Worst Credible Process Fire: Experiences from the Norwegian Petroleum Industry

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Abstract
The term Worst Credible Process Fire (WCPF) was introduced to the Norwegian Petroleum Industry as a complement to the probabilistic approach to define design loads for offshore facilities. Currently there are mainly two documents about the WCPF being the SINTEF report (2017) and the definition in NORSOK S-001 (2018). The WCPF concept have only been used within the industry for a few years and combined with the limited literature there might be some challenges that need to be considered. To investigate this, interviews were held with safety experts from various actors within the industry. With these interviews it was possible to address what the challenges are and if the perspectives vary within the industry. Similar concepts such as worst-case scenarios, maximum credible scenarios and worst maximum credible scenarios were also studied as a complement to the interview study. The thesis found that some of the main challenges were subjectivity in scenario selection, lack of probability perspective and limited documentation for heat loads, temperatures and fire duration.

The thesis concluded that the view of the WCPF was not unified as the PSA is asking what is done and the industry how it is done. New companies did not seem to be unfairly affected by the limited literature in comparison to older companies. There were also some disagreements within the industry on how to approach the analysis. Variations within the industry could be approached in three separate ways, being transparency, standard methods and further clarification of the WCPF. Currently the literature surrounding WCPF could be considered enough but could be improved with additional clarifications. Lastly, the way barriers are credited in the WCPF could be improved and more justifiable with a higher focus on barrier management.

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Best regards: Linnéa Tengvall, Stavanger 2019

A. ABBREVIATIONS

ARAMIS	Accidental Risk Assessment Methodology for Industries
BD	Blowdown
CCR	Central Control Room
EDP	Emergency Depressurisation
ESD	Emergency Shutdown
HC	Hydrocarbon
HSE	Health Safety and Environment
MIMAH	Methodology for the Identification of Major Accident Hazards
MIRAS	Methodology for the Identification of Reference Accident Scenarios
MCS	Maximum Credible Scenario
PDCA	Plan Do Check Act
PFP	Passive Fire Protection
PSA	The Petroleum Safety Authority Norway
PSD	Process Safety
RAS	Representative Accident Scenario
SSIV	Sub Sea Isolation Valve
WAS	Worst Accident Scenario
WCPF	Worst Credible Process Fire
WCS	Worst Case Scenario
WMCAS	Worst Maximum Credible Accidental Scenarios

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1 INTRODUCTION

1.1 THE NORWEGIAN OIL AND GAS INDUSTRY

In 2018 there were about 39 active companies on the Norwegian shelf (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019b). 25 of them were operators while the remaining were production licensees. Different companies can share a production license but only one is made the operator. The shared licence makes it possible for smaller companies to learn from bigger ones with more experience (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019b).

The number of companies have become lower in recent years. It is a global trend and is the result of companies being bought up or joined together as a response to a more uncertain market. Still, new companies are entering the Norwegian oil industry and have proportionally increased their production. Production from international companies has instead decreased, though is still proportionally large (Norwegian Petroleum Directorate, 2019c). The main product in Norway has been liquid oil but gas production has gotten bigger and now represent over half of the total production (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019a).

The operator is responsible for assuring that the rules and regulations are followed (Petroleum Safety Authority Norway, 2017b, pp. 5-7). The Petroleum Safety Authority Norway (PSA) sets the regulations, control if standards are acceptable and supervise the Norwegian Continental Shelf (NCS). The supervision responsibility covers operators, licensees, entrepreneurs and shipowners (Petroleum Safety Authority Norway, 2017b, pp. 9-11).

The regulations are function and risk based, and cover health, safety and environmental (HSE) risk. The central regulations in this thesis were the Framework Regulations, Facilities Regulations and Management Regulations which cover everything from design of facilities, risk reduction principles and barrier management. These regulations are legally binding, and a principle stated in one of the regulations will apply to the rest of them.

The industry has been based on a probabilistic approach to risk. This has since shifted to view risk in the form of uncertainty. The probabilistic approach is still very prominent and used as a basis when designing platforms. The Facilities Regulations include probabilistic criteria that states the platform shall be able to withstand accidental loads with certain statistical return periods, typically 1/10 000 years[1]. Fires with lower probabilities does not need to be reflected in the design. As systems are getting safer, the probabilities for accidents get lower. This can cause areas to be without fires above the 1/10 000 years threshold, meaning there is not a fire that can be used for design basis. This causes a problem since facilities technically do not need to reflect a possible fire when designing these areas.

The PSA wants the focus to be on robust design solutions. To complement the probabilistic approach, a new term was introduced called the Worst Credible Process Fire (WCPF). The WCPF is a new tool to define accidental loads for design of facilities. Probability is not explicit in this definition. Instead of calculating failure rates of barriers and ignition rates the WCPF assumes complete functionality of some barriers while other barriers remain uncredited. In probabilistic terms this can be viewed as some barriers being given a failure rate of 0% and others 100%. The barriers' assumed functionality is then the main factor in how credibility is considered with this approach.

[1] This is known as the "10^{-4} requirement"

1.2 THESIS PROCESS

This thesis was reworked as it was written which affected the scope and question formulations. Still, the original plan is important to disclose.

The first step was understanding the Norwegian Petroleum Industry, which includes rules and regulations, active actors, the offshore process system and safety systems. For those already active in the industry this would already be known. For me, this thesis was my first look at the petroleum industry.

The second step was understanding the main topic *Worst Credible Process Fire (WCPF)*. The literature surrounding WCPF was and still is quite limited. Because of this, interviews were scheduled with various experts in the industry (consultants, engineers and operators) and the Petroleum Safety Authority Norway (PSA). The result from these interviews was then used as a basis for problem scanning and to identify the main question formulation. Parallel to the interviews a literature study of similar topics was made to gain insight on how similar concepts are defined and used in the chemical process industry.

The main topics that were considered as the main question formulation were:

- The variation in how cut-off rates[2] are chosen and how this variation can be more contained.
- Inconsistencies on how barriers are credited and the reliability of credited barriers, mainly concerning the fire, water system and the drain system.
- How new and international companies work with the WCPF definition considering that they were not part of the discussion as the concept was invented, and the limited literature.

The topic that ended up being chosen was how new and international companies handled the WCPF definition. Considering that the Norwegian Petroleum Industry has seen an increase in new smaller companies in recent years this perspective seemed relevant. New companies with various backgrounds were then contacted for more interviews. The original thesis plan can be seen in Figure 1.

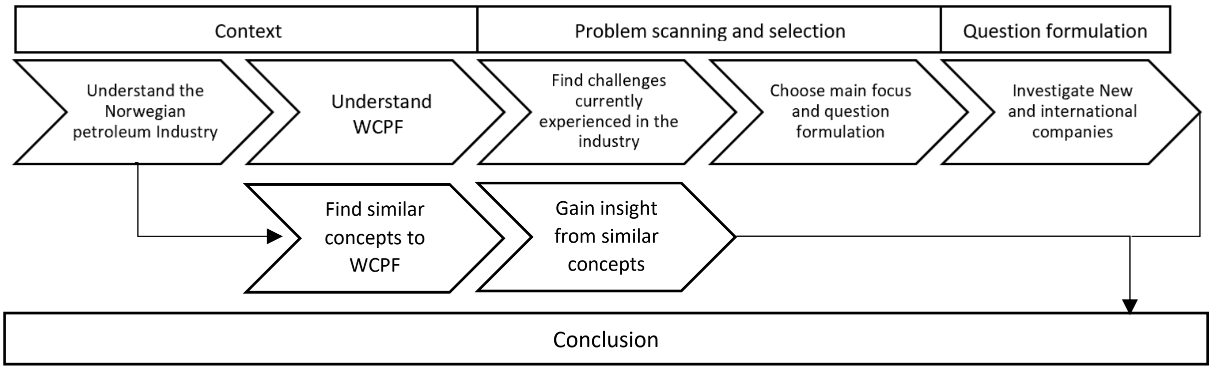

Figure 1: Original thesis plan

The thesis was then reworked due to limited time and few responses from new and international companies. The initial interviews and the literature study were already made and gave a strong foundation for the thesis, but the focus needed to change. In the end two safety experts from new

[2] The cut-off rate is the leak rate of hydrocarbons of which the corresponding fire is evaluated not to be critical to the structure anymore.

companies were interviewed. One company did have an international background but the focus became mainly on the smaller size and age of these two companies.

This was not considered enough as an own section and the cut-off rates and barriers were also further investigated. The consultants were contacted to discuss the variation of cut-off rate selection and the operators to discuss the historical reliability of the fire water and drain system. The final thesis process can be seen in Figure 2.

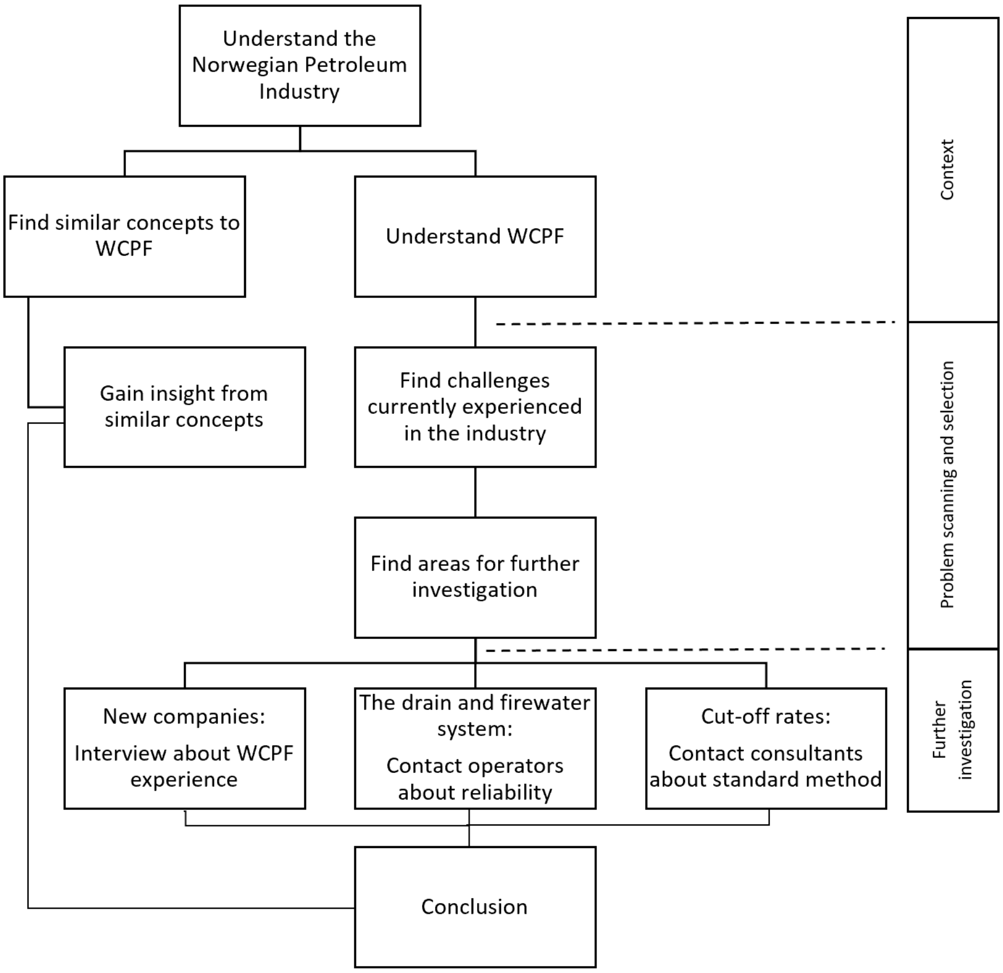

Figure 2: Final thesis process

1.3 SCOPE AND LIMITATIONS

WCPF is used, being the Norwegian Petroleum Industry, is very broad and the context is crucial to understanding the fundamental standpoints the industry is based on. It is impossible to cover this entire context, but this thesis covered A WCPF scenario takes place in the process segment of an offshore facility. Because of this, other areas of the facilities were not as explored. Risers[3] and wells were discussed though.

The context in which the relevant background information of the industry in Chapter 2 and in Appendix A and B.

[3] Subsea pipeline for hydrocarbons from the seabed to the installation.

The literature study of similar concepts looked at the chemical process industry but not at the nuclear industry. A total of 9 interviews are not enough for statistical significance since the respondents have various roles within the industry. Rather the interviews cover the main concerns and challenges from different perspectives. Positive aspects of the WCPF might not be as highlighted in this thesis since the initial goal was to identify the main challenges.

In the end these became the question formulations this thesis aimed to answer:

> *What are the experienced challenges when working with WCPF? Does the industry and the PSA have a united view on the WCPF and its challenges?*
>
> *How can possible variations in the industry be addressed?*
>
> *Is the current definition and literature surrounding WCPF adequate considering the importance of the analysis?*
>
> *Are new companies affected by the limited literature differently?*
>
> *Are barriers credited in a consistent and reliable way?*

1.4 READING GUIDE

Considering the possible variation of knowledge about the Norwegian Petroleum Industry a small reading guide is provided below. Those who are very unfamiliar with the offshore process system and the Norwegian Petroleum Industry can also view Appendix A and B.

> Chapter 2: Covers the context of this thesis and briefly describes the risk management in the Norwegian Petroleum Industry and the relevant safety systems.
>
> Chapter 3: Covers the methodology for this entire thesis.
>
> Chapter 4: Covers the WCPF specific literature and context, and the literature study of similar concepts.
>
> Chapter 5: The interview result for the initial six interviews and the PSA.
>
> Chapter 6: Includes the result of the further investigated topics, being cut-off rates, the drain- and fire water system and new companies.
>
> Chapter 7: Discussion and conclusion.
>
> Chapter 8: Proposals for further work.

2 RISK MANAGEMENT IN THE NORWEGIAN PETROLEUM INDUSTRY

Below is a brief description on risk management within the Norwegian oil industry. In Appendix A there is more information about the process and technical safety systems. In Appendix B there is additional information about uncertainty, risk and barrier management and rules and regulations.

2.1 PROCESS RISKS AND SAFETY SYSTEMS

This thesis investigated hydrocarbon (HC) fires from the process segments of an offshore facility among with barriers that aim to contain leaks and fires. In the case of WCPF, process vessels with large HC volumes like separators and coalesces are especially hazardous. Large gas volumes in certain gas segments could also be dangerous if leaked and ignited. There are many barriers and safety systems on an offshore facility, however all these barriers are not discussed in this thesis. Table 1 below shows the relevant safety systems.

Table 1: Overview of safety systems, information taken from NORSOK S-001.

Relevant safety systems		
System	**Function**	**Credited in WCPF analysis**
Open Drain and Bunding	Limits consequences - by limiting HC volume and spreading of oil. Passive barrier.	Credited
Passive Fire Protection (PFP)	Limits consequences - by avoiding damage on equipment and structures. Passive barrier.	Credited
Detection System	Detection - detects heat, gas and smoke also activates the ESD- EPD- and PSD system.	Assumed credited
Emergency Depressurisation (EDP) (also referred to as Blowdown (BD) System)	Limits consequences - by reducing inventory and pressure. Active barrier.	Credited
Process Safety (PSD) System	Lowers probability of accident - by ensuring process conditions do not exceed the safety limits. Active barrier.	Not credited
Fire Water System	Limits consequences - by limiting fires and explosions and cools structures and equipment. Active barrier.	Not credited
Emergency Shutdown (ESD) System	Limits consequences - by dividing and isolating process segments. Active barrier.	Credited

2.2 RISK CONCEPT IN THE NORWEGIAN PETROLEUM INDUSTRY

Traditionally risk has had a probability-based definition where the consequences and the likelihood of an event describes the risk. This has since changed to incorporate uncertainty.

The International Organization for Standardization (ISO) changed their definition to "*Risk is the effect of uncertainty on objectives*". The Norwegian Petroleum Safety Authority followed this change with the current definition of *"Risk means the consequences of the activity with associated uncertainty"* (Hafver, et al., 2015, p. 779).

This change was motivated by three main arguments as described by Hafver, Lindberg, Jakopanec, Pedersen, Flage and Aven (2015, p. 780). The arguments being:

- There are more ways to quantify uncertainty than with probabilities.
- Probabilities do not disclose their strength-of-knowledge[4] when used.
- More types of probabilities than frequentist probabilities are relevant to risk assessments.

When going from risk as a concept to risk assessments, risk representation, and later risk measures there will always be assumptions and uncertainty. There will be risks outside the scope of a risk analysis and errors and in the models used, the strength-of-knowledge in the assessment and models are therefore important to disclose (Hafver, et al., 2015, pp. 780-783). Figure 3 shows a Venn diagram of how each level in the risk assessment process is unable to cover the entirety of the level above (Hafver, et al., 2015, p. 780).

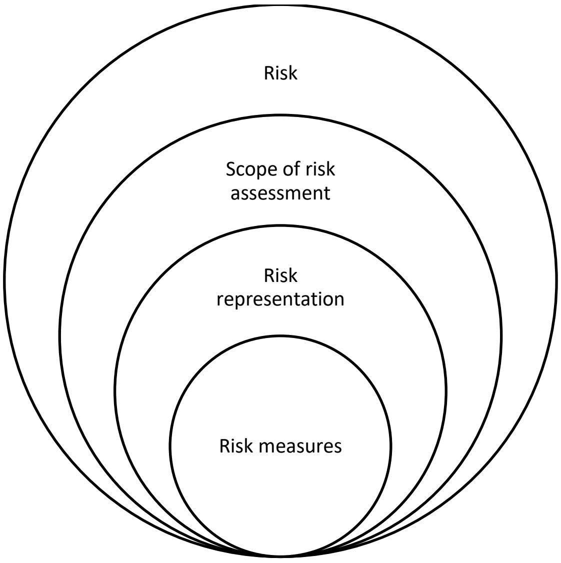

Figure 3: Venn diagram of risk and the risk assessment process. Based on the figure in "Risk—from concept to decision making" by Hafver, et al. (2015) p. 780.

The approach to uncertainty in risk assessments can be probabilistic or deterministic. The difference between them mainly being that a deterministic approach uses a representative scenario and does not consider probability. A probabilistic approach addresses variation and frequency with probabilistic models (Paté-Cornell, 1996; Aven, Baraldi, Flage, & Zio, 2014). The differences between deterministic and probibalistic approaches is further explained in Appendix B. The WCPF is an example of a deterministic approach in contrast to the probabilistic approach commonly used in the industry.

2.3 THE PROBABILISTIC FRAMING OF NORWEGIAN REGULATIONS

The Norwegian Petroleum Industry has historically used a probabilistic approach to risks as a basis for designing offshore facilities (Falck & Skramstad, 2000). The probabilistic framing of the Norwegian regulations can be seen in the Management Regulations (Chapter 5, Section 17) where analysing accident sequences and consequences is mandatory in risk assessments. It can also be seen in the Facilities Regulation (Chapter 3, Section 11 & Chapter 10, Section 56) where the load bearing structures are required to withstand loads of a likelihood greater than 10^{-2}/year and main safety functions withstanding accidental loads of higher likelihoods than 10^{-4}/year. This probabilistic basis is important to remember when introducing a deterministic approach such as the WCPF.

[4] A means to quantify uncertainty for assumptions, models and conclusions in risk analyses.

2.4 HIERARCHY OF THE RULES AND REGULATIONS

The rules and regulations are built up in a hierarchy where acts, laws and regulations are legally binding, and guidelines and standards aim to support the responsible party to fulfil the legal requirements, see Figure 4 (Petroleum Safety Authority Norway, 2019b, pp. 25, 27; Petroleum Safety Authority Norway, 2019e). A company can therefore decide to not follow a standard if their solution comply with the legally binding documents. The requirements are function based rather than purely technical. This allows more flexibility to fulfil the requirements and the regulations are not in constant need of updates due to technological advancements (Petroleum Safety Authority Norway, 2017b, p. 25).

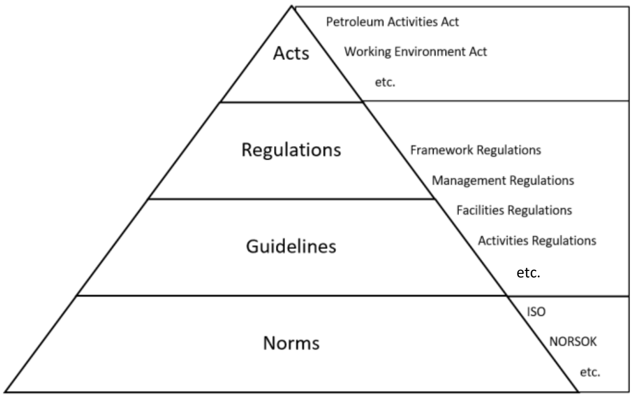

Figure 4: A triangular hierarchy showing how the offshore safety regulations are built up with some examples to the right. Acts and regulations are legally binding while norms and guidelines support to meet these requirements.

2.5 PRINCIPLES AND REQUIREMENTS

All principles and requirements will not be discussed in this thesis. The most relevant principles are the risk reduction principles from the Framework Regulations (Chapter 2, Section 11). In terms of requirements the most relevant are the main safety functions from the Facilities Regulations (Section 7, Chapter 2) and requirements regarding barriers from the Management Regulations (Section 5).

Risk reduction principles

- *Risk reduction shall be taken as far as possible to limit the harm to people, the environment or material assets.*
- *The responsible party shall pick solutions that give the best results granted that the cost benefit is not disproportionate.*
- *Solutions that lower the uncertainty if there is insufficient knowledge shall be chosen.*
- *Factors with the potential of harm shall be replaced with factors with less harmful potential.*

<u>*Main safety functions*</u>

The following functions shall be maintained in the event of an accident:

- *“preventing escalation of accident situations so that personnel outside the immediate accident area are not injured,*
- *the capacity of main load-bearing structures until the facility has been evacuated,*
- *protecting rooms of significance to combatting accidents so that they remain operative until the facility has been evacuated,*
- *protecting the facility's safe areas so that they remain intact until the facility has been evacuated,*
- *at least one escape route from every area where personnel are found until evacuation to the facility's safe areas and rescue of personnel have been completed.”*

<u>*Barrier management*</u>

Barriers shall always be able to:

- *“Identify conditions that can lead to failures, hazard and accident situations,*
- *reduce the possibility of failures, hazard and accident situations occurring and developing,*
- *limit possible harm and inconveniences.”*

2.6 DESIGN AND DIMENSIONING LOADS

The Facilities Regulations (Section 3 and 11) describe design loads and dimensioning loads that are used as a basis when designing a facility. The loads can vary from installation to installation since they are not fixed values. The dimensioning load is the load that corresponds to the likelihood of 10^{-4} per year. The design load needs to at least cover the dimensioning load but is usually slightly larger for additional robustness and to account for uncertainty. If the uncertainty is high the gap between the dimensioning load and design load will be increased. The design load is then used as the basis for designing the facility.

The main thing to note is that up until recently the main method to decide the design loads and dimensioning loads have been probabilistic due to the probabilistic criteria of 10^{-4} per year. The WCPF is now entirely a deterministic approach to determine dimensioning and design loads.

3 METHODOLOGY

Two methods were used to investigate WCPF, being a literature study of similar concepts and interviews. Both the study of similar concepts and the interviews were motivated by the limited literature. The term WCPF has its roots in concepts commonly used in the chemical process industry and nuclear industry. It was therefore deemed useful to investigate the "relatives" of the WCPF. Interviews also provided practical experiences from the industry. This allowed a better understanding of the WCPF and a basis for problem screening. The nuclear industry was though not investigated in this thesis.

3.1 LITERATURE STUDY OF SIMILAR CONCEPTS

Keywords were put in to three academic databases to perform the study of similar concepts. These databases were:

- LUBsearch
- Oria
- Google scholar

Regular google searches were also used. The motivation behind these regular searches were that many health, safety and environmental organisations among with chemical process organisations have official websites and that these websites might have relevant information. The mostly used keywords in the academic databases and google were:

- Worst credible
- Maximum credible
- Worst credible scenario
- Maximum credible scenario
- Maximum credible accident
- Worst accident scenario
- Worst-case scenario

The results of these keywords would then be scanned based on first the title and then the abstract. In the Oria database and LUBsearch some filters were also used. These filters focused on risk management, chemical engineering and the petroleum industry. The relevance of the articles from the databases was decided based on two factors:

- Does it explain the general setup[5] of the accident scenario?
- Does it explain how the concept can/should be used?

Most of the sources appeared multiple times for different keyword searches. In the end the literature study was mainly limited to these re-occurring sources. This was a deliberate choice party to limit the scope of the thesis but also because these re-occurring sources were deemed the most relevant.

One source was found through a different approach. This source was *"ARAMIS project: A comprehensive methodology for the identification of reference accident scenarios in process industries*" by Delvosalle, Fievez, Pipart, & Debray (2006). This source was found through the article *"Worst maximum credible accidental scenarios (WMCAS) - A new methodology to identify accident scenarios*

[5] The conditions the accident scenario is based on, such as leak volume, barriers, probability etc.

for risk assessment" by Zhang, Zhao, Wang, Yuan, & Cheng (2017). I decided to view the original source since it was used as a basis for the Worst Maximum Credible Accidental Scenarios methodology.

