exceedence frequency		1,80E-05	1,80E-06	1,80E-05	1,27E-07	1,27E-06
Imediate fatalities		4	4	4	4	4
Probability of following fire		0	0	0	0	0
Explosion reaching utility area		No	No	No	No	No
Explosion reaching other decks		No	No	No	No	No
Evacuation fatalities		0	0	0	0	0
Impact on evacuation		0	0	0	0	0
Impairment of escape		0	0	0	0	0
Impairment of main load bearing structure		0	0	0	0	0
Impact on SOV		0	0	0	0	0
PLL		**7,20E-05**	**7,20E-06**	**7,20E-05**	**5,06E-07**	**5,06E-06**
Evacuation due to explosion on intermediate deck, process area, gas						
Explosion size		Medium	Medium	Medium	Medium	Medium

Exceedence frequency	9,50E-06	9,50E-07	0,0000095	6,68E-08	6,68E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	yes	yes	yes	yes	yes
Evacuation fatalities	4	4	4	4	4
Impact on evacuation	No	No	No	No	No
Impairment of escape	No	No	No	No	No
Impairment of main load bearing structure					
Impact on SOV	No	No	No	No	No
PLL	**7,60E-05**	**7,60E-06**	**7,60E-05**	**5,34E-07**	**5,34E-06**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Large	Large	Large	Large	Large
Exceedence frequency	5,80E-06	5,80E-07	0,0000058	4,08E-08	4,08E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	1	1	1	1	1
Explosion reaching utility area	yes	yes	yes	yes	yes
Explosion reaching other decks	yes	yes	yes	yes	yes
Evacuation fatalities	12	12	12	12	12
Impact on evacuation	No	No	No	No	No
Impairment of escape	No	No	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05	0,05	0,05
Impact on SOV	No	No	No	No	No
PLL	**0,0000928**	**9,28E-06**	**0,0000928**	**6,52194E-07**	**6,52194E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Small	Small	Small	Small	Small
Exceedence frequency	2,50E-05	0,000025	2,50E-06	1,76E-06	1,76E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	0	0	0	0	0
Explosion reaching utility area	no	no	no	no	no
Explosion reaching other decks	No	No	No	No	No
Evacuation fatalities	0	0	0	0	0
Impact on evacuation	0	0	0	0	0
Impairment of escape	0	0	0	0	0
Impairment of main load bearing structure	0	0	0	0	0
Impact on SOV	0	0	0	0	0
PLL	**1,00E-04**	**1,00E-04**	**1,00E-05**	**7,03E-06**	**7,03E-07**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Medium	Medium	Medium	Medium	Medium
Exceedence frequency	1,40E-05	1,40E-05	1,40E-06	9,84E-07	9,84E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	4	4	4	4	4
Impact on evacuation	No	No	No	No	No
Impairment of escape	No	No	No	No	No
Impairment of main load bearing structure					
Impact on SOV	No	No	No	No	No
PLL	**1,12E-04**	**1,12E-04**	**1,12E-05**	**7,87E-06**	**7,87E-07**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Large	Large	Large	Large	Large
Exceedence frequency	8,00E-06	8,00E-06	8,00E-07	5,62E-07	5,62E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	1	1	1	1	1
Explosion reaching utility area	Yes	Yes	Yes	Yes	Yes
Explosion reaching other decks	yes	yes	yes	yes	yes
Evacuation fatalities	12	12	12	12	12
Impact on evacuation	No	No	No	No	No
Impairment of escape	No	No	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05	0,05	0,05
Impact on SOV	No	No	No	No	No
PLL	**1,28E-04**	**1,28E-04**	**1,28E-05**	**9,00E-06**	**9,00E-07**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Small	Small	Small	Small	Small
Exceedence frequency	1,80E-05	1,80E-06	1,80E-05	1,27E-07	1,27E-06
Imediate fatalities	4	4	4	4	4
Probability of following fire	0	0	0	0	0
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	No	No	No	No	No
Evacuation fatalities	0	0	0	0	0
Impact on evacuation	0	0	0	0	0

Impairment of escape	0	0	0	0	0
Impairment of main load bearing structure	0	0	0	0	0
Impact on SOV	0	0	0	0	0
PLL	**7,20E-05**	**7,20E-06**	**7,20E-05**	**5,06E-07**	**5,06E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Medium	Medium	Medium	Medium	Medium
Exceedence frequency	9,50E-06	9,50E-07	0,0000095	6,68E-08	6,68E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	4	4	4	4	4
Impact on evacuation	NO	NO	NO	NO	NO
Impairment of escape	No	No	No	No	No
Impairment of main load bearing structure	No	No	No	No	No
Impact on SOV	No	No	No	No	No
PLL	**7,60E-05**	**7,60E-06**	**7,60E-05**	**5,34E-07**	**5,34E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Large	Large	Large	Large	Large
Exceedence frequency	5,80E-06	5,80E-07	5,8E-06	4,08E-08	4,1E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	1	1	1	1	1
Explosion reaching utility area	Yes	Yes	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	8	8	8	8	8
Impact on evacuation	Yes	Yes	Yes	Yes	Yes
Impairment of escape	No	0	No	0	No
Impairment of main load bearing structure	0,05	0,05	0,05	0,05	0,05
Impact on SOV	No	No	No	No	No
PLL	**0,0000696**	**6,96E-06**	**6,96E-05**	**4,89145E-07**	**4,89E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Small	Small	Small	Small	Small
Exceedence frequency	2,50E-05	2,50E-05	2,50E-06	1,76E-06	1,76E-07
Imediate fatalities	4	4	4	4	4
Probability of following fire	0	0	0	0	0
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	No	No	No	No	No
Evacuation fatalities	0	0	0	0	0
Impact on evacuation	0	0	0	0	0
Impairment of escape	0	0	0	0	0
Impairment of main load bearing structure	0	0	0	0	0
Impact on SOV	0	0	0	0	0
PLL	**1,00E-04**	**1,00E-04**	**1,00E-05**	**7,03E-06**	**7,03E-07**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Medium	Medium	Medium	Medium	Medium
Exceedence frequency	1,40E-05	1,40E-05	1,40E-06	9,84E-08	9,84E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	4	4	4	4	4
Impact on evacuation	0,007	0,007	0,007	0,007	0,007
Impairment of escape	0	0	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0,007	0,007	0,007
PLL	**1,12E-04**	**1,12E-04**	**1,12E-05**	**7,87E-07**	**7,87E-07**
FAR					

