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Preface

This thesis accounts for risk management and safety issues related to the decommissioning phase of offshore installations. The work has been done to create a modified risk management process that will minimize the risk for decommissioning work at offshore installation.

I hereby declare that this Master's thesis has been performed in accordance with the regulations at the University of Stavanger, Norway.

Stavanger, June 2016

Ayesha Saeed

Dedication

I am dedicating this thesis to my $1^{1/2}$-year-old daughter and my loving husband for all the cooperation, motivation and giving me the possibility to fulfill my dream of doing Masters.
Thank you for all your love, guidance and support, which were a source of my motivation to work hard and succeed in my thesis. Thank you for everything.

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Abstract

Most of the offshore oil and gas installations are going towards the cessation of their production life, which means that the decommissioning activity will be increasing in years to come. Decommissioning of the offshore installation is a complex and challenging task. A proper risk management process is needed to identify safety challenges and issues associated with decommissioning activities.

In this thesis, some significant safety challenges and issues have been identified. The thesis proposes a risk management process that determines the cause and consequences of each hazard by using Bayesian network. Uncertainty assessment procedures have also been included for the risk analysis results to provide useful information to decision makers. In addition, mitigation techniques for identified hazards have been suggested.

In the end, a case study has been carried out to implement and show that proposed risk management process provides a better way to foresee decommissioning safety issues and control them effectively. In this thesis, Shell *Leman BH* field is used as a case study. The comparison is made between Shell risk control framework and suggested risk management process for particular points like risk definition, risk acceptance criteria, and risk assessment matrix. For these particular points, it is found that the general Shell risk management framework provides a vulnerable mitigation plan as it doesn't include uncertainty associated with the probability values according to new risk perspective proposed by Aven (2013) and by risk definition of PSA (2016). The proposed risk management process in this thesis applied to identify the hazards for decommissioning of Leman BH field. The analysis procedure results given by proposed process is providing better management and mitigation procedure for the safety issues. The proposed risk management process provides a better decision making as it uses Bayesian network together with uncertainty analysis.

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List of Abbreviations

ALARP	As Low As Reasonably Practicable
BN	Bayesian Network
CETS	Commission on Engineering and Technical Systems
DAG	Directed Acyclic Graph
DECC	Department of Energy and Climate Change
DNV	Det Norske Veritas
FAR	Fatal Accidental Rate
HLV	Heavy Lift Crane Vessel
HSE	Health and Safety Executive
ICAF	Implied Cost of Averting Fatality
IMO	International Maritime Organization
IOG	International Association of Oil & Gas Producers
IRPA	Individual Risk Per Annum
ISO	International Standard Organization
NCS	Norwegian Continental Self
NPD	Norwegian Petroleum Directorate
OSPAR	Oslo and Paris Convention
PSA	Petroleum Safety Authority
ROV	Remotely Operated Vehicle
SLB	Schlumberger
SOK	Strength Of Knowledge
SPE	Society of Petroleum Engineers
UKCS	United Kingdom Continental Shelf
UKOOA	UK Offshore Operator Association
UNCLS	United Nations Conventions on the Law of Se

1 Chapter 1 – Introduction

1.1 Background

There are over 7000 offshore oil and gas production installations and platforms on the continental shelves of over 53 countries all over the world. (Techera, 2015). Over 4,000 of them situated in the Gulf of Mexico, 1000 in Asia, 700 in the Middle East (Bemment, 2001) and 625 in the North Sea (ABB, 2015) and rest in other areas. In the upcoming years, offshore decommissioning activity will increase because the mature fields are going toward the end of their production lifecycle. Decommissioning of these installations is a complex and challenging process.

As first oil fields been discovered in Norwegian North Sea area in 1969 and different offshore platforms and other installation were started to emerge in the 1970s, little or no consideration has been taken in the decommissioning phase of these installations. Therefore, removal of old installations is a complicated process because decommissioning phase was not considered during their design.

Decommissioning is the final phase of oil and gas operation that includes unplugging and abandoning of wells, removing the infrastructure, doing remediation work and cleaning the project site. Offshore installations consist of different substructures like topside, jacket or concrete structure remaining on seabed through its weight (gravity based). Each installation has its size and weight depending upon the water depth, environmental condition, and available technology at the time of construction. Large topside structures can be of 50,000 tons, and the gravity-based can be hundreds of thousands of tons. (Techera, 2015). The estimated material weight of offshore installations in UKCS that will be removed in upcoming years is shown in *Table 1-1*.

Table 1-1 UKCS Decommissioning material weight estimation (UK, O & G,2015)

Forecast Activity 2015 to 2024			
	Central and Northern North Sea/West of Shetland	Southern North Sea and Irish Sea	Total UK Continental Shelf
Number of wells for plugging and abandonment	950	274	1,224
Proportion of wells that are platform wells	55%	73%	-
Topside modules to be removed	255	66	321
Topside weight to be removed	288,000 tonnes	78,890 tonnes	366,890 tonnes
Number of platforms	22	57	79
Substructure weight to be removed	105,140 tonnes	46,200 tonnes	151,340 tonnes
Number of mattresses to be removed	6,145	3,350	9,495
Subsea infrastructure to be removed	80,230 tonnes	2,250 tonnes	82,480 tonnes
Number of pipelines to be decommissioned	598	179	777
Length of pipelines to be decommissioned	2,189 kilometres	3,429 kilometres	5,618 kilometres
Total tonnage coming onshore	492,250 tonnes	127,330 tonnes	619,580 tonnes

There is a small experience of removing the structure from the North Sea, only 30 small steel structures and subsea installations have been successfully decommissioned in the shallow water (30-50meters) of Southern North Sea. The largest structure that has been decommissioned is the Odin Platform in the North Sea in 1997; it was a steel structure with weight more than 6,200 tons.(Gibson, 2002).

In the coming twenty-five years, there will be more than 150 platforms in North sea going to be decommissioned (BBC, 2016) as of the increase in maintenance costs and safety concerns for older platforms will be increasing year by year. This removal process will consist of both single small structures and heavy structures in the North Sea.

Therefore, the decommissioning activities consist of a broad category of operations that involves risk to both personnel (contractors, etc.) and the environment. The safe operations of decommissioning processes and activities require proper assessments of risks. The companies are using their general risk management frameworks when they plan for decommissioning activities. Decommissioning and safety issues are connected with each other and require a modified risk management process which takes into account the decommissioning activities.

As due to less decommissioning activity in last few years, there is little risk data available and no publically available document that considers safety issues and risk management process for decommissioning. Most companies are using same safety and risk management procedures for decommissioning activities as for installation activities. As due to low oil prices, and increase in older platforms , the decommissioning activity is going to increase. Hence, there is a need to produce a document that proposes a risk management process by taking the decommissioning activities and safety issues into account. It should also consider the latest research and technology both in decommissioning and risk management areas.

1.2 Purpose

The primary objectives of this thesis are:

- Identify critical safety issues during offshore decommissioning.
- Establish suitable approaches and methods for how to assess and mitigate safety hazards during offshore decommissioning.

1.3 Scope of the study

This thesis provides the information for safety issues that can arise during offshore decommissioning by thoroughly studying the main decommissioning phases. It also considers the environmental impacts as a result of decommissioning activities. A risk management process is proposed here to handle these safety issues by using Bayesian networks. Uncertainty assessment of the risk analysis results has also been suggested. It has been proposed risk mitigation techniques for safety hazards for offshore decommissioning.

Finally, it compares the proposed risk management process with Shell risk management framework. However, this comparison has not been made in detail due to the limited amount of time.

1.4 Outline of Thesis Report

This thesis is divided into seven chapters and an appendix.

Chapter 1 providing an introduction, purpose, and scope of the thesis. It is describing the reasons about why it is necessary to write the thesis on decommissioning.

Chapter 2 describe the decommissioning rules and regulations and main steps for decommissioning. It also provides information related to decommissioning options and describe different methods that can be used to decommission the offshore installations.

Chapter 3 outlines and determine the major safety challenges that can arise during offshore decommissioning by thoroughly studying each decommissioning phase. It also brings up the decommissioning impacts on the environment.

Chapter 4 is the major part of this thesis work as the risk management process has been proposed here for offshore decommissioning. Bayesian models are proposed to achieve risk analysis. After that uncertainty assessment procedure is mentioned for risk analysis results. Finally, the risk mitigation techniques been suggested is recommended against each identified hazard.

Chapter 5 consider the Shell Leman BH field as a case study. This chapter provides the comparison of Shell general risk management framework used with the proposed risk management process for some selective points of decommissioning activities.

Chapter 6 doing discussion and conclusion and provide information for future work.

Chapter 7 showing the references for the thesis, and

Appendix A is about different platform types.

1.5 Limitations

The primary focus of this thesis is to determine the major safety challenges and to offer a risk management process to handle these challenges. Therefore, the detailed calculation work like probability calculation for Bayesian models is not included here. Secondly, the Bayesian network models covering only the main causes and consequences related to each decommissioning hazard. There may be some other causes exist for safety hazards, but they are not the part of this thesis.

2 Chapter 2 – Offshore Decommissioning

2.1 Introduction

When fields are not economical to produce they need to be shut down. Then the offshore infrastructure that has been serving the field for all its operations need to be removed and decommissioned. Offshore decommissioning is the last phase for a platform.

The chapter starts by giving the definition of decommissioning. The next session of this chapter explains what kind of different rules and regulations that have been set up for decommissioning processes. The chapter briefly describes the various decommissioning steps that are part of the whole decommissioning phase. The last session of the chapter describes in short the different methods of removing topsides and jackets that are being used in industry.

2.2 Definition

The UK Offshore Operator Association (UKOOA) defines decommissioning like that:
"*The process which the operator of an offshore oil and gas installation goes through to plan, gain government approval and implement the removal, disposal or reuse of a structure when it is no longer needed or its current purpose*." (Gibson, 2002)

Decommissioning is the phase which is usually initiated when the offshore installation is not going to be used for future or current fields. This involves removing all the structures belong to the field that has been shut down. After removal, disposal or reuse of these structures is also part of the decommissioning phase.

When there is going to initiate an offshore decommissioning phase, it needs to follow up the rules and regulations. The next section discusses the decommissioning rules and regulations.

2.3 Rules and regulations

International rules and regulations together with national laws, industry standards and authorities regulate the oil and gas sector. The worldwide regulatory framework for decommissioning of offshore installations consist of Geneva Convention on the Continental Shelf 1958, Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter 1972 (London Dumping Convention), UN Convention on the Law OF Sea (UNCLOS) and IMO *Guidelines and Standards for the Removal of offshore Installations and Structures on the Continental Shelf* 1989.