3.1.1 Error sources in literature study

There are many more similar concepts that could have been investigated. It is possible that a larger literature study would find concepts even closer related to the WCPF. By extension a larger literature study could then give more tailored method suggestions and advice. The screening process used is subjective and there is a possibility that some useful sources were screened away. This said, because of the reoccurrence of many of these articles I do believe that the most relevant articles were included.

3.2 INTERVIEW METHODOLOGY

I first interviewed six safety experts from various backgrounds within the industry, followed by an interview with the Petroleum Safety Authority Norway (PSA) and lastly two interviews with new operators in Norway. The initial contact with the first 6 respondents and the PSA was made by my supervisor Andreas Falck. I then gained the contact information to schedule these interviews. These interviews laid the basis for problem screening and gave an overview of the industry's experiences with WCPF.

New companies were contacted since their experience could be different from the larger operators. The plan was to give the new companies a larger focus. However, some of the newer companies declined the interview or did not respond and the thesis was reworked as explained in chapter 1. When reaching out to the new companies their different backgrounds were considered. These backgrounds were:

- Licensee but not operator
- International background
- Bought an already operating platform that they now operate
- Operator and are currently developing their own field

In the end two new companies were interviewed. The summaries of all interviews and interview questions can be found in Appendix C.

3.2.1 About the respondents

Table 2 displays all respondents with brief backgrounds of their expertise and companies among with an explanation of why they were contacted.

Table 2: Overview of respondents.

Overview of respondents			
Respondent	**Background of respondent**	**Company information**	**Motivation for respondent**
Consultant 1	Fire and explosion analysis and quantitative analysis	Large Consultancy in Norway	High focus on uncertainties and limitation of tools and methods used in the industry
Consultant 2	Risk analysis and probabilistic modelling	Large Consultancy in Norway	Experience of probabilistic analysis used in the industry
Engineer 1	Quantitative risk analysis and barrier and safety management	Large Engineering company in Norway	Experience of barrier performance and installation of barriers
Operator Expert 1	Fire and explosion simulation	Large Operator in Norway	Experience of simulation tools and fire dynamics
Operator Expert 2	Technical safety engineering	Large Operator in Norway	Experience of safety-systems on offshore facilities
Operator Expert 3	Technical safety and barrier management	Large Operator in Norway	Experience of safety-systems on offshore facilities
PSA respondents	Petroleum engineering and chemical process engineering	Supervisory Authority of offshore industry in Norway	Great understanding of legal requirements. Overviews the result of the implementation in the industry.
New Company 1	Technical safety expert	International company and new small operator in Norway. Currently deciding the design of the platform, they will operate.	Can provide an outsider perspective Experience of safety-systems on offshore facilities
New Company 2	Technical safety expert	New small operator in Norway, Company bought an old installation. A lot of personnel and expertise transferred from the old operator to the new company.	Can provide an outsider perspective Experience of safety-systems on offshore facilities

3.2.2 Questions

The interviews were semi-structured. This allowed some freedom by not forcing a detailed script while still having a general structure and topics that should be covered (Mann, 2016, p. 91). In addition, prompts where used for some of the topics to guide the interview (Jacob & Furgerson, 2012, p. 4). There was an overall outline of main questions for each interview but the specifics and follow up questions varied between them and all the prompts might not have been covered.

Open-ended questions can be more preferred than yes or no questions to encourage free answers (Jacob & Furgerson, 2012, p. 3). Depending on the literature, the preferred amount of detail of the questions varied from asking only about one thing at a time to long elaborate multidimensional questions (Wärneryd, 1990, p. 62; Jacob & Furgerson, 2012, p. 4).

I deemed flexibility more important than exactly recreating the questions for each interview. In general, the questions where longer and included multiple angles at the same time. Occasionally, there were yes or no questions and the respondent would elaborate on their answer.

For the initial six interviews I wanted to know the respondents' thoughts about the WCPF definition and experience when working with the WCPF concept. The questions had a slight negative undertone because these interviews were used for problem screening. There were also some themes I wanted to cover. These were how the WCPF was affected by variation, if the cost and workload changed significantly and lastly the effects of barriers since they are imbedded in the definition.

The questions for the PSA were based on the result from the initial six interviews and brief explanations of the result from the initial six interviews were given for context. I wanted to know how the PSA viewed the definition, their thoughts about the literature, along with choices behind credited barriers and the lack probabilistic aspects in the definition.

For the newer companies the main goal was to understand their company background and how it could affect their work with the WCPF and if they saw different challenges compared to the rest of the industry.

In table 3 below the general question subjects for the interviews are shown. These questions worked as a guide through the interviews. The main questions were sent out in advance to the respondents except for the first interview with Consultant 1.

Table 3: Shows the general questions for the different interviews.

General question subjects		
Initial 6 interviews	**PSA**	**New Companies**
What do you consider the main challenges with WCPF?	Is WCPF well defined? Why? Why not?	What phase is our company currently in?
Do you think WCPF is well defined?	How do you balance freedom of interpretation and flexibility with strict guidelines?	Has your company been involved with the discussion surrounding WCPF?
Does the interpretation of WCPF vary within the industry?	Probability is not explicit in the current WCPF definition. What are your thoughts about this?	Do consultants provide you with risk assessments or are they done inhouse?
How do you choose a WCPF scenario?	It is mainly structural consequences the WCPF focuses on. What are your thoughts about this?	Do you think it is less or more difficult for a newer or international company to interpret the WCPF requirements?
What tools are currently used?	Is there a need for additional guidelines?	Is there a need for additional guidelines? Why? Why not?
What barriers are you accounting for?	Why is fire water not considered in the WCPF definition?	If there are any, what do you consider the main challenges with WCPF?
How does the WCPF concept affect workload and cost?	Is there a way to include risers and wells that is not probabilistic?	What do you think of the WCPF definition?
How does the WCPF concept change the design of installations?	Is the current literature surrounding WCPF enough and up to date?	

3.2.3 Place and time

The placement of the interview can affect power dynamics and the comfort of the respondent during the interview (Mann, 2016, p. 63). To not take up too much time of the respondents' day, the in-person interviews were held at the respondents' institution. For the interviews that were held over the phone or Skype, the respondent would be inside their office or in a videocall room and I would be in a meeting room at the University. The interviews lasted between 30 minutes to 1 hour.

3.2.4 Language

Talking in a second language could lead to less detailed answers (Mann, 2016, pp. 63-64). The chosen language for the interviews was English even though this was a second language for most of the respondents. This decision was made since having interviews in Swedish and Norwegian could result in misinterpretations during the interviews. The interview with the PSA was held in Norwegian and Swedish though.

3.2.5 Anonymity

Anonymity can be thought of as a spectrum. On one end the respondent is easily identifiable and on the other completely anonymous. It can be difficult to balance these two ends of the spectrum. To give context to the answers might demand some loss of anonymity (Saunders, Kitzinger, & Kitzinger, 2015, p. 617). In this report the name of the respondents and the companies are not being mentioned, that said, brief descriptions about the respondents and their companies were given since context to their perspectives were important.

3.2.6 Documenting the interviews

The interviews were recorded. The information could be specific and detailed and thus recordings were preferred. Notes were made as an option if the respondent was uncomfortable with being recorded. This option was however never used.

The recordings were transcribed and then summarised. If the same topic was discussed at different points in the interview the summaries tried to collect them at the same place. Since many subjects are intertwined this was however not always possible. The summaries were then used for analysis.

3.2.7 Analysis of interviews

Many topics were chosen before the interviews started. Some of these topics were part of the main questions and others as follow-up questions. A few topics were discovered during the interviews. Because many topics were intertwined, they were often discussed simultaneously during the interviews. Table 4 below shows the topics for the initial six interviews, Table 5 for the PSA interview and Table 6 for the new and international companies.

The summaries were then read through again to find comments related to these topics and compared them with each other. Because the topics often correlated each topic is not displayed as an own section in the result.

Table 4: A table showing planned and discovered topics for analysis for the initial six interviews.

Initial six interviews, Consultants, Engineer, Operators		
Topics part of planned main questions	**Topics part of planned follow up questions**	**Topics discovered during interviews**
Main challenges	Cut-off rates	Risers and Wells[6]
View of definition	Duration	Documentation of PFP
Variation	Escalation	New and international companies
Scenario selection	Spray-fires	Probability, explicit vs implicit
Simulation	HC Volume	Fire water system
Barriers	Guidelines	The word credible
Workload and cost	Open drain	Subjectivity
Change of installation design	Blow down	
	Use of consultants	

[6] Early discovery and was later included as a follow-up question.

Table 5: A table showing planned and discovered topics for analysis for the PSA interview.

Interview with Petroleum Safety Authority Norway		
Topics part of planned main questions	**Topics part of planned follow up questions**	**Topics discovered during interviews**
View of definition	Scenario selection	Documentation of temperature
Guidelines	Cut-off rates	Documentation of heat fluxes
Exclusion of fire water	Duration	
Risers and wells	Documentation of PFP	
SINTEF report and literature	Follow ups on installations	
New and international companies		

Table 6: A table showing planned and discovered topics for analysis for the interviews with new companies.

Interviews with new companies		
Topics part of planned main questions	**Topics part of planned follow up questions**	**Topics discovered during interviews**
Involvement in WCPF discussion	Experience with WCPF	Redesign of old installations
Use of consultants	Effects on design	Knowledge transfer between operators
Comparison to larger operators	Comparison to probabilistic approach	
Guidelines		
Main challenges		
View of definition		

3.2.8 Errors sources during interviews

The interview questions were slightly different between consultants, engineers and operators. The questions also varied within the same actor group. This is partly due to unintentional change of wording when asking the main questions, lack of time and different follow up questions. This leads to some topics being discussed by fewer respondents or that the respondents answer could be affected by the change of wording. Due to the small sample size, there is no guarantee the opinions of the respondents represent the entire industry, however considering the different backgrounds and experience of the respondents the main areas of concern and discussion should have been covered. It should also be noted that the interview results among with the conclusions drawn were based on my interpretation of the interviews and are subjective.

4 LITERATURE OVERVIEW

In this chapter the history of the Worst Credible Process Fire (WCPF) is explained among with a few other deterministic approaches to risk and design of hazardous systems.

4.1 THE WORST CREDIBLE PROCESS FIRE

The idea of the WCPF goes back to before the probabilistic approach was prominent within the industry. Currently there are only two documents concerning WCPF. The SINTEF report named *"Hvordan defineres"worst credible process fire"?"* (2017) and the current definition in NORSOK S-001 (Standards Norway, 2018).

4.1.1 Background of the WCPF concept

Older versions of Norwegian regulations describe a deterministic approach to defining accidental and design loads. The quotes below describe a scenario setup that the facility is meant to withstand[7].

The 1980s Regulation for productions- and auxiliary systems on production installations, (Chapter 6, Section 2) defines fire potential as:

> *"The total heat load pr. unit area that is released when the combustible material in the area is completely combusted."*

The combusted amount refers to the available hydrocarbons in an ESD segment since the same regulations also describes sectioning of the process when describing the ESD system (Chapter 8, Section 2).

The 1992 Regulations relating to explosion and fire protection of installations in the petroleum activities (Chapter 1, Section 3) has a similar statement for fire loads:

> *"The total quantity of heat released in the case of complete combustion of all combustible materials in an area, including materials in walls, decks and ceilings."*

In comparison to the regulations from 1980, the 1992 regulations also clearly state to account for probability as part of the acceptance criteria[8] (Chapter 4, Section 14), which the dimensioning fire needs to be in accordance with (Chapter 1, Section 3). The Facilities Regulations from 2001 did not include this deterministic approach and the industry instead adapted to the probabilistic approach with the 10^{-4} requirement.

Around 2010, the deterministic approach was revisited. This was after an audit on Sleipner[9] where there was no fire event with a probability greater than 10^{-4}/ year, meaning that there was no fire that needed to be reflected in the design due to the low probability. This then resulted in a change in the Facilities Regulations section 33.

The thought effects of the WCPF approach was further explained in a project by Norsk olje og gass (2017) mainly in appendix 1 of this project. In this appendix they explain that the change from the probabilistic requirement gives more focus on the possible accidents, consequences and robustness of platforms rather than the likelihood of leaks and ignition (Norsk olje og gass, 2017, p. 10). The intention was to initiate planning of escape routes, exits and lifeboats differently, with more robust designs and with the benefit of increased personnel safety. They also identified a possibility to reduce cost since

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[7] Both fire potential and fire load were translated to "brannbelastning" in Norwegian.
[8] The acceptance criteria define the acceptable level of risk.
[9] Installation owned by Equinor former known as Statoil.

needed information for decisions is available earlier and consequences of changes are easier understood (Norsk olje og gass, 2017, p. 10). The change was also anticipated to lead to additional need of Passive Fire Protection and increased costs in comparison to what has been common under the probabilistic approach. This said in comparison to what was common 20 years ago, Norsk Olje and gass states that there still is not that much of a change (Norsk olje og gass, 2017, p. 9).

4.1.2 The current legal requirements

The current Facilities Regulations Section 11 (Chapter 3) states that the facility should be designed so relevant accidental loads do not cause unacceptable consequences, (for example loss of main safety functions). It also states that fire water should not be accounted for when deciding design loads and as earlier mentioned, the dimensioning loads should as a minimum meet the 10^{-4} requirement. Section 33 in the same regulations (Chapter 5) states that ESD valves shall section and isolate the hydrocarbon volumes from spreading, which is similar to earlier regulations.

The WCPF as described in NORSOK S-001 is a solution proposal to requirements stated in the regulations, the WCPF term is never used in the actual regulations. As mentioned earlier, standards are separate from legal requirements and are simply a solution proposal to meet them. In reality, the standards referred to in the regulations (e.g. NORSOK S-001) are normally used in design, as the alternative require much more documentation. The extra documentation stems from the operator's obligation to provide the PSA proof that their solution is robust enough.

4.1.3 The SINTEF report

The SINTEF report investigated how the petroleum industry in Norway had been using and defining the WCPF concept. The project was an initiative from the PSA (SINTEF, 2017, p. 7). Letters were sent out to six operators with six questions asking them to provide thorough answers (SINTEF, 2017, p. 8). At the time, the NORSOK S-001 standard was being updated and would come to include the WCPF definition and this was one of the reasons the report was made.

The six questions were (my translation from Norwegian) (SINTEF, 2017, p. 8):

1. *"How is WCPF defined?*
   - *What simulations are used?*
   - *Which methods are used today?*
   - *Are different tools used?*
   - *Does the methodology vary between different suppliers?*
2. *Which factors affect the choice of heat loads?*
3. *Which internal and other requirements apply?*
4. *How are the requirements followed up after modifications on installations?*
5. *How have the analyses defined escalations out of the area?*
6. *Are process shutdown valves credited by the WCPF definition?"*

The report concluded that:

- The term WCPF was not fully integrated in the industry and that there were not clear enough regulations on how to calculate and interpret the WCPF.
- Many of the same tools were used in different projects and simulations and response calculations were sometimes subcontracted (SINTEF, 2017, p. 14).
- Heat loads could be taken from the 2008 NORSOK S-001 standard and KFX tools could be used to account for the transient behaviour of the fire (SINTEF, 2017, p. 19). Commonly referenced requirements were NORSOK S-001 (2008) and NORSOK Z-013 (2010) but it could vary slightly between different projects (SINTEF, 2017, p. 21).

The answers of how requirements were followed up were quite generic due to limited insight (SINTEF, 2017, p. 23). Escalation was defined/interpreted very different between the operators with these two examples being given[10].

1. *"Analyses that define escalation as occurring when a fire load exceeds the capacity of the fire separation between the main areas. Here is not smoke nor heat radiation counted in a neighbouring area as escalation unless it is a consequence of the fire partition itself being destroyed.*
2. *Analyses that also define heat radiation over a certain level (heat flux and / or duration) as escalation"* (SINTEF, 2017, p. 24).

Because of the wide range of interpretations relating to escalation, the report argued for a more explicit description of escalation with the upcoming definition of WCPF in NORSOK (SINTEF, 2017, p. 31).

The report found that the practices of crediting PSD valves varied between operators (SINTEF, 2017, p. 27). That said, the conclusion of the report states that the effects of fire water and PSD valves should not be credited in the definition of WCPF. EDP and ESD can however be credited (SINTEF, 2017, p. 2). Lastly the report concluded that, if the goal is a consistent approach throughout the industry there is a need for more specifications concerning assumptions (SINTEF, 2017, p. 6).

4.1.4 NORSOK S-001

NORSOK S-001 (2018) tried to accommodate some of the conclusions and concerns addressed in the SINTEF report which resulted in the current definition of WCPF.

A Worst Credible Process Fire (WCPF) is described as an ignited leak in the ESD segment causing the worst exposure of main load bearing structures with regards to duration, heat loads and escalation.

NORSOK S-001 states that possible escalation to other ESD segments and for wellhead areas should be considered. Escalation is said to normally not prolong the duration of the fire but increase the fire size for a certain time period. The barriers that can be credited are the ESD valves, EDP valves among with open drain and bunding (Standards Norway, 2018, p. 17). The drain system shall in turn be able to handle the full fire water capacity and the leak rate of the WCPF (Standards Norway, 2018, p. 31).

Two typical WCPF scenarios described in NORSOK are:

- A fire from a liquid segment resulting in a duration above the current critical duration relating to main load bearing structures.
- A jet fire from the largest EDP segment escalating to a liquid segment.

NORSOK S-001 also states that the loads from the WCPF shall be covered by the design accidental load and the fire shall not escalate to HC risers or to the wells (Standards Norway, 2018, p. 17).

4.2 SIMILAR CONCEPTS

Concepts like Worst Case Scenarios or Worst Credible Scenarios are commonly used in the process industry and often discussed in risk assessments (Center for Chemical Process Safety, 2012, p. 112). The exact wording of these terms varies, for example Worst Credible Incident, Worst Credible Case and Maximum Credible Event but they embody the same idea of not being the worst-case but still being significant (Center for Chemical Process Safety, 2019). The sections below look at some of these concepts and their methodologies.

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[10] My translation from Norwegian

4.2.1 Worst Case Scenario/ Worst Accident Scenario

A Worst Case Scenario (WCS) similarly to a Worst Accident Scenario (WAS) assumes failure of all safety systems and release of the entire mass (chemical) which results in maximum damage. The frequency of such events varies but it can range between 10^{-5} and 10^{-6} times/year. The probability of occurrence is often ignored though for these scenarios (Markowski & Siuta, 2017, p. 654: Zhang, Zhao, Wang, Yuan, & Cheng, 2017, p. 87).

The accuracy of the calculations (relating to consequences) highly depends on the ability of the analyser (Zhang, Zhao, Wang, Yuan, & Cheng, 2017, p. 87). How a worst-case is valued can also be a structural issue. It could imply the worst release but could also consider weather conditions and other factors that would make the consequences larger. As a result the same release could be valued to have different consequences depending on how it is defined by the analyser (Hauge, et al., 2014, p. 86). Markowski and Siuta argues that WCS might not be a justifiable approach due to the low probability of the scenarios. The approach does however put an upper limit of what consequences could occur which can be useful to know. It should also be noted that these kinds of accidents have occurred in the past, for example Texas City (2005) and Piper Alpha (1988) (Markowski & Siuta, 2017, p. 654).

4.2.2 Maximum Credible Scenario/ Maximum Credible Accident Scenario

Maximum Credible Accident analysis is widely used in the chemical process industry. With this credible approach, it is not always the scenario with the worst consequences that are chosen to be the most credible[11], due to low probability (Khan & Abbasi, 2002, p. 472). When choosing a scenario, factors such as safety measures, the chemicals handled by the industry, the reactions, physical conditions, material of vessels, layout, and environmental conditions have to be considered (Khan & Abbasi, 2002, pp. 470-471).

According to Markowski and Siuta (2017, p. 653) the maximum credible scenario (MCS) approach could be considered more justifiable, compared to the WCS since it considers frequency, the severity of the consequences and take existing control measures into account. They also explain that MCS events can in some cases be referred to as representative accident scenarios[12] (RAS). The selection of RAS/MCS can use a risk matrix to easier view the differences between multiple scenarios if the ranking of the hazards is not self-evident. Markowski and Siuta does note though that matrices indicate subjectivity which might affect the result (Markowski & Siuta, 2017, p. 654).

To lower the subjectivity, Khan and Abbasi proposed a systematic procedure to decide which scenarios are the most credible ones (Khan & Abbasi, 2002, pp. 467-468). To rank and select the most credible scenario, a credibility factor C can be calculated for all the scenarios with different indexes such as Dow's fire and explosion index (Dow FEI) and the estimated probability of a scenario. The higher the value of C the more credible the scenario is. But even with this more systematic approach there can still be variation from analyst to analyst (Khan & Abbasi, 2002, p. 472). Khan and Abbasi (2002, pp. 471-472) notes that the estimation of probability can be considered a bit rough, and more thorough analysis methods like fault trees should be used later in the process for more exact values. The process of choosing MCS with the credibility factor can be seen in Figure 5.

[11] The most credible event can be viewed as the event with the worst combination of consequences in relation to its probability.

[12] Representative scenarios to aid in design of processes or installation of safety measures.

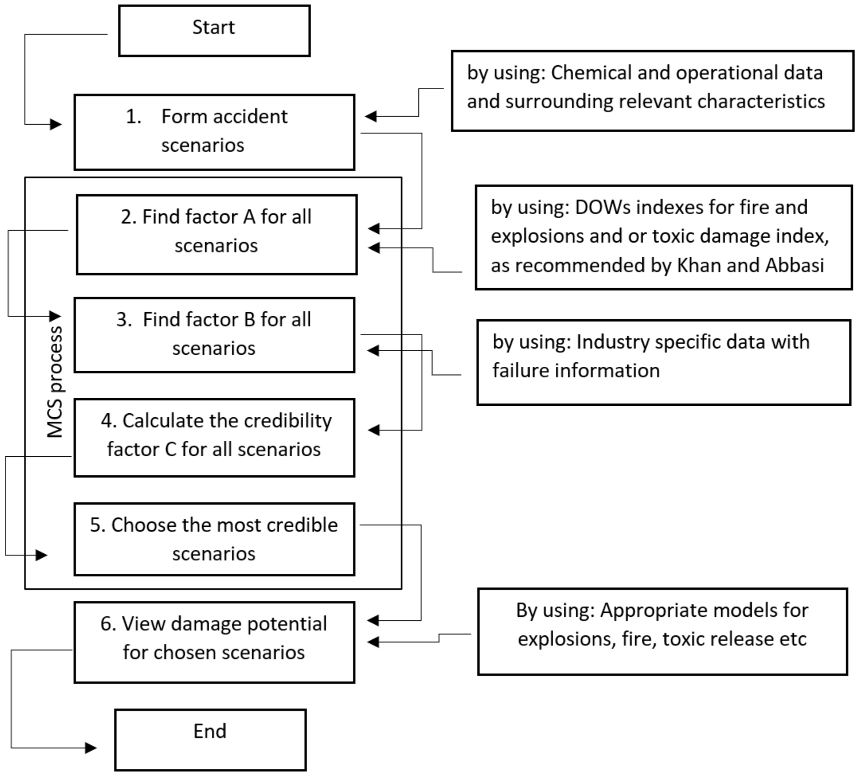

Figure 5: The process of choosing an MCS. The picture is an edited version of the original figure by Khan & Abbasi (2002) p. 469 in "A criterion for developing credible accident scenarios for risk assessment".

4.2.3 Reference Accident Scenarios and Worst Maximum Credible Accidental Scenarios

There are currently three main methods used to determine an accident scenario. Two of them were described above being Worst Accident Scenarios (WAS) and Maximum Credible Accident Scenarios (MAS/MCS) but there is also a third of reference accident scenarios (RAS).

In this case RAS should not be confused with MCS as described above. RAS - Reference Accident Scenarios - is based on the Accidental Risk Assessment Methodology for Industries (ARAMIS) project (Delvosalle, Fievez, Pipart, & Debray, 2006). RAS, in the ARAMIS project, is scenarios that considers safety systems and display the real hazard potential using the MIMAH and MIRAS methodology.

In the first method - Methodology for the Identification of Major Accident Hazards (MIMAH) - the major accident hazards are in this case WAS (or WCS). The hazards are based on the hazardous equipment and substances used in the process and assumes no functioning safety systems. The MIMAH method is shown in Figure 6.

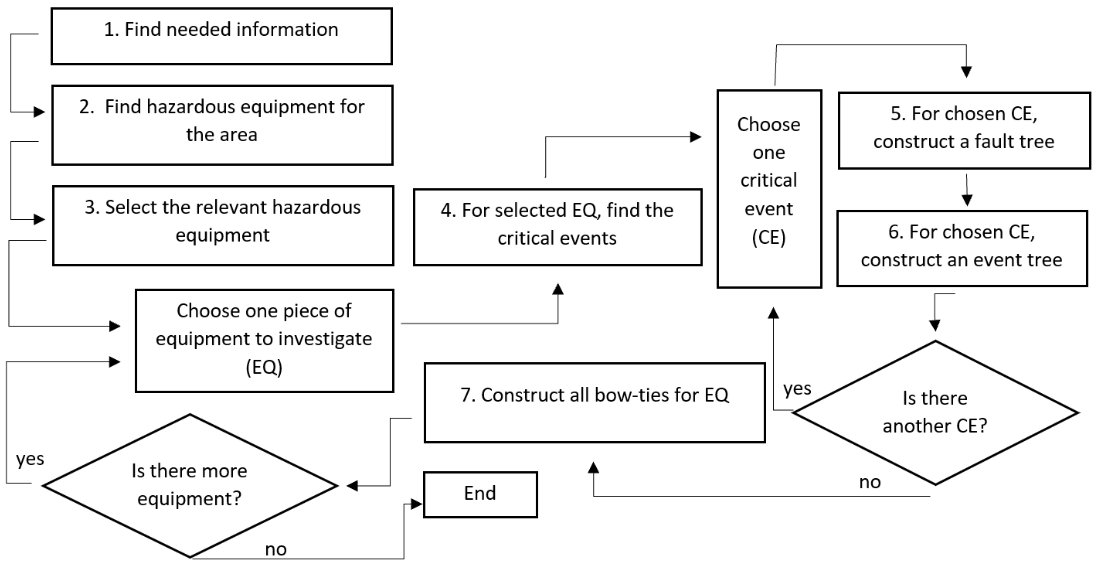

Figure 6: Choosing WAS scenarios with MIMAH method. The figure is an altered version of the original figure by Delvosalle, Fievez, Pipart, & Debray (2006) p. 202 in "ARAMIS project: A comprehensive methodology for the identification of reference accident scenarios in process industries".