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Large	Large	Large	Large	Large
Exceedence frequency	8,00E-06	8,00E-06	8,00E-07	5,62E-07	5,62E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	1	1	1	1	1
Explosion reaching utility area	Yes	Yes	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	8	8	8	8	8
Impact on evacuation	0,007	0,007	0,007	0,007	0,007
Impairment of escape	0	0	0	0	0
Impairment of main load bearing structure	0,007	0,007	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0,007	0,007	0,007
PLL	**9,60E-05**	**9,60E-05**	**9,60E-06**	**6,75E-06**	**6,75E-07**

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea

Explosion size	Medium	Medium	Medium	Medium	Medium
Exceedence frequency	1,40E-05	1,40E-05	1,40E-06	9,84E-07	9,84E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	0,5	0,5	0,5	0,5	0,5
Explosion reaching utility area	No	No	No	No	No
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	4	4	4	4	4
Escape fatalities	12	12	0	12	12
Tail wind	0,092	0,092	0,092	0	0
Probability of fire at sea given an exploson with a following fire	0,5	0,5	0,5	0,5	0,5
Impact on evacuation	0,007	0,007	0,007	0,007	0,007
Impairment of escape	3,22E-07	3,22E-07	3,22E-07	0	0
Impairment of main load bearing structure	0,007	0,007	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0,007	0,007	0,007
PLL	**1,16E-04**	**1,16E-04**	**1,12E-05**	**7,87E-06**	**7,87E-07**
FAR					

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea

Explosion size	Large	Large	Large	Large	Large
Exceedence frequency	8,00E-06	8,00E-06	1,40E-06	5,62E-07	5,62E-08
Imediate fatalities	4	4	4	4	4
Probability of following fire	1	1	1	1	1
Explosion reaching utility area	Yes	Yes	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes	Yes	Yes
Evacuation fatalities	8	8	8	8	8
Escape fatalities	6	6	6	6	6
Tail wind	0,092	0,092	0,092	0	0
Probability of fire at sea given an exploson with a following fire	0,5	0,5	0,5	0,5	0,5
Impact on evacuation	0,007	0,007	0,007	0,007	0,007
Impairment of escape	3,22E-07	3,22E-07	3,22E-07	0	0
Impairment of main load bearing structure	0,007	0,007	0,007	0,007	0,007
Impact on SOV	0,007	0,007	0,007	0,007	0,007
PLL	**9,79E-05**	**9,79E-05**	**1,87E-05**	**6,75E-06**	**6,75E-07**
SUM PLL	**1,41E-03**	**9,23E-04**	**6,38E-04**	**5,74E-05**	**4,42E-05**
FAR	**(PLL*10^8)/manning*total manned hours per year**			**0,465624643**	**0,358630918**
Delta PLL from base case		4,88E-04	7,73E-04	4,18E-05	5,50E-05

9.11.2 Leak duration with additional SSIVs

Source: CRA p. 34

	Gas-lift	Gas export & riser	Oil riser	Multiphase
All leaks	1,10E-01	2,10E-03	2,10E-03	4,20E-03
subsea small leak	3,50E-03	1,30E-03	1,30E-03	2,60E-03
subsea medium leak	3,10E-04	1,10E-04	1,10E-04	2,20E-04
Subsea large leak	4,10E-04	1,40E-04	1,40E-04	2,80E-04
Above water small leak	8,20E-04	2,70E-04	2,70E-04	5,50E-04
Above water medium leak	3,30E-04	1,10E-04	1,10E-04	2,20E-04
Above water large leak	4,90E-04	1,60E-04	1,60E-04	3,30E-04

SSIV	1	Yes	Yes	No
Leak duration [hour]	>1	0,0833	0,0833	>1
Leak duartion [s]	3600	300	300	3600

Gas release rates   Only interested in riser without SSIV

	Gas lift			Multiphase		
	Initilal gas release rate [kg/s]	Average release without SSIV [tonn]	Average release with SSIV [tonn]	Initilal gas release rate [kg/s]	Average release without SSIV [tonn]	Average release with SSIV [tonn]
Medium leak	50	90	14,375	15	50,4	4,3125
Large leak	300	540	86,25	200	720	57,5

9.11.3 CBA of Additional SSIV

LCC of SSIV at Gas -lift																					
	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,934579439	0,873438728	0,81629788	0,762895	0,71298618	0,666342	0,62275	0,582009105	0,543933743	0,508349292	0,475093	0,444012	0,41496445	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	60000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Risk differences							Risk differences over 20 years													
	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation			Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation							
	(Base case_PLL - SSIV_PLL)	value of life offshore	(Above water large leak + Subsea large leak)/2 * (Average release without SSIV-Average release with SSIV)+(Above water medium leak+ Subsea medium leak)/2 * (Average release without SSIV-Average release with SSIV)	cost/ton	(Base case_PLL - SSIV_PLL)			Diff in PLL	(Base case_PLL - SSIV_PLL)*20	value of life offshore	er large leak + Subsea large leak)/2 * (Average release without SSIV-Average release with SSIV)+(Above water medium leak+ Subsea medium leak)/2 * (Average release without SSIV-Average release with SSIV)*20										
	4,18E-05	300000000	0,2283875	15000000	4,88E-04	3077000000			8,36E-04	300000000	4,56775	15000000	9,76E-03	3077000000							
Diff in FAR		300000000						Diff in FAR	0	300000000											
Diff in PLL	DeltaC_n1	12540	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in leaks	DeltaC_n2	3425812,5	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06	3,43E+06
Diff in assets	DeltaC_n3	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06	1,50E+06
PLL	LCC_yearly	-5,15E+07	4,31E+06	4,03E+06	3,77E+06	3,52E+06	3,29E+06	3,08E+06	2,88E+06	2,69E+06	2,51E+06	2,35E+06	2,19E+06	2,05E+06	1,92E+06	1,79E+06	1,67E+06	1,56E+06	1,46E+06	1,37E+06	1,28E+06
	LCC	-3,74E+06																			