In addition to international regulations, there are fifteen regional conventions worldwide that used to protect the environment and marine life. The Oslo and Paris Convention (OSPAR) is the main convention protecting the marine environment in the North Sea and North East Atlantic. Also, Norwegian rules and regulations for decommissioning activities are The Petroleum Act 1996, Pollution Control Act, the Harbors and Navigation Act and the Working Environment Act. (Gibson, 2002)

The thesis will briefly describe the UNCLOS, OSPAR Decision 98/3 and the Norwegian Petroleum Act 1996.

2.3.1 United Nations Conventions on the Law of Sea

Article 60 of this Law states that

"*Any installations or structures which are abandoned or disused shall be removed to ensure the safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organization. Such removal shall also have due regard to fishing, the protection of marine environment and the rights and duties of other States. Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed*." (UNCLS, 1994)

This law appeared on 16, November 1994. It says that the partial removal of installations or structures is allowed in a case where abandoned structures do not affect the fishing and other marine environment and rights and duties of the states.

2.3.2 Oslo and Paris Convention (OSPAR)

The Convention for the Protection of Marine Environment of the North- East Atlantic entered into force on 25th March 1998. There are 16 contracting parties for OSPAR some of them are European Union, Spain, Portugal, Luxemburg, Switzerland, France, Norway and the United Kingdom. It is the replacement of Oslo Convention for the Prevention of Marine Dumping from Ships and Aircraft and the 1974 Paris Convention on Prevention of Marine Pollution from Land-based Sources. In July 1998 a new framework called OSPAR Decision 98/3 was established for the decommissioning of offshore installations by the Ministerial meeting of OSPAR Commission.

Paragraph 2 of Decision 98/3 states that "*The dumping and the leaving wholly or partly in place of disused offshore installations within the maritime area is prohibited*." However, paragraph 3 "*Permit consideration of derogations in the case of concrete structures and concrete anchor bases and for the footings of steel structures weighing more than 10000 tons put in place before 9 February 1999*". (Bemment, 2001)

The main points of OSPAR are (Gibson, 2002):

- All installations installed after 9 February 1999 (when OSPAR 98/3 came into force) must remove completely.
- The topside of all platforms must be returned to shore.
- All steel installations with a jacket weight less than 10000 tons must be completely removed for reuse or disposal on land.
- For steel facilities with jacket weight greater than 10000 tons, it can be considered that footings can be left in place. This consideration is allowed in a case if the removal of these footings have severe safety issues, environmental effects, and technical problems.
- The OSPAR Decision 98/3 do not apply to pipelines.
- In future, all new steel structures must be completely removed.

However, in the Norwegian continental shelf, no concrete structure has been removed yet because of the cost issues and incompatible technology (Christian, 2014). Operators like ConocoPhillips have received the permit to leave the concrete structure in place. ***Figure 2-1*** shows an example of a concrete tank on Ekofisk 2/4-T Complex (PSA, 2009).

Figure 2-1 Ekofisk 2/4-T tank (PSA, 2009)

2.3.3 The Norwegian Petroleum Act

Act 29 November 1996 No.72 related to petroleum activities describes the rules and regulations about petroleum activities on the NCS. The chapter 5 of this law covers the cessation of the petroleum activities. The primary focus is on the planning and permits for the decommissioning process.

Section 5-1 states that the requirement for a decommissioning plan must be submitted to the Ministry by the operator at least two years before the production license expires but no more than five years before.

Section 5-2 states that the operator shall notify the Ministry if the facility is expected to be shut down before the current production license expires. (NPD, 2015)

The rules and regulations are used to protect the both environment and marine life. The decommissioning within the North Sea needs not only to follow up the OSPAR, and for the Norwegian North Sea, Norwegian petroleum act is also required for planning and getting permits.

After a brief introduction to rules and regulations of offshore decommissioning, decommissioning steps needs to be outlined. The next section is briefly explaining the decommissioning steps.

2.4 Decommissioning steps

According to (SPE, 2015) offshore decommissioning involves ten main following steps:

2.4.1 Project Management

Project management outlines the scope of the project, initial planning and contracting. It should start before the last well gets shut down. It is because the derrick barges are limited in numbers and many operators contact these vessels in advance. Secondly, the field operators review the plan and study the rules and regulations to gain approval from the government.

2.4.2 Engineering analysis

In this step detailed plan is made with different possible options. Risk assessment is carried out to for environmental and human protection. This step also performs the economic analysis and cost estimates

2.4.3 Regulatory Compliance

Decommissioning permits are required to be applied in advance because it can take longer time for approval. Operators often hire consultants to ensure that their organizations are following the regulations. The previous section has already described in detail rules and regulation for decommissioning.

2.4.4 Preparation

After completing the permits work, platform removal groundwork can be started. It includes cleaning and flushing of tanks, process equipment, and piping and makes them hydrocarbon free. The modules on the platform are separated using cutting the pipe and cables between the modules. The jacket is prepared for removal by removing marine growth with the help of underwater workers. If the pad eyes are not pre-installed or not in acceptable condition, are also installed to lift the modules.

2.4.5 Well Abandonment

This step is one of the major cost of the decommissioning process. Therefore, it can be divided into two phases, planning phase and execution phase. Data collection and preliminary inspections are performed during the planning phase. The best method to use for Plugging and abandonment is decided according to the condition of the field. Finally, the plan is submitted for approval. The abandonment phase involves well entry preparations, filling the well with fluid, removal of downhole equipment, cleaning out the wellbore, plugging open hole and perforated intervals at the bottom of the well.

2.4.6 Conductor Removal

It is a requirement that all platform equipment including conductor casing is removed 15 ft down the sea floor or to a depth approved by Regional supervisor based upon the type of platform and natural condition. There are three methods available to remove the conductor casing serving, pulling and offloading. In severing conductor is removed by explosive or mechanical cutting, pulling use the case jacket to cut the conductor into 40 ft long segments and offloading use the crane to lay down each conductor casing section in a platform area.

2.4.7 Structure Removal

After completing the removal of conductors, structural removal step can be started. There are different ways to remove the platform depending upon the size of the platform, water depth, platform design and lifting barge capacity.

2.4.8 Pipeline and Cable Removal

In some cases if the pipelines and power cables are not affecting the environment and fishing operation they are allowed to be decommissioned in place. Therefore, to decommission the pipelines at the location, there is a requirement to disconnect the pipelines from the platform and then flushing and filling with fresh sea water is essential. After cleaning and filling the open end of the pipeline is plugged and buried three ft below the sea floor and covered with concrete.

2.4.9 Material disposal

In this step, different materials are separated such as topside, jacket, modules and support structures. According to the condition of materials, it is estimated that which equipment is possible to repair and reuse. The remaining material is scrapped or disposed of as hazard waste.

2.4.10 Site clearance

Site clearance is the last step of decommissioning process in which it assures that no debris is left behind. Remotely operated vehicle (ROV) and divers checked the area to identify further and remove any residue left behind. Finally, the environmental impact is noted, and the area is declared clear for marine traffic and fishing operations.

Therefore, to understand that what decommissioning options are available and what are main methods to decommission the offshore installation there is need first to know about the types of different platforms that are described in Appendix A. The offshore structures in the North Sea with their type of platform, location and numbers are given in Table 2-1 below:

Table 2-1–North Sea offshore installations (ABB, 2015)

Country	Steel Jacket	Concrete Substructure	Subsea	FPSO	Total
UK	227	12	56	17	312
Norway	69	13	54	9	145
Netherlands	118	2	7	0	127
Denmark	39	0	0	0	39
Germany	1	1	0	0	2

Before describing the decommissioning methods, it is important to describe a different kind of decommissioning options or processes. The decommissioning methods are explained briefly in the following section.

2.5 Decommissioning Options

There are different options to decommission the offshore installation as shown in the figure below. But after OSPAR Decision 98/3 all facilities with jacket weight less than 10000 tons must completely remove for reuse or disposal on land. However, for the installations that have jacket weight greater than 10000 tons, it can be considered that footings can be left in place.

This consideration is allowed in a case if the removal of these footings have severe safety issues, environmental effects, and technical problems.

The possible decommissioning options has been shown in Figure 2-2 below:

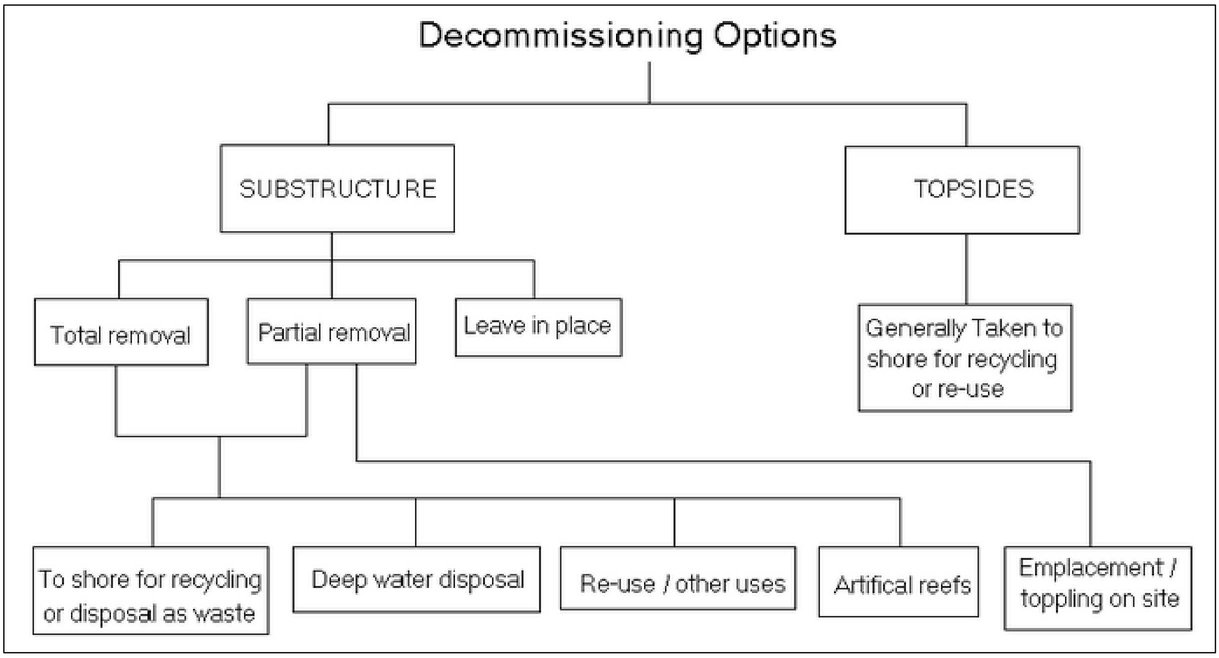

Figure 2-2 Offshore Decommissioning options (Gibson, 2002)

2.6 Decommissioning methods

There are different decommissioning methods which are used for removal of the platform, topside and jacket structures. The criteria for selecting the best removal methods depends on the nature of the platform, available resources, and the overall costs. The general decommissioning methods after the OSPAR Decision 98/3 is given below.