The second method, methodology for the identification of reference accident scenarios, (MIRAS) uses a MIRAS diagram which then chooses a RAS from the WAS identified in MIMAH. The MIRAS method does though consider functioning safety systems. This adds more credibility to the WAS and describes the real potential hazards (Delvosalle, Fievez, Pipart, & Debray, 2006, p. 201). Zhang, Zhao, Wang, Yuan and Cheng (2017, p. 88) notes however that even though the MIRAS method comes with advantages it is quite complex and takes a long time to complete. The steps in MIRAS are shown in Figure 7 below.

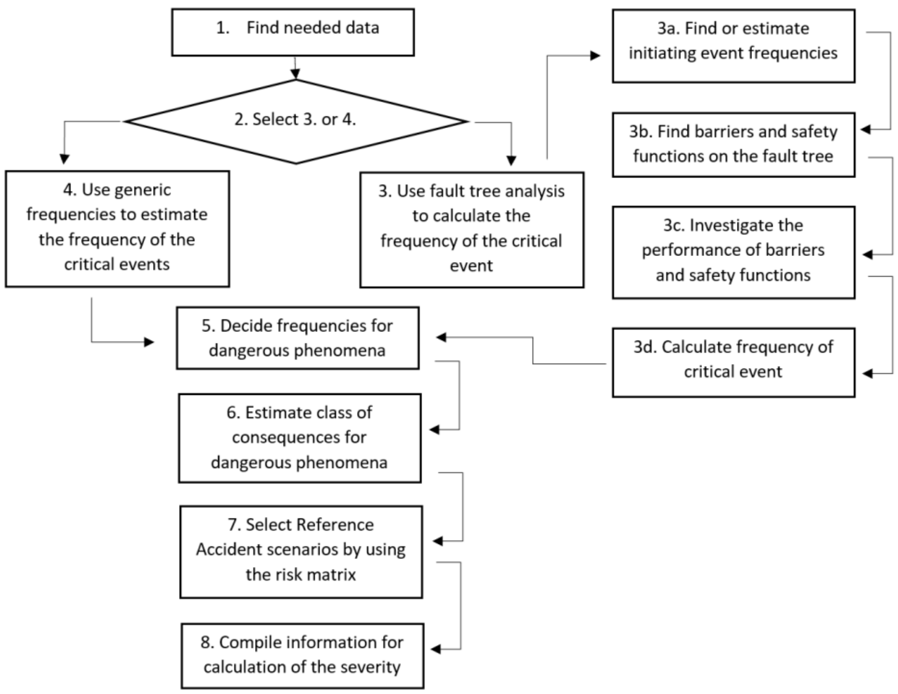

Figure 7: The steps of the MIRAS method, which is applied for every bowtie created in MIMAH. Picture is an altered version of the original figure by Delvosalle, Fievez, Pipart, & Debray (2006) p. 208 in "ARAMIS project: A comprehensive methodology for the identification of reference accident scenarios in process industries".

To combat the shortcomings of WAS/WCS, MAS/MCS and RAS from the ARAMIS project a new methodology of Worst Maximum Credible Accidental Scenarios (WMCAS) was developed by Zhang, Zhao, Wang, Yuan and Cheng. The method aims to find all WAS/WCS that could occur in the process with MIMAH but then determine MAS/MCS among these WAS with the Credibility factor C instead of using the MIRAS method (Zhang, Zhao, Wang, Yuan, & Cheng, 2017, p. 99). The method for choosing WMCAS can be seen in Figure 8.

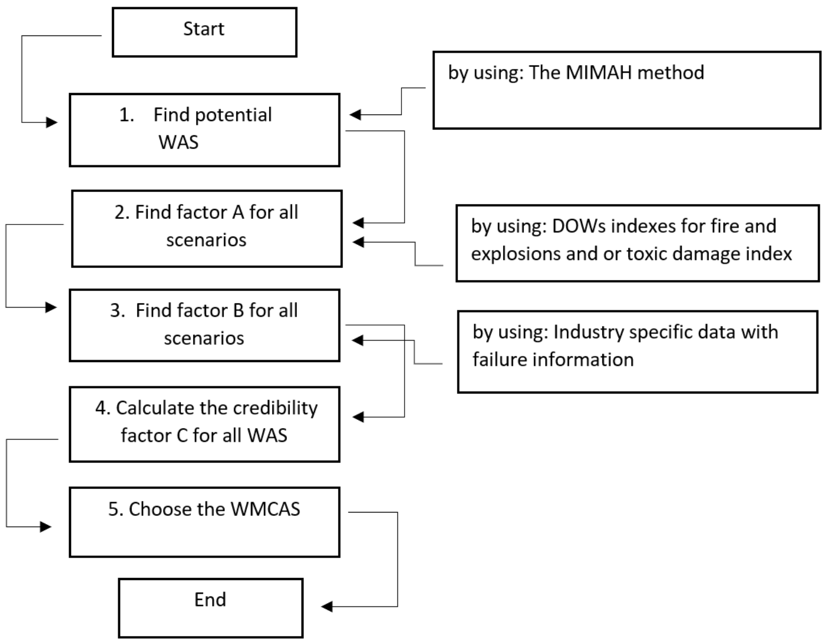

Figure 8: Method of choosing WMCAS. The figure is an altered version of the original figure by Zhang, Zhao, Wang, Yuan, & Cheng (2017) p. 92 in "Worst maximum credible accidental scenarios (WMCAS) - A new methodology to identify accident scenarios for risk assessment".

4.3 OVERVIEW OF CONCEPTS

Table 7 below displays an overview of the WCPF and the similar concepts since the differences can be difficult to see at first glance.

Table 7: Overview of similar concepts.

Overview of similar concepts and WCPF

Name of concept	Abbreviation	Safety systems	Level of sophistication	Comparison method
Worst Credible Process Fire	WCPF	Are credited	Low-Medium: Probability is not explicit but indirectly considered due to credited safety systems	No explicit comparison method in current definition
Worst Case Scenario	WCS	None	Low: Probability is not considered. No upper bound, there is always worse possible circumstances.	Worst consequences = The worst-case scenario
Maximum Credible Scenario/ Maximum Credible Accident Scenario	MCS, MCAS	Are credited	Medium: The credibility of the scenario is based on the combination of probability vs consequences. Uses the credibility factor C	Risk Matrix Credibility factor C
Reference Accident Scenarios (ARAMIS project)	RAS	Are credited	High: Uses MIMAH and MIRAS method. Thorough bow-tie analysis of scenarios and probabilities	Risk matrix
Worst Maximum Credible Accidental Scenarios	WMCAS	Are credited	Medium: The credibility of the scenario is based on the combination of probability vs consequences. Uses MIMAH for hazard identification and the credibility factor C for evaluation	Credibility factor C

4.4 LITERATURE DISCUSSION

A general setup is described for the WCPF with safety systems but how to rank scenarios is not disclosed in NORSOK S-001 nor in the SINTEF report. What can be considered credible will instead be up to the risk assessor in each project which leaves room for subjectivity.

In some ways the current WCPF setup have a lot in common with the WCS approach. The WCS approach also describes a general setup, but assuming complete failure of safety system and that the entire available volume of the chemical is leaked. The level of detail in the setup are similar even though the scenario setup is different. The WCPF approach might therefore suffer the same problems as the WCS approach. As mentioned above, weather conditions are not described in the WCS approach, and the consequences depend on how far you push various parameters and circumstances. This structural issue can to a degree be seen in the SINTEF report where assumptions surrounding safety systems and escalation varies. Some of these issues were addressed in the new NORSOK S-001 but weather conditions are for example not mentioned.

Not too surprisingly the WMCAS approach and MCS approach are quite similar, since the WMCAS approach was based on the MCS approach. The main difference being that the first step of developing accident scenarios is more detailed with the MIMAH method for WMCAS. The difference MIMAH does is that it looks for WCS while the MCS method considers credibility from the start. In a way the WMCAS approach is looking for the most credible among the worst scenarios.

It may be possible to take inspiration from the ranking of MCS or WMCAS to lower subjectivity in terms of ranking scenarios for the WCPF. The credibility factor gives a direct number making the ranking process less subjective. However, probability is an explicit part of the credibility factor calculations. One of the positives with the WCPF was the possibility for early decision-making as described by Norsk olje og gass. If probability is made an explicit part of the WCPF process, this possibility might disappear. To add to this, the lack of detail in probability estimation was mentioned as an issue for MCS, which could be addressed by the MIRAS method but as earlier established it takes a lot of time to execute this method, which was the reason it was not used for WMCAS. It would also shift the focus even more to probability.

The question is if the similar concepts can provide solutions to some of the challenges facing WCPF. To avoid structural problems associated with the WCS, the WCPF could need even further specification to avoid this immediate variation. One example being the weather conditions that could influence the consequences. The credibility factor answers the question of how to rank scenarios more objectively. It does however come with the cost of making early decision-making more difficult. Depending on the level of detail in the probability estimation it could also take a lot of time. If probability is added in explicitly this could also change the focus back from consequences to probability. This might be in conflict with the desired effect of the change as mentioned by Norsk olje og gass.

5 RESULTS: OPERATORS, CONSULTANTS, ENGINEER & PETROLEUM SAFETY AUTHORITY

5.1 RESULT: OPERATORS, CONSULTANTS AND ENGINEER

Below are summaries of the main findings from the first six interviews. What is listed in 5.1.2 as main challenges is not individually discussed in the segments 5.1.3-5.1.13. These last segments cover topics in which opinions differed among with topics I wanted to cover during the interviews. Note that many topics also overlap. Not every topic as mentioned in the methodology is discussed as its own segment. For example, *scenario selection* and *variation* ranges from *simulation*, *escalation* to *cut-off rates* etc. For this reason, some topics were spread out over multiple topics. In other cases, topics such as *use of consultants* and *spray-fires* are found under other topics such as *workload and cost* and *simulation*.

5.1.1 View of the definition

The definition of WCPF was seen as clear and a net positive and the industry has become more unified in its approach in comparison to a few years ago. The positives are a better focus on scenarios and consequences rather than probability (Engineer 1), less changes in early project phases due to limited information (Operator 3) and avoiding not having a dimensioning fire due to low probability. The earlier discussion about ESD- and PSD valves was solved with only ESD valves being credited now. Operator 1 mentioned a desire to look more at consequences outside of simply structural ones.

Consultant 1 put it as *"Even though the worst credible approach is not a very good of an approach, it might still be better than the alternatives"* as they were commenting on possible variations and uncertainty. Even though concerns and possible improvements were discussed none of the respondents deemed the WCPF approach to be worse than earlier approaches.

5.1.2 Main challenges

Below is a list of what the respondents deemed to be the main challenges with the WCPF.

- Arranging scenarios and scenario selection
- Defining what can be considered as credible
- Lack of explicit probability perspective
- Risers and wells are not considered in the WCPF concept
- In some cases: low cost-benefit with this approach considering the consequences
- Simulation and modelling: There can be different levels of simplification used, there is also uncertainties in models that might be overlooked[13]
- Long lasting fire durations[14]
- Documentation of fire walls[15]

5.1.3 The word credible

Some of the respondents directly commented on the word credible itself (Consultant 1, Engineer 1 & Operator 2). They questioned what it means in practice, if it is linked to frequency and how to account for safety systems and that interpretations of the word can be subjective.

[13] Consultant 1: There are many assumptions about the properties of the leak which can lead to false confidence.

[14] Operator 1: The durations can be longer than the PFP and construction are documented to withstand.

[15] Operator 3: Even though the respondent mentioned this as a main challenge in the grand scope this could still be considered a minor issue since the platforms most likely will be intact after the documented time (2 hours for firewalls).

5.1.4 Subjectivity

The respondents agreed that the definition was clearly defined but there was still differing opinions about the subjectivity of the actual implementation. The engineer highlighted the subjectivity as a tool to tailor-make the design for the specific installation. The subjectivity could also be a problem since it causes variations depending on who does a risk analysis (Operator 3). Consultant 1 highlighted how small details matter and the challenge of finding a balance between strict guidelines and openness for subjective interpretations. Ranking of scenarios, escalation and chosen cut-off rates were topics that often were affected by subjectivity.

5.1.5 Cost and workload

The WCPF might add additional PFP which could be more expensive than that of the probabilistic approach (Consultant 2). That said, it would not necessarily be that different from earlier and in some cases maybe save money due to less changes in early project phases (Operator 3). The workload among eventual extra cost was generally deemed to not to be a huge problem considering the importance of the analysis. That said, some analyses demanded a lot of resources which could be costly (Operator 2). All the operator safety experts mentioned that they hired consultants for many different risk analysis calculations.

5.1.6 Simulation

There were some disagreements about the best way to simulate the scenarios. Operator 2 and Engineer 1 explicitly preferred simplifications while Operator 1 and Consultant 2 preferred as realistic simulations as possible. Simplifications were many times associated with higher heat loads and a global exposure. The more realistic simulations would result in smaller heat loads and exposure. This could lead to less PFP being needed. Advanced simulations would however demand more resources.

Consultant 1 seemed quite sceptic of many tools and talked about uncertainties in the models. Small changes to a scenario with advanced tools could affect the resulted heat loads. They stressed the importance of doing sensitivity analysis to make sure conclusions are robust to variations in input parameters. Consultant 2 seemed more confident in the tools and focused more on the positive elements, being the ability to incorporate the transient behaviour of the leak, ventilation and realistic heat loads.

Multi-phase leaks or spray fires are more difficult to simulate. Consultant 2 did not consider this the main issue of the WCPF. Operator 1 mentioned spray fire simulation as an improvement possibility. Spray fires are mostly approximated as jet fires and more advanced methods for spray fires could be more used in the future. Currently there is though some variation in when the jet fire is changed to a pool fire.

5.1.7 Barriers

The blowdown system did not seem to raise many concerns. The consensus was to be aware of its limitations, but it was otherwise a very reliable barrier. The open drain was deemed more unreliable if sand, debris or small objects were blocking it. Operator 3 mentioned that the full drain capacity might only be checked every 5-6 years, in between those check-ups you will not actually know if it works as intended.

The fire water system is currently not credited but two of the respondents (Operator 2 & Operator 3) mentioned that it could be important to consider some of its effects. In older installations the fire water system could cover the module in water which could cause the oil to spread on top of it, which could be problematic. The fire water system also has a cooling effect on the structure which is positive when dealing with high heat loads. According to Operator 2, the fire water system was uncertain back in the 80s and 90s but has gotten a lot better in recent years.

Consultant 1 mentioned a logical contradiction where the likelihood of safety systems failing could be proportionally large to the actual leak scenario of the WCPF. Consultant 2 and Operator 1 argued that since the WCPF scenario already is remote that it would be unreasonable to not account for the available barriers.

5.1.8 Escalation

On some platforms escalations are very unlikely, on others you can do a rupture analysis or different simulations to find the probable escalation. Usually the escalation is said to increase the extent but not the duration and happens early, this is because you still have high pressure in the system (Operator 1 & 3). The question is if you should assume that the escalation happens when the analysis says it does. Part of escalation is also how you consider risers and wells. Due to the variation, there might be a need for guidelines surrounding escalation (Operator 3 & 2).

5.1.9 Cut-off rate and duration

The preferred cut-off rate[16] varied during the interviews. The smallest cut-off rate mentioned was 0,1 kg/s and the biggest 10 kg/s. If the cut-off rate was not chosen generically, a way to do it was too look at what the structure could withstand, which could vary a lot between different installations (Engineer 1 & Operator 2).

The duration also varied with a mention of gas fires of 30 minutes to pool fires lasting up to 8 hours. One way to limit the duration was by choosing higher cut-off rates. Long durations imply a large volume of HC and another alternative could be to add additional ESD valves to lower the volumes (Operator 2).

5.1.10 HC volume

Some assumed that the entire HC volume would be credited (Consultant 1) while others instead looked at the leak rate, combustion rate and assumed some of the HC would be drained away (Operator 1). Sometimes the larger volume will not cause the worst exposure since the fire is limited by the air supply, large fires could also burn outside the facility which would not transfer heat to the structure (Consultant 1 & 2). A part of the HC volume is also how you account for escalation and segmentation (Operator 3).

5.1.11 Risers and wells

Generally, risers would be considered if the frequency was too high or if the WCPF could escalate to risers and result in a collapse (Operator 2 & 1). Because the considerations of riser and wells are frequency based, it is mainly the number of risers and wells that determine if you need to account for them or not (Operator 3). Consultant 2 mentioned the exclusion of risers as problematic and could affect wellhead modules unfairly. Operator 3 gave an example of designing for riser fires but not the entire duration, just enough for evacuation. They also mentioned that there are structures like flare towers or cranes outside the process system that might need to be considered if they could cause damage.

5.1.12 Documentation of PFP

Three of the respondents (Engineer 1, Operator 1 & 3) mentioned the lack of documentation for fire walls and other structures as a concern. The WCPF often result in longer durations than what these structures are documented for. This can be problematic since this introduces uncertainties related to whether these structures will withstand the fire.

5.1.13 Outsiders: New companies

Even though the definition has become clearer with NORSOK S-001, the Engineer thought it could be difficult for a new operator to know where to start. If you have not been a part of the discussion for the last few years and worked on different projects, the definition might not be enough. Operator 2 mentioned that an international contractor probably would not know what to do, which could be a problem if you want to have international collaborations.

[16] The leak rate of which the corresponding fire is evaluated not to be critical anymore.

5.1.14 Follow up on changes

Operator 2 talked about how to follow up the changes on platforms. Because the concept is so new, this procedure is a bit uncertain, but the operator said that they usually updated the risk analysis and acted based on it.

5.2 ELABORATIVE BASIS FOR PETROLEUM SAFETY AUTHORITY INTERVIEW

The elaborations below were used as a basis for the PSA interview and as the initial problem screening for further investigation.

5.2.1 The definition and further specifications

It seemed like the definition in itself was not the main issue. The NORSOK S-001 standard was regarded as good enough or very clear. The definition seems to describe *what* to investigate but not really *how* to investigate it. Based on the interviews there seems to be a need for additional guidelines on scenario selection, escalation, cut-off rates and maybe some additional information or requirements concerning barriers.

5.2.2 SINTEF report might be outdated

The NORSOK definition was mainly the result of the SINTEF report. Operator 3 mentioned that the SINTEF report was written quite some time ago and the projects the report was based on were even older. Since there are only two documents about WCPF, if one of these sources could be considered outdated there is only half a page about WCPF that can be used.

5.2.3 Outsiders: New and International companies

As highlighted by the Engineer and Operator 2 there could be some confusion when trying to understand the WCPF concept if you have not been part of the discussions in the industry. Possible unclarities could affect these companies more. This might discourage international collaborations and limit the choices for Norwegian operators or make it more difficult for new operators to establish themselves. At worst this confusion could lead to less safe practices but more likely this could cause expensive changes in later project phases.

5.2.4 Cut-off rates

The wide range for cut-off rates might not be the problem since different installations and different designs might require different cut-off rates. What can be problematic is the significant differences in the structural integrity approach[17] to the generic approach in NORSOK. This could imply a need for a more standardized approach other than the current generic values.

5.2.5 Barriers

Most seem to agree that you should be allowed to account for the available barriers. However, it is important to ensure these barriers can be approximated to work 100% of the time in a risk analysis if they are credited. The effectiveness of the drain is connected to the fire water system that is currently not accounted for. Since these systems are so connected it seems peculiar to consider one system but not the other.

5.2.6 Escalation

The SINTEF report noticed different approaches to escalation and this issue should probably not be considered solved yet. Escalation was somewhat clarified in NORSOK but exactly when escalations happens can vary. As mentioned above, escalation may need guidelines due to the experienced variation.

[17] Instead of using generic values from NORSOK the structural robustness is instead used as a basis for choosing the cut-off rate.

5.2.7 Risers and wells

How to better include riser and well leaks with this deterministic approach is a bit unclear. If the SINTEF report is updated this could maybe be one of the new issues to discuss. Considering the many different types of platforms with some of the new ones barley having any process equipment it seems a bit misguided to only have a probabilistic approach for risers and design for a WCPF with barely any process equipment, as mentioned by Consultant 2.

5.2.8 Documentation

The duration of the WCPF can many times be longer than what is documented for. This either causes a need for additional documentation or a need to lower the combustible volume, which in turn can lower the duration.

5.3 RESULT: PETROLEUM SAFETY AUTHORITY

5.3.1 Requirements and regulations

The PSA agreed NORSOK S-001 made the WCPF definition clearer than before. They mentioned that the concept has been around since the 80s but have been somewhat forgotten when the probabilistic approach was introduced. With function-based requirements you are still allowed to not follow the standard as long as you show that the requirements are met. The PSA have an observer that makes sure the standards meet the regulations. New specifications might be made if it is proven that additional requirements are needed for the WCPF. Currently they did not see a need for more specifications and there is not a plan for more literature.

5.3.2 Guidelines

The PSA have seen different interpretations and methods when looking at escalation and that could imply a need for a guideline. They have also seen varying cut-off rates which is alright as long as there is a methodology for choosing a certain rate. They acknowledged however that if the rates vary a lot throughout the industry it could be good to look into. Different installations have different prerequisites, so the PSAs focus is not on the exact procedure but the reasoning behind the methods used and if the requirements are met.

5.3.3 Limited literature and documentation

When asked about if the SINTEF report should be updated, they stated that there is no current plan to update it. That said, there is a project that aims to collect information if new areas come up and to inform about it. Some concerns the PSA have noticed during inspection is:

- The duration of the fire simulations had varied, and some stopped the simulations after one hour. This became clearer with the new NORSOK S-001 and that the duration was unrelated to safe evacuation.
- The ESD valves are not documented for the temperatures the WCPF can reach. The PSA have asked about fire testing because of it.
- PFP uses test from ISO22899 which uses heat fluxes of 250 to 300 kW/m^2. But multiple installations have specified design loads for 350 kw/m^2. There are high heat flux tests, but they used different methods. A project has been started to specify those high heat fluxes.

5.3.4 Consequences and probability (risers)

The discussion surrounding risers was brought to attention when asked about consequences and probability in relation to the WCPF. They explained that there are escalations that could give large environmental consequences that are not covered in WCPF but that the idea was that the process fire should not escalate to a riser. In NORSOK it states that risers and ESD valves should be protected for accidental loads. Riser fires are usually so rare that they are outside what you design for and that they because of it might not be handled currently. There is a lot of discussion though surrounding Sub Sea Isolation Valves (SSIV) to reduce the duration and volume of such leaks.

5.3.5 Barriers

I brought up some of the comments surrounding drain and the fire water system. The reason the fire water system is not credited is the historical reliability of the system, which has not been actual to change. The open drain is required to have the capacity to handle fire water and the WCPF. The drain should be followed up on like any other safety system to make sure it works as intended. The PSA know of projects where the drain system has been changed due to low capacity.

5.3.6 Follow ups

The PSA follow up on changes related to the WCPF similarly to how they follow up on safety systems to make sure it meets the requirements. If changes are not done properly they will be noticed during the next inspection by the PSA. The PSA asks about changes relating to the WCPF. Changes in the separator segment are usually the most relevant to look at due to the segments' large size. Since there are fire loads that are higher than what have been tested new evaluations might be needed.

5.4 COMPARISON OF PETROLEUM SAFETY AUTHORITY AND INDUSTRY

The focus was seemingly different between the PSA and the industry. The PSA did not really see a need for further specifications or guidelines as long as the requirements are met. The current definition in NORSOK S-001 was considered enough. The industry was more focused on the actual implementation and there was seemingly a need for additional information. There was also the question of what credible actually means. The issue surrounding documentation was mentioned both by the industry and the PSA. Since the PSA have asked about additional fire testing and started a project surrounding it, documentation seemed to be a currently handled issue. Relating to barriers the industry and the PSA seemed to agree about possible issues in the drain systems among with the improvement of the fire water system.

If the goal still is to have a unified industrial approach to the WCPF, the industry still seems to struggle. The industry and PSA agree that the definition became clearer with the definition in NORSOK S-001. Even if the industry follows the definition in NORSOK S-001 and technically meets the requirements during audits, there is still a lot of room for subjective interpretation. Lastly, similarly to how NORSOK describes what to do but not how, the PSA seemed to focus on what is done and the industry on how it is done.