Delta PLL over 20 years	0,000836
Invest cost	60000000
O&M cost over 20 years	0
Saved materila cost	30031520
Cost per avoided loss of life	3,58E+10

The total cost of an avoided loss of life is 35.8 billions NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LCC of SSIV at Multiphase riser																					
	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,934579439	0,873438728	0,81629788	0,762895	0,71298618	0,666342	0,62275	0,582009105	0,543933743	0,508349292	0,475093	0,444012	0,41496445	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	60000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Risk differences							Risk differences over 20 years													
	Difference in risk to p	Valuation	Diff. environment risk	Valuation	Diff. asset	Valuation			Difference in risk to personne	Valuation	Diff. environment risk	Valuation	Diff. asset	Valuation							
	(PLL_explosion-PLL_e	value of life offshore		cost/ton				Diff in PLL	(PLL_explosion-PLL_explosion	value of life offshore											
Diff in PLL	5,50E-05	300000000	0,2190285	15000000	7,73E-04	3,08E+09			1,10E-03	300000000	4,38E+00	15000000	1,10E-03	3,08E+09							
Diff in FAR		300000000						Diff in FAR		300000000											
Diff in PLL	DeltaC_n1	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04	1,25E+04
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in leaks	DeltaC_n2	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06	3,29E+06
Diff in assets	DeltaC_n3	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06	2,38E+06
PLL	LCC_yearly	-5,08E+07	4,96E+06	4,63E+06	4,33E+06	4,05E+06	3,78E+06	3,54E+06	3,30E+06	3,09E+06	2,89E+06	2,70E+06	2,52E+06	2,36E+06	2,20E+06	2,06E+06	1,92E+06	1,80E+06	1,68E+06	1,57E+06	1,47E+06
	LCC	4,06E+06																			

Delta PLL over 20 years	0,0011
Invest cost	60000000
O&M cost over 20 years	0
Saved material cost	3384700
Cost per avoided loss of life	5,15E+10

The total cost of an avoided loss of life is 51.5 billion NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

9.12 Cold Installation during Maintenance

9.12.1 Fire when cold

Fire after empty pipes | 90% reduction | 0,1

Major gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00				K1	H1	3,09E-05	0	0	0	0	0	0	0	0	0	0,00E+00
		No																
	9,833E-01				1,00E+00	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
	No		1,00E+00		No													
		0,00E+00	No		0,00E+00	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		yes			Yes													
				1,00E+00		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			0,00E+00	No														
			Yes	0,00E+00		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
3,14E-05				Yes														
					9,50E-01	K6	H6	4,25E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,27E-06
			8,53E-01		No													
	1,67E-02		No		5,00E-02	K7	H7	2,24E-08	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	6,71E-08
	yes				Yes													
				0,00E+00		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01	No														
			Yes	1,00E+00		K9	H9	7,71E-08	0	0	0	1	0	0	1	4	0	Is already a
				Yes														
								3,14E-05										
															PLL			1,34E-06

Medium gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00				K1	H1	2,11E-05	0	0	0	0	0	0	0	0	0	0,00E+00
		No																
	9,833E-01				1,00E+00	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
	No		1,00E+00		No													
		0,00E+00	No		0,00E+00	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		yes			Yes													
				1,00E+00		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			0,00E+00	No														
			Yes	0,00E+00		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
2,15E-05				Yes														
					9,50E-01	K6	H6	2,91E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,73E-07
			8,53E-01		No													
	1,67E-02		No		5,00E-02	K7	H7	1,53E-08	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,59E-08
	yes				Yes													
				0,00E+00		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01	No														
			Yes	1,00E+00		K9	H9	5,28E-08	0	0	0	1	0	0	1	4	0	Is already a
				Yes														
								2,15E-05										
															PLL			9,19E-07

Major oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00 No				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
	0,000E+00 No				0,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		1,00E+00 yes	0,00E+00 No		1,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				0,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00 Yes	1,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
4,55E-05					9,50E-01 No	K6	H6	3,69E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,11E-04
	1,00E+00 yes		8,53E-01 No		5,00E-02 Yes	K7	H7	1,94E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	5,82E-06
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	6,69E-06	0	0	0	1	0	0	1	4	0	Is already a
								4,55E-05										
															PLL			1,16E-04

Medium oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00 No				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
	0,000E+00 No				0,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		1,00E+00 yes	0,00E+00 No		1,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				0,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00 Yes	1,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
3,30E-05					9,50E-01 No	K6	H6	2,67E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,02E-05
	1,00E+00 yes		8,53E-01 No		5,00E-02 Yes	K7	H7	1,41E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,22E-06
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	4,85E-06	0	0	0	1	0	0	1	4	0	Is already a
								3,30E-05										
															PLL			8,44E-05

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of		Imideate fatalities	Evacuation fatalities	PLL
				W2W landing/SOV fire	Main load bearing strucutre - fire			
Pump, cooling-, Water injection, vent, and scrubber								
		0						
		Yes				0	0	0,00E+00
4	1,1409E-10							
		No						
		1		0	0	0	0	0
					PLL			0

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of		Immideate fatalities	Evacuation fatalities	PLL
Pump, oil export			Prosess fire	W2W landing/SOV fire	Main load bearing strucutre - fire			
		9,50E-01	0	0,2	0,05	0	0	0,00E+00
		No						
1	1,1409E-10	5,00E-02	0,75	0,2	0,05	4	0	2,28E-11
		Yes						
					PLL			2,28E-11

SUM PLL of Fire 2,03E-04

9.12.2 CBA of Cold Installation

LCC of Cold Instalation, empty pipes

N	20
p	1,07
Days without production	80

		1	2	3	4	5	6	7	8	9	10
	year	1	2	3	4	5	6	7	8	9	10
	1,0+p^-n	0,934579439	0,873438728	0,816297877	0,762895212	0,712986	0,666342	0,62275	0,582009105	0,54393374	0,508349292
	IC_n	0	0	0	0	0	0	0	0	0	0
	RC_n	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09