2.6.1 Piece Small

Piece small as name refer is a decommissioning method which uses mechanical and other cutting techniques to cut down the platform structures into smaller pieces. Those small pieces of structures are sent to shore by lifting them using the existing cranes on platforms or temporary cranes.

This method is only considered for structures weigh up to 20 tons (ABB, 2015). Piece small is a suitable removal approach as heavy lift crane vessel (HLV) or cargo barges are not required, while using this method will require an intense amount of resources and time to cut the big offshore structure into pieces.

2.6.2 Reverse Installation

Reverse installation involves disintegration and removal of topsides and platform deck in reverse order to that they were installed. This method requires detailed planning about the order in which different modules detaches from the topside and deck. Detailed planning for lifting helps to minimize the utilization of lifting vessel and maximize the efficiency of the method.

2.6.3 Single Lift

In **Single lift** method, a whole topside is being removed as a single element. The process includes the setting the cutting line and then lift the entire topside as one unit using heavy lift crane vessels (HLV). This method requires the least amount of lifting time. The maximum weight HLV can lift is 48000 tons (ABB, 2015). Sufficient structural integrity and sufficient reinforcement are important factors to be considered while planning to use the single lift as removal method.

2.6.4 Large Module Combined Removal

This method involves removal of many modules together. The benefits of lifting many modules together include efficient usage of heavy lifting crane vessels and better time management and cost reduction for decommissioning. The different modules location and weight decide if they can be lifted together or not. The method in comparison to reverse installation needs more design and engineering studies before being used to raise topside modules together.

2.6.5 Refloating

All the four methods that were described above are being used to remove topside removal, while refloating is the method that removes the jackets, given that topsides are removed already.

Buoyancy tanks in Figure 2-3 are used for steel jacket to lift the jacket from the seabed and float it from the platform location to sheltered waters where it can be cut up using piece small methods or some other mechanical techniques.

This method was used in 2009 for the DP2 jacket from Total's Frigg field in the Norwegian North Sea (Offshore-mag, 2009).

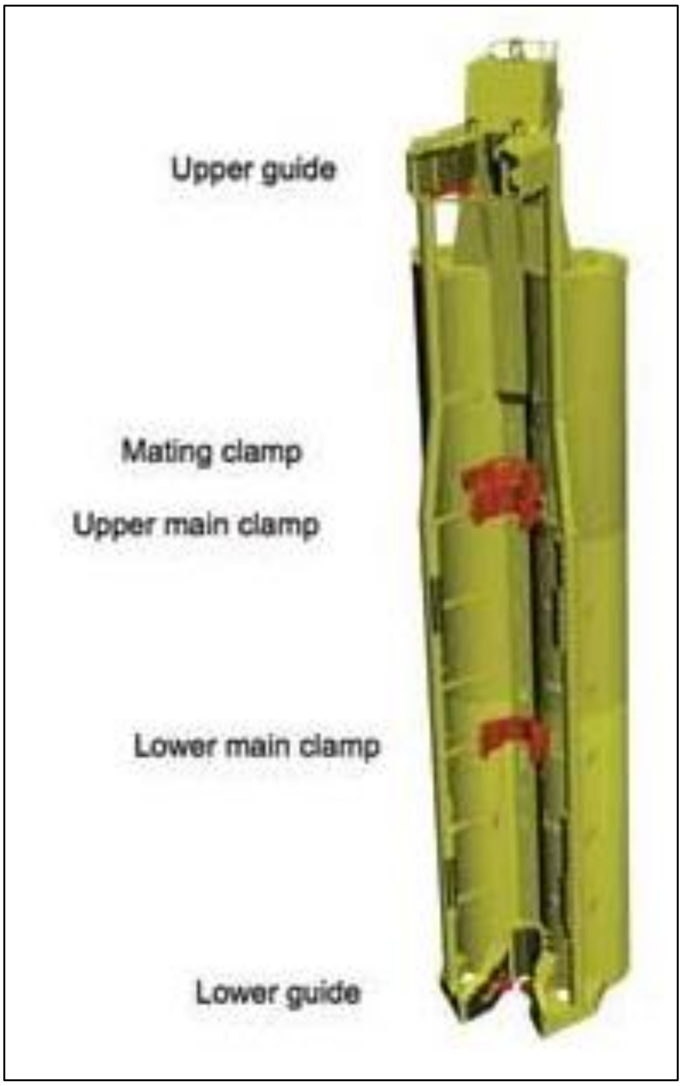

Figure 2-3 Buoyancy tank assembly (Offshore-mag, 2009)

3 Chapter 3 – Safety Challenges and Decommissioning

Safety is the main part of planning and management of all phases of a decommissioning project. A proper safety plan should be build up from initial planning to final removal process. A safe decommissioning, dismantling and disposal of offshore installations depends on upon the proper risk assessment and risk management.

Only a small amount of historical data is available regarding risk due to limited decommissioning experience in the North Sea. However, safety plan can be made for the decommissioning process by the identification of significant hazards. Hazard identification involves "identifying substances, objects or processes with the potential to cause harm" (Bemment, 2001).

3.1 Safety Challenges in Decommissioning operations

According to (Bemment, 2001) the activities that involve hazards during decommissioning are:

- Well plugging and abandonment
- Cutting of conductors and appurtenances
- Disconnecting, purging and sealing pipelines and risers
- Removal of platform inventory
- Making process trains safe
- Final shutdown
- Topside and substructure removal
- Removing of drill cutting pieces
- Loading to means of transport
- Unloading from transport
- Disposal

3.1.1 Well plugging and abandonment challenges

Well plugging and abandonment is a challenging process and demand high cost and proper planning. It involves following steps: (SPE, 2015)

- Well entry preparations
- Use of slick line unit
- Filling the well with fluid
- Removal of downhole equipment

- Cleaning out the well bores
- Plugging open-hole and perforated intervals at the bottom of the well
- Plugging casing stubs
- Plugging of annular space
- Placement of a surface plug
- Placement of fluid between plugs

All these steps mentioned above are highly sensitive, and care should be taken to carried out these activities. The pressure of the well is required to be monitored continuously during the abandonment and plugging process. The change in pressure difference can be harmful and often lead to the discharge of harmful gasses and liquids. The situation can become more serious and dangerous if other decommissioning activities are carried out at the same time. As a result, fire and explosion can occur due to the pressure difference. According to the condition and environment of each well, well plugging and abandonment require equilibrium between the inner and outer pressure.

During cleaning of well bores and removing of downhole equipment proper training and monitoring of safety system is needed to avoid any accidents. Well plugging at the exact location is a challenging task. It should be done more precisely and accurately to prevent any leaks in future. The quality of cement used for plugging should be checked and controlled. Because leaking after abandonment is also harmful to marine life and the environment.

Table 3-2 shows some fatalities occurred in 2014 globally. It shows that largest number of fatalities has taken place during well services that are **16**. A proper risk management process is needed to reduce the fatality rate during well plugging and abandonment in future. Table 3-1 shows the estimated number of wells that are going to be plugged and abandoned on the Norwegian Continental Shelf from 2015 to 2025 are 284, out of these 269 are platform wells and 15 subsea wells. (UK O&G, 2016)

Table 3-1 Decommissioning activity forecast 2015-2024 (UK O&G, 2016)

	Number of Wells 2015 to 2024	Proportion of Platform Wells
Total	284	95%
Norwegian North Sea	281	96%
Norwegian Sea	3	0%
Barents Sea	No activity	No activity

Table 3-2 Fatalities by incident activity 2014 (IOG, 2015)

Activity	Number of fatalities
Construction: Construction, commissioning, decommissioning	6
Diving: Diving, subsea, ROV	0
Drilling: Drilling, workover, well services	16
Lifting: Lifting, crane, rigging, deck operations	6
Maintenance: Maintenance, inspection, testing	4
Office: Office, warehouse, accommodation, catering	0
Production: Production operations	3
Seismic: Seismic/survey operations	1
Transport – Air: Transport – Air	0
Transport – Land: Transport – Land	6
Transport – Water: Transport – Water, incl. marine activity	2
Unspecified: Unspecified – other	1

3.1.2 Cutting of conductors and appurtenances

Cutting of conductors and appurtenances is usually carried out by the thermal, explosive and electrochemical method. These methods require ROV and divers for underwater cutting. The safety of the divers is the primary concern of this activity. Risk will be increase with a number of divers working on it. The most recommended method for conductor cutting is an explosive method, which requires high responsibility and proper risk management process.

Explosive cutting can damage the well plugging. Therefore, enough barriers are necessary on the wells to minimize the risk. It can also disturb the drill cutting process and throw the oil based mud at some distance from the platform. This oil based mud is harmful to the marine environment. Finally, the lifting of disconnected conductors and cutting into manageable segments can be hazardous and require proper planning.

3.1.3 Disconnecting, purging and sealing pipelines and risers

In some cases, pipelines can be left in a safe condition on the seabed if they are not disturbing fishery operations and not harmful for the environment. They are required to be cleaned and flushed properly. After cleaning, the pipeline should be buried below the sea floor and covered by concrete.

This operation involves divers that cover the pipeline with steel or concrete. If there is a need to lift the pipeline, then divers cut it into suitable pieces and attached a hook for lifting. The cutting and lifting operations involve risk for divers. During lifting, objects can fall, or pipeline can break due to corrosion. Transportation of these pipelines also demands proper consideration.

3.1.4 Removal of platform inventory

The removal of the unwanted material like hydrocarbons and other toxins is a difficult task and involves risks and hazards. A platform built 30 to 40 years ago have dangerous substance like asbestos which is not allowed to use in Norway since 1982. Table 3-3 shows the estimated amount of hazard material of one installation in the southern part of the North Sea that is planned to be decommissioned in the coming years.