6 FURTHER ASSESSMENT OF DEFINED CHALLENGES

6.1 TOPIC SELECTION

Three topics were chosen for further investigation. Being:

- The variation in how cut-off rates[18] are chosen and how this variation can be more contained.
- Inconsistencies on how barriers are credited and the reliability of credited barriers, mainly concerning the fire water system and the drain system.
- How new companies work with the WCPF definition considering that they were not part of the discussion as the concept was invented and the limited literature.

All of these were considered for being the main focus of the thesis before it was reworked. The selection process to arrive at these three topics was mainly a process of elimination.

Variation was one main theme I wanted to include in the interviews. It was found in many different areas, for example fire duration, escalation and choice of cut-off rates. The cut-off rate variation was an unexpected finding, which also affected the duration of the fire and the methods for choosing cut-off rates also varied. Even though cut-off rates in itself were not a WCPF exclusive issue, it was a very important factor in how a WCPF fire scenario will look like. This was why it was chosen as a contending topic.

Another main theme during the interviews was barriers. Other than the drain and fire water system was the lacking documentation surrounding PFP. The drain and fire water system became a contending topic since the use of these system are imbedded in the WCPF definition itself.

Lastly the choice of making new and international companies a contending topic was mainly based in the actuality of this topic. With the trend of new companies entering the Norwegian Petroleum Industry this perspective became highly relevant.

6.2 METHODOLOGY OF DEFINED CHALLENGES

The methodology for new companies was interviews and is explained in chapter 3. For the two other topics I decided to contact some of the respondents again. This communication was mainly done via email. Information gained from the earlier interviews was also used when suited.

6.2.1 Cut off rate selection

Consultants are usually performing the risk assessments and choosing cut-off rates. This would mean they have most experience with this issue and may also be familiar with the differences in methodology.

To gain this knowledge I reached out to the two consultants from the initial six interviews. In this email I briefly mentioned the variation in cut-off rate selection methodology and asked what a guideline would need for it to be functional.

6.2.2 Reliability of the drain and fire water system

The operators oversee the maintenance of the installations safety systems. The reliability of these systems and practical experiences would therefore most likely be known by the operators.

I decided to contact the safety experts, Operator 2 and 3, again to get more insight on the fire water and drain follow ups. In the email I described the experienced inconsistency and asked about the historical

[18] The cut-off rate is the leak rate of hydrocarbons of which the corresponding fire is evaluated not to be critical to the structure anymore.

reliability of these systems. I also asked Operator 2 if they had any examples on how often these systems are tested.

6.3 RESULT AND DISCUSSION: THE CUT-OFF RATE VARIATION

Both consultants started the discussion with why the cut-off rate varies. It is hard to decide a universal cut-off rate since different installations have different prerequisites and structures. For some installations a cut-off rate of 5 kg/s would be very conservative while for others not close to low enough. Another aspect is that it is a multidiscipline problem since it considers the structural integrity and not only fire dynamics. It is most likely not enough for a collapse if a single beam loses its integrity. Rather a combination of failing beams and structures could cause a collapse. This was also brought up by Operator 2 in the original interview, where they could remove an entire column without the structure collapsing.

Rather than having a standard value it could thus be more reasonable to have a standard method. This method would require a lot of transparency regarding assumptions and tools. Consultant 2 explained that the analyst that uses a standard method could specify heat loads, exposure, duration, the geometrics of the module and ventilation conditions among with the used tools for the calculations. It was also explained by Consultant 1 that depending on which assumptions are made, the resulting cut-off rate could vary for the same installation, but that these rates could be considered equally valid. All of this need to be considered in a standard methodology.

The current cut-off rates mentioned in NORSOK S-001 are 2 kg/s and 0,1 kg/s (Standards Norway, 2018, p. 20). When the analyst deems these cut-off rates unfitting, they then use other methods to find a cut-off rate. A standard method could hopefully minimize the possible variation from using different methods while remaining flexible enough to account for the different prerequisites for installations.

A functional requirement could be:

"The cut-off rate has to be chosen in such a manner that it does not cause danger to the structural integrity.

The methodology used for choosing a cut-off rate should:

- *consider both the dynamics of the fire and the effect on structural elements of the installation*
- *define assumptions in a clear and transparent manner*
- *define uncertainties in a clear and transparent manner*
- *consider the uncertainties of the assumptions and methods to assure a robust result. This can be done with a sensitivity analysis."*

This would mean that simplifications are allowed but should be easily understood and be considered in such a way that it does not cause harm to the installation. Assumptions and uncertainties could concern fire modelling, materials of the installation, wind and ventilation conditions etc.

6.4 RESULT AND DISCUSSION: DRAIN AND FIRE WATER SYSTEM

When asked about the reliability of the fire water system, Operator 2 and Operator 3 said it has become more reliable in recent years, but older systems are still used. There is also the question if the systems will work when you actually need them. Operator 2 explained that there have been challenges with rust in carbon steel pipelines. The rust blocked the nozzles to the point that water was unable to come out. Newer installations with a fire water system of stainless steel or titanium do not have the same amount of problems. The problematic pipelines on older installations are being replaced because of this.

Concerning the drain system Operator 3 explained that it could be difficult to test the drain system and the testing could vary. In full scale tests there have also been many occasions when the drain capacity was not high enough. This was thought to either be caused by a small drain design or because of blocking during operation. To avoid blocking the drain is regularly washed as part of maintenance. In the original interview Operator 3 also mentioned that newer drain systems were more reliable. Operator 2 explained that the drain system was followed up with periodic maintenance and gave two examples. On one installation it is followed up every 6 months and another every 12 months. The deluge system to the fire water was followed up at the same interval for these two examples.

As mentioned by Operator 3 and the PSA the main reason as to why the fire water system is not accounted for is part of the historical reliability of the system. Even though the drain and fire water system might be followed up regularly with approximately the same frequency, the full-scale capacity testing of the drain might occur more seldom. As mentioned above both systems have had problems historically and both systems can have problems today especially on older installations.

Engineer 1 mentioned in the original interview, if a barrier is part of the safety strategy it must be maintained properly. The PSA also stated that if the capacity is too low, they could require to update or change the drain system.

The same argument as to why fire water cannot be accounted for could easily be applied to the drain system, "How do we know it will work when we need it?". I believe since these systems are so connected to each other this inconsistency becomes even more important. As you assume a failure rate 0 % for the drain system and 100% for the fire water system.

6.5 RESULT: NEW COMPANIES

Both companies got familiar with the term through discussions with the PSA. New company 2 got in contact with it after an audit with PSA where they had not considered WCPF into the design. New company 1 have not yet performed any calculations surrounding WCPF but are in the work of looking into it in the assessment phase of their project.

Both companies use consultants to perform their risk assessments and the work is then checked inhouse. When asked whether it is more or less difficult for a new or smaller company to interpret the requirements, New company 1 expressed that they might be more reliant on the consultancies expertise than if they had done the calculations inhouse but that WCPF is quite new for all companies. New company 2 expressed that they could not see a difference if they could use consultancies.

In comparison to the probabilistic approach, New company 1 pointed to that WCPF does not take the probability into account which could result in significant consequences that then rules out some design concepts. They also pointed out the ALARP principle[19] and questioned the cost-benefit. It is easier to point at a numeric value when discussing with decision-makers which the probabilistic approach allowed. New company 2 saw that it is a different way of thinking but if the requirements are clear it is not that different to work with WCPF. When asked if there was a need for a guideline New company 1 responded that there should be more information on how to use the WCPF.

The main challenges New company 2 identifies were that the WCPF could have resulted in a major redesign if the installation had not been considered robust enough. For New company 1 the concern was to not be able to meet the requirements.

If the calculations had concluded that the installation was not robust enough the financial aspect would be easier for a larger company. For old installations there will always be questions surrounding cost and

[19] ALARP means "As Low As Reasonably Practicable" and describes the risk level that is deemed reasonably practical considering the cost-benefits of controlling the risk (Health and Safety Executive, 2019).

reinvestments in platforms that has a limited amount of years left in service. This could be troublesome for larger companies as well.

New company 2 mentioned that they might not be representative for a smaller company since they took over the work that the old company had done. That said, some of the other companies that were originally contacted had also bought an already operating platform and might have similar experiences. New company 1 also stated that it might in some ways be easier for them compared to older companies since the WCPF is their starting point and they do not need to adapt a current design to fit the criteria.

7 FINAL DISCUSSION

What are the experienced challenges when working with WCPF? Does the industry and the PSA have a united view?

There are many things the industry and the PSA agree upon. For example, the WCPF is mainly seen as a positive change, and that the NORSOK definition made things clearer. The differences and challenges are instead seen in the application of the term. There was no single issue that was highlighted by all respondents, instead a broad view from different perspectives were given. What the various respondents considered to be the main challenges are listed below.

- *The meaning of credible*:
  What is considered credible can be subjective. It is unclear how to interpret credible in practise and if it is linked to frequency.
- *Arranging scenarios and scenario selection*:
  Different strategies are used when it comes to the details of defining scenarios. The results of the studies can therefore vary depending on the method. It is also difficult to arrange scenarios and pick the most credible one.
- *Simulation and modelling:*
  There are uncertainties in the models that might be overlooked and could affect the conclusions. Depending on the prerequisites of a company, different levels of simplifications might need to be used where simplifications mostly leads to higher heat loads.
- *The fire duration and documentation*:
  The durations the WCPF causes are what the equipment and firewalls are documented to withstand. There is also lack of documentation regarding temperatures and heat fluxes. The lack of documentation might lead to long discussions about uncertainty even though the installation most likely still will be intact[20].
- *No explicit probability perspective and in some cases questionable cost-benefit*:
  Because probability is not calculated and only considered indirectly by the word credible, a company might need to design for very remote scenarios. The WCPF concept might not follow the ALARP principle either because frequencies are not calculated.
- *Risers and wells*:
  Risers and well releases are not covered in the WCPF approach and follow a probabilistic requirement. This means that these events might not be handled currently due to low probability.

As discussed in chapter 5.4 the PSA and the industry have different focuses. The PSA focuses on what is done and the industry focuses on how it is done. This said, the PSA and the industry agree on some shortcomings such as the documentation issue.

It is important to note that there were disagreements within the same actor groups and within the industry. For example, regarding the confidence in models and simulations, realistic modelling vs simplifications, whether the lack of probability perspective is positive or negative and whether subjectivity could be viewed as a positive. There were also differences in how to approach the WCPF relating to scenario selection. In turn because consultants are seemingly in charge of the implementation of the WCPF these different perspectives can then lead to different approaches. This can in turn lead to different results depending on which consultant is hired.

[20] As mentioned by Operator 3.

In conclusion due to the different focuses between the industry and the PSA, and the differences in approach to the WCPF, the view cannot be considered united. However, these disagreements are part of important discussions surrounding safety and uncertainty which should not be considered negative.

<u>How can possible variations in the industry be addressed? Is the current definition and literature surrounding WCPF adequate considering the importance of the analysis?</u>

The word *credible* caused some confusion. Considering the importance of the analysis words within the term should be clear. Is it related to frequency or the general circumstances of the scenario? How do you know if assumptions outside the definition could be considered credible? If risk assessors interpret the word differently risk assessments will start to deviate immediately.

Other variations relate to escalation and cut-off rates. How to credit escalation has become a bit clearer in NORSOK S-001 but it is still unclear when to assume escalation happens etc. Cut-off rates have been discussed above. In this case a standard method is more useful than standard values. It is possible that other parameters such as assumed HC volume and escalation could use more guidelines or a general method to get a more unified approach within the industry. Standard methods and guidelines would still need to be flexible to allow a degree of tailor-making for the facilities due to different prerequisites.

If we look at similar concepts the Worst Case Scenario has a similar problem to the WCPF, what the word *worst* means, and how far the scenario can be pushed. The credibility of the WCPF is currently based in its use of safety systems but there are many other factors to consider that affect the scenario. In those cases what is a credible HC volume or wind direction? Should they be like the safety systems, be binarily credited or not credited, or should they be linked to frequency? Then what would be considered a credible frequency?

In terms of possible variation when ranking scenarios, the credibility factor C could be of use. It would also address the word credible more directly. But as concluded in chapter 4.4 this could come at the cost of shifting back the focus to probability. The large uncertainties concerning probability with these rare types of events would also reoccur and the variation might not be lowered with this approach. The ability to make early decisions might also disappear if one wanted to make thorough probability estimations. How to rank and select scenarios will always face subjectivity and uncertainty and therefore transparency might be the best solution.

In conclusion variation could be addressed in a few ways:

- by standard methodologies
- by further clarifying the definition and circumstances of the scenario
- with transparency

So, considering that the WCPF is used as basis for design loads on facilities, is the current literature enough?

The industry knows, based on the current definition, what but not exactly how to approach the WCPF. It manages very well, but it is new territory that the industry still is adapting to. As of now there is only one document that defines the WCPF since the SINTEF report is seemingly out of date. Half a page is quite little considering the importance of the WCPF. The requirements in the regulations (Facilities Regulations, section 33) does not necessarily need clarification, but rather how to meet them in a unified way. If the how is clearer the analyses would also become less subjective. For this reason, the literature could probably be considered *enough* but could be improved with more guidance.

<u>Are new companies affected by the limited literature surrounding WCPF differently?</u>

Contrary to my initial speculations, new companies do not seem to be affected by the limited literature more than older and larger companies. Smaller and newer companies might however rely more on the expertise of the consultancies and need a more hands-off approach due to more limited resources. Expensive changes to the installation could also affect a smaller company more. This said, finances and limited budgets still affect larger operators. Even though smaller companies have not taken part in the WCPF discussion from the beginning they are seemingly not in a clear disadvantage, if a disadvantage at all. When building new platforms adapting to this approach immediately might even be considered an advantage. The staff in these companies might also carry many years of experience from the industry even if the company itself is young.

<u>Are barriers credited in a consistent and a justifiable way in the WCPF definition?</u>

The barriers are chosen to represent the credibility of the WCPF scenario. There is some consistency in that both the drain system and PFP are passive barriers and are credited. The ESD and EDP systems are automatically activated by the detection system, but so does PSD system. As have been discussed in chapter 6.4 the same arguments as to why the drain system can be credited could be applied to the fire water system and vice versa. For this reason, the way barriers are credited in the definition is not *consistent.*

To not credit the fire water system is part of historical reliability of the system. This was exemplified by Operator 2 when rust in pipes and nozzles made water unable to come out. To assume a failure rate of 0% for the fire water system in these situations would be way too optimistic. The focus from the PSA is on robust designs. To not account for the fire water system does increase the robustness of the design for any scenario and is in line with the risk reduction principles stated in the Management Regulations. If the drain system is well maintained and well dimensioned the failure rate of 0% could be considered reasonable. But for some systems this might not be the case.

The blowdown system was viewed as reliable. To assume a high functionality is therefore reasonable. For the passive fire protection, the issue instead becomes the documentation for high temperatures and long durations. While within the limits of the documentation a high functionality could be reasonable but outside of the documentation it would be optimistic to assume a failure rate of 0 %. There is also the logical contradiction that the WCPF scenario has a proportionally much lower probability of happening than what the barriers have of failing.

The assumptions as of now seem reasonable but highlighting the importance of maintenance and gaining more documentation for PFP would justify these assumptions even further.

7.1 ERROR SOURCES

The focus of the interviews was to identify issues and therefore the positive outcomes of the WCPF concept may be less highlighted in the thesis. In order to have a complete picture of the implementation of the WCPF concept more interviews within the same actor groups would be needed. As discussed in chapter 3.1.1 and 3.2.8 there is also a level of subjectivity in how the interviews were analysed and how literature of similar concepts where chosen. It should also be noted that these interviews are too few to show statistical significance and rather cover a wide range of reflections from the industry.

8 FURTHER WORK

Ask consultancies: A project similar to the SINTEF project could be made with some of the major consultancies in Norway. It could ask for detailed descriptions of how escalation, scenario selection is approached etc. Another alternative is to use one or a few installations with different prerequisites and budgets and then ask the consultancies to identify the WCPF scenarios and motivate their methodology. Either strategy would highlight the differences in methodology clearer with more data than in this thesis. Regardless if a project like described above is made I believe that if the industry wants to address subjectivity and variation, the consultancies should get a bigger focus then they have had previously.

Specify the word credible: The consideration of barriers already differentiates the WCPF concept from the WCS. That said, it is still possible to account for different volumes when drain is considered among with wind conditions etc. I believe there is a need to further address what the word credible means in practice.

Investigate another concept for risers and wells: The consideration of risers is to a degree looked into with the SSIV as mentioned by the PSA. Even if the WCPF approach is not suited for risers nor the wells, it could be useful to find other possibilities to get around the lack of measures due to low probability. Similarly, to how the WCPF addressed some of the shortcomings of the probabilistic approach, another approach could be implemented for these kinds of hazards.

Address the gaps in the current documentation: Documentation surrounding heat loads and temperatures is currently looked into according to the PSA. There is still the issue with duration for the current documentation. Even though the structures might still be intact it is important with documentation to settle the uncertainties when the current values are surpassed. Even though these tests are expensive there seems a need for this kind of documentation to lower the uncertainty.

Highlight the importance of the barriers' performance: The effectiveness and vulnerability of the barriers can vary from installation to installation. It is not reasonable that a system can be accounted for if it is regularly determined to have problems on one installation, but it should not affect the ability to account for that same system on other installations where it works as intended. I believe it should be made more explicit what is expected of the barrier management in order to account for a safety system in a WCPF analysis.

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Appendix A:

Process and Safety Systems

A1 PURPOSE OF THE OFFSHORE PROCESS PLANT

The process starts in the wells underneath the water. The products from the wells are however not pure oil or gas from the start. It is instead a mixture of oil, gas, water, sand and other contaminants such as salts, nitrogen, CO_2 and H_2S. The oil and gas mixture cannot be sold or transported under these circumstances and thus needs to be treated. The main goal of the offshore facility is thus to separate oil and gas and to remove water and other contaminants to the required level set by the purchaser and for safe transportation. Oil can be stored and then be transported by boat or by oil pipelines while the produced gas can be transported through gas pipelines from the offshore facility. Refineries and gas plants will then further process the oil and gas (Aker Solutions, 2019; Lake & Arnold, 2007, pp. III-1 - III-3).

A2 PROCESS DESCRIPTION

An overview of the process in an example facility can be seen in Figure A1. The oil, gas among with water and contaminants are first treated in a separator. This first separator is a high-pressure separator or also called a production separator. A separator can be two-phased or three-phased. A three-phase separator can separate the oil, gas and water from each other while a two phased only separate liquids and gases. Inside the separator there can be weirs, buckets and mist extractors to make the separating process more efficient. A simplified picture of a separator can be seen in Figure A2. Lighter components in the oil after the separation can flash into gas due to decreased pressure. The oil can however be stabilized in an atmospheric tank or be treated in additional separators with decreasing pressure in each separator. The flashed gas is then compressed and treated together with the separator gas (Lake & Arnold, 2007, pp. III-3 - III-4).

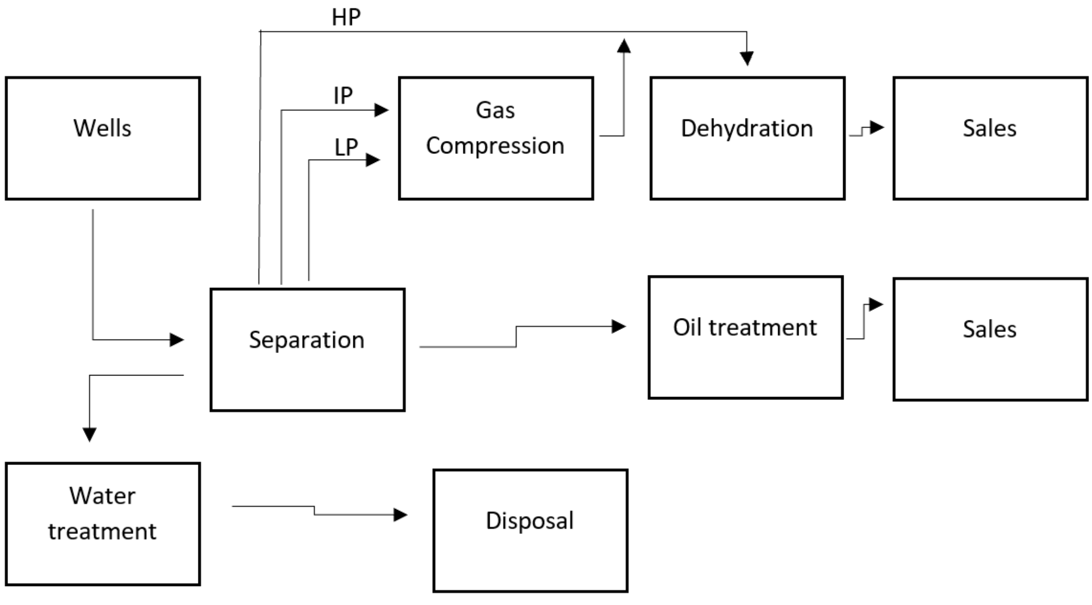

Figure A 1: Overview of the process for a typical oil facility. HP indicates high-pressure, IP indicates intermediate pressure and LP indicates low-pressure. The picture is an altered version of the original picture by Lake & Arnold (2007) pp. III-4, in "Petroleum engineering handbook; Facilities and construction engineering, Vol. 3".

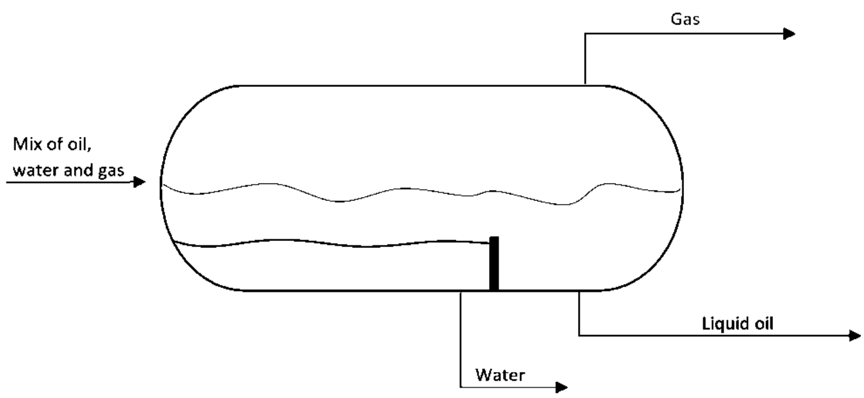

Figure A 2: A overview of a three-phase separator.

After the separation process there is still a need for additional treatment. The oil will still have some water left inside of it which can be treated with a coalescer (Lake & Arnold, 2007, pp. III-96). After the treatment the oil can be stored in a dry tank and later transported to the purchaser (Lake & Arnold, 2007, pp. III-5). The water can have remaining oil inside of it and can be treated with water skimmers and hydro cyclones and filters. All these methods can be combined with each other (Lake & Arnold, 2007, pp. III-6). CO_2 can cause corrosion in combination with water and H_2S can be toxic. Because of this the gas needs to be treated for these substances. These components can be removed with an amine system. The remaining water inside the gas also needs to be removed. This can be done with a glycol contractor (Lake & Arnold, 2007, pp. III-5 - III-8, III-96). An overview of a gas plant can be seen in Figure A3.

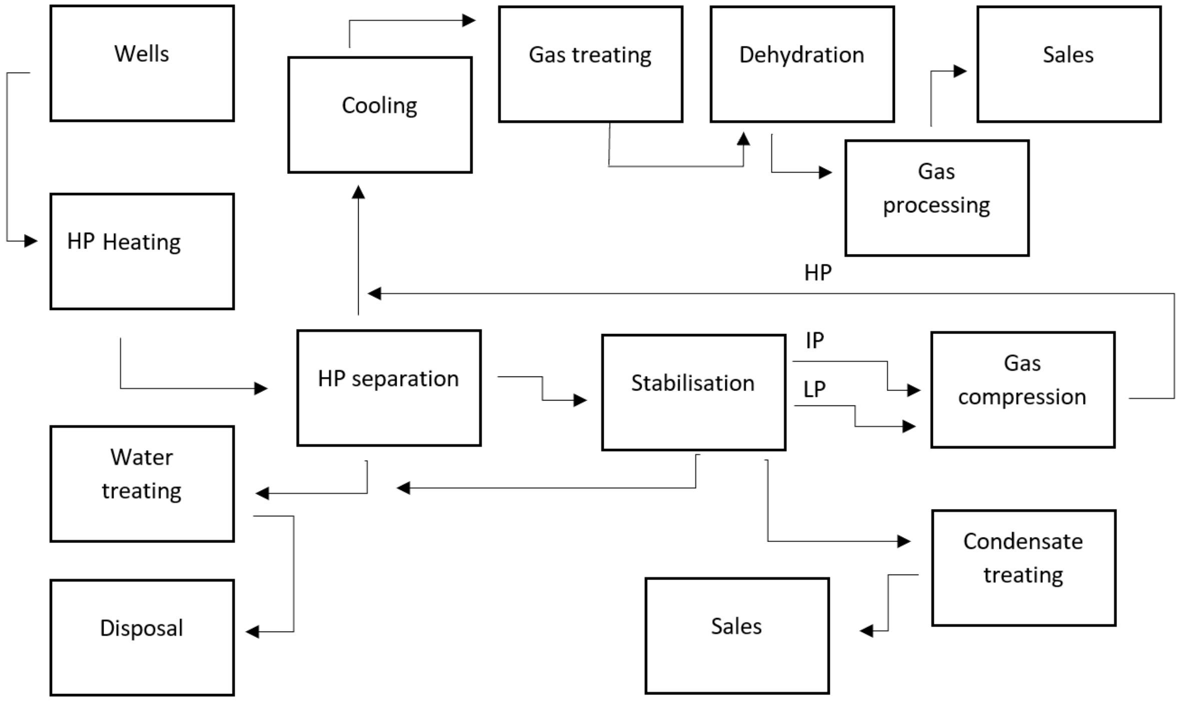

Figure A 3: Overview of gas facility. The picture is an altered version of the original picture by Lake & Arnold (2007) pp. III-7, in "Petroleum engineering handbook; Facilities and construction engineering, Vol. 3".