		11	12	13	14	15	16	17	18	19	20
	year	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,475093	0,444011959	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	0	0	0	0	0	0	0	0	0	0
	RC_n	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion-PLL_explosion-cold)+ (PLL_fire-PLL_fire cold)	value of life offshore		cost/ton	(PLL_explosion-PLL_explosion-cold)+ (PLL_fire-PLL_fire cold)	
Diff in PLL	1,93E-03	300000000		15000000	1,93E-03	3,08E+09
Diff in FAR		300000000				

Risk differences over 20 years

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion-PLL_explosion-cold)+ (PLL_fire-PLL_fire cold)	value of life offshore		cost/ton	(PLL_explosion-PLL_explosion-cold)+ (PLL_fire-PLL_fire cold)	
Diff in PLL	3,85E-02	300000000	0,00E+00	15000000	3,85E-02	3,08E+09
Diff in FAR		300000000				

		1	2	3	4	5	6	7	8	9	10
Diff in PLL	DeltaC_n1	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06
PLL	LCC_yearly	-1,61E+09	-1,50E+09	-1,40E+09	-1,31E+09	-1,23E+09	-1,15E+09	-1,07E+09	-1,00E+09	-9,35E+08	-8,74E+08
	LCC	-1,82E+10									

		11	12	13	14	15	16	17	18	19	20
Diff in PLL	DeltaC_n1	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05	5,78E+05
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06	5,93E+06
PLL	LCC_yearly	-8,17E+08	-7,63E+08	-7,14E+08	-6,67E+08	-6,23E+08	-5,82E+08	-5,44E+08	-5,09E+08	-4,75E+08	-4,44E+08

Delta PLL over 20 years	0,038524
Invest cost	0
O&M cost over 20 years	18285558835
Saved material cost	118538348
Cost per avoided loss of life	4,72E+11

The total cost of an avoided loss of life is 472 billion NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10
Discounted O&M cost	1613109717	1507579175	1408952500	1316778037	1230633680	1,15E+09	1,07E+09	1E+09	938844542	877424806

	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	820023182,8	7,66E+08	716240005,9	6,69E+08	6,26E+08	5,85E+08	5,46E+08	5,11E+08	4,77E+08	4,46E+08

LCC of Cold Instalation, closed pipes

N	20
p	1,07
Days without production	56

		1	2	3	4	5	6	7	8	9	10
	year	1	2	3	4	5	6	7	8	9	10
	1,0+p^-n	0,934579439	0,873438728	0,816297877	0,762895212	0,712986	0,666342	0,62275	0,582009105	0,54393374	0,508349292
	IC_n	0	0	0	0	0	0	0	0	0	0
	RC_n	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09

		11	12	13	14	15	16	17	18	19	20
	year	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,475093	0,444011959	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	0	0	0	0	0	0	0	0	0	0
	RC_n	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09	1,21E+09

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_fire-PLL_fire cold)	value of life offshore		cost/ton	(PLL_fire-PLL_fire cold)	
Diff in PLL	1,83E-03	300000000		15000000	1,83E-03	3,08E+09
Diff in FAR		300000000				

Risk differences over 20 years

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_fire-PLL_fire cold)	value of life offshore			(PLL_fire-PLL_fire cold)	
Diff in PLL	3,65E-02	300000000	0,00E+00	15000000	3,65E-02	3,08E+09
Diff in FAR		300000000				

		1	2	3	4	5	6	7	8	9	10
Diff in PLL	DeltaC_n1	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06
PLL	LCC_yearly	-1,12E+09	-1,05E+09	-9,81E+08	-9,17E+08	-8,57E+08	-8,01E+08	-7,49E+08	-7,00E+08	-6,54E+08	-6,11E+08
	LCC	-1,27E+10									

		11	12	13	14	15	16	17	18	19	20
Diff in PLL	DeltaC_n1	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05	5,48E+05
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06	5,62E+06
PLL	LCC_yearly	-5,71E+08	-5,34E+08	-4,99E+08	-4,66E+08	-4,36E+08	-4,07E+08	-3,81E+08	-3,56E+08	-3,32E+08	-3,11E+08

Delta PLL over 20 years	0,03654
Invest cost	0
O&M cost over 20 years	12799891184
Saved material cost	112433580

Cost per avoided loss of life	3,47E+11	The total cost of an avoided loss of life is 347 billion NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	1129176802	1055305422	986266749,9	921744626,1	861443575,8	8,05E+08	7,52E+08	7,03E+08	657191179,4	614197364	574016228	5,36E+08	501368004,2	4,69E+08	4,38E+08	4,09E+08	3,82E+08	3,57E+08	3,34E+08	3,12E+08

LCC of Cold Instalation, Base case

	N	20																			
	p	1,07																			
	Days without production	56																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,934579439	0,873438728	0,816297877	0,762895212	0,712986	0,666342	0,62275	0,582009105	0,54393374	0,508349292	0,475093	0,444011959	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09	1,73E+09

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_fire-PLL_fire cold)	value of life offshore		cost/ton	(PLL_fire-PLL_fire cold)	
Diff in PLL	0,00E+00	300000000		15000000	0,00E+00	3,08E+09
Diff in FAR		300000000				

Risk differences over 20 years

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_fire-PLL_fire cold)	value of life offshore			(PLL_fire-PLL_fire cold)	
Diff in PLL	0,00E+00	300000000	0,00E+00	15000000	0,00E+00	3,08E+09
Diff in FAR		300000000				

Diff in PLL	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in FAR	DeltaC_n1	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PLL	LCC_yearly	-1,61E+09	-1,51E+09	-1,41E+09	-1,32E+09	-1,23E+09	-1,15E+09	-1,07E+09	-1,00E+09	-9,39E+08	-8,77E+08	-8,20E+08	-7,66E+08	-7,16E+08	-6,69E+08	-6,26E+08	-5,85E+08	-5,46E+08	-5,11E+08	-4,77E+08	-4,46E+08
	LCC	-1,83E+10																			