Table 3-3 *Hazard material evaluation for decommissioning* (Christian, 2014)

Material	Estimated amount (tons)
Absorbent, oil polluted	3,58
Asbestos	50,95
Batteries	1,66
Contaminated concrete	12,37
Crude oil	8,62
Debris of heavy metal contaminated paint	0,66
Diesel	9,08
Diluent, thinner	0,01
Gear, motor and lube oil	13,15
Glycol	0,06
Heavy metal contaminated debris	227,85
HG Scale from cleaning process	16,68
Hypochlorite solution	0,03
Light fittings	2,28
Mercury fluorescent tubes	0,13
NORM	1,65
Oil and zinc contaminated Mud	2,54
Oil cartridge filters	0,12
Oil with more than 15% water	8,24
Other oil waste	0,73
PCB windows	1,36
Smoke detectors radioactive	0,01
Soda lye	0,24
Spill oil	1,28
Sulfuric Acid	0,02
Sum hazardous material	363,3

The disposal of the toxic and another hazard material depends on upon the nature and environment of each substance, but if possible they should be removed in their original containers.

The main risk in this operation is that person involves in cleaning can be affected by a hazardous material. They can experience a lack of oxygen or confined spaces during cleaning of vessels and other equipment. Proper planning and management can reduce the risk. For this operation, the person should be well trained and prepared for any emergency situation. Protective clothing, proper equipment, and specialized logistics for cleaning and handling disposal can reduce the risks. Strict control of ignition sources and inventory can also decrease the possibility of fire and explosion.

3.1.5 Making process trains safe challenges

It is important that process trains should be made safe for further operations like cutting, welding, and topside lifting. To start these operations all pipes and valves need to be cleaned.

However, it has been observed that sometimes these operations still be dangerous after cleaning too. The residue that absorbed in vessels or pipes can blowback during cutting or hot work on these pipes. The situation can become more severe if there is a significant time gap between cleaning and cutting. (Bamidele, 1997)

There is a need to make risk management process in advance to make these operations safe. Therefore, experience and trained persons should perform these activities, and they are prepared for any emergency situation.

3.1.6 Challenges during final shutdown

Last closure of the machinery, safety system, and other utilities also demand high care and responsibility. There is a need to consider the number of workers, life support system and other sources of power before doing any final shutdown. Temporary generators can provide power supply on the installations or in some cases flotel can be parked near the facility to provide the power for communication and safety systems. To avoid any dangerous, there should be close coordination between installation and flotel parties and workers should be prepared for any emergency situation.

Cutting of electrical cables can be harmful if dead and live cable are mixed and can increase the risk of electrocution. Therefore, these cables should be separated properly to avoid any dangerous situation. Cutting off power cables can also produce toxic fumes and fires. During the cutting of electrical wires **three fatalities** has been observed globally in 2014. (IOG, 2015). So proper risk management process is required before final shutdown operation.

3.1.7 Topside and substructure removal challenges

There are different removal methods for topside and other structures as have been described in chapter 2. During lifting process, loose objects can fall. It is required to make sure that all loose object are securely fastened. A weight of the lifting load should be clearly marked, and center of gravity of the equipment must be known.

In 2014, it was reported that **five fatalities** happened by falling from a height, and **six fatalities** have occurred during lifting work globally. (IOG, 2015). It is a significant amount of fatality rate, and it needs to be reduced in future. It demands proper risk management process for topside and substructure removal because good planning and management can quickly overcome the dangerous situation and be helpful in reducing fatality rate.

3.1.8 Challenges to drill cutting pieces' removal

In the start of 1960s, drill cutting pieces were discharged into the sea. Due to this, the old platforms have large mounds of these pieces. The height of the drill cutting piles has been approximated 2 to 20 meters in the Northern and Central North Sea. (Breuer, 2004). The largest cutting mounds are estimated more than 26-meter-high with area 20,000m^2 and volume 45,000m^3. (Torgeir Bakke, 2013)

Removing of these drill cutting pieces at the bottom of the platform is a challenging process and demand proper training. Cutting pieces can contain extremely toxic material at their base because some platforms drilling involves diesel-based mud.

A proper clothing and special handling tools are required to make sure the safety of divers during this process.

3.1.9 Transport loading and unloading challenges

Loading and unloading the structure to means of transport requires high responsibility and care. Objects should be adequately lifted and safely transferred to the transport barge. Simple slings can lift lighter loads but for heavy loads specialized rigging equipment and underwater welding pad eyes are necessary. It is recommended that grillage pads should be installed on the transport barge To avoid punching the barge with a sharp edge and to secure the load during transit,

The consequences of falling large objects are severe and can lead to sudden deaths. **Eight fatalities** recorded in 2014 during transportation. (IOG, 2015). So proper plan and calculations are required to carry out this step.

3.1.10 Challenges during disposal

The offshore material that will be disposed on NCS from 2015 to 2024 is 166,850 tons. (UK O&G, 2016). This process includes cleaning and handling of hazardous waste, deconstruction, reuse, recycle, disposal and waste management. The step by step disposal process is shown in Figure 3-1.

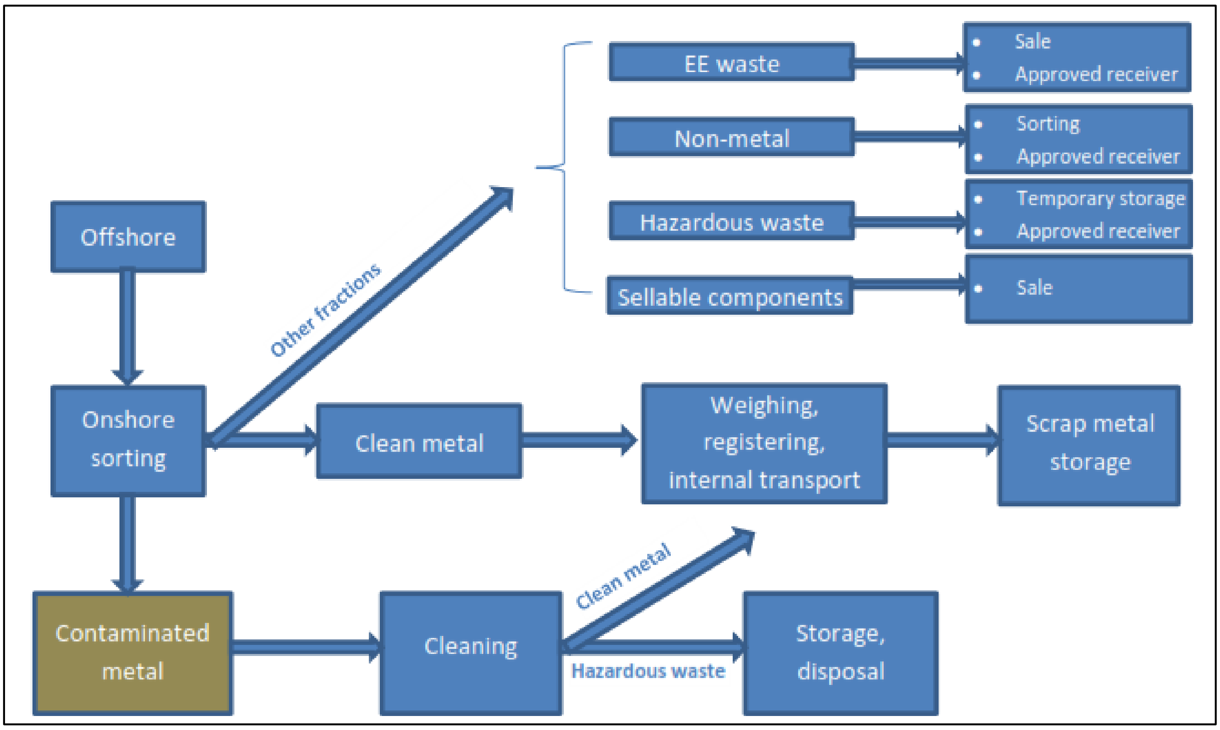

Figure 3-1Disposal handling process from offshore to disposal (Christian, 2014)

Handling and disposal of offshore waste is a challenging process. The different material used to make topsides. These metals can have severe impacts on workers and the surrounding environment. So proper training and skilled persons are required to do this job. They should be prepared for any emergency situations and can escape out easily from a dangerous area. Good risk management process and training are essential to carry out this step.

3.2 Environmental Impacts

The decommissioning process has many environmental impacts that need to be considered. These impacts are from planning of removal activity to final disposal. The Norwegian Petroleum Act 1996 requires that an environmental impact assessment should be carried out during the preparation phase of the decommissioning process. OSPAR decision 98/3 also includes the steps that should be taken into account when assessing disposal options. The steps that should be considered by OSPAR are given below:

- "*Impacts on the marine environment including exposure of biota to contaminants associated with the installation, biological impacts arising from physical effects, conflicts with marine culture and the conservation of species (protection of their habits) and interferences with other legitimate uses of the sea.*"

- *Impacts on other environmental compartments including emission to the atmosphere, leaching to groundwater, discharge to surface fresh water and effects on the soil.*
- *Consumption of natural resources and energy associated with reuse or recycling.*
- *Other consequences to the physical environment which may be expected to result from each option.*
- *Impacts on amenities, the activities of communities and future on uses of the environment.*" (Bemment, 2001)

According to the UK oil and gas (2012) the environmental impacts that need to be considered during decommissioning process are:

- Gaseous emission
- Discharge to the sea
- Underwater noise
- Disturbance to the seabed
- Drill cutting pieces
- Dropped objects
- Dismantling, recycling, and disposal

3.2.1 Gaseous emission/ Energy usage

The amount of energy used to decommission an installation is important. The vessel used for lifting, cutting and transportation purpose release a significant amount of CO_2, NO_2, and SO_2 during fuel combustion. In 2011, CO_2 emission from UK offshore oil and gas industry was 3.7 percent of total UK CO_2 emission. (O&G UK, 2016). In 2012, the total emission of gasses on the NCS was 12.3 million tons CO_2, 50000 tons NO_2 and 800 tons SO_2. (Christian, 2014)

3.2.2 Discharge to the sea

During vessel operations discharge of sewage, food waste, ballast water, and treated bilge water takes place into the sea. But this discharge doesn't have long term hazards on birds, fishes, and other marine life. However, the release of chemicals during cleaning and flushing of pipelines and removal of topside and jacket should be strictly controlled through Offshore Chemical Regulations

3.2.3 Underwater noise

Vessel operations produce an underwater noise like by use of dynamic positioning system, during cutting and seabed excavation works. The noise generated during the decommissioning process is of low intensity and shorter duration as compared to the noise produced during the installation process (UK Oil & Gas, 2012). However, the effect of noise that disturbs the marine mammals needs to be accounted for during assessing environmental issues due to decommissioning activities.

3.2.4 Disturbance to the seabed

The lifting and cutting of jacket legs can create a disturbance on the seafloor. This disturbance of seabed can influence the marine organism that lives there. However, the magnitude and duration of influence depend on a number of excavations.