It is important to note that all facilities will have variations in the process system and the explanation above is mainly to get a general understanding of how the process works.

A3 PROCESS RISK

With this process system comes a lot of hazards. In this thesis we are looking at HC releases during production. HC leaks can come from process equipment, risers or an uncontrolled leakage from a well which is also called a blowout. The danger with HC leaks is if they are ignited, they can cause fires and explosions. In this thesis we will mainly talk about jet and pool fires among with spray fires.

A jet fire is commonly understood as a fire resulting from a HC gas leak from a pressurised container and can be very turbulent. A pool fire is instead result from igniting the vapour above a HC liquid. Spray fires are in comparison to jet fires often associated with liquid leaks (Khalique, 2016, pp. 58-59, 186-187). In this thesis spray fires are associated with leaks consisting of both gas and liquid (2-phase leak) causing a spray like effect.

In this context it is the volume, the placement and the leak rate that affect the end fire size and its severity. In the case of a WCPF, process vessels with large HC volumes like separators and coalescers causes the biggest threat. There may also be large gas volumes in certain EDP segments that could be dangerous if leaked and ignited[21]. Because volume is not the only factor that affects the severity of the fire, the WCPF definition specifies to look at the worst heat loads and exposure to load bearing structures.

A4 TECHNICAL SAFETY

Below are short descriptions of safety systems mentioned in this thesis. These systems work together as barrier elements to ensure the barrier functions are maintained in case of a HC leak, but all of them are not accounted for in a WCPF analysis. Note that there are more safety systems on a facility than the ones mentioned below. The description aims to give a better understanding of their purpose and function on the platform in relation to the topic of this thesis. The systems mentioned below mainly limit the consequences of a HC fire, apart from the detection system which identifies the hazard and can activate other systems. The information below are taken from the NORSOK S-001 standard (Standards Norway, 2018) and the Facilities Regulations. For more information about barrier management see Appendix B.

A4.1 OPEN DRAIN AND BUNDING

According to the standard all tanks and vessels with flammable liquid should be equipped with bundings and a drain system. The open drain system will limit the volume while bundings limit the area the liquid can spread to. The drain system is divided in two, the open drain and the closed drain. The open drain system disposes of chemicals, hydrocarbons and seawater. The closed drain system instead empties process equipment. This thesis will look at the open drain system since it is covered by the WCPF scope. The open drain then has the requirement to handle the liquid leak rate associated with the WCPF among with the full fire water capacity (Standards Norway, 2018, pp. 17, 30-31). The drain system should also be equipped with seals to avoid spreading of flammable gases to other areas via the drain system (Standards Norway, 2018, p. 32).

[21] Large gas volumes give potential for high explosion risk, but this is not covered in this thesis.

A4.2 FIRE AND GAS DETECTION SYSTEM

It is required for facilities to be equipped with a detection system that can identify fires and gas leaks (The Facilities Regulations, Chapter 5, Section 32). The system is connected to and activates other systems. Some of these systems are the fire water-, PSD-, ESD- and EDP system.

The gas detection system aims to identify flammable or toxic leaks before the concentration becomes dangerous (Standards Norway, 2018, p. 44). The detection system combined with connected systems can be described to work as follows "if X out of N detectors identifies danger Y action Z starts".

In case of gas detection – if 2 out of N (2ooN) detectors, N >= 3 - identifies concentration levels above the limit the ESD system is activated and an alarm is set off, other systems may be activated if they are specified in the Safety Strategy, for example the EDP system (Standards Norway, 2018, p. 47). In case of fire detection there are smoke, flame and heat detectors. For these detectors the danger is confirmed if 2ooN, 2ooN or 1ooN for N>= 3,3 and 2 are activated. Firefighting equipment and the alarm will activate upon detection and the ESD and EDP system will activate if the fire is in hazardous areas (Standards Norway, 2018, p. 59). It is not explicitly said that the detection system can be accounted for in a WCPF analysis (Standards Norway, 2018, p. 17). That said since it is connected to the ESD- and EDP system it could be assumed that it can be accounted for since these systems can be accounted for.

A4.3 PROCESS SAFETY SYSTEM

A facility with process equipment must have a functioning process safety system in place (The Facilities Regulations, Chapter 5, Section 34). The process safety system aims to avoid accidental releases by ensuring the process conditions does not exceed the safety limits for the process system, this control lowers the probability of an accidental event. Some of the actions taken by the process safety system are pressure relief, shutdown of heat input, shutdown of process and utility equipment and stop of HC flow. The amount of actions depends on the severity of the deviation (Standards Norway, 2018, p. 32). PSD valves should be located as close as possible to the pressure vessel and have a fail-safe function (Standards Norway, 2018, p. 33). This system is not allowed to be accounted for in a WCPF analysis according to the current definition in NORSOK S-001. The use was though discussed in the SINTEF report with some operators accounting for the PSD system.

A4.4 EMERGENCY SHUTDOWN

In comparison to the PSD system the ESD system is allowed to be accounted for in a WCPF analysis (Standards Norway, 2018, p. 17). The ESD system is also a mandatory system to have (The Facilities Regulations, Chapter 5, Section 33) and it aims to prevent and limit hazardous events (Standards Norway, 2018, p. 35).

The ESD valves divide and isolate the process segments which limit the volume of available hydrocarbons in the event of a leak. The valves are also positioned with a fail-safe function. Some valves are always categorized as ESD valves, examples of such valves are the nearest shutdown valve to a hydrocarbon riser, the nearest valves to large liquid vessels and well isolation valves (Standards Norway, 2018, pp. 36-37).

The ESD functions are divided into a hierarchy. If a high level is activated the levels below including the PSD system shall also be activated. Some of the ESD actions are shutdown of riser valves, shutdown and sectioning of HC process facilities, initiation of EDP, ignition source isolation and shutdown of main power generator (Standards Norway, 2018, p. 37).

A4.5 EMERGENCY DEPRESSURISATION SYSTEM (BLOWDOWN) AND FLARE/VENT SYSTEM.

The emergency depressurisation (EDP) system aims to reduce the inventory and pressure in a process segment. This lowers material stress and reduces the leak rate and leak duration which would lower the probability of ruptures and fire size in case a leak gets ignited. Larger vessels with more than 1000 kg of hydrocarbons are required to have a depressurisation system, this is not required for smaller segments (usually less than 100 kg) (Standards Norway, 2018, pp. 41- 42).

The system is automatically activated if a fire is detected in a hazardous area like risers, process or wellhead areas. In some cases, the EDP system is automatically activated by gas detection otherwise this is done manually. The EDP system is also allowed to be accounted for in a WCPF analysis (Standards Norway, 2018, p. 17).

A4.6 FIRE WATER SYSTEM

The fire water system works to limit fires and explosions and cooling of equipment and structures. It is mandatory to have a functioning fire water supply on facilities with accommodation and should be able to ensure fire water to any area in the facility (The Facilities Regulations, Chapter 5, Section 36: Standards Norway, 2018, pp. 89-90). The fire water system is part of the active fire protection and shall be possible to activate even if all other systems are failing. The sprinkler and deluge system shall also cover all relevant fire scenarios (Standards Norway, 2018, pp. 91, 94). The fire water system is however not allowed to be accounted for in a WCPF analysis (Standards Norway, 2018, p. 17).

A4.7 PASSIVE FIRE PROTECTION

Passive fire protection aims to ensure fire protection for pipes, equipment and relevant structures. It should also be designed without the consideration of the cooling-effect from firefighting equipment (The Facilities Regulations, Chapter 5, Section 29). To avoid unacceptable ruptures, piping, vessels and process equipment shall also have thorough fire resistance. This can be done by adding PFP, increased wall thickness, material selection and use of EDP. The load bearing structures, along with fire divisions (that divides high fire risk areas or protects areas with important safety functions) are required enough PFP to withstand the design fire (Standards Norway, 2018, pp. 86-88). Passive fire protection can be accounted for in a WCPF analysis (Standards Norway, 2018, p. 17).

Appendix B:

Risk management in the Norwegian petroleum industry

B1 The Norwegian petroleum industry

25 of the companies in 2018 were operators and the remaining 14 were production licensees. Different companies can share a production license where one of them is made the operator. The shared licence makes it possible for smaller or new companies to learn from bigger or older ones with more experience. A wide range of companies also promote competition (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019b). As of mars 2019, eight new companies have filed for pre-qualification, and are undergoing evaluation to become either licensees or operators (Norwegian Petroleum Directorate, 2019b).

It can also be important to mention relevant administrative and governmental bodies. The Ministry of Petroleum and Energy aims to ensure the best possible use of the natural resources while still within acceptable environmental consideration (Ministry of Petroleum and Energy, 2019). The Norwegian Petroleum Directorate is then an advisor to the Ministry of Petroleum and Energy and provide data and overviews of the petroleum activities and production in Norway (Norwegian Petroleum Directorate, 2019a). In turn the Petroleum Safety Authority Norway (PSA) has the responsibility to ensure safe practises and working environment. The PSA has a supervisory responsibility within the industry and provide their expertise to the Ministry of Labour and Social Affairs (Petroleum Safety Authority Norway, 2019d).

Historically speaking, the main product has been liquid oil from Norwegian petroleum production but in later years gas production has gotten bigger proportionally to now represent over half of the total production, see Figure B1. In total Norway produced 226.7 million Sm^3 of oil equivalents with 121,56 being gas in 2018 (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019a). The numbers for 2019 are not up to date.

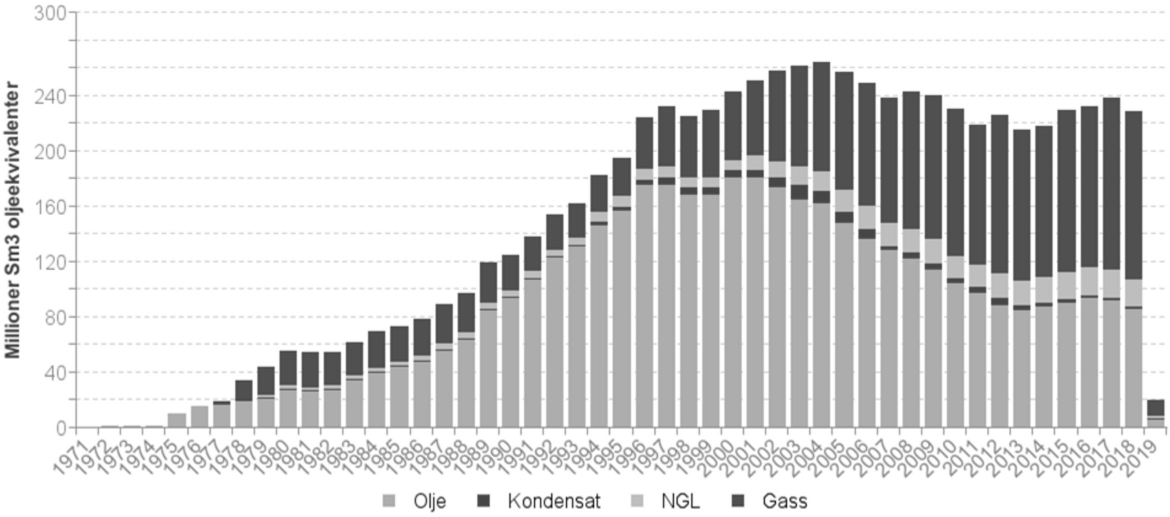

Figure B 1: Picture showing the historical production of petroleum products in Norway. The picture was retrieved from "Historical production" (Norwegian Petroleum Directorate, Norwegian Ministry of Petroleum and Energy, 2019a).

B2 HIERARCHY OF OFFSHORE SAFETY REGULATIONS

The rules and regulations can be said to be built up in a hierarchy where acts and regulations are legally binding, and guidelines and norms aims to support the responsible party to fulfil the legal requirements. The hierarchy can be seen in Figure B2 below.

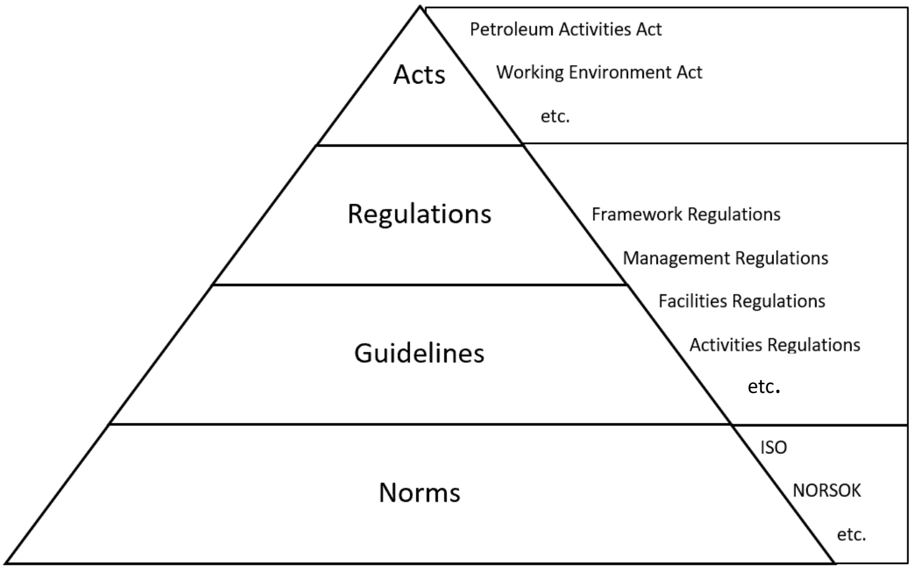

Figure B 2: A triangular hierarchy showing how the offshore safety regulations are built up with some examples to the right. Acts and regulations are legally binding while norms and guidelines supports to meet these requirements.

The Framework Regulations and Management Regulations consists of principles that are applicable to the rest of the regulations. These principles guide the philosophies and requirements described in the Activities Regulations and Facilities Regulations. In other words, these principles among the relevant laws and acts lays the foundation for the operation and safety for offshore facilities.

Examples of these principles are the risk reduction principles in Chapter 2 (Section 11) of the Framework Regulations. Principles also cover the responsible party. The responsible party in this context are operators, who must ensure that all requirements are lived up to (Petroleum Safety Authority Norway, 2019c).

What is written in different standards are solution proposals but not legally binding. Guidelines can also help to better interpret the regulations (Petroleum Safety Authority Norway, 2019b; Petroleum Safety Authority Norway, 2019e). A company can therefore choose to deviate from standards and guidelines as long as they live up to the legal requirements. In reality companies rarely deviate from standards since the alternative require much more documentation to prove that the solutions follow the regulations. In this thesis the main standards are NORSOK S-001 (covered in Appendix A) and NORSOK Z-013.

How regulations and requirements work in practise can be seen in Figure B3.

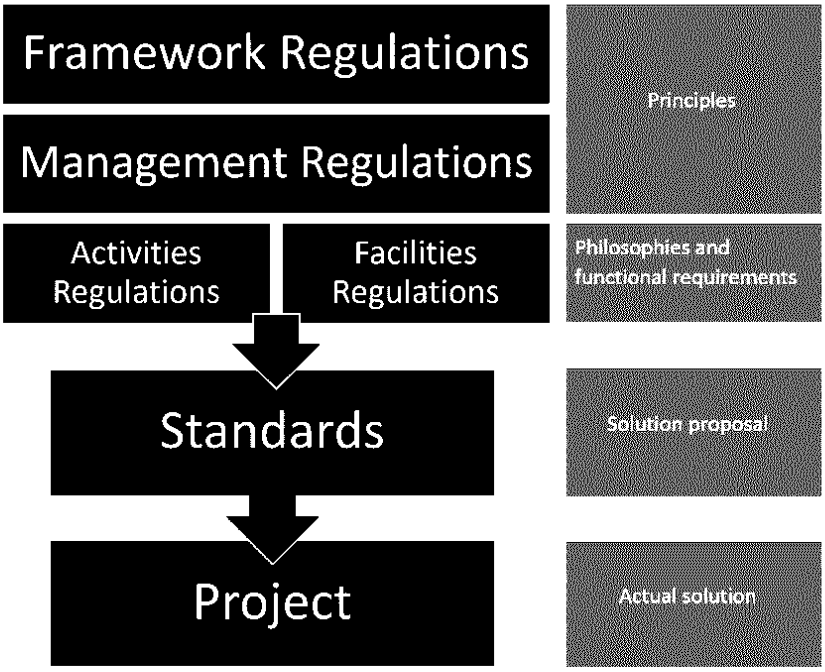

Figure B 3: The figure displays how the principles and requirements relates to the end project.

B3 LAWS AND REGULATIONS

The Norwegian petroleum industry needs to follow several acts. The relevant acts are displayed in the list below provided by the PSA website (Petroleum Safety Authority Norway, 2019a). Some of the acts are directly under the PSAs authority while others relate to HSE regulations and working environment (Petroleum Safety Authority Norway, 2017b, p. 23).

- *Petroleum activities*
- *Working environment*
- *Harmful tobacco effects*
- *Fire and Explosion Prevention Act*
- *Electrical Supervision Act*
- *Pay agreements application*
- *Svalbard Act*
- *Pollution control*
- *Health personnel*
- *Patients' rights*
- *Communicable diseases control*
- *Health and social preparedness*
- *Product control*[22]

The main regulations for this thesis are the Framework Regulations, the Facilities Regulations and the Management Regulations. The three most central regulations are shortly described below.

[22] Petroleum Safety Authority Norway, (2019a).

B3.2 THE FRAMEWORK REGULATIONS

The Framework Regulations cover health, safety and the environment in the petroleum industry and aims to promote high health, safety and environmental (HSE) standards (Section 1). It states requirements surrounding HSE and risk reduction (Chapter 2), Management (Chapter 3), Emergency preparedness (Chapter 4) and Establishment of safety zones (Chapter 8). It also includes offshore provisions to the working environment act (Chapter 5).

The risk reduction principles (Chapter 2, Section 11) state:

- *Risk reduction shall be taken as far as possible to limit the harm to people, the environment or material assets.*
- *The responsible party shall pick solutions that gives the best results granted that the cost benefit is not disproportionate.*
- *Solutions that lower the uncertainty if there is insufficient knowledge shall be chosen.*
- *Factors with the potential of harm shall be replaced with factors with less harmful potential.*

Other examples of principles from the Framework Regulations are the use of Norwegian language (Chapter 2, Section 13) and that the responsible party needs to ensure that the contractors they hire follow the regulations and correct deficiencies when found (Chapter 3, Section 18).

B3.3 THE MANAGEMENT REGULATIONS

The Management Regulations provides principles surrounding risk management and decision making. Risk management and barriers are covered in Chapter 2, Internal requirements and decision-making in Chapter 3, Risk analysis and assessments in Chapter 5 and Follow-up and improvement in Chapter 6.

It states among other things that:

- *Solutions which lower the likelihood of hazards and dangers shall always be preferred, the best risk reducing measures shall always be chosen (Chapter 2, Section 4).*
- *There shall always be barriers in place that can identify conditions that imply danger, reduce possibility of failure and limit possible consequences and harm. If there is need for more than one barrier they should work independently (Chapter 2, Section 5).*
- *Assumptions shall be expressed clearly so they can be followed up on if they form the basis for a decision (Chapter 3, Section 11).*
- *Analyses shall provide the necessary decision basis for health, safety and environment. The purpose of each analysis should be clear, the presentation should be balanced, and criteria should be set for updates or new analyses (Chapter 5, Section 16).*
- *The responsible party shall also ensure that all management systems function as intended and identify technical, organisational and operational weaknesses (Chapter 6, Section 21).*

B3.4 THE FACILITIES REGULATIONS

The Facilities Regulations cover the design and outfitting of facilities. The main safety functions are listed in Section 7 (Chapter 2) and shall remain intact even during an accidental event.

The safety functions state to:

- *Prevent escalation of accident situations to avoid injuries of personnel outside the immediate accident area.*

- *Maintain the capacity of main load-bearing structures until the facility has been evacuated.*
- *Rooms of significance shall be protected so that they remain operative until the facility has been evacuated.*
- *The facility's safe areas shall be intact until the facility has been evacuated.*
- *From every area with personnel there shall be at least one escape route until rescue of personnel and evacuation to the facility's safe areas have been completed.*

The regulation also states that a facility should always be equipped with safety functions that detect abnormal conditions, prevent abnormal conditions and limit the damage caused by accidents (Chapter 2, Section 8). The regulation also includes information surrounding physical barriers (Chapter 5), work environment (Chapter 3 and 4) and emergency preparedness (Chapter 6).

Different terms are used to define fires and loads for design of a facility (Section 3 and 11). A design fire is the fire associated with the design accidental loads that are used as basis to design a facility. The design fire has a minimum requirement to cover the dimensioning fire.

Dimensioning loads should not be smaller than loads associated with an accidental event with a likelihood of 10^{-4} per year. In other words, accidental events with a higher likelihood than 10^{-4} shall be covered by the dimensioning load. The main safety functions shall also be intact for loads equal to or lower than the dimensioning load.

The dimensioning load is then used as a reference for the design load which determines the actual design of the facility. Usually the design loads are slightly larger to allow for more robustness. This can be easier understood in a graph, see Figure B4.

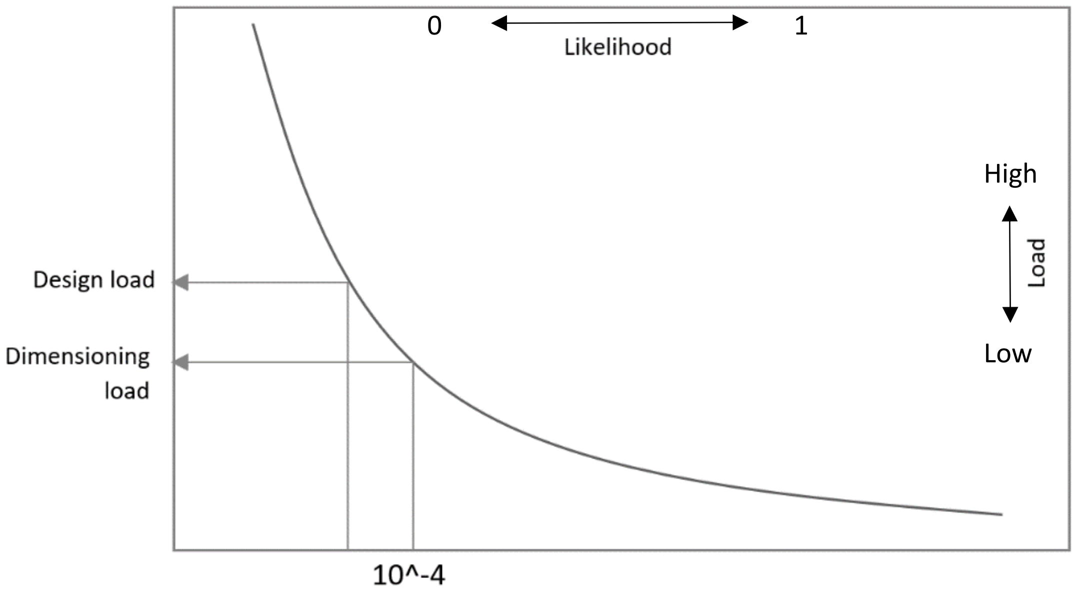

Figure B 4: The graph shows the relation between the dimensioning load and the design load with a probabilistic approach.

B4 RISK AND UNCERTAINTY IN THE NORWEGIAN PETROLEUM INDUSTRY

Risk is usually defined as the product of the consequences of an event and the frequency of an event. In ISO 31000: 2009 risk was defined as *"effect of uncertainty on objectives"* (International Organization for Standardization, 2019). The risk term was in turn also changed in the Norwegian petroleum industry to cover uncertainty in a more explicit way. The term was reframed as

"risk means the consequences of the activities, with associated uncertainty"

(Petroleum Safety Authority Norway, 2016, pp. 6-7). This was to bring more attention to the uncertainties related to the consequences which also includes the probability. This focus on uncertainty encourage better quality of knowledge and humbleness before making big decisions. The clarification of the risk concept also serves to put focus on the consequences of the entire activity of a facility and not on specific actions or events. Risk is created by all actions within the petroleum industry from design to operation and management (Petroleum Safety Authority Norway, 2016, p. 11).

B4.1 HIERARCHICAL BREAKDOWN OF RISK

As described by Hafver, Lindberg, Jakopanec, Pedersen, Flage and Aven (2015, p. 780) risk can be broken down into different hierarchical levels, as visualized by Figure B5 below. Assumptions have to be made for each level and the true risk can thus not be captured (Hafver, Jakopanec, Eldevik, Volent Lindberg, & Pedersen, 2016, p. 11).