Delta PLL over 20 years	0
Invest cost	0
O&M cost over 20 years	18285558835
Saved material cost	0

Cost per avoided loss of life	#DIV/0!	The total cost of an avoided loss of life is XXX billion NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	1613109717	1507579175	1408952500	1316778037	1230633680	1,15E+09	1,07E+09	1E+09	938844542	877424806	820023182,8	7,66E+08	716240005,9	6,69E+08	6,26E+08	5,85E+08	5,46E+08	5,11E+08	4,77E+08	4,46E+08

9.13 SOV

9.13.1 Explosion with SOV positions

Personell on decks		Use of SOV					
Weather deck:	4	Planned mai	48			48	
Intermediate deck, process area:	4	Critical corre	8			8	
Intermediate deck, utility area:	4						
Cellar deck, process area:	4		**Manning**	**Days/ year**	**Hour/ per day**	**Hours/ year**	kilde: CRA p. 23
Cellar deck, utility area:	4		Planned maintenance	48	11	528	
			Unplanned	8	11	88	0,076712
Assumed Explosionloads from process area and we	0,7 barg		Total	56		616	0,07028

Position	frequency [/year]	West	East	300 m
Case				
Evacuation due to explosion weather deck, gas				
Explosion size		Small	small	Small
Exceedence frequency		1,05E-06	1,05E-06	1,05E-06
Imediate fatalities		4	4	4
Probability of following fire		0	0	0
Explosion reaching utility area		No	No	No
Explosion reaching other decks		No	No	No
Evacuation fatalities		0	0	0
Impact on evacuation		0	0	0
Impairment of escape		0	0	0
Impairment of main load bearing structure		0	0	0
Impact on SOV		0	0	0
PLL		**4,22E-06**	**4,22E-06**	**4,22E-06**
FAR	**(PLL*10^8)/manning***	**0,034227**	**0,034227**	**0,034227**
Evacuation due to explosion weather deck, gas				
Explosion size		Medium	Medium	Medium
Exceedence frequency		2,811E-07	2,81E-07	2,81E-07

Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**1,12E-06**	**1,12E-06**	**1,12E-06**
Evacuation due to explosion weather deck, gas			
Explosion size	Large	Large	Large
Exceedence frequency	7,03E-08	7,03E-08	7,03E-08
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	Yes	Yes	Yes
Explosion reaching other decks	Yes	Yes	Yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	No	No	No
Impact on SOV	No	No	No
PLL	**5,62E-07**	**5,62E-07**	**5,62E-07**
Evacuation due to explosion weather deck, liquid			
Explosion size	Small	small	Small
Exceedence frequency	1,19E-07	1,19E-07	1,19E-07
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0

Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**4,779E-07**	**4,78E-07**	**4,78E-07**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Small	Small	Small
Exceedence frequency	1,27E-06	1,27E-06	1,27E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	No	No	No
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**5,06E-06**	**5,06E-06**	**5,06E-06**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Medium	Medium	Medium
Exceedence frequency	6,677E-07	6,68E-07	6,68E-07
Imediate fatalities	4	4	4
Probability of following fire	0,5	0,5	0,5
Explosion reaching utility area	No	No	No
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	4	4	4
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure			
Impact on SOV	No	No	No
PLL	**5,34E-06**	**5,34E-06**	**5,34E-06**

Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size	Large	Large	Large
Exceedence frequency	4,076E-07	4,08E-07	4,08E-07
Imediate fatalities	4	4	4
Probability of following fire	1	1	1
Explosion reaching utility area	yes	yes	yes
Explosion reaching other decks	yes	yes	yes
Evacuation fatalities	12	12	12
Impact on evacuation	No	No	No
Impairment of escape	No	No	No
Impairment of main load bearing structure	0,05	0,05	0,05
Impact on SOV	No	No	No
PLL	**6,522E-06**	**6,52E-06**	**6,52E-06**

Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Small	Small	Small
Exceedence frequency	1,757E-06	1,76E-06	1,76E-06
Imediate fatalities	4	4	4
Probability of following fire	0	0	0
Explosion reaching utility area	no	no	no
Explosion reaching other decks	No	No	No
Evacuation fatalities	0	0	0
Impact on evacuation	0	0	0
Impairment of escape	0	0	0
Impairment of main load bearing structure	0	0	0
Impact on SOV	0	0	0
PLL	**7,03E-06**	**7,03E-06**	**7,03E-06**

Evacuation due to explosion on intermediate deck, process area, liquid			
Explosion size	Medium	Medium	Medium
Exceedence frequency	9,84E-07	9,84E-07	9,84E-07
Imediate fatalities	4	4	4

9.13.2 CBA of SOV Positions

LCC of SOV at 300 m

	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0p^-n	0,934579439	0,873438728	0,816298	0,762895212	0,71298618	0,666342	0,62275	0,582009105	0,543933743	0,508349292	0,475093	0,444011959	0,41496445	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion_West - PLL_explosion_300m)	value of life offshore		cost/ton	(F(accident_west)-F(accident_300m))	
Diff in PLL	4,07E-07	300000000	0	15000000	0,011755	3,08E+09
Diff in FAR	3,00E-03	300000000				

Risk differences over 20 years

		Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
		(PLL_explosion_West - PLL_explosion_300m)	value of life offshore		cost/ton	(F(accident_west)-F(accident_300m))	
Diff in PLL		8,14E-06	300000000	0	15000000	0,2351	3,08E+09
Diff in FAR		6,00E-02	300000000				

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Diff in PLL	DeltaC_n1	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02	1,22E+02
Diff in FAR	DeltaC_n1	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05	9,00E+05
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07
	LCC_yearly	114,1121495	106,6468687	99,66997	93,14950539	87,0556125	81,36039	76,03774	71,06331167	66,41430997	62,06944857	58,00883	54,21386022	50,6671591	47,35249	44,25466	41,35949	38,65373	36,12498	33,76167	31,55296
	LCC	1293,529139																			

Cost difference of change from west to 300 m distance

LCC 1,29E+03 NOK

Will cost XXX million NOK.