3.2.5 Drill cutting pieces

There are mounds of drill cutting polluted with oil based or synthetic drilling fluids under most of the old platforms. Before lifting the structure, these mounds should be removed. The problem is that these mounds have the buried part of installations that should be removed first before lifting the structure. Removing of these polluted mounds release toxic materials and can affect the marine environment. Environment monitoring of these operations is a necessary and required permit from Climate and Pollution Agency.

3.2.6 Dropped objects

During cutting and lifting operations, larger objects can accidentally fall into the sea. An example of the falling object is Petronius module of 3600 tons that fell from DB50 into the Gulf of Mexico together with the crane block. The module is still on the seabed 1750 feet below the water surface. (Bemment, 2001). These objects can interact with fishing tackle. Side scan sonar and ROV surveys can be used to identify these objects before declaring that the seabed is free from obstruction.

3.2.7 Dismantling, recycling and disposal

When material arrives onshore for dismantling, a large number of environmental issues can arise such as noise, smell, chemical and radioactive discharge. A traffic problem can also occur during transferring of these offshore material to the site. Radioactive material ^{226}Ra found in waste from platforms that have been removed from NCS. Therefore, during this process, it is important that worker health should be considered to avoid inhalation of radioactive material. It is necessary to minimize or prevent the release of radioactive material to water, air and soil to protect the environment.

To handle all different above described safety challenges and to control the fatality rate during the decommissioning process and its impact on the environment, we require a proper risk management process. The next chapter will explain the basic concept of risk and how can we manage such risk using risk management process.

4 Chapter 4 – Risk Management Process

Risk Management process explains the steps needed to take to fulfill the risk management process for any project or any activity.

Risk process is put in place to monitor and to control the risks, removing all uncertainty.The risk process involves hazards identification and quantifying the risks. The risks are then documented and allow to put right action to prevent and reduce the likelihood that risk will occur.

Before the risk management process is set up for decommissioning activities, it is needed to define and describe the risk management terms briefly.

4.1 Risk Management Terms

4.1.1 Risk and risk description

To the end, the literature has defined risk in many different ways, some of which are explained below.

ISO 31000 (2009) defined risk as the "*the effect of uncertainty on objectives*". The uncertainty can trigger an effect that could be a positive or negative deviation from what is expected. The risk defined in the finance world can be both positive and negative deviations from expected values.

According to **PSA** (2016), risk can be defined as "*the consequences of an activity with associated uncertainty."* The term consequences here used as a mutual term for all types of impacts. This term is not limited to only loss of lives, assets loss, and environmental impact but it also includes unwanted conditions and events that lead to such consequences. The uncertainty here *is somebody's uncertainty about what the consequences will be*. It is associated with both uncertainties that which events can occur and what can be the implications of these events.
Aven (2013a, p5) defines risk as hazard or threats and consequences and associated uncertainties.

$$\text{Risk} = (A, C, U)$$

Here A is an event or hazard/ threat; C is the associated consequences and U is the uncertainty. The event A is the part of consequences C; then risk can be simplified as

$$\text{Risk} = (C, U)$$

Here C is consequences including event A, and U is the associated uncertainties.

In risk management process, first, the risk needs to assess and managed properly such that all possible events or hazards are taken into account. Therefore, there is a need to describe the risk. According to definition of risk by Aven (2013a, p5), it has two components

Consequences and **Uncertainties**

Therefore, the corresponding risk description according to Aven (2013a, p6) is denoted as

$$(A^{/}, C^{/}, Q, K)$$

$A^{/}$ is the specified event,

$C^{/}$ is the specified consequences,

Q is measure of uncertainties, and probability (P) is one tool to express uncertainty (other tools also exist to express uncertainty)

K is the background knowledge that $A^{/}$, $C^{/}$, and Q is based on.

If A is a part of C as in risk definition (C, U), then risk description will be

$$(C^{/}, Q, K)$$

Measure of uncertainty Q is expressed as

$$Q = (P, SoK)$$

Here P is subjective, or knowledge base probability and SoK is the judgment of the strength of knowledge

4.1.2 Subjective and Frequentist probability

4.1.2.1 *Subjective probability*

"*The probability P (A) =0.1 (say) means that the assessor compares his/her uncertainty (degree of belief) about the occurrence of the event A with the standard of drawing at random a specific ball from an urn that contains 10 balls*." (Aven, 2013b)

Subjective probability denoted by P or P (A/K) shows that probability is based on knowledge K. Subjective probability use background knowledge to describe the uncertainties about the occurrence of any event and its consequences. This type of probability is used in real life situations for example what will be the sea level in next ten years because we cannot repeat the situation again and again in real life to find out the exact number.

4.1.2.2 *Frequentist probability Pf*

Frequentist probability Pf is defined as "*The relative fraction of time the event occurs if the situation studied were hypothetically repeated an infinite number of times. The variation in the outcomes of the experiment that generates the true value of P_f is often referred to as aleatory (stochastic) uncertainty*". (Aven, 2013b)
Frequentist probability is used where we can perform experiment an infinite number of times, which is not possible in real life. Therefore, it will not be discussed further in this thesis.

4.1.3 Risk management

According to ISO 31000 (2009), risk management can be defined as the coordinated set of activities and methods that are used to direct and control the risks to the organization.
In this thesis, risk management will be applied to minimize the risks to personal, environment and assets during decommissioning activities. The principle of As Low As Reasonably Practicable (ALARP) is utilized to decrease the risk.

4.1.4 ALARP

ALARP principle is that in which risk should be reduced in that content that it is practically acceptable. *Figure 4-1* explains the ALARP principle. According to figure if the risk is in the green region then it will be acceptable, but there is a need to make sure that risk will remain at that level and will not increase in future. The risk is conditionally acceptable when risk appears in yellow or light orange region.The condition says that the risk is acceptable if risk reduction is impracticable or if cost is grossly disproportionate to the improvement gained.
If risk lies in the red region, then it will be unacceptable, and risk mitigation measures should be applied here.

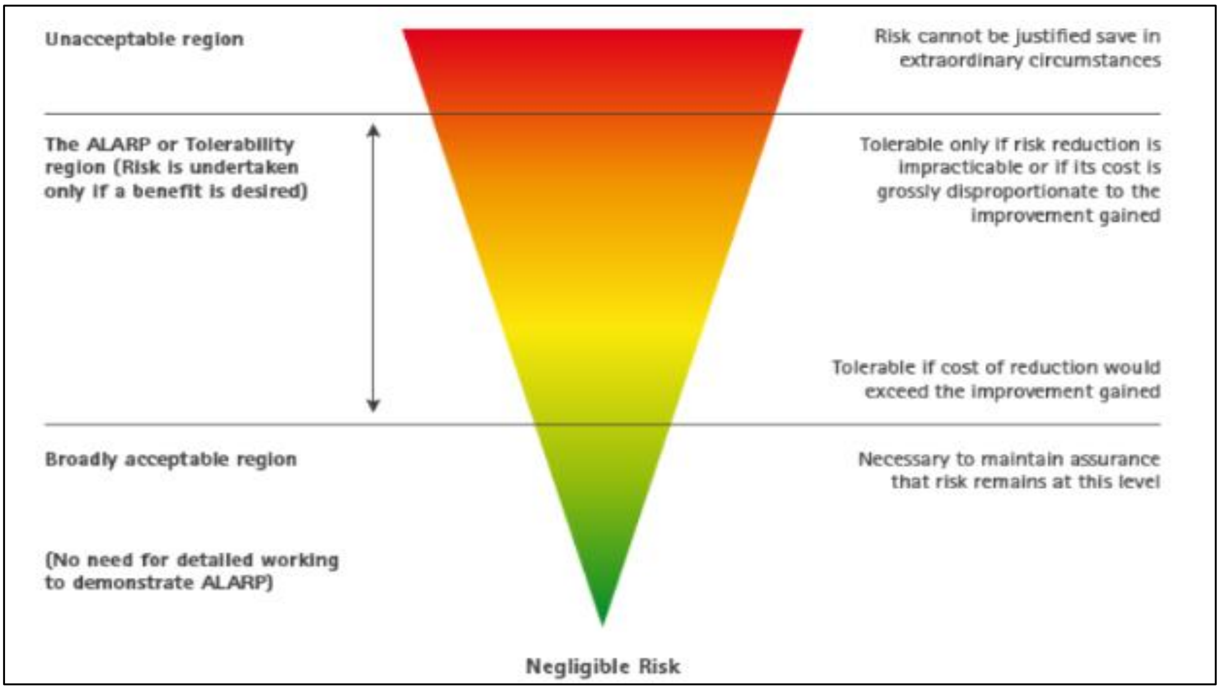

Figure 4-1 ALARP principle (DNV, 2013)

4.2 Risk management process

Figure 4-2 shows the proposed risk management process with regards to decommissioning. The figure explains each step of the risk management process. If we apply this risk management process for decommissioning activities then in next section, we will see how we can reduce the risks to the principle of ALARP.