The first level *Risk* refers to the true risk as described by the risk definition. It refers to the entire activity, both economic and health risks, all possible consequences of the activity. Whether the risk analyst knows about these risks is irrelevant for the true risk level (Hafver, et al., 2015, p. 780).

Assumptions and decisions start at the second level, the *Risk assessment scope.* All consequences might not be relevant for a certain analysis. The scope cannot capture the entire risk and thus the scope is narrowed down to a few investigated attributes. The risk analyst might also be unaware of certain risks. These hidden risks could still affect stakeholders even though they are unaware of their existence (Hafver, et al., 2015, p. 781).

The third level *Risk representation* defines models for the chosen attributes. These models will be unable to capture the attributes perfectly. There will be assumptions in these models and model errors. It is usually not possible to compare the model outcome to reality and thus there will always be model output uncertainty among with input quantity uncertainty (Hafver, et al., 2015, pp. 781-782).

Lastly the fourth level *Risk measures* define how the risk shall be evaluated. One risk measure might cover one aspect of risk but not all. To get a more complete picture different measures could be combined. In the petroleum industry it is common to measure based on Potential Loss of Life, Individual Risk and F-N curves. These measures do not disclose the strength-of-knowledge and are purely probabilistic. To communicate the uncertainties may be difficult but simultaneously very important to make well informed decisions (Hafver, et al., 2015, p. 782).

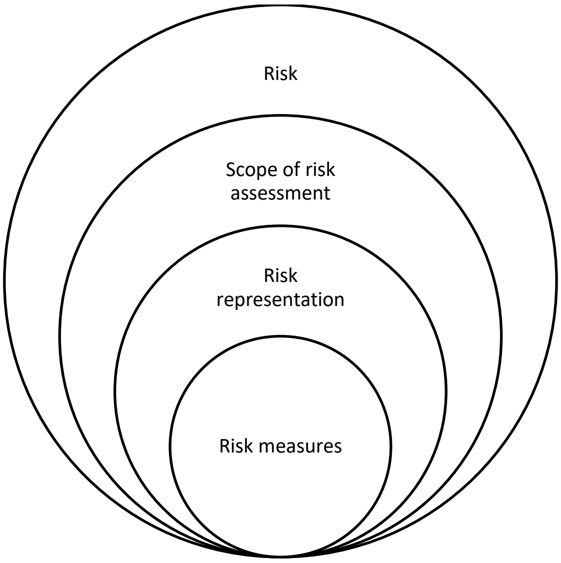

Figure B 5: Venn diagram of risk and the risk assessment process. Based on the figure in "Risk—from concept to decision making" by Hafver, et al. (2015) p. 780.

B4.2 STRENGTH-OF-KNOWLEDGE WHEN FACING UNCERTAINTY

A commonly used term when discussing uncertainty is strength-of-knowledge. It is used as a tool to describe uncertainty for assumptions, models and conclusions in risk analyses (Petroleum Safety Authority Norway, 2016, p. 8). The strength-of-knowledge can help to address how justifiable an assumption is. This can guide risk analysers through important decisions. If a probability of a hazard is deemed to be low but the strength-of-knowledge is weak[23], the risk may still be deemed as unacceptable. If the strength-of-knowledge is high the same result will instead be deemed acceptable. Even if conservatism is applied as a measure for low strength-of-knowledge it can affect scenarios differently, which in turn could affect the ranking and prioritization of the scenarios. To better visualize the strength-of-knowledge for a certain scenario different symbols can be used in a risk matrix where certain and uncertain scenarios can be given different symbols (Hafver, Jakopanec, Eldevik, Volent Lindberg, & Pedersen, 2016, pp. 16-18).

B4.3 DETERMINISTIC VS PROBABILISTIC APPROACHES TO RISK AND UNCERTAINTY

Risk and uncertainty can be approached in different ways. This approach can be deterministic or probabilistic.

A deterministic approach does not focus on the probability of an event but instead use a representative scenario. This scenario can be based on an earlier event or estimated by the risk analyst. By extension the deterministic approach includes a lot of subjectivity since the chosen scenario can involve different amount of conservatism. Cost-benefits are also difficult to measure with this approach (Paté-Cornell, 1996, pp. 95-96, 100). The WCPF approach is in turn a deterministic approach.

Shortly explained a probabilistic approach to risk assessment asks, "*What can happen? How likely is it? What are the consequences?*" (Aven, Baraldi, Flage, & Zio, 2014, p. 9). In systems with limited amount of data subjective probabilities can be used. These probabilistic models try to thoroughly address inherent variability in the system with distributions. These subjective distributions can then be

[23] Meaning that this evaluation is based on weak knowledge

updated with Bayes' formula when new information about the variable is revealed. The result, a predictive distribution, is then decided by applying the law of total probability and will include both knowledge-based and variation-based uncertainties (Aven, Baraldi, Flage, & Zio, 2014, pp. 9-11). This applies to the offshore systems since the data on offshore accidents is scarce. The results of a probabilistic analysis can be presented in a risk curve (probability of exceedance plotted against the loss levels per time unit). The uncertainties and assumptions in these curves might not be seen explicitly. To address this the curve itself can also be shown with a distribution and a mean curve (Paté-Cornell, 1996, pp. 97-102).

B5 RISK MANAGEMENT IN THE NORWEGIAN PETROLEUM INDUSTRY

Principles surrounding risk management are described in the Management Regulations as mentioned above with risk reduction principles, barrier management and HSE management (Chapter 2).

The PDCA cycle provides a model for management systems (Petroleum Safety Authority Norway, 2018, p. 12). It is shown if Figure B6 with the steps of plan-do-check-act. The circle then indicates that good management is an ongoing process. If one of the steps are not included the cycle falls apart making improvements within the organisation more difficult.

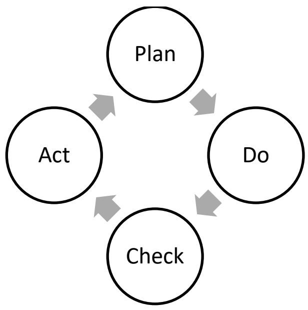

Figure B 6: Illustration of the PDCA cycle of plan-do-check-act.

The management system is run by people and more human aspects should also be considered for a well-functioning management system. There needs to be trust in the management for personnel to report issues with no fear of repercussions. It is then important for management to follow through on promises and make sure to learn from the reported incidents. To have trust in the management should not be misinterpreted as having a consensus culture. Dialog is crucial and should not only be about management giving information to personnel but rather involving everyone in heathy discussions (Petroleum Safety Authority Norway, 2018, pp. 23-26, 29-30).

Safety and financial gain are not necessarily a conflict of interest, however sometimes conflicts will occur. For example, a safety implementation can be very expensive to install or demand a lot of resources. In the event of these types of conflicts, solutions are easier to find in early project phases rather than later. In high risk industries like the petroleum industry these conflicts are quite common, and it is more difficult to find a good balance. To make better decisions, knowledge is crucial (Petroleum Safety Authority Norway, 2018, p. 12).

When making these important decisions uncertainties and assumptions should be stated clearly. An element of conservatism should be used to make decisions more robust. If there is a lack of information in one area, effort should be made to find this information and close the information gap. If an assessment has too many assumptions and is too uncertain, the conclusion will have little impact

(Petroleum Safety Authority Norway, 2018, pp. 17-18). In the case of a conflict of interest concerning safety, rather than argumenting as to why a safety proposal should be implemented, arguments should be made as to why it should not. The idea is to take risk management as far as possible and if the arguments as to why a safety measure should not be implemented are weak the measure will be installed (Petroleum Safety Authority Norway, 2018, p. 20).

B6 BARRIER MANAGEMENT IN THE NORWEGIAN PETROLEUM INDUSTRY

A portion of risk management is barrier management, where the main purpose of barrier management is risk reduction. Barriers is a complement to an inherently safe design and work to either detect factors that could imply danger, prevent hazardous events from occurring or limit damage and consequences if the hazardous event occurs (Petroleum Safety Authority Norway, 2017a, pp. 4,10). Barrier management then involves the coordinated activities to maintain existing barriers and establish new ones to fulfil their functions at any given time (Petroleum Safety Authority Norway, 2017a, p. 10).

Each barrier consists of barrier elements that work together to ensure the function is fulfilled. The barrier elements can be technological, operational and organisational. Technical elements relate to the equipment used, operational elements instead relates to what tasks needs to be performed and the organisational elements refers to which personnel and what competences is needed to ensure the barrier function (Petroleum Safety Authority Norway, 2017a, pp. 9,14). For example, a smoke detection system has the function to identify a hazard with a technical barrier element of smoke sensors.

It is easier to understand the purpose and the effect of a barrier with a bowtie model where proactive and reactive barriers among with different incident scenarios and possible outcomes are clearly visualised, see Figure B7 (CGE Risk Management Solutions, 2018). A bowtie is also a way to visualise how multiple barriers work together to lower the probability of the hazardous event or limit the consequences of it.

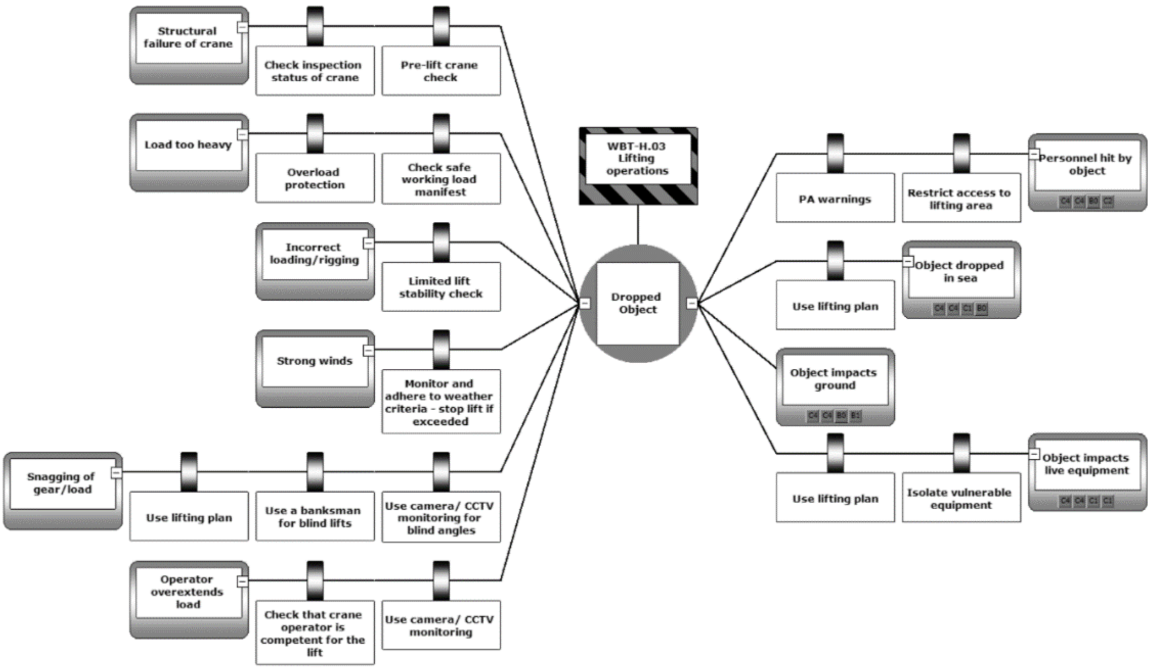

Figure B 7: Illustration of the bowtie model from CGE Risk Management Solutions, the picture was retrieved from "BowTieXP feature overview" (CGE Risk Management Solutions, 2018).

Figure B8 shows the main steps in barrier management, which consists of identifying the hazards and after that identify the barrier functions, elements and then performance requirements for these barriers. The barriers must also maintain their function over time and cannot be neglected after their installation (Petroleum Safety Authority Norway, 2017a, pp. 5,20). Barrier management is in other words a continuous process which requires maintenance of existing barriers but also improvements of older ones and establishment of new ones (Petroleum Safety Authority Norway, 2017a, p. 5). The management loop of plan-do-check-act is used through all project phases in barrier management, see Figure B9, from concept and design to removal (Petroleum Safety Authority Norway, 2017a, p. 17).

Priority should be given to barriers that lower the likelihood of a hazardous event rather than limit the consequences. Passive barriers are also preferred over active barriers that need activation or require actions to be taken for it to work. By extension, this implies that technical systems are preferred over barrier elements that require human intervention (Petroleum Safety Authority Norway, 2017a, p. 13). Sometimes that means that there are only technical elements included in a certain barrier function (Petroleum Safety Authority Norway, 2017a, p. 13).

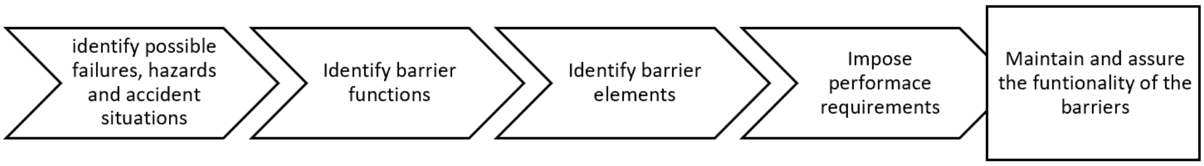

Figure B 8: Key steps in barrier management, the picture is an altered version of the original from "Principles for barrier management in the petroleum industry; Barrier Memorandum 2017" (Petroleum Safety Authority Norway, 2017a, p. 11).

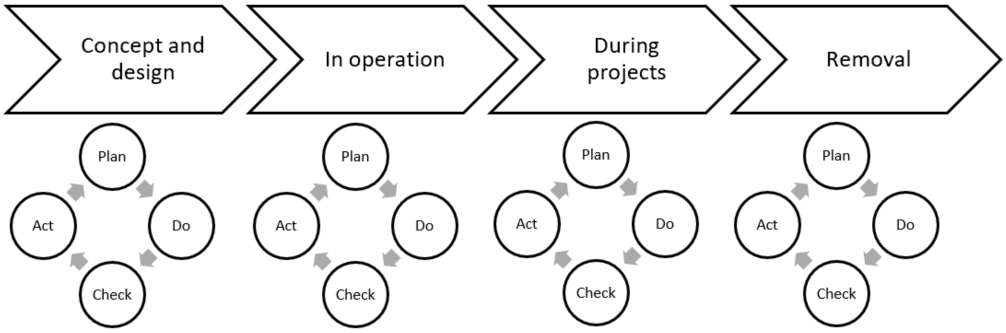

Figure B 9: The PDCA cycle is present through all project phases, the picture is an altered version of the original picture from "Principles for barrier management in the petroleum industry; Barrier Memorandum 2017" (Petroleum Safety Authority Norway, 2017a, p. 17).

B7 RISK ASSESSMENT IN THE NORWEGIAN PETROLEUM INDUSTRY

In the Management Regulations (Chapter 5, Section 17) there are requirements for risk assessments that state that risk analyses should identify hazards, initiating events, accident sequences and consequences and risk reducing measures. Risk assessments should then lay the foundation for decision-making. It also states that the assessments should be updated if there are significant changes or otherwise every five years.

The risk assessment process is further described in the NORSOK Z-013 standard. The general process for a risk assessment is to first establish the context of the analysis followed by hazard identification then risk analysis and looking into initiating events, accidental sequences and lastly find risk reducing measures and provide a balanced overview of the risk picture (Standards Norway, 2010, pp. 16-18). The risk assessment process can be seen in Figure B10. The context defines the scope, objectives, responsibilities and methods used in the assessment (Standards Norway, 2010, p. 19). The hazard identification process finds the hazards in the evaluated system with potential sources and consequences and also try to identify risk reducing measures (Standards Norway, 2010, p. 22). This will then form the risk picture.

The risk picture should provide a foundation of decision-making and include a balanced view of the assessment with boundaries, risk acceptance criteria, uncertainty and risk exposure (Standards Norway, 2010, p. 25). Throughout the many project phases there will be a need for monitoring and updates of the risk assessments, the new context has to be established and the assessment changes accordingly considering the new context (Standards Norway, 2010, p. 29).

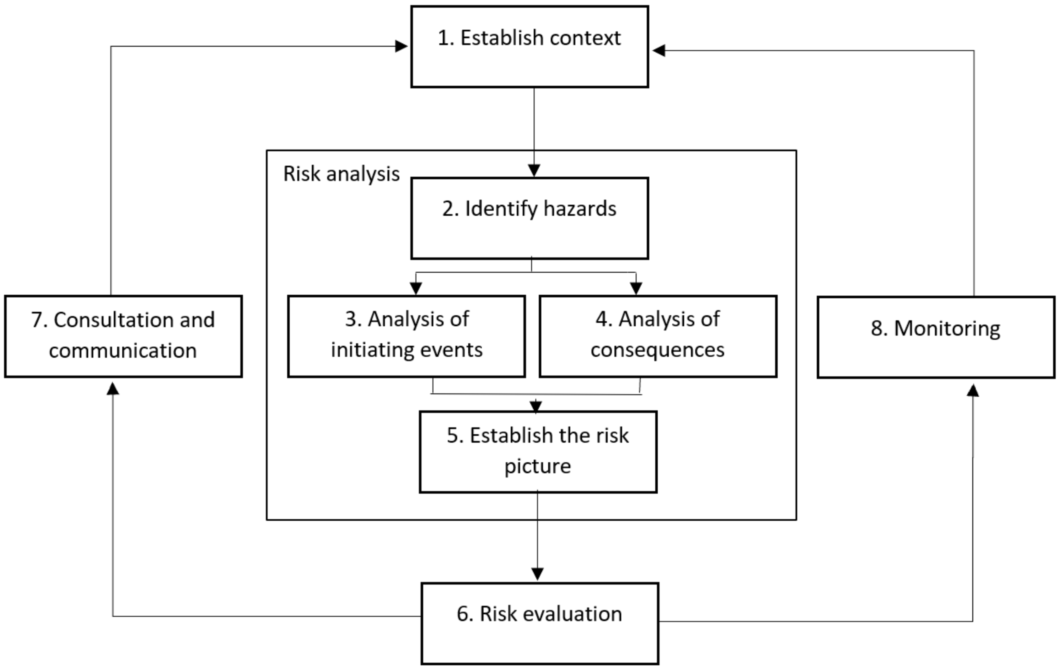

Figure B 10: The risk assessment process. The picture is an altered version of the original figure in from NORSOK Z-013, "Risk and emergency preparedness assessment" (Standards Norway, 2010, p. 19).

Appendix C:

Interviews

C1 INTERVIEW QUESTIONS IN PRACTICE

Below are the questions used in the interviews. To make the questions easier to read outside the context of the interview they have been slightly altered. However, the differences between the interviews and variations of the same subject can still be seen. The questions were different depending on the role of the respondent but the questions could also change depending on earlier answers since the interviews were semi-structural. Some changes in wording were unintentional however. The number of questions also vary depending on the number of follow up questions during the interviews.

C1.1 CONSULTANT 1

- What is your profession and how long have you been in this industry?
- What do you consider the biggest challenges with this new definition or this new concept?
- How does this new definition affect the work and workload compared to when you calculated with frequency?
- There can be a lot of uncertainties related to the leak, like gas to liquid percentage among with water and other contaminants. How do you account for those?
- How do you decide release profile and cut-off rates?
- Is it easy to know how to decide heat loads or does it change depending on, whether it is pool fire or a jet fire?
- Is it assumed that the entire volume is covered in the fire or that some of it will not burn?
- Are PSD valves accounted for? Sometimes it seems that they are and sometimes they are not.
- Drains, can you account for those, do they work? And blow down time/ rate is it standardized or different for different installations?
- Are there any other barriers, you mentioned PFP, but are there any other important barriers I have left out?
- Do you feel I have missed to ask about something important and what would that be?

C1.2 CONSULTANT 2

- What is your profession and how many years have you been in this industry?
- What do you consider the biggest challenges with this new concept (WCPF)?
- Do you think WCPF fire is well defined?
- Could the current definition be improved?
- Does it add in workload, is it cost driving?
- Does everyone interpret the definition in the same way?
- How do you know the composition and form of the HC leak?
- How are factors like release profile, cut off rate, combustion rate, volume, heat load and duration decided?
- How is escalation covered in practice?
- How does the WCPF approach compare to the probabilistic approach used before?
- How do you account for barriers? Can they or should they all be credited? How do you know they work in practice?
- Do you think I have missed to ask you about something, what would that be?
- What simulations are made and what tools are used? (Question through E-mail.)

C1.3 ENGINEER 1

- How many years have you been in this industry and what is your profession?
- What do you consider the biggest challenges with WCPF?
- Do you think it is generally well defined?
- Is it a problem that people can interpret it differently depending on who does the analysis?
- How much can it (risk analysis) vary between the consultant companies?
- When you try to accommodate a WCPF how much extra cost and workload does it add compared to the dimensioning fire that uses frequency?
- Do consultants usually provide you with cut-off rates, and other parameters or do you calculate some of it yourselves?
- How can the different scenarios vary between different installations?
- Could it vary which barriers are installed on different installations or is it mostly the same? Which barriers are preferred? And does it vary which barriers are used to combat a WCPF?
- I have heard that sometimes the drain system should be accounted for and sometimes it should not because it might not work. How do you consider drain?
- What tools are used when choosing scenarios and simulations of scenarios, how can you be sure that the assumptions in these tools are exact or appropriate?
- How do you choose the cut off rate when working with excel, do you use a standard or do you have internal documents?
- If you use KFX, do you have to check the heat loads that are in the standard, or does KFX provide appropriate heat loads?
- Do you feel like I have missed to ask about something that would be important to know, and what would that be in that case?

C1.4 OPERATOR 1

- What is your profession and how many years have you been in this industry?
- What would you say are the main challenges with WCPF?
- Does it add a lot of extra cost and workload when you try to accommodate for WCPF?
- Do you think the current definition is well defined? How would you improve it?
- How does a WCPF compare to a dimensioning fire with frequency?
- Do different consultants interpret the definition differently?
- When you choose scenarios, how can you be sure about the uncertainties in the models, and how much does it affect the end-result?
- Is it easier to design for fires than explosions?
- How do you choose cut-off rates?
- Many parameters affect the duration like release profile and whether you account for the drain system. How do you decide the HC volume? How does the fire progress over time?
- Some of these tools that you mentioned do they account for open drain? What parts does these programs consider in the simulations?
- Should barriers be considered when there is a risk that they might not be functioning?
- Risers are not included in the process system, but could give maybe the worst consequences, should they be included?
- How is escalation covered, does it vary between different platforms?

- How do you decide the blowdown time, how much can it affect the end fire?
- Do you use heat loads that are from the simulation programs or the ones in NORSOK?
- How can spray fires be reflected in the form of heat load?
- Am I interpreting you correctly, is too much conservatism used? For each simplification there is maybe an element of conservatism added?
- How accurate are the models about spray fires and how sensitive are they?
- When you hire consultants and engineering companies, are there differences between different companies or are their interpretations the same?
- Is there anything more you think is important for me to know going forward with this thesis?

C1.5 OPERATOR 2

- Could you briefly tell me about your profession and your experience in the industry?
- What would you say are the biggest challenges with WCPF?
- How much can the interpretations vary within the industry?
- Do you think the definition could be improved so it does not vary, or is it a problem at all that it can vary?
- When choosing a scenario what are the most important parts to consider?
- How different is it to calculate for the WCPF compared to the dimensioning fire that is calculated with frequency?
- The fires have very significant durations. How can you find that kind of fire protection that can last for that amount of time?
- How do you choose cut-off rate and blowdown time?
- Are there any assumptions surrounding barriers that you use when calculating for a WCPF? Does it vary?
- How do you account for spray fires? Are the models good enough? How do you handle those?
- When designing, is PFP the most important part (safety system to consider)?
- Should you account for barriers if they are uncertain?
- If you could ask the PSA about something what would that be?
- Am I interpreting you correctly, the industry is still adapting to the new definition?
- In an earlier interview it was brought up that it could be more difficult to understand the concept as a company from the outside that has not been involved with the discussion earlier. What are your thoughts about that?
- Do incentives clash, am I interpreting you correctly?
- What tools are you using inhouse?
- Do engineering companies act differently?
- How do you deal with the infinite number of fire scenarios?
- Is uncertainty in the models discussed enough or should there be more focus on it? What is your view on uncertainty?
- Riser fires are not included in the process system, but they could still cause danger, should they be included in some way?
- What are the most critical points in the process system?
- Is escalation the factor that varies the most?
- How do you follow up on changes on the platform?
- Is there anything else you would like me to know going forward?

C1.6 OPERATOR 3

- Can you tell me a bit about your profession and your experience in the industry?
- What would you consider the main challenges?
- Do you think the WCPF is well defined?
- How is escalation considered?
- How can you handle variation and subjectivity?
- It was discussed in an earlier interview about structures and segments that are considered to be outside the process system, should they be considered? What is your opinion?
- How do installations change with the implementation of the WCPF compared to the dimensioning fire that uses frequency?
- Is the discussion surrounding ESD and PSD valves clearer now?
- How do you choose a WCPF scenario?
- Are you taking heat loads from NORSOK or are you using heat loads from simulations?
- What tools are you using?
- Which barriers do you account for and how can it vary between different installations?
- Does the implementation of WCPF change the workload or the cost to earlier or is it pretty much the same as before?
- How do you choose the cut-off rate? Does it vary between installations?
- Is there anything more you would want me to know going forward?