Delta PLL over 20 years	0,00000814
Invest cost	0
O&M cost over 20 years	0
Cost per avoided loss of life	0

The total cost of an avoided loss of life is XXX trillions NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LCC of SOV at east position

	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0p^-n	0,934579439	0,873438728	0,816298	0,762895212	0,71298618	0,666342	0,62275	0,582009105	0,543933743	0,508349292	0,475093	0,444011959	0,41496445	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion_West - PLL_explosion_east)	value of life offshore		cost/ton	(F(accident_west)-F(accident_east))	
Diff in PLL	-7,63E-07	300000000	0	15000000	0,01176	3,08E+09
Diff in FAR	-6,00E-03	300000000				

Risk differences over 20 years

		Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
		(PLL_explosion_West - PLL_explosion_east)*20	value of life offshore		cost/ton	(F(accident_west)-F(accident_east))*20	
Diff in PLL		-1,53E-05	300000000	0	15000000	0,2352	3,08E+09
Diff in FAR		-1,20E-01	300000000				

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Diff in PLL	DeltaC_n1	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02	-2,29E+02
Diff in FAR	DeltaC_n1	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06	-1,80E+06
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07	3,62E+07
	LCC_yearly	-213,9252336	-199,9301249	-186,8506	-174,626714	-163,20254	-152,5257	-142,5474	-133,221884	-124,5064337	-116,361153	-108,7487	-101,6343375	-94,985362	-88,77137	-82,96389	-77,53635	-72,46388	-67,72325	-63,29276	-59,15211
	LCC	-2,42E+03																			

Cost difference of change from west to east

LCC -2,42E+03 NOK

Will cost XXX million NOK.

Delta PLL over 20 years	-0,00001526
Invest cost	0
O&M cost over 20 years	0
Cost per avoided loss of lif	0

The total cost of an avoided loss of life is 1,23 trillions NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

9.14 Deluge System

9.14.1 Explosion with Deluge System

Case		90% reduction, adjusted for manning	90% reduction
Evacuation due to explosion weather deck, gas			
Explosion size		Small	small
Exceedence frequency		1,05E-07	1,50E-06
Imediate fatalities		4	4
Probability of following fire		0	0
Explosion reaching utility area		No	No
Explosion reaching other decks		No	No
Evacuation fatalities		0	0
Impact on evacuation		0	0
Impairment of escape		0	0
Impairment of main load bearing structure		0	0
Impact on SOV		0	0
PLL		**4,22E-07**	**6,00E-06**
FAR	**(PLL*10^8)/manning***	**0,003422704**	**0,048701299**
Evacuation due to explosion weather deck, gas			
Explosion size		Medium	Medium
Exceedence frequency		2,81118E-08	4,00E-07
Imediate fatalities		4	4
Probability of following fire		0,5	0,5
Explosion reaching utility area		No	No
Explosion reaching other decks		No	No
Evacuation fatalities		0	0
Impact on evacuation		0	0
Impairment of escape		0	0
Impairment of main load bearing structure		0	0
Impact on SOV		0	0
PLL		**1,12E-07**	**1,60E-06**
Evacuation due to explosion weather deck, gas			
Explosion size		Large	Large
Exceedence frequency		7,03E-09	1,00E-07
Imediate fatalities		4	4
Probability of following fire		1	1
Explosion reaching utility area		Yes	Yes
Explosion reaching other decks		Yes	Yes
Evacuation fatalities		0	0
Impact on evacuation		No	No
Impairment of escape		No	No
Impairment of main load bearing structure		No	No
Impact on SOV		No	No
PLL		**2,81E-08**	**4,00E-07**
Evacuation due to explosion weather deck, liquid			
Explosion size		Small	small
Exceedence frequency		1,19E-08	1,70E-07
Imediate fatalities		4	4
Probability of following fire		0	0
Explosion reaching utility area		No	No
Explosion reaching other decks		No	No
Evacuation fatalities		0	0
Impact on evacuation		0	0
Impairment of escape		0	0
Impairment of main load bearing structure		0	0
Impact on SOV		0	0
PLL		**4,77901E-08**	**0,00000068**
Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size		Small	Small
Exceedence frequency		1,27E-07	1,80E-06
Imediate fatalities		4	4
Probability of following fire		0	0
Explosion reaching utility area		No	No
Explosion reaching other decks		No	No
Evacuation fatalities		0	0
Impact on evacuation		0	0
Impairment of escape		0	0
Impairment of main load bearing structure		0	0
Impact on SOV		0	0
PLL		**5,06E-07**	**7,20E-06**
Evacuation due to explosion on intermediate deck, process area, gas			
Explosion size		Medium	Medium
Exceedence frequency		6,67655E-08	9,50E-07
Imediate fatalities		4	4
Probability of following fire		0,5	0,5
Explosion reaching utility area		No	No
Explosion reaching other decks		yes	yes
Evacuation fatalities		0	0
Impact on evacuation		No	No
Impairment of escape		No	No
Impairment of main load bearing structure			
Impact on SOV		No	No
PLL		**2,67E-07**	**3,80E-06**

Evacuation due to explosion on intermediate deck, process area, gas

Explosion size	Large	Large
Exceedence frequency	4,07621E-08	5,80E-07
Imediate fatalities	4	4
Probability of following fire	1	1
Explosion reaching utility area	yes	yes
Explosion reaching other decks	yes	yes
Evacuation fatalities	0	0
Impact on evacuation	No	No
Impairment of escape	No	No
Impairment of main load bearing structure	0,05	0,05
Impact on SOV	No	No
PLL	**1,63048E-07**	**0,00000232**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Small	Small
Exceedence frequency	1,76E-07	2,50E-06
Imediate fatalities	4	4
Probability of following fire	0	0
Explosion reaching utility area	no	no
Explosion reaching other decks	No	No
Evacuation fatalities	0	0
Impact on evacuation	0	0
Impairment of escape	0	0
Impairment of main load bearing structure	0	0
Impact on SOV	0	0
PLL	**7,03E-07**	**1,00E-05**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Medium	Medium
Exceedence frequency	9,84E-08	1,40E-06
Imediate fatalities	4	4
Probability of following fire	0,5	0,5
Explosion reaching utility area	No	No
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Impact on evacuation	No	No
Impairment of escape	No	No
Impairment of main load bearing structure		
Impact on SOV	No	No
PLL	**3,94E-07**	**5,60E-06**