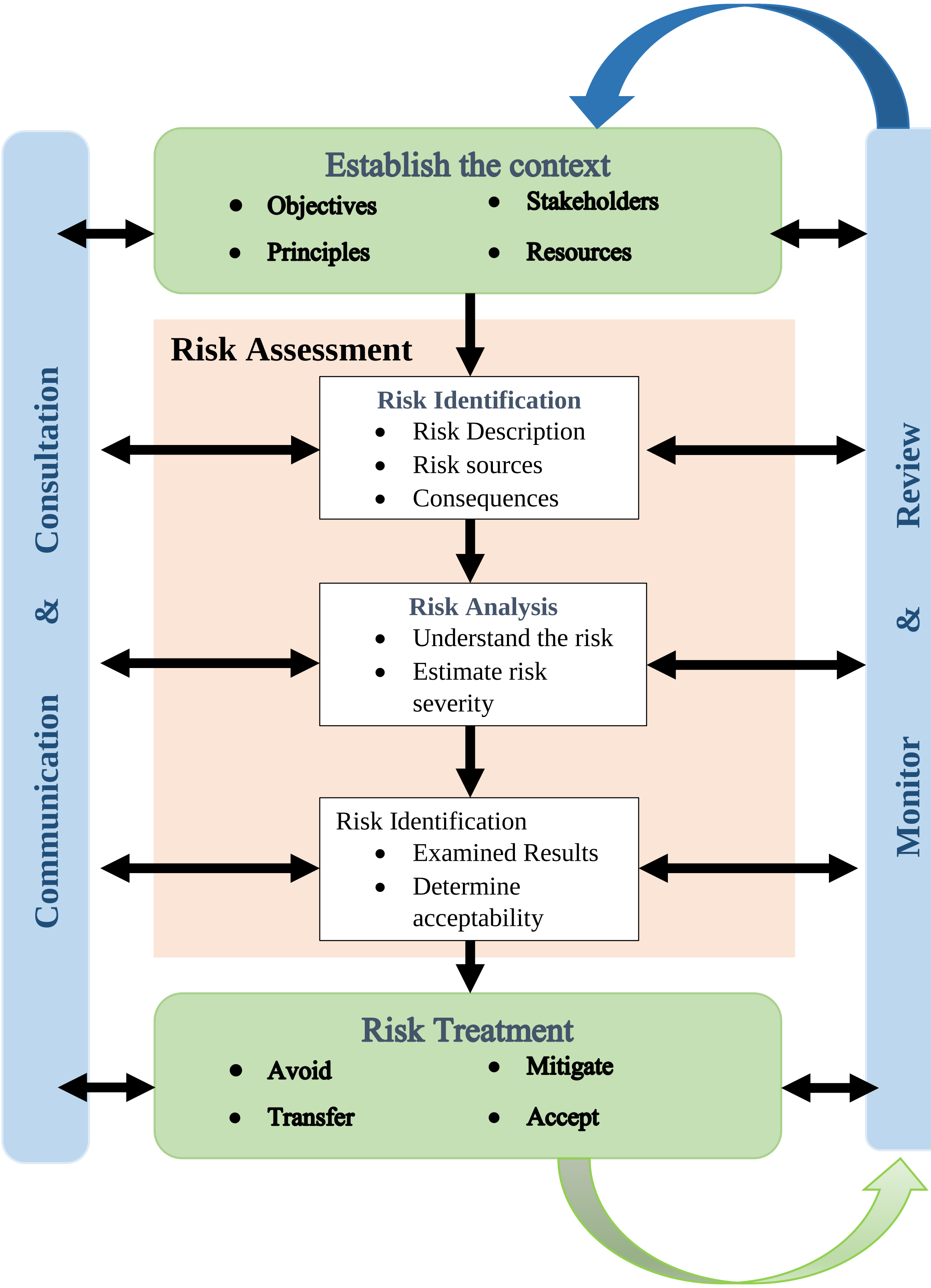

Figure 4-2 Risk Management Process partly adapted from (ISO31000, 2009a)

4.2.1 Establish the context

This step finds out that what are primary objectives and stakeholders of the decommissioning project. Which risk criteria would be acceptable for the interested parties and what are available resources and costs related to that?

In decommissioning projects, the aim is to minimize the risks by ALARP principle during removal and abandonment activities. Stakeholders for decommissioning projects are operating companies, petroleum authorities, and environmental organizations, public and fishing industry (Aven, 2007). Regarding cost and time, these terms depend on the type, location and size of the platform but the government covers 70 to 80% cost regarding tax relief.

Figure 4-3 shows decommissioning submarkets forecast from 2015 to 2025 in the Norwegian offshore oil and gas. According to figure, the decommissioning cost for the year 2016 to 2017 will be from 1,200 to 1,300 million dollars.

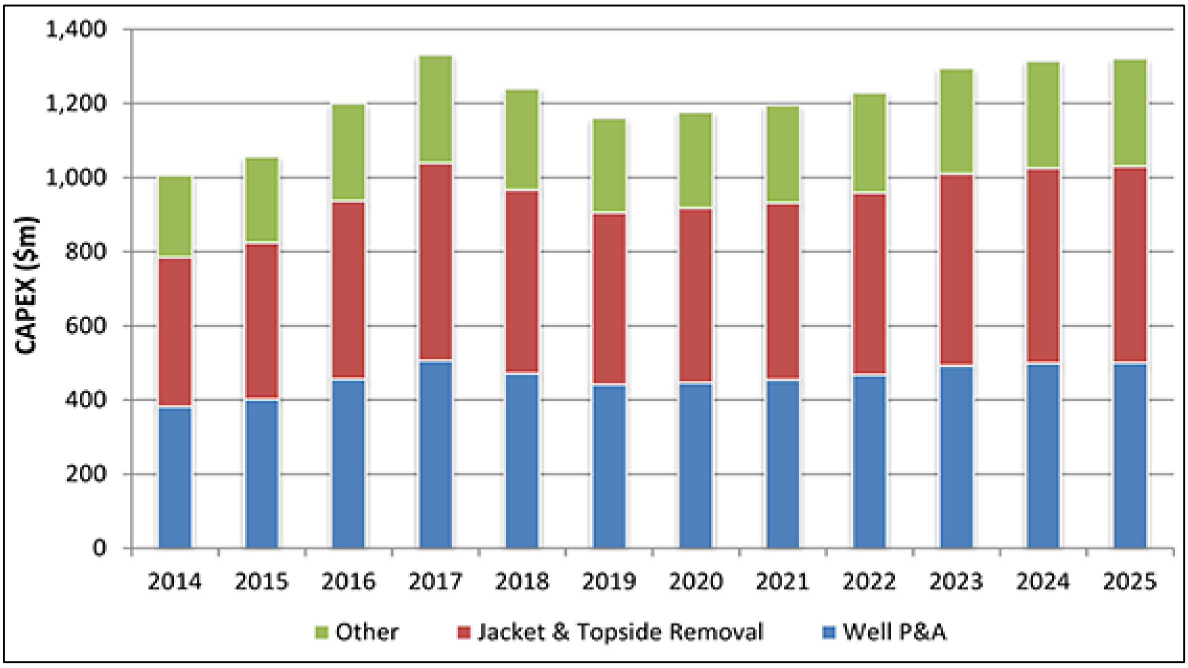

Figure 4-3 Decommissioning market forecast - NCS 2015-2025 ($m) (vision gain, 2015)

It's hard to find out the exact time frame for decommissioning activities because it depends on the availability of rigs, machinery, structure maintenance costs, oil prices, company strategy and many others.

The step 1 of the risk management process for decommissioning of offshore installations has been shown in the Table 4-1 below.

Table 4-1 Step 1 of risk management process for decommissioning projects

Establish context	Objective	Principle	Stakeholders	Cost	Time
Decommissioning of offshore installations	Minimize Risk, Safety of persons, environment and assets, Organization reputation	ALARP	Operating companies, petroleum authorities, environmentalists, Fishing industry, public	Estimated from 1200 to 1300 million dollars for 2016 to 2017 on the Norwegian Sea	Depend on structure maintenance costs, structure re-use for new fields, barge vessel availability, and location.

4.2.2 Risk assessment

Risk assessment consists of three steps

- Risk identification
- Risk analysis
- Risk evaluation

4.2.2.1 *Risk identification*

Risk identification consists of finding, identifying and describing risk. It involves identifying the sources of risk, which areas are going to influence from these sources and how these sources are generated and what will be their consequences. The main point in this assessment is to identify the relationship between risk sources and consequences. (ISO, 2009)
Identifying the risk sources will help the risk analysts in the next stages. Of course, it’s hard to determine all sources, but the finding of the possible risk sources and significant consequences will assist the decision maker to catch the most suitable methods and models. Effective communication with all stakeholders is of great importance at this stage.

Risk identification for decommissioning projects has been summarizing in Table 4-2. It includes hazards that can occur during decommissioning activities. Table 4-2 column “Description of risk” describe these hazards. The “activity” column outline the activities during which the hazard will occur, what will be the background of this hazard is mention in “source of risk" column.Finally, the "Consequences" column describe the what will be the consequences of the activity and its hazards.

The main hazards that can occur during decommissioning activities are loss of well control, bulk explosion, drop of objects, the release of hydrocarbons, toxic materials, and blowback.

The primary hazard that can occur during well plugging and abandonment is the loss of well control. (Bamidele, 1997). The inner and outer pressure difference can cause leaking of harmful materials that can cause fire and explosion.

The bulk explosion is another hazard in decommissioning activities that can occur during cutting and welding process. It requires proper dimension for welding purpose. The difference in diameters between piles and casing can cause a bulk explosion. (CETS, 1996, P16). As a result, serious injuries and deaths can occur.

Falling objects during lifting and removal activities can readily happen because old platforms have severe wear and tear due to corrosion. So any breakage can occur during lifting operations. If the pipelines are too long, then they can collide with other platforms and ships. As a result, equilibrium will be disturbed, and the object can fall into the sea. If the pad eyes are too old or full of corrosion and the weight of the lifting object is higher than estimated, then falling can happen. Falling objects can cause injuries and fatalities. The divers and marine life can also be affected by these objects.

Most of the offshore installations have toxic materials. Old facilities have material like Asbestos in their formation which is dangerous and new installations has banned the material since 1982 in Norway. In decommissioning projects cleaning and disposal activities involves the release of this hazardous material. So proper clothing and mask are essential to carry out these activities.

Another hazard in decommissioning activities is blowing back during cutting and hot works on pipes and vessels. Even though these vessels are cleaned from the hazardous material but there is a chance of residue left on these vessels. So during hot work these residues can blow back and explosion can occur. As a result, there is a chance of severe injuries.

The drill cutting pieces that have been stored at the bottom of the platform represents a high hazard. They should be removed before lifting the legs of the platform. The toxic material or diesel-based mud at the bottom of pieces have a severe effect on marine life and the environment.

Table 4-2 Hazard identification and consequences

Description of risk	Activity	Source of risk	Consequences
1. Loss of well control	Plugging and abandonment of wells	Failure of pressure controls system	Fire, explosion, injuries and fatalities of persons, pollution increase, effect on marine life
2. Bulk explosion	Cutting and welding of conductors and appurtenances	Mishandling of equipment, difference between diameters of pile and construction drawing	Can damage well plugging, flipping of oil based mud, disturbance of drill cutting process, effect on marine life
3. Drop of object	Lifting and removal activities	Collision with platform or other ship, hooks breakdown, overweight	Risk to the divers, Environmental impact, injuries or fatalities
4. Release of hydrocarbon and toxic materials	Cleaning and Disposal activities	Old platforms materials	Lack of oxygen, diseases and fatalities in persons, fire, explosion, environmental impact
5. Blowback	Cutting or hot work on pipes or vessels	Residue left in pipes or vessels, large time frame between cleaning and cutting	Fire, explosion, injuries or fatalities, Impact on Environment
6. Drill cutting pieces	Cleaning	Diesel based mud at the bottom of pieces	Effect on environment and marine life

4.2.2.2 *Risk analysis*

After identified the risk the next step is to analyze the risk. This step understands the nature, source, cause and consequences of the risks and determines the level of the risk.