C1.7 PSA

- Can you tell me a bit about your background and how you started working for the PSA?
- Is WCPF well defined? Why, why not?
- How do you balance flexibility and strict requirements?
- In earlier interviews it was brought up that probability is not an explicit part of the definition, and also that the focus is mainly on structural damages, what are your thoughts on this?
- How are riser fires handled now?
- Is there a need for more guidelines? What are your thoughts?
- In the earlier interviews there was quite a wide range of cut-off rates mentioned from 0,1 to 10 kg/s. What are your thoughts about it?
- Currently you cannot account for fire water, why is it not allowed?
- In earlier interviews some problems with the open drain system have been discussed, with clogging and low capacity. How do you deal with these problems?
- There is not that much literature about WCPF, and the SINTEF report was written quite early in the discussion, is there a need to update the report or does it still reflect the discussion today?
- How are changes on platforms followed up on?
- Would new companies or international companies know what to do in a WCPF project since they may not have been part of the WCPF discussion? Could this be a problem?
- Why was the term WCPF chosen?
- Is there anything else you would like me to know or I have not asked about?

C1.8 NEW COMPANY 1

- In what phase is your company currently in?

- Have your company been involved with the discussion surrounding WCPF?
- Is there any other concepts you can relate to the WCPF or is it completely new?
- What was/ is the experience when working with a WCPF project?
- Are you doing any calculations inhouse or will you be using consultants?
- Do you think it is less or more difficult for a new or international company to interpret the WCPF requirements?
- What are the differences when working with WCPF compared to probabilistic requirements?
- Is it a good or a bad thing (the difference for designing for a WCPF)? It could have a significant impact on the design but the design would be safer?
- Is there a need for additional guidelines? Why, why not? What would that guideline need in order for it to work?
- If there are any main challenges, what would you consider those to be?
- What do you think about the WCPF definition?
- How significant could the cost be? (Compared to designing with probabilistic approach.)
- Is it easier to design with the probabilistic requirement?
- Do you think I have forgotten to ask you about something important, what do you feel like I should know?

C1.9 NEW COMPANY 2

- What is your profession, and can you tell me briefly about your company?
- What phase is your company currently in?
- How has your company been involved with the discussion surrounding WCPF?
- What is the experience when looking into or working with a WCPF project?
- The new NORSOK S-001 had not come out yet I am assuming then?
- Do you use consultants to provide risk assessment or do you do them inhouse?
- As a newer company do you think it is more or less difficult to interpret the WCPF requirements?
- What would you consider the biggest differences between working with WCPF requirements compared to probabilistic requirements? Is there anything you prefer over the other?
- If there are any, what would you consider the main challenges concerning WCPF?
- If we pretend that you had to redesign the platform, do you think that it would be as easy or as difficult for a smaller company to do compared to a bigger company?
- You mentioned that there were some difficulties with choosing a method, maybe some of the concerns have been solved with the new definition, but is there a need for additional guidelines or what would you have liked to have back then?
- Was the expertise from the earlier company transferred to the current company?
- Is there anything you think I should know that I have not thought to ask you about?

C2 ABOUT THE SUMMARIES

Below are summaries of each separate interview based on a transcription of the interviews. Note that these summaries are not exact quotes from the interviews. The summaries try to stay as true to the original interview as possible but more confined to make the reading experience easier, names and companies have also been hidden to provide anonymity. Many of the interview subjects are intertwined and connected, the summaries are therefore sectioned based on the subject covered rather than the question asked, due to the floating nature of conversation. Some topics that were covered at different times during the interview will be placed together rather than scattered chronologically in the summaries. Also, if the respondent had additional information that they found important that information is placed first in the interview summary. In the summaries the “I“ and “me” among with “we“ and “us” refers to the respondent and the company the respondent is associated with and should not be confused with me - the student - writing this thesis.

C3 SUMMARY OF INTERVIEW: CONSULTANT 1

C3.1 MAIN CHALLENGES

The biggest main challenge is to find a definition for something so complex as a major accidental fire event. It is also very hard to arrange two fires in the same facility based on consequences. The worst credible is based on the assumption that you can arrange all the fires and pick the worst one. In addition it is difficult to find what is credible because it is very subjective.

C3.2 DEFINITION

The definition is written on half a page which makes it seem straight forward and easy to initially agree on. When it comes to the actual implementation the small details matter which can become very challenging. If you make strict guidelines you lose flexibility.

What valves to account for was a challenge a few years back but the PSA have been very clear so that it is not a challenge now.

It is a challenge to find the balance between openness for subjective interpretations and a strict guideline. It can also be a bit dangerous to define it too strictly because there are a lot of uncertainties relating to an event that is occurring so rarely.

C3.3 COMPARISON TO DIMENSIONING FIRES THAT USES FREQUENCY

In the regulations from the 1980s there was a concept like that of the WCPF. Gradually the concept of frequency was introduced to design for events with a probability of every 10 000 years rather than the worst possible outcome. The dimensioning fires have similar challenges to the WCPF. It is difficult to see if small intense fires lasting for long periods of time are less or more severe than a large fire exposing different areas and locations for a short period of time.

> *“Even though the worst credible approach is not a very good of an approach it might still be better than the alternatives.”*

C3.4 COST DRIVING

The cost of additional PFP is not enormous, which is probably why it is required to design for the WCPF rather than the worst credible explosion. If you add PFP in the right places you can design to withstand a WCPF within reasonable cost limits.

C3.5 PROBABILITY CONTRADICTION

You construct very special cases of how the fire develops with very low occurrences but then assume some safety systems are functioning. The probability of those safety functions failing are probably large compared to the very special developments of the fire you constructed yourself.

It might be possible to develop some guidelines for the fire exposure you want to withstand but without being so specific. When you define a very specific fire scenario you might think you have more control than you actually have. It might be possible to have some prescriptive requirements.

C3.6 UNCERTAINTIES IN MODELS AND TOOLS

Detailed modelling can capture very important phenomena which would be impossible to guess, but you should make sure you are not too confident in the details of the result if your conclusion relies heavily on it.

When deciding liquid to gas percentage in the leak, water cut among other details, you use very detailed modelling or very advanced tools but there are a lot of uncertainties inside these tools. When using an advanced tool it seems very realistic, but it is easy to forget how uncertain it is and all the assumptions the model depends on. It might create some false confidence.

You can create a very specific fire scenario with leak point, ignition, rupture of other pipes and get an exact representation of heat loads from that fire. If you run that scenario through a model twice you will get the same results. In reality when you try to construct the same fire twice the two very similar scenarios will result in different heat loads. This is easy to forget when you model in detail.

C3.7 RELEASE PROFILE, CUT-OFF RATE, HEAT LOADS AND SENSITIVITY

For release profile, cut-off rate and combustion rates if you follow the standard and generally accepted rules, I think you could often end up with the same type of conclusions. This consistency is a strength even though there are uncertainties. Leak profiles and cut-off rates are generally well defined, but you could be very sensitive to small differences. You should also include scenarios that does not go according to plan so you know how vulnerable you are to your assumptions. It is important to know if your conclusions are sensitive to some specific assumption. It varies within the industry how heat loads are handled, I think it is handled quite well and there tend to be some conservative assumptions.

The thing I am a bit worried about is the way WCPF is documented. It is very sensitive to the exact leak rate that is the worst credible. If you choose a higher leak rate but with a shorter duration it will expose different parts of your structure and this exposure could end up in a collapse within a short time frame. A good approach is to define the amount of HC that can be combusted which decides the upper limit of energy that can be transferred to the structure.

C3.8 VOLUME OF HC AND WELLS

You usually assume that the entire volume of HC burns. A small fire will entirely burn inside your facility but larger fires will also burn outside the facility. I you have a fire above your facility you still assume that everything burns but not all that burns will cause heat load to the facility.

There are some special cases for example producing wells. It is a common understanding that you do not design for blowouts unless the potential is very high. If you do an artificial gas lift and get an annulus which might be a couple of kilometres down. To some extent the release of that gas can cause a fire which would be a part of the WCPF. Those kinds of details might be inconsistent today. But I think for the most part it is quite consistent what hydrocarbon volumes should be used.

C3.9 BARRIERS

Drain you can account for, but it can be a bit inconsistent. Experience from offshore operations shows that the drains might not be functioning properly during large HC liquid releases. It can also be clogged by sand among other things. You also have bunding around large liquid vessels which should limit your pool fire size if it works.

In my experience the blowdown has actually improved for the last couple of years. The blowdown rate in newbuilds are much quicker than what they were 15 to 20 years ago. Blowdown makes your gas fires much shorter but there can be too much optimism sometimes when you account for it. So, you should know how sensitive you are to in respect to blowdown.

It is important to know the effectiveness of these barriers. The assumptions can be a bit too simplistic on how well they work.

C4 SUMMARY OF INTERVIEW: CONSULTANT 2

C4.1 MAIN CHALLENGES

The first issue is that it does not incorporate the probability of occurrence explicitly. For some modules you will find this scenario to be very low. If you have big segment with a large inventory you could end up designing for a very remote scenario. The simpler you make the requirements the more likely it is to find some peculiar situations where it leads to cost driving design loads.

The second issue is it only reflects leaks from process equipment and not risers and blowouts. This cause a biased fire design for process modules compared to wellhead modules. The categories you split up the different fire scenarios in does not matter for the structure itself.

C4.2 DEFINITION

I think the definition itself is quite straightforward. It is not very difficult to define a process leak itself. It is also clear when it comes to what kind of barriers you can account for being ESD valves, open drain, blow down and grating. I think it is required to reflect escalation so then it depends on how serious that escalation is then. But I think when it comes to that part of the definition it is also quite clear on how to account for it, but it will increase the fire duration and you need to add your escalated scenario to the initial scenario.

I think it is more or less interpreted in the same way, but the resulting fire load are not calculated consistently. When it comes to find the leak scenario that generates the fire with the longest duration, it is typically that the duration is the problem here, that a long duration generates a lot of energy over time and then that heats up the structure and weakens the structure over time. But the definition does not say anything about how many scenarios you need to consider. Even if the release scenario and the barriers are clearly defined there are infinite wind conditions you can combine the scenario with. When it comes to the fire scenarios and how to perform the study it might vary within the industry. Some consultants will assume that all the liquid is available for combustion but that can be erroneous because some of the liquid will be drained away by the open drain system. Maybe there should be a guideline as to how many scenarios should be investigated.

C4.3 WORKLOAD AND COST

Compared to the importance of setting the fire scenario it is not that time consuming. It could be very cost-driving because many cases leads to design fires with very long durations which causes problems for the structural integrity. In some cases the probability for the scenario is very low but you still need to design for a very substantial heat load.

C4.4 SIMULATION AND MODELLING

I think most consultants, or at least those working at my company think the models are acceptable in terms of precision particularly for gas leaks. It is more difficult with multi-phase leaks but there are tools that reflect that as well, but I do not think it is the main issue in terms of WCPF. The composition among other data is usually acquired from process simulation models like Hysys or Unisim. Information about the blowdown system is usually included in a flare report which describes the capabilities of the depressurisation system. That flare report is based on a process simulation model, like Hysys or Unisim.

In KFX there has been implemented a model that reflects the open drain but it has not been released commercially yet, then you will catch the dynamic behaviour of the fire better. You can do it with simplified models even though it is difficult to make an assumption of how much oil has been taken away by the drain system.

There are three main attributes you need to reflect being the duration, the extent and the heat load. The extent of the fire and the heat load are best simulated like KFX or FireEX which can incorporate the dynamics and the transient behaviour of the leak. Then you have a model reflecting the energy of the leak throughout the leak scenario. It is also important to account for the ventilation conditions because access the air is crucial for the fire. A large leak does not necessarily have the most significant exposure. This is something these advanced CFD tools can reflect.

In order to do this you also need a geometrical model and the engineer performing the study has to have the right competence. So it is quite time-consuming but then again compared to the value of the study itself, I think we are talking about small costs here.

If you use the established generic heat loads from NORSOK S-001 and combine it with the leak scenario, the duration and use a cut-off rate of 1kg/s you will end up with a massive fire exposure that the structure cannot sustain.

C4.5 COMPARISON OF WCPF TO FREQUENCY-BASED FIRES

I think in general previously it was quite common to set significant heat loads based on frequency. Also the generic approach was quite commonly used so the difference is not that big. The main difference is the duration of the fire load. With the WCPF you can end up with a design fire lasting 30 minutes to one hour or several hours, but the actual effect on the design is not that big. But of course, there have been cases where I have been encountering problems in terms of how to design for the heat loads. Before you could use detailed probabilistic studies to optimize the design so that PFP was not required, now you do not have the freedom to do that.

C4.6 BARRIERS

There are potential scenarios that are worse than the WCPF if one of the barriers fail. As always when it comes to risk management you have to perform a risk evaluation and weigh between the cost and the gain. The WCPF have a frequency that is very low and remote, so I think assuming that the barriers are functioning seems fair when you consider the probability of occurrence for the leak scenario. The worst possible hole size, generating the longest fire duration in the segment is already in itself quite conservative.

When it comes to riser leaks you model the barriers themselves with the probability of failure. That is what we did before with the probability of failure for ESD valves and blowdown valves, and you include these probabilities in your assessment. Usually those scenarios were seen as residual risk due to the low probability of failure.

C5 SUMMARY OF INTERVIEW: ENGINEER 1

C5.1 GENERAL REFLECTIONS

I think it is good to focus on the consequences of a scenario rather than the frequency. It is still important to discuss the uncertainties of the frequencies, but I feel it is the wrong focus compared to the actual scenarios that you can get on your installation. The data we have on major accidental events are so few and the uncertainties are so big and you can basically get whatever result you want. I feel the WCPF has shifted the discussion to a more productive one.

If you come from outside the industry and try to interpret what this (WCPF) is… In Norway we have worked with the PSA and have sort of a clique that knows what has been going on with WCPF for the past four to five years. If you come from the outside it could be a big challenge to understand what this is. If you have not worked on a project addressing this (WCPF) it could be very hard.

C5.2 MAIN CHALLENGES

First, what does worst credible mean? What can be considered credible? Is it linked to frequency? The WCPF is not the worst case so you have to limit your consequences. You are allowed to look at the blowdown system, which is a very reliable safety system, which I think is a good thing that you can actually reflect that into the fire that you design your platform for. You can look at the ESD valves but not the PSD valves. The challenge is how to define it and what to account for and not account for. There is room for interpretation.

Another main challenge is that most separators contain so much oil that you can have a fire lasting six to eight hours and there are not any PFP that actually work for that amount of time. If you have a cut-off rate at 1 kg/s you can get a leak lasting for a lot of hours. One way to get around this is to look at the structure and find how big of a fire you would need for it to result in a critical collapse. A cut-off rate was decided for each area which could be 10 kg/s which means that you can cut off the tail of every fire scenario and the duration becomes more reasonable.

C5.3 DEFINITION

I think, in the beginning the industry struggled quite a lot but now there have been so many projects that the discussion among consultants, engineering companies and operators have started to convert to the WCPF definition. There is still room for interpretation, but I think it is a good thing. It means you can look at your platform and tailor-make it for your installation with your barrier management and your safety strategies. So I think it is defined well enough.

C5.4 VARIATION BETWEEN CONSULTANTS

It can be a problem that it can be interpreted differently and to choose to design less robustly. If you go to different consultancies you can get different answers.

C5.5 ITERATIVE PROCESS

As an engineering company we need to take responsibility for the whole designing process and for us it is a good thing that there is room for interpretation. It is about how you do the response evaluations afterwards and how you implement these fires into the design.

It is an iterative process. Someone calculates the fire loads then there are discussions about the least robust structural element that have not been defined in that fire scenario and then you go back and move the fire away from that structural element. As long as the iterative process is good there should not be that much to worry about.

C5.6 COST AND WORKLOAD

It is not that different from the dimensioning fires (that uses frequency). Parameters such as the blow down rate, unacceptable rupture rate, gas inventory and oil inventory are input you need for the dimensioning fire anyway so there is not that much extra work now that a methodology is in place.

Cut-off rates among other parameters can be calculated inhouse but it varies. In some projects it is done by consultants and in some cases by ourselves. It is a matter of capacity.

C5.7 BARRIERS

The WCPF is used to dimension the PFP and to know where to put the PFP. It is clear that you cannot account for active firefighting or the fire water system. You can account for the ESD, BD and difference in elevation but not PSD valves. The boundaries and barriers are quite clearly defined both active and passive. The WCPF is a tool for defining the barriers in my head.

The drain can be blocked by small items and it is not a very efficient barrier. To account for the drain system is simply a judgement you must make in a project. If you have an oversized drain system maybe you should account for it, if you have a more conventional drain system maybe you should not. Sometimes it does not matter that much if you look at it in a response analysis. If the drain system is an important safety function and part of your safety strategy, then you will be forced to have a safety standard for that system.

C5.8 STRUCTURAL ELEMENTS

Sometimes you have one to three critical structural elements and the most critical part is whether that structural part is inside the fire. It can be more important than the fire size and location. It is something you need to form an opinion on for each project.

C5.9 TOOLS

The process discipline has access to process simulation and can also determine the blowdown. The safety discipline does not use process simulation tools for designing the WCPF. So we have these tools inhouse. But the we – the safety discipline – do not use process simulation tools for designing the WCPF. We simplified excel sheets with some empirical equations that can simulate the blowdown. You put in hole size and pressure that define the leak scenario and the output is a simplified transient leak based on this input. The result can then be checked with the process discipline who have in depth knowledge.

Fire simulation tools such as KFX are used as well but those are based on the transient leak profile. The heat loads are taken directly from the KFX model, the heat loads are then put into FAHTS which translates the heat loads to temperature. By taking information from FAHTS and your structural model you can then see where you have your most vulnerable structural member.

C6 SUMMARY OF INTERVIEW OPERATOR EXPERT 1

C6.1 MAIN CHALLENGES

The main challenge is the very long durations, far longer than any PFP or construction are documented to withstand. There are also problems with how to simulate it. You can also end up with a lot of protection for something with very low consequences.

C6.2 COST AND WORKLOAD

It can add extra cost, but it is alright if you get safety for the money, but that is not always the case since you may design for a very remote scenario and also quite low consequences.

C6.3 DEFINITION

I think the definition could look closer at the consequences that are unacceptable and not only at general requirements for firewalls and structures. To have firewalls and structures that are intact after four hours can be relevant if it is necessary to avoid a blowout. The requirements could be relaxed if the chances for a blowout are low.

What I am afraid of is an environmental disaster, anything to avoid a process fire to escalate to a blowout. As long as that barrier is intact, then I would not care if a firewall is destroyed internally. The idea with protection lasting far longer than what you need for evacuation is to avoid escalation to the wells with a blowout and an environmental catastrophe.

C6.4 COMPARISON OF WCPF TO DIMENSIONING FIRES WITH FREQUENCIES

One risk with the dimensioning fires is that the frequencies for having fires have become very low with the newer models. In some areas you end up not having a dimensioning fire or a very mild scenario. It is not reasonable to not have a dimensioning fire. I think that is one of the reasons for the PSA to come up with the WCPF, and I agree about that, but the WCPF should be modified.

C6.5 VARIATION OF INTERPRETATION

I think definition became clearer with the NORSOK S-001 but it has always been a problem that consultants use different methods. And also, I must say, that it can depend a lot on the area you are looking at, what protection you have and what methods you use to calculate. In some cases, you can use simple conservative methods and determine that you can withstand the fire. In other cases, you use finer advanced simulations to be more realistic because you cannot afford to be conservative. We accept that they (consultants) use different methods, but they have to use methods that are suited for the area they are looking at.

C6.6 INCENTIVES

There are many players with different motives. You have suppliers with one view and engineering companies with another and then there are consultants too. It varies from time to time but when looking at the advice they give you also should look at the motives behind it. Some like to do as little engineering work as possible others like to deliver as much as possible. It can be a problem, but it is mostly part of how we form our contracts.

C6.7 SCENARIO SELECTION

It is difficult to choose the right scenarios, where the leak starts, ignites and escalates. There is a big difference in how spray fires are modelled and how long you assume it is a jet fire and when it becomes a pool fire.

C6.8 CUT-OFF RATE SELECTION

A common starting point for consultants is a cut off rate of 2 kg/s. It is a very conservative approach and is one way we know to limit the duration of the fire. To determine how long the protection needs to survive we look at how big of a fire we need for the structure to fail, it is often much higher than 2 kg/s.

C6.9 RELEASE PROFILE

The most used method is that your fire is limited by the leak rate. In the beginning you have a high leak rate but not everything can burn within the module. Then you can assume that what is not burned is drained away. It is possible to do more realistic fire simulations with bundings and drains.

C6.10 HEAT LOAD SELECTION

We do both (use standardized values and simulations), depending on how good of a simulation you have. The best way is to model as realistic as possible and take heat loads directly from the simulations. But it is important to account for the transient behaviour of the fire in the simulation and to not use stationary examples for too long.

C6.11 DRAINS IN SIMULATION

KFX can account for bunding and drain and calculates how the oil spreads and where it is removed. I think it is a method that will be used more in the future. It takes more simulation time and requires more input data that is difficult to find. During the start of a leak you have high pressure and the oil can spread everywhere. Later when there is little pressure the oil will be much closer to the leak point, then you can look if the oil is within a bunding.

C6.12 UNCERTAINTY WITH BARRIERS

We have chosen to work with the worst possible leak rate in the worst possible location and to account for the barriers. It would be meaningless if we were unable to account for any barriers. It is very unrealistic that everything fails in the worst location.

> *"The probability of it happening would be so remote that it would be more probable to get a meteor on the platform."*

C6.13 ESCALATION

Some platforms are designed and protected in such a way that escalations are not expected. On installations where you can get escalations, we use simulations to find where and when it happens. Realistically an escalation leads to a big increase in the extent of the fire but not a longer duration. Escalations happens when you have pressure in the system.

If the fire can escalate to the riser and it could cause a collapse, then it is not acceptable. There are many different types of risers, some of them cause short fires others cause fires that would last for days. In some situations, it would be way too strict to give risers the same considerations as the wells. You have to look at the consequences and act based on that.

C6.14 BLOWDOWN

For jet fires and gas fires the blowdown time is crucial for the duration. Due to the transient behaviour, the jet fire will move through the module as the leak rate goes down. It is beneficial to look at it realistically since it does not expose the same points with high heat loads for long durations.

For pool fires the blowdown is not quite that important but can affect duration. When you have high pressures inside the system the oil will come out with a high leak rate which should be taken into account.

C6.15 CONSERVATISM

Almost all simplifications cause a worse fire. When you calculate these stationary fires you get the effect that the surroundings are heated all the time, in reality you start the fires with cold surroundings which are heated as the fire goes on. It is also conservative when you use these stationary fires and try to make a transient curve out of them. For each simplification an element of conservatism is added.

C6.16 SPRAY FIRES

Spray fires are often modelled as gas or jet fires and that is probably a quite good approximation. If you model it as a sonic jet fire you will have several hundred meters per seconds of gas coming out, so it will not be long until you have quite low pressure. If you model them as a liquid leak you get far lower velocities as the pressure goes down. It is an improvement possibility. I think they will be modelled as spray fires more often in the future.

There are uncertainties with these models (spray fire models) but they give quite realistic results. There is no other way to get better results of how a spray fire will look like and what heat load it will give. The models have been there for quite some time, but they have not been used so much. It takes a lot of time and competence to perform those simulations.

C7 SUMMARY OF INTERVIEW: OPERATOR EXPERT 2

C7.1 MAIN CHALLENGES

It is how you define the fire. I also think it is done in many different ways. Also how you define a fire that is small enough to not affect the platform among with cut off rate.

C7.2 DEFINITION

It can be better defined, but it will vary between big installations with big segments to smaller installations. It cannot be installation specific, but it could be possible to do some kind of standardization. It is unclear how many fire scenarios and fire simulations you should perform. The ESD segments are quite clear. I think we (the industry) are still kind of trying to figure out how to handle it. If you have an international contractor, they would probably not have a clue, the best way is to get a Norwegian contractor to do it. I think that can be a bad thing, if you want it to be more international.

C7.3 VARIATION WITHIN INDUSTRY

I think it can vary quite a lot, we barely knew what to do in a project around 2013-2014. The interpretation of how big segments and volumes that can be released among how to define what the worst credible is, the size, durations, escalation from one segment to another are found in a lot of different ways.

C7.4 COMPARISON TO DIMENSIONING FIRE WITH FREQUENCY

Other than the WCPF there is HC fire scenarios and dimensioning fire scenarios that also need to be considered. It is many different calculations that all need to be considered. Earlier it was mainly the dimensioning fire scenarios and others were not done, and now only the WCPF is handled and that is not correct either.

You can have no dimensioning fire in an area because the frequency is to low, but you may still have a very large WCPF. So, then you need a two hour rated fire wall and also a two hour integrity for a standard HC. It can be very different, but it does not necessarily have a big impact. If you have no dimensioning fire the WCPF can affect how much PFP you will add to the structure and which structure beams you need to protect.

C7.5 DURATION

Normally we say they (fires) last for one to two hours, by then you have evacuated and shut down everything, if you still have a fire maybe the installation will collapse. If the fire duration is longer you might need smaller HC segments, more ESD valves and smaller volumes.