Evacuation due to explosion on intermediate deck, process area, liquid

Explosion size	Large	Large
Exceedence frequency	5,62E-08	8,00E-07
Imediate fatalities	4	4
Probability of following fire	1	1
Explosion reaching utility area	Yes	Yes
Explosion reaching other decks	yes	yes
Evacuation fatalities	0	0
Impact on evacuation	No	No
Impairment of escape	No	No
Impairment of main load bearing structure	0,05	0,05
Impact on SOV	No	No
PLL	**2,25E-07**	**3,20E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Small	Small
Exceedence frequency	1,27E-07	1,80E-06
Imediate fatalities	4	4
Probability of following fire	0	0
Explosion reaching utility area	No	No
Explosion reaching other decks	No	No
Evacuation fatalities	0	0
Impact on evacuation	0	0
Impairment of escape	0	0
Impairment of main load bearing structure	0	0
Impact on SOV	0	0
PLL	**5,06E-07**	**7,20E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Medium	Medium
Exceedence frequency	6,67655E-08	9,50E-07
Imediate fatalities	4	4
Probability of following fire	0,5	0,5
Explosion reaching utility area	No	No
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Impact on evacuation	NO	NO
Impairment of escape	No	No
Impairment of main load bearing structure	No	No
Impact on SOV	No	yes
PLL	**2,67E-07**	**3,80E-06**

Evacuation due to explosion on cellar deck, process area, gas

Explosion size	Large	Large
Exceedence frequency	4,07621E-08	5,80E-07

Imediate fatalities	4	4
Probability of following fire	1	1
Explosion reaching utility area	Yes	Yes
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Impact on evacuation	Yes	Yes
Impairment of escape	No	No
Impairment of main load bearing structure	0,05	0,05
Impact on SOV	No	No
PLL	**1,63048E-07**	**2,32E-06**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Small	Small
Exceedence frequency	1,76E-07	2,50E-06
Imediate fatalities	4	4
Probability of following fire	0	0
Explosion reaching utility area	No	No
Explosion reaching other decks	No	No
Evacuation fatalities	0	0
Impact on evacuation	0	0
Impairment of escape	0	0
Impairment of main load bearing structure	0	0
Impact on SOV	0	0
PLL	**7,03E-07**	**1,00E-05**

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Medium	Medium
Exceedence frequency	9,84E-08	1,40E-06
Imediate fatalities	4	4
Probability of following fire	0,5	0,5
Explosion reaching utility area	No	No
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Impact on evacuation	0,007	0,007
Impairment of escape	0	0
Impairment of main load bearing structure	0,007	0,007
Impact on SOV	0,007	0,007
PLL	**3,94E-07**	**5,60E-06**
FAR		

Evacuation due to explosion on cellar deck, process area, Liquid

Explosion size	Large	Large
Exceedence frequency	5,62E-08	8,00E-07
Imediate fatalities	4	4
Probability of following fire	1	1
Explosion reaching utility area	Yes	Yes
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Impact on evacuation	0,007	0,007
Impairment of escape	0	0
Impairment of main load bearing structure	0,007	0,007
Impact on SOV	0,007	0,007
PLL	**2,25E-07**	**3,20E-06**

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea

Explosion size	Medium	Medium
Exceedence frequency	9,84E-08	1,40E-06
Imediate fatalities	4	4
Probability of following fire	0,5	0,5
Explosion reaching utility area	No	No
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Escape fatalities	12	12
Tail wind	0,092	0,092
Probability of fire at sea given an exploson with a following fire	0,5	0,5
Impact on evacuation	0,007	0,007
Impairment of escape	2,263E-09	2,263E-09
Impairment of main load bearing structure	0,007	0,007
Impact on SOV	0,007	0,007
PLL	**4,21E-07**	**5,63E-06**
FAR		

Evacuation due to explosion on cellar deck, process area, Liquid, with fire at sea

Explosion size	Large	Large
Exceedence frequency	5,62E-08	8,00E-07
Immediate fatalities	4	4
Probability of following fire	1	1
Explosion reaching utility area	Yes	Yes
Explosion reaching other decks	Yes	Yes
Evacuation fatalities	0	0
Escape fatalities	6	6
Tail wind	0,092	0,092
Probability of fire at sea given an exploson with a following fire	0,5	0,5
Impact on evacuation	0,007	0,007
Impairment of escape	2,263E-09	2,263E-09
Impairment of main load bearing structure	0,007	0,007
Impact on SOV	0,007	0,007
PLL	**2,38E-07**	**3,21E-06**

SUM PLL		5,78E-06	8,18E-05
FAR	(PLL*10^8)/manning*	0,046947861	0,663642322

9.14.2 Fire with Deluge System

Fire after empty pipes 90% reduction 0,1

Major gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00 No				K1	H1	3,09E-05	0	0	0	0	0	0	0	0	0	0,00E+00
	9,833E-01 No				1,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		0,00E+00 yes	1,00E+00 No		0,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				1,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
3,14E-05			0,00E+00 Yes	0,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
			8,53E-01 No		9,50E-01 No	K6	H6	4,25E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,27E-06
	1,67E-02 yes				5,00E-02 Yes	K7	H7	2,24E-08	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	6,71E-08
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	7,71E-08	0	0	0	1	0	0	1	4	0	Is already a
								3,14E-05										
															PLL			1,34E-06

Medium gas leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		1,00E+00 No				K1	H1	2,11E-05	0	0	0	0	0	0	0	0	0	0,00E+00
	9,833E-01 No				1,00E+00 No	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		0,00E+00 yes	1,00E+00 No		0,00E+00 Yes	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
				1,00E+00 No		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
2,15E-05			0,00E+00 Yes	0,00E+00 Yes		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
			8,53E-01 No		9,50E-01 No	K6	H6	2,91E-07	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,73E-07
	1,67E-02 yes				5,00E-02 Yes	K7	H7	1,53E-08	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,59E-08
				0,00E+00 No		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01 Yes	1,00E+00 Yes		K9	H9	5,28E-08	0	0	0	1	0	0	1	4	0	Is already a
								2,15E-05										
															PLL			9,19E-07