The main risk that has been identified in decommissioning of offshore installations has been summarized in Table 4-2. The next step is to find the cause and consequences of each hazard. Commonly used methods to analyze the cause and consequences of any hazards are fault trees, event trees, Markov models and Bayesian networks. (Aven, 2013a, p3). In this thesis, Bayesian network models have been used to analyze the cause and main consequences of the decommissioning hazards that are described in section 4.3.

The main reasons for choosing Bayesian models is that they provide better interconnections among different causes as compared to fault and event tree analysis. They can incorporate with an infinite number of states, and they inherently consider conditional properties. (Rausand, 2011).

After analyzing the risks, the next step in risk management process is to evaluate the risk.

4.2.2.3 *Risk evaluation*

Risk evaluation used the result of risk analysis and examined that is there need to take actions and how early it required doing so? In addition to using results from risk analysis stage, it will also consider risks in terms of costs, benefits, and acceptability. During this process, the stakeholder's needs, issues and their concerns should be examined. Risk evaluation correlates the result of risk analysis with the acceptable criteria and finds out that which risks require early treatment. So it provides information for the risk treatment stage.

Individual risk criteria

Average acceptable criteria for individual risk (based upon general HSE criteria for individual risk) for offshore installations given by **Schofield (1993)** as:

- Maximum tolerable risk for installations in general 10^{-3} per person-year
- Benchmark for new/modern installations 10^{-4} per person-year
- Broadly acceptable for any installation 10^{-6} per person-year

In terms of FAR, the criteria for offshore workers described by **CMPT (1999**) is

- Maximum tolerable risk for installations in general 30
- Benchmark for new/modern installations 3
- Broadly acceptable for any installation 0.03

HSE (2006) defined Individual Risk Per Annum (IRPA) as "the chance of an individual becoming a fatality." An IRPA of 1x 10^{-3} means for each individual, every year, there is 1 in 1000 chance of a fatal accident.

The assessment principle according to **HSE (1998)** is stated as:

"*Duty holders should set their own criteria for the acceptability and tolerability of total individual risk. However, it is common practice for the maximum tolerable level of individual risk of fatality to be set at 1 in 1000 per year, and for the broadly acceptable level of individual risk to be set in the range 1 in 1 million per year.*"

However according to **Abrahamsen & Aven (2012),** the risk acceptance criteria defined by operators are not very much in favor of society. There is a need to have stricter risk acceptance criteria than those defined by the operator. Therefore, the risk acceptance criteria defined in HSE regulations issued by Petroleum Safety Authority Norway (PSA) is a concrete risk acceptance criterion, $\mathbf{1 \times 10^{-4}}$ criteria for safety functions should be applied to the early design of petroleum installations.

Cost-benefit criteria

According to DNV (2001), cost-benefit analysis is defined as:

"Cost-benefit analysis is used to assess the safety measure on a project by comparing the cost of implementing the measure with the benefit of the measure, in terms of risk-factored cost of the accidents it would avert."

The purpose of the cost-benefit analysis is to show that implementation of safety measure would be useful or not. It converts the value of life in terms of cost to determine the acceptable level. For this purpose, implied a cost of averting fatality (ICAF) is defined as the expected cost per expected number of saved lives. (Aven, 2008, p30)

$$\text{ICAF} = \text{Expected Cost} \, / \, \text{Expected no.of saved lives}$$

To understand the value of ICAF, the term Value of Preventing the statistical Fatality (VPF) is used. In offshore industry, VPF is in the range of £1million to £10million. (DNV, 2001). However according to **HSE (2006),** the typical value of ICAF for offshore industry is around £6million is considered to be the minimum level, i.e. a proportion factor of **6**. This value will be used according to ALARP and defines "what is judged as grossly disproportionate". Use of proportion factor 6 means that it will take account the potential for multiple fatalities and uncertainties.

4.3 Bayesian network

Bayesian networks are represented by Directed Acyclic Graph (DAG). The structure of DAG consists of a set of nodes and set of edges. The nodes represent the random variables, and edges between nodes represent probabilistic dependencies among the variables.

Figure 4-4 shows the basic Bayesian network in which A and B are parent node while the C is a child node. The arrows that connect A to C and B to C are edges.

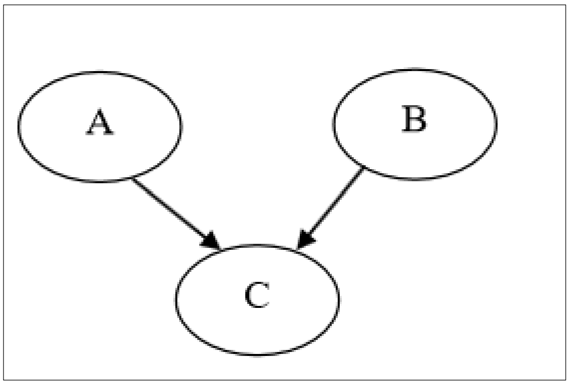

Figure 4-4 Basic Bayesian Network

The Bayesian formula given below enables to add new information with the given or known data.

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

This equation means that probability of A Given B is equal to the probability of B given A multiply by the probability of A divided by the probability of B.

Decommissioning Hazards and Bayesian Network

Bayesian network is an important consideration to determine the causes and consequences of any hazard during decommissioning projects. The relationship among different events provides useful information about the occurrence of the hazard. If we assign the probabilities to each event in these models, then they can determine that how severe is the risk from that event.

Since this section describing the Bayesian models for general decommissioning hazards, therefore, probabilities has not been assigned here. According to the type of installation, size, location and age, probabilities can be allocated to each cause. After assigning the probabilities to each cause, Bayesian model will then be able to find out the probability of occurring that hazard (for example Loss of well control) during decommissioning of a particular installation.

4.3.1 BN model for Loss of Well Control

Figure 4-5 shows the Bayesian network model for loss of well control. It represents the major cause that leads to loss of well control. During well abandonment and plugging, pressure variation occurs. If this variation goes above the specified limit then leaking of gas and fluid starts. If it becomes unable to control this increased pressure or if the barrier system fails, then there are chances that workers can lose the control of the well. As a result, fire and explosion can occur that leads to injuries and fatalities.

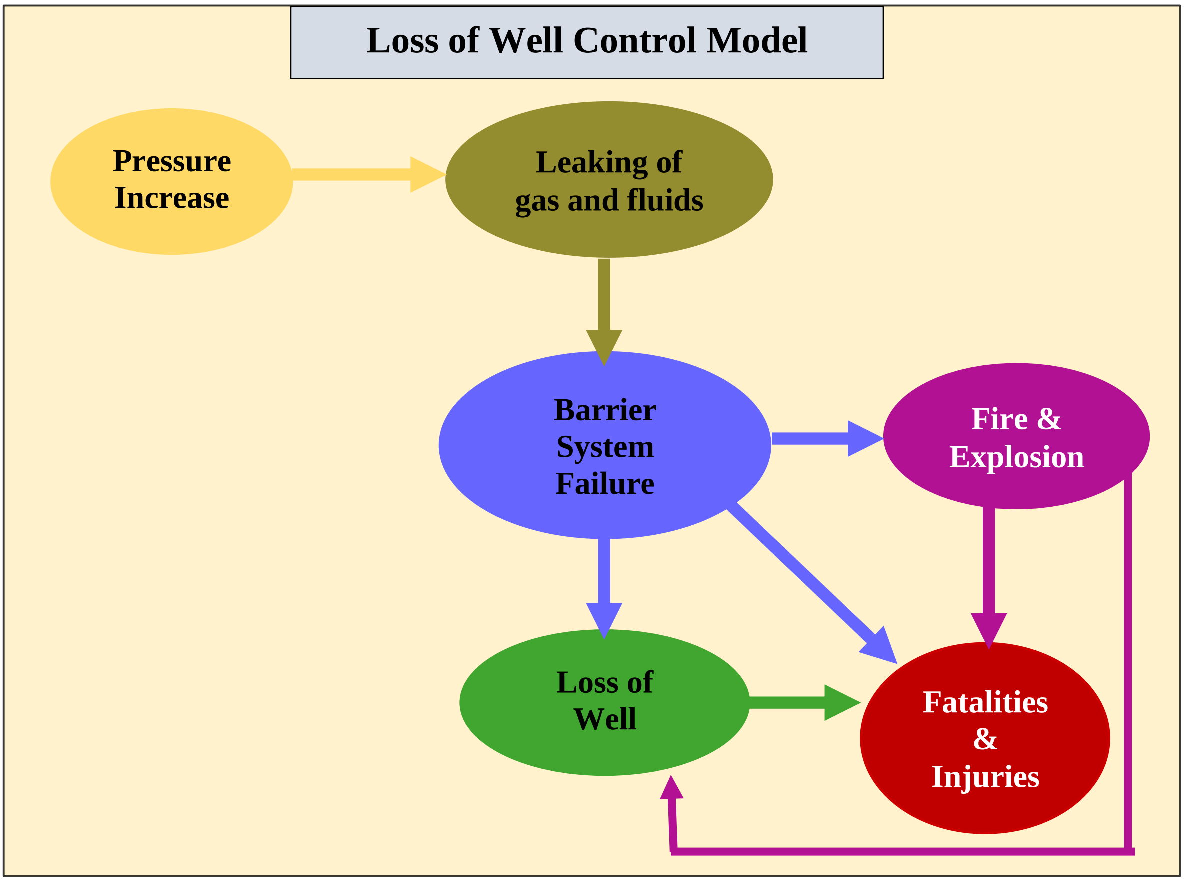

Figure 4-5 BN model for Loss of Well Control

4.3.2 BN model for Bulk Explosion

Figure 4-6 represents the Bayesian model for the bulk explosion. It shows that how bulk explosion can raise during decommissioning of offshore installations and what can be the consequences from this hazard. Bulk explosion can occur during cutting and welding of conductors and appurtenances. If the size of the cutting piles varies from construction drawing then due to the difference in diameter of the bulk charges, a bulk explosion can occur with no delay. (CETS, 1996). This explosion can damage the well plugging and disturb the cutting process. It can also cause injuries of sea-divers depending upon the type of explosion.