C7.6 CUT-OFF RATE

We have done some checks to find how big of a fire that can cause the structure to lose its integrity. For a smaller platform it was 0,5 kg/s another 2 kg/s, there have also been 5 kg/s and 10 kg/s so it can vary.

C7.7 STRUCTURAL INTEGRITY

If you have a big area the fire has to be very large in order to expose enough of the structure for it to result in a collapse. If one beam does not last the entire fire duration it does not really matter because the rest of the structure would ensure that you do not have any collapse. In one project you could remove an entire column because the structure in between could take all the loads. It is about how you optimize your structure.

C7.8 OPEN DRAIN AND BUNDING

I think it varies how much liquid is drained away and how it will affect the duration. The drain may not be functioning, it can be blocked with sand or debris. If you have large pool fires and nothing is drained away the entire volume will burn, but normally that will not happen. For liquid fires it is very important how you can divide your areas with bundings so the liquid will not spread. From what I have seen the methods are good enough to take the drain system into account.

C7.9 BLOWDOWN

The blowdown time is part of the design development and you have requirements that you should blowdown to 7 bar within 15 minutes or quicker, so the blowdown time is decided during the design. If you have an older installation the blowdown time might be longer.

Gas fires are usually quite short. If you have special compressor segments you can have a long depressurisation time because the vessels are not designed to depressurize as quickly as possible. Normally the fire duration is 30 minutes to 1 hour. The liquid fires are the main issue.

C7.10 LAYOUT

The layout is not always accounted for. The pipes will go up and down with higher points and lower points. Maybe too much of the liquid is calculated in the WCPF because it will actually not leak because it depends on where you have the leak in the segment. The calculation could be more accurate, but then it is about if you want a robust design or to optimize.

The structure design does not really account for fire design, if you are lucky you do not need fire protection.

C7.11 BARRIERS AND FIRE WATER SYSTEM

I think you should account for it (Barriers in WCPF definition) because they should be in full operation. And you should have good control over them.

You do not account for the fire water systems, nor any cooling of the structure due to the fire water system. The fire water can flood the area and then the oil might be on top and spread because you have so much water. Back in the 80s and 90s there was a lot of trouble with the fire water due to corrosion and bad maintenance so it did not come any water when they tested it. But now the fire water system is in good shape.

C7.12 INCENTIVES AND ECONOMY

Here at - *company name*- we have a lot of experts like -*person*- that have worked on WCPF in different projects and got the experience, but other companies might not have that experience. I think the consultancy companies make a lot of money in helping us.

It might not be that difficult to perform the calculations but that some within the industry like it to be their expertise area and use it as a business advantage. From the operator side it can be an expensive analysis to do. For some older installations in the operator phase the budget is very limited and then you have to simplify endlessly which becomes hopeless because you do not have the money to do a thorough analysis. It is a complicated situation.

C7.13 SIMULATIONS

We have fire simulations inhouse but often not the capacity to do it ourselves unless it is very small and defined. Usually the fire simulations and the structural simulations are subcontracted. Maybe it would be good to do a comparison between the contractors and see how they do it and how it effects the result.

C7.14 INFINITE FIRE SCENARIOS

You divide the fire scenarios into sections with smaller and bigger scenarios. It is not possible to get the perfect transient behaviour. The fire is moved around to find a specific leak location. It is not possible to be completely realistic because it would take a lot of time and money.

You could calculate endlessly and have very small differences. Simplifications might not exactly be realistic, but you need to see if it is reasonable, that would be preferable in my view. Simplifications could then maybe be tested against advanced models.

C7.15 RISER FIRES

My experience is that riser fires are kind of taken into account if they have a probability above 10^{-4}, normally the probability is very low. The riser fires can be short on some installations due to the blowdown system. But if a long riser starts to burn there might not be that much you can do about it and it will burn for a long time.

C7.16 ESCALATION

How account for escalation can be done very differently, you can increase the duration or increase the size. Normally if a pipe ruptures you will have a small increase in the fire and then it goes back again.

In risk analysis you calculate the leak duration based on the pressure and content of the segment. For big leaks you normally have short duration, medium ones maybe you have the dimensioning for the WCPF. But how you account for escalation can be done very differently, there should probably be a guideline for that as well.

C7.17 FOLLOW UP ON CHANGES ON PLATFORMS

If there is a modification project, we will normally update the risk analysis and make adjustments based on that. You might change a PSD valve to an ESD valve, so the segments become smaller. You have to ensure it does not get worse than what you have calculated for. Because it is new it is unclear if all engineering companies know how to do it.

It is unclear how to follow it up because it is not necessarily included in the documentation or procedures, so it is possible to miss things.

C8 SUMMARY OF INTERVIEW: OPERATOR EXPERT 3

C8.1 GENERAL REFLECTIONS

The introduction of the WCPF is mainly positive. You have a lot of process equipment and we should not pretend that leaks do not happen. It is better to design for a process fire than to argue that the probability is too low. It is also easy to calculate compared to the probabilistic approach, it is not as affected by the leak frequency models or the ignition models and historic values. And it is not that sensitive to the risk analysis supplier, so my opinion is that it is good for the industry.

C8.2 MAIN CHALLENGES

With long durations there are problems with the documentation of the firewalls among with the penetration in the firewalls. The documentation for the firewalls is up to two hours and with the penetration it is only documentation for one hour. It can be an issue if you need additional documentation to ensure the fire will not spread.

This is still minor problems in the entire risk picture. It could lead to a lot of discussions about what happens after two hours but I do not think that is so important. The platform will probably still be intact after two hours. So, it is maybe just a documentation problem.

C8.3 DEFINITION

It is well defined. The definition in NORSOK S-001 has not been around for long so it is still unclear how the definition functions in practice. The PSD and ESD discussion is finished.

The SINTEF report was written very early, it asked for analyses that already were performed and even older. Back then there was not a clear definition. I think just to have it defined in S-001 is a good step forward but there can still be uncertainties with open drain, escalation, fire water and the cooling effect. The drain was still put in the S-001 because it should be possible to account for it.

There are also some uncertainties with different persons, risk analyses, companies and which scenarios to consider. The worst exposure and leak rate can be very subjective and dependent on the person that does the analysis.

C8.4 FIRE WATER SYSTEM AND DRAIN

A new installation can have good draining capacity so maybe there will not be any water on the floor. For older installation you can have a lot of water on the floor and the oil could be on top of it and spread and then most likely the water and not the oil would be drained away.

It is not easy to determine the functionality of the drain after a few years of operation, you may check it every five to six years with a deluge test. If you check only every six years how can you know that it is perfect?

C8.5 ESCALATION

I think how it is usually done is the problem, it can be done in different ways. For a new installation we would do a rupture analysis for acceptable ruptures. The question is if you should assume the escalation happens when the analysis says it happens or should you assume it happens later in respect to the total duration. If you look at the rupture analysis you say that the equipment is exposed to $250kW/m^2$ and how long it can withstand that but all segments might not be exposed to that through the whole scenario. Maybe there should be some guidelines or standards regarding how you should account for escalations.

C8.6 STRUCTURES TO CONSIDER

There can be some discussions about what structures to consider. In the definition it is structures and fire walls, but we also look at other big structures that can cause big damage if they fail like the flare tower or cranes.

C8.7 COMPARISON TO DIMENSIONING FIRES WITH FREQUENCY

If you use a probabilistic approach for process leaks the probability might be too low and you would end up without a dimensioning fire in the area.

With the probabilistic approach you make a curve with all the different fire durations and pick the one that represents 10^{-4}. If you then have only very short fire durations and very long you would design for a scenario that does not exist. With the WCPF approach there is more focus on ESD valve location and placement to avoid escalation.

The WCPF can result in installations having to design for longer fire durations with more PFP but in most cases you would need some PFP anyway.

C8.8 RISERS

It is only the number of risers that decide if you must design for a riser fire or not which is not reasonable. I would not use the worst credible fire approach, that took the whole duration, but maybe design for 10 to 15 minutes. Sort of the worst case but not the duration. So, you have a plan.

C8.9 SEGMENTATION AND BLOWDOWN

The blowdown has a different segmentation from the ESD segments which are also different from the PSD segments. When choosing a scenario, you may have separated by ESD then you might have a PSD valve in the middle and then a check valve. So, the ESD segment is actually divided in three. If you are going to blowdown that segment you would need more than one blowdown valve. This has to be considered when you look at the blowdown. This is also to account for escalation to HC equipment.

C8.10 LEAK RATE

When you try to find the leak that gives the worst exposure you try to find the fire that have exactly enough fuel to burn within the module. The worst fire is the fire that has exactly enough air. If it has too much fuel the fire will burn outside, and you will not have as much exposure in that area.

C8.11 SCENARIO SELECTION

You have to look at many different scenarios. Gas and oil, high pressure and low pressure, different leak rates. Many times you end up with something that starts like a jet fire for a few minutes which then escalates to another segment and ignite a pool fire.

C8.12 HEAT LOADS

How you choose heat loads can vary. Using the NORSOK values is quite easy and gives you quite conservative results which can be useful in the early phases of a project. In later phases fire simulations (mainly KFX) give you more realistic heat loads and not a global load that effects everything.

C8.13 PFP ON HC EQUIPMENT

Other than the ESD, blowdown, grating and open drain, you can also account for the PFP on the HC equipment. When you do rupture analysis you find what would be unacceptable ruptures and acceptable, for the unacceptable you then isolate that equipment and assume the isolation is enough. During maintenance you sometimes take away the PFP but you will still assume that the PFP is there and withstands the fire.

C8.14 CUT-OFF RATE

I would think that the normal way would be to look at the fire duration down to 0,1 kg/s.

C8.15 COST AND WORKLOAD

It can be a higher cost because you have to design for longer fire durations. It can also reduce the cost and workload because it is less uncertain and that makes it easier in earlier project phases. I early phases you would have very little information and the probabilistic approach needs a lot of input. This can lead to fire loads increasing for each project phase. With WCPF you can avoid changes to the design in the project phases which would be very expensive.

So, it is both positive and negative but less uncertain I will say. So, you know you have to design for longer durations, but at least you know what you design for.

C9 SUMMARY OF INTERVIEW: PETROLEUM SAFETY AUTHORITY NORWAY

This interview was held in Norwegian and Swedish. The summary below is therefore also translated from Norwegian. There were two respondents present during this interview however, they will not be referred to separately in the summary nor in the report since the respondents were in agreement with each other and elaborated on each other´s answers. This interview will simply be referred to as PSA.

C9.1 DEFINITION

Before the new definition in NORSOK the term was a bit uncertain. The idea is to protect yourself against what could be considered the WCPF, it is clearer now in NORSOK.

C9.2 THE BACKGROUND OF THE WCPF DEFINITION

We were not the one that choose the WCPF definition, it was more NORSOK. We are just stating that you should be able to withstand the worst fire you can have which are isolated by the ESD valves, but the term itself was not us.

This concept is actually something that we have had in the regulations for a long time. In an old document is says that sectioning valves shall be installed in the process in a matter so that the maximum fire load do not overpower the fire resistance in the area, it is from the 80s, so it is an old concept. It is possible that with the probabilistic approaches this was somewhat forgotten.

C9.3 REGULATIONS AND STANDARDS

We have function-based requirements which enables you to choose your own solutions, we can still refer to different standards like NORSOK and signal that if you follow the standard you will meet the requirements, in this case mainly NORSOK S-001. If you have a reason to go in another direction you are free to do so as long as you can prove it still meets the requirements. We have also seen that standards can be interpreted differently as well, especially with new terms. Even if you think it is well defined it can still be interpreted differently. When a standard is reviewed, we have an observer that is involved in the process to ensure that the standard meets the regulations. So, we are involved in the process in NORSOK and for some international standards as well.

C9.4 ADDITIONAL FOCUS ON PROBABILITY AND CONSEQUENCES

In the definition you define what you consider an unacceptable fire, fire segments and how it escalates to other segments and how you account for that. It says that it should not escalate outside of the area, and it should not escalate to risers as a consequence of the process fire.

There are escalations out of the area or risers that could give large environmental consequences and there are fires that are not covered in the WCPF. The idea is that a process fire should not escalate to a riser. Many risers may be placed tightly together, and you also need to ensure that an event on one riser does not escalate to the others.

Usually those fires (riser fires) are so rare that they are outside of what you design for. It is often discussed that you should be aware of the consequences in the event of a riser fire. In NORSOK it says that risers and riser fires and ESD valves should be protected for accidental loads. Riser fires is one of those events that you might not be able to handle, and that they might not be handled currently. We have a lot of discussions surrounding SSIV to reduce the duration and volume of the leak.

C9.5 IS THERE A NEED FOR MORE GUIDELINES?

Concerning escalation, we could see that there are different interpretations about how and when you do escalation. So, there it might be a need because there are a few different methods that are used.

It is important to be concrete but at the same time there are many different prerequisites, the installations are all different, and you should be clear about the expectations rather than what they have to do. I think that is our standpoint.

C9.6 VARYING CUT-OFF RATES IN INTERVIEWS, 0,1 UP TO 10 KG/S

It is something we can see, that the cut off rates vary. As long as the consequences and the structure has been considered and investigated to withstand it, that there is a methodology and not just that you randomly pick a rate of 10.

It is a bit difficult to define because there can be different building techniques and materials in the structures. NORSOK usually provide values that are conservative. You have to prove that your values are good enough and make sure that you can withstand the value you pick. But if it is a big variation it could be good to look into it.

C9.7 WHEN ARE NEW SPECIFICATIONS MADE?

Our standpoint is that we have these functional requirements and that you can use standards, and then there are minimum requirements like that of WCPF, if it can be proved that there is a need for more minimum requirements other than just the function… I do not think we think there is a need now for more specific requirements. The report maps the differences in the industry which is usually the start of defining issues, then you work to collect more data and information to then find if there is need for more specifications in NORSOK. But we can also see that the regulations can be misunderstood.

C9.8 BARRIERS, OPEN DRAIN AND FIRE WATER SYSTEM

The historical aspect of reliability of the fire water system is the reason you do not account for it and its effect when you design. It is very clear in NORSOK. It has not been relevant to change it either.

The open drain is a barrier in itself and should be intact. The requirement for open drain is to handle it (WCPF + fire water), that is its purpose after all. However, there can still be problems on some installations and in those cases the fire water might not help anyway.

There have been projects where they change the drain system because it did not have the capacity it should. You do analyses to see that barriers work, you have specifications to make sure it is functioning and not clogged, it should be followed up like any other safety system. As with all safety systems there can be problems but as in the definition you can account for open drain.

C9.9 LIMITED LITERATURE, IS THERE A NEED FOR UPDATES OF THE SINTEF REPORT?

We discover some issues when we inspect, for example that some stopped the simulations after one hour with the assumption of safe evacuation. That has been clarified in the new NORSOK, that the duration is not related to safe evacuation.

Another thing we have observed, in WCPF you should take into account that the ESD valves are functioning but when it comes to fire testing the valves, especially on older installations, we can see that the firesafe on the valves are not documented for, like in API 6FA, as high temperatures you can reach in a HC fire. In the worst fire it might be able to escalate out of the fire area. So, we have asked questions about fire testing with those valves.

Another thing, it is quite new, for PFP you use a fire test from ISO 22899 and that standard uses heat fluxes that are 250 to max 300, but there are multiple installations that have specified design loads of about 350 kW/m^2. So, it has been a discussion if that standard is enough for those high heat loads, so a project has been started to specify those high heat flux test. There are some high heat flux tests today but it is not standardized and they are done in a few different ways, but the work is ongoing concerning that.

There is no current plan to update the SINTEF report, it was describing the discussion then and there, but it is possible that new things come up and there is a need to collect more information and inform about it. There is a project about this, so there are things that show up but there is no current plan to update the report.

C9.10 FOLLOW UP ON CHANGES

If they have not done WCPF changes properly it is something we notice during the next inspection. We follow it up in the same way like any other barrier, so it is not that special, but if you get big modifications on the platform and new segments that are larger than what you based your calculations on, or larger than what you had in your evaluation… (implied problematic). We ask them if they have done new evaluations considering the WCPF, the segment that includes the separator is often the most relevant, if there are modifications there since it is the largest segment most of the time. You have to know your prerequisites, so we follow up the changes and look at consequences. Now that there have been known that the fire loads may be higher than what have been tested for before there might be new WCPF evaluations.

C9.11 ENOUGH LITERATURE FOR OUTSIDERS

The ones that are doing the projects will probably know the answer to this better, but our starting point is that what is currently written should be enough. But as we have seen in the report there have been different uses of method, but there is no plan to further the literature as far as we are concerned. But if it can be motivated to do more, then we would need to look into it. When we supervise it this is something we ask about.

I think we think it is defined, but there can of course be different interpretations that motivates a need. If there is a need we would of course want to know about it. There have been difficulties even for some older companies with this new definition but with the NORSOK it became more (clear).

C10 SUMMARY OF INTERVIEW: NEW COMPANY 1

C10.1 INTRODUCTION OF COMPANY

It is a smaller company in Norway but is large internationally. The company has become an operator in Norway quite recently but has had partnerships and licences before. As the operator they are currently in the assessing phase of the -name- project and are quite soon to decide on what concept they want to follow through on. This means that they have not started designing or building the platform yet but studies for the concept selection are starting to become relevant and the WCPF is an aspect that needs to be considered.

C10.2 THE DISCUSSION

We have not been involved. The company is quite new, me as well, so we have not been in contact with NORSOK or other companies that has worked with it (WCPF) either.

C10.3 WORKING ON A WCPF PROJECT

This is the first project for us, and it is quite new and we have not done any work around design accidental loads yet. I have worked with it (loads) before on previous projects. So, I think it is new for the company but the people working here have worked with it before. We will be developing some experience in the next phase of the project. As we go on to the concept selection stage and perform concept safety studies with third party contractors, we are going to design with respect to NORSOK S-001. It includes what we need to consider for the Worst Credible Process Fire. So, it is on the radar and will be included in these concept safety studies. We are still developing the management system that is aligned with Norwegian regulations and standards. So that is something that will be developed as the project goes on.

C10.4 THIRD-PARTY CONTRACTS

We do not have any inhouse competencies for the calculations, so we are going to recognize third party contractors. We have written the scope of work for these concept safety studies and will be sending it out soon. Most of the studies will be parallel to the engineering design work which will be carried out as part of the concept safety studies as well. Those third-party contractors will be recognized contractors, specialised contractors in Norway. Maybe we will check that work inhouse. It is required to do a third-party verification of that work. Then I would expect that the engineer design contractor has comments on the WCPF studies because it will have a significant impact on the design.

C10.5 IS IT LESS OR MORE DIFFICULT TO INTERPRET THE REQUIREMENTS IN COMPARISON TO OLDER OPERATORS?

Not really sure about that one, I guess if we are using third party contractors we are relying on their expertise, modelling and input. If we were doing it inhouse maybe we would have more control. WCPF is quite new for all companies in the new NORSOK, but maybe the other companies were involved with the discussion when the standard was updated which can give them more insight into the requirements and the background.

C10.6 COMPARING WCPF TO THE PROBABILISTIC APPROACH

I guess the worst case can have a very low probability, which you will have to take account for and the consequences might be very significant, and have a significant impact on the design, it is something we will be looking at and that might rule out some concepts and might have an effect on the viability of the project as well. To design for the worst case and not accounting for the probabilistic part, it could have a significant impact, but we do not know that yet.

If you think about the ALARP principle, do you actually gain that much by designing for the WCPF as opposed to design accident loads (that includes frequency)? It does not take into account the cost element in the design, and you might not get that much benefit compared to taking into account the probabilistic part.

It is easier to stick to a numerical value and demonstrate to the decision-makers that we need to design to meet the requirements. Because they can see the benefit in relation to the cost, and you get a value on the risk benefit based on a probabilistic approach compared to simply a consequence approach.

C10.7 IS THERE A NEED FOR MORE GUIDELINES?

Basically, there is half a page on WCPF in NORSOK with typical scenario examples, but it does not cover everything I think. It should describe how it should be used, it does not show how you should use it in the actual design. And if it is being interpreted differently by different companies then it is not really a standard. So, then there should be more information or a guideline on how it should be used.

C10.8 WHAT WOULD THE GUIDELINE NEED?

This is quite new for me as well, but maximum heat loads to be used, some sort of limits of leaks that can occur, maybe historically as well. If there have not been that kind of fire in real life then, then it is hard to verify the WCPF if they can actually occur. There must be some limits on the assessment and what a WCPF is or you can end up with something you cannot design against, especially if you are eliminating the probabilistic part.

C10.9 MAIN CHALLENGES

Basically, if we cannot meet the requirements, so it is said that we shall design to the WCPF but there is only so much you can do. Your barriers may become too large and the fire wall capacity cannot maintain the integrity during a WCPF you calculate. We do not have a project yet, but it is both interpreting the standard and using it in the project, and then demonstrate that we actually design to what we assess is possible, with physical limitations.

C10.10 THE WCPF DEFINITION

It is okay but does not fit in to the normal risk acceptance criteria and risk reduction principles and philosophy. So, we are going to design to firstly meet our criteria and beyond that we will use the ALARP principle. But the WCPF does not fit in to that since it does not account for the probabilistic part. So, the cost might be disproportionate because the probabilistic part is not accounted for.

C10.11 HOW SIGNIFICANT COULD THAT COST BE?

We have no way of knowing, we do our engineering work, and you do not find out until quite late in the process as well, in the design process, because you have to do some engineering work first to know what your risk is initially. So, as you are designing you might need to rethink things.

C10.12 OTHER REFLECTIONS

We do not know what the impact of the design and operation will be compared to the previous standard when we just used safety functions and the ALARP principle. If there is disproportionate cost compared to the risk benefit it is hard to know the implications of it yet, and as a company we do not have any experience with the earlier standard. So maybe this is easier for us since this is our starting point with WCPF compared to the previous version. We can just design for WCPF and we do not need to adapt a current design with the previous standard. But until we do the assessment we will not know.

C11 SUMMARY OF INTERVIEW: NEW COMPANY 2

C11.1 ABOUT THE COMPANY

The company is fairly young and just became an operator a few months ago. They bought an installation from a larger oil company together with the organisation and I was a part of the transaction. The personnel had the possibility to transfer to the new company so operation and organisation is basically the same, or the same people in a bit new roles. Previously I worked for the company that operated the installation for the last 25 years so I have previous experience from the larger oil company that has operated the installation. So, I worked with that in the earlier company and inherited the studies done previously.

C11.2 INTRODUCED TO WCPF

We started to look into WCPF after an audit with the PSA where they pointed out that we had not considered the effect of the WCPF on -*installation*-. Based on that we used the same contractor we used to do the quantitative risk analysis for -*installation*- to look into the WCPF on -*installation*- based on the existing volumes of HC in -*installation*- and compared that to the design criteria which were used when the installation was constructed. The study concluded that the design was more robust than required to cope with the WCPF, so it was not that much work or studies required to conclude that the installation could handle the WCPF.

C11.3 WORKING WITH A WCPF PROJECT

When we started to look into it, we struggled to find a method to define the WCPF. We ended up using the SINTEF report to set up the criteria for defining the WCPF (NORSOK S-001 had not come out yet). The design was very robust to the kind of fires we can experience today so it was not that comprehensive exercise to verify the design.

C11.4 CONSULTANTS

We use consultants, the same as we had for the former risk analysis on the platform. They have known the design and the risk analysis for the platform for several years. Both in the previous company and now as a small operator in Norway with one or two persons per discipline we heavily rely on contractors for more detailed studies. We work with them with methodologies and they do the analysis.

C11.5 INTERPRETING REQUIREMENTS

The installation was designed and documented for practices in Norway, so the documentation was already there. As long as we can use consultancies expertise to do the evaluations, I cannot see a difference for us, with the size of the company.

C11.6 DIFFERENCES BETWEEN WCPF REQUIREMENTS TO PROBABILISTIC REQUIREMENTS

For me it is not that different, it is another way of thinking. We are not used to requirements like this, with not taking probability into account but as long as the requirements are clear it is not that different to work with the problem. We had some discussions with the PSA in the beginning just for requirements for older installations but when that was clarified I do not see a general difference in the way it is working. We tend to like the probabilistic just because that is what we are used to working with in the oil industry, but as long as the requirements gets more specific, I cannot say I prefer one over the other.

C11.7 MAIN CHALLENGES

When doing an evaluation on an older installation it could have resulted in a major redesign to withstand the WCPF, that was the main concern when we started the work, if we cannot conclude that the design is robust it might require a comprehensive redesign of the platform so that was the main concern. But we quickly saw that the design was robust enough in our case, so it ended up not being a challenge. For us it was not that different from any other studies that we do to verify the robustness of the design for the platform.

C11.8 IF REDESIGN HAD BEEN NEEDED

Financially it would off course be easier with a bigger company as you have possibility to do the things required, for an installation as old as ours it will always be a question of cost even if we had the money. To do a massive reinvestment in an older installation with a lifetime less than maybe five to ten years… I would assume that would be difficult for a larger company as well. And in a smaller company the problem is more or less that if we need to do larger investments without increasing the production and somehow get funding for it, but overall, I do not think the process would be that different in a larger or smaller company.

C11.9 MAY NOT BE REPRESENTATIVE OF SMALLER COMPANIES

I do not think we are that representative for a smaller company that has worked with WCPF, we basically took over the work that -*older company*- had done and just kept the documentation that they had.