Major oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
		No																
	0,000E+00				0,00E+00	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
	No		0,00E+00		No													
		1,00E+00	No		1,00E+00	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		yes			Yes													
				0,00E+00		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00	No														
			Yes	1,00E+00		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
4,55E-05				Yes														
					9,50E-01	K6	H6	3,69E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	1,11E-04
			8,53E-01		No													
	1,00E+00		No		5,00E-02	K7	H7	1,94E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	5,82E-06
	yes				Yes													
				0,00E+00		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01	No														
			Yes	1,00E+00		K9	H9	6,69E-06	0	0	0	1	0	0	1	4	0	Is already a
				Yes														
								4,55E-05										
															PLL			1,16E-04

Medium oil leak	Internal ignition	External ignition	Escalation to other equipmen due to explosion	Spreading to other area due to exploision	Significant escalation to other equipment due to fire	End event			Impairment of		Escalation		Impairment of			Imideate fatalities	Evacuation fatalities	PLL
						Nr.	Gruping	Frequency	Utility fire	Process fire	Process - fire	Process - expl.	W2W landing/SOV fire	Main load bearing strucutre - fire	W2W landing/SOV - explo.			
		0,00E+00				K1	H1	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
		No																
	0,000E+00				0,00E+00	K2	H2	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
	No		0,00E+00		No													
		1,00E+00	No		1,00E+00	K3	H3	0,00E+00	0	0	1	0	0	0	0	0,00E+00	0	0,00E+00
		yes			Yes													
				0,00E+00		K4	H4	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,00E+00	No														
			Yes	1,00E+00		K5	H5	0,00E+00	0	0	0	1	0	0	1	0,00E+00	0	0,00E+00
3,30E-05				Yes														
					9,50E-01	K6	H6	2,67E-05	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	8,02E-05
			8,53E-01		No													
	1,00E+00		No		5,00E-02	K7	H7	1,41E-06	0,225937	0,75	0,05	0	0,2	0,05	0	4	0	4,22E-06
	yes				Yes													
				0,00E+00		K8	H8	0,00E+00	0	0	0	0	0	0	0	0	0	0,00E+00
			1,47E-01	No														
			Yes	1,00E+00		K9	H9	4,85E-06	0	0	0	1	0	0	1	4	0	Is already a
				Yes														
								3,30E-05										
															PLL			8,44E-05

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of		Imideate fatalities	Evacuation fatalities	PLL
				W2W landing/SOV fire	Main load bearing strucutre - fire			
Pump, cooling-, Water injection, vent, and scrubber								
		0						
		Yes				0	0	0,00E+00
4	1,1409E-10							
		No						
		1		0	0	0	0	0
				PLL				0

Component	Internal ignition	Spreading to other equipment	Impairment of escape routes	Impairment of		Immideate fatalities	Evacuation fatalities	PLL
Pump, oil export			Prosess fire	W2W landing/SOV fire	Main load bearing strucutre - fire			
		9,50E-01	0	0,2	0,05	0	0	0,00E+00
		No						
1	1,1409E-10	5,00E-02	0,75	0,2	0,05	4	0	2,28E-11
		Yes						
				PLL				2,28E-11

SUM PLL of Fire 2,03E-04

9.14.3 CBA of Deluge System

LCC of Deluge System

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	N	20																			
	p	1,07																			
	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1,0+p^-n	0,93457944	0,873438728	0,816297877	0,762895212	0,712986	0,666342	0,62275	0,582009105	0,54393374	0,508349292	0,475093	0,444011959	0,414964	0,387817	0,362446	0,338735	0,316574	0,295864	0,276508	0,258419
	IC_n	51300000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RC_n	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000	214000

Risk differences

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion_west-PLL_explosion_Deluge_90%_manned)+(PLL_fire-PLL_fire_90%)	value of life offshore		cost/ton	(PLL_explosion_base case_SSIV-PLL_explosion_Deluge_90%)+ (PLL_fire-PLL_fire_90%)	
Diff in PLL	1,92E-03	300000000		15000000	3,16E-03	3,08E+09
Diff in FAR	2,13E-03	300000000				
	2,09E-04					

Risk differences over 20 years

	Difference in risk to personnel	Valuation	Diff. environment risk	Valuation	Diff. asset risk	Valuation
	(PLL_explosion_west-PLL_explosion_Deluge_90%_manned)+(PLL_fire-PLL_fire_90%)*20	value of life offshore		cost/ton	(PLL_explosion_base case_SSIV-PLL_explosion_Deluge_90%)+ (PLL_fire-PLL_fire_90%)*20	
Diff in PLL	3,84E-02	300000000	0,00E+00	15000000	6,31E-02	3,08E+09
Diff in FAR		300000000				

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Diff in PLL	DeltaC_n1	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05	5,76E+05
Diff in FAR	DeltaC_n1	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05	6,39E+05
Diff in environment	DeltaC_n2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diff in assets	DeltaC_n3	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06	9,71E+06
PLL	LCC_yearly	-3,85E+07	8,80E+06	8,22E+06	7,68E+06	7,18E+06	6,71E+06	6,27E+06	5,86E+06	5,48E+06	5,12E+06	4,78E+06	4,47E+06	4,18E+06	3,91E+06	3,65E+06	3,41E+06	3,19E+06	2,98E+06	2,78E+06	2,60E+06
	LCC	5,87E+07																			

Delta PLL over 20 years	0,0384084
Invest cost	51300000
O&M cost over 20 years	2267119
Saved material cost	194171008
Cost per avoided loss of life	-3,66E+09

The total cost of an avoided loss of life is 5 billion NOK over 20 years.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discounted O&M cost	200000	186915,888	174687,7457	163259,5754	152579,0424	142597,2	133268,4	124549,9	116401,8209	108786,749	101669,8584	95018,56	88802,39185	82992,89	77563,45	72489,2	67746,92	63314,88	59172,78	55301,67

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Evaluation of Safety Systems at an Unmanned Production Platform

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