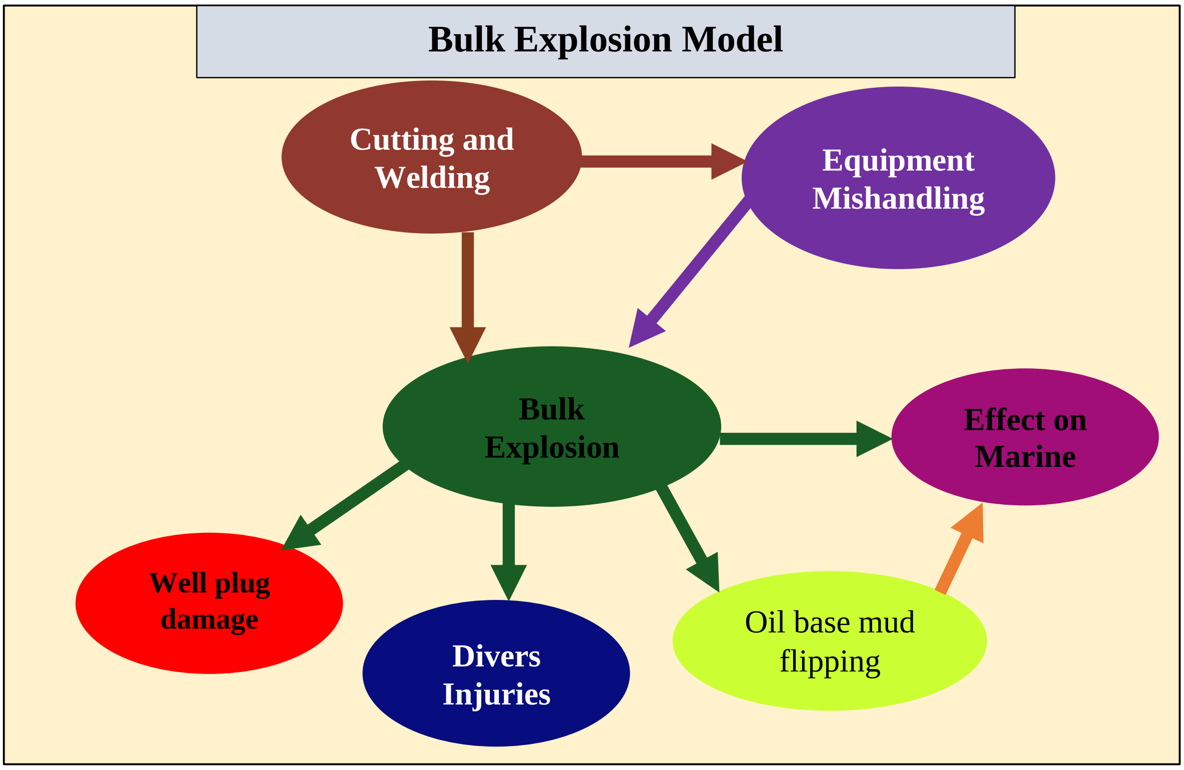

Figure 4-6 BN model for Bulk Explosion

4.3.3 BN model for Drop of Objects

BN model or drop of objects has been shown in Figure 4-7. It represents the major events for the drop of the object. It indicates that hook breakdown during lifting, object collision with platform or ship, breaking of objects due to corrosion, underestimate weight and lifting during severe weather are the main reasons for a drop of objects. These fall object can disturb the marine environment and are dangerous for sea-divers and workers.

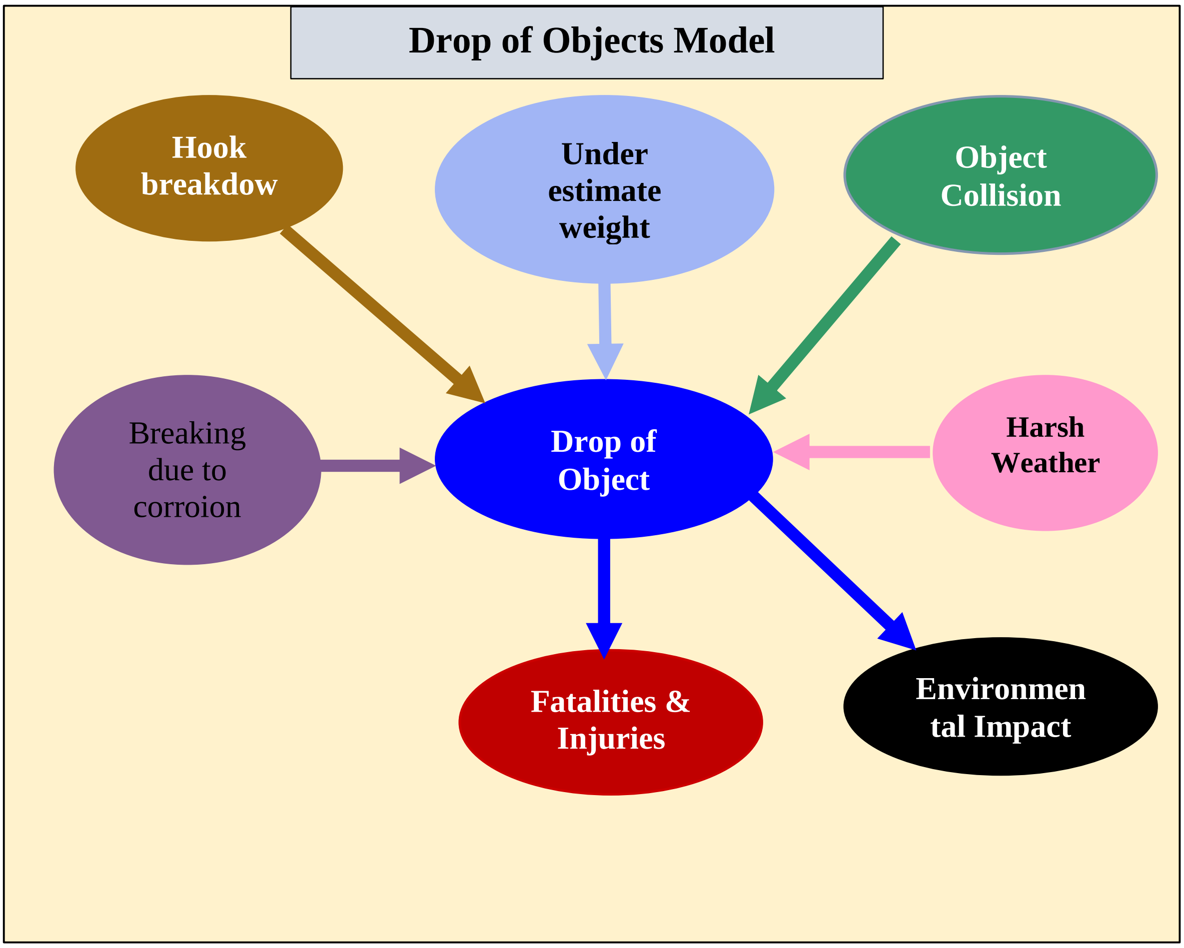

Figure 4-7 BN model for Drop of Object

4.3.4 BN model for Hydrocarbon and Toxic Release

Figure 4-8 shows the Bayesian model for hydrocarbon and toxic release. It represents the activities that lead to the release of hydrocarbon and toxic release. It also lists the consequences of the release.

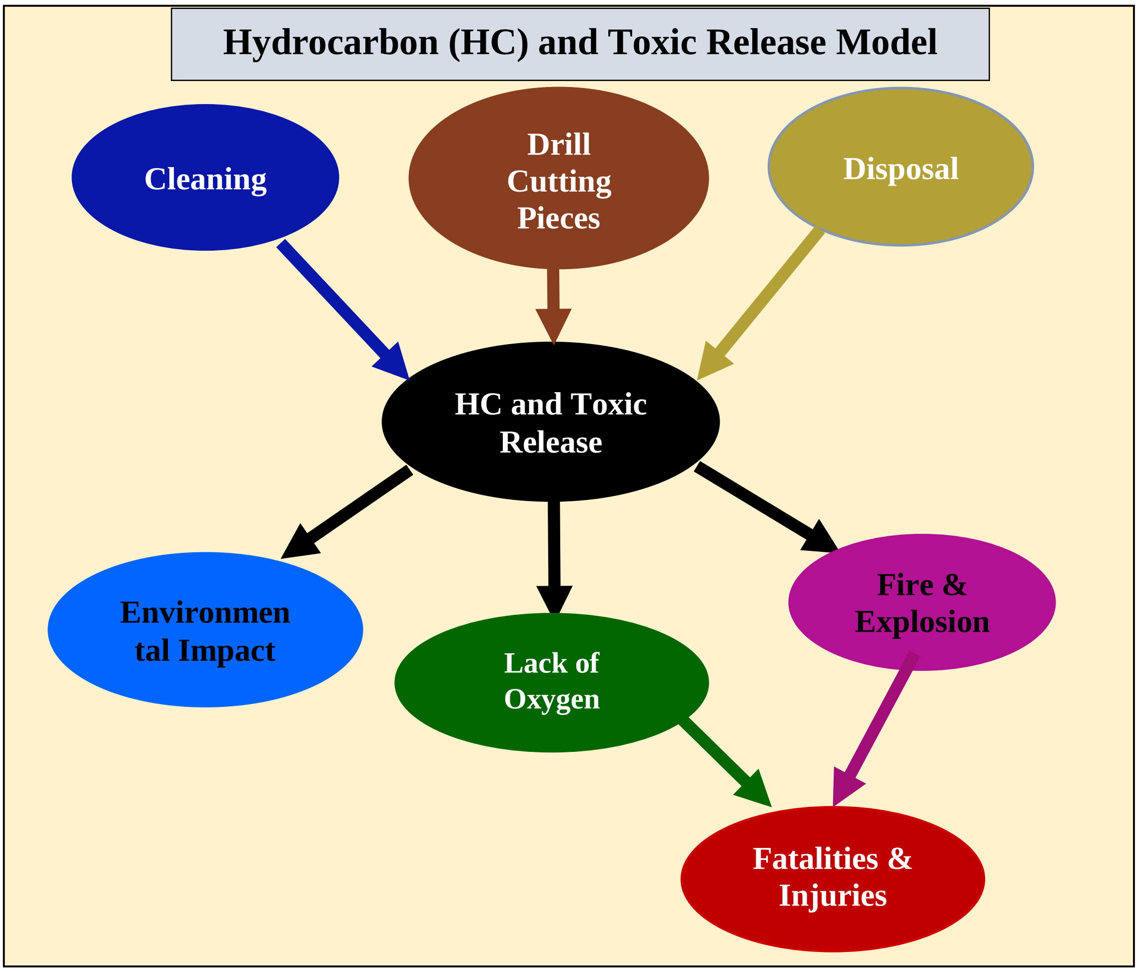

Figure 4-8 BN model for Hydrocarbon and Toxic Release

4.3.5 BN model for Blowback

Bayesian network model for blowback has been shown in Figure 4-9. It represents that if some residue left in pipes and vessels after cleaning too or there is a substantial time gap between cleaning and cutting then during cutting operations and hot work blowback can occur. Due to blowback fire and explosion happen that leads to fatalities and injuries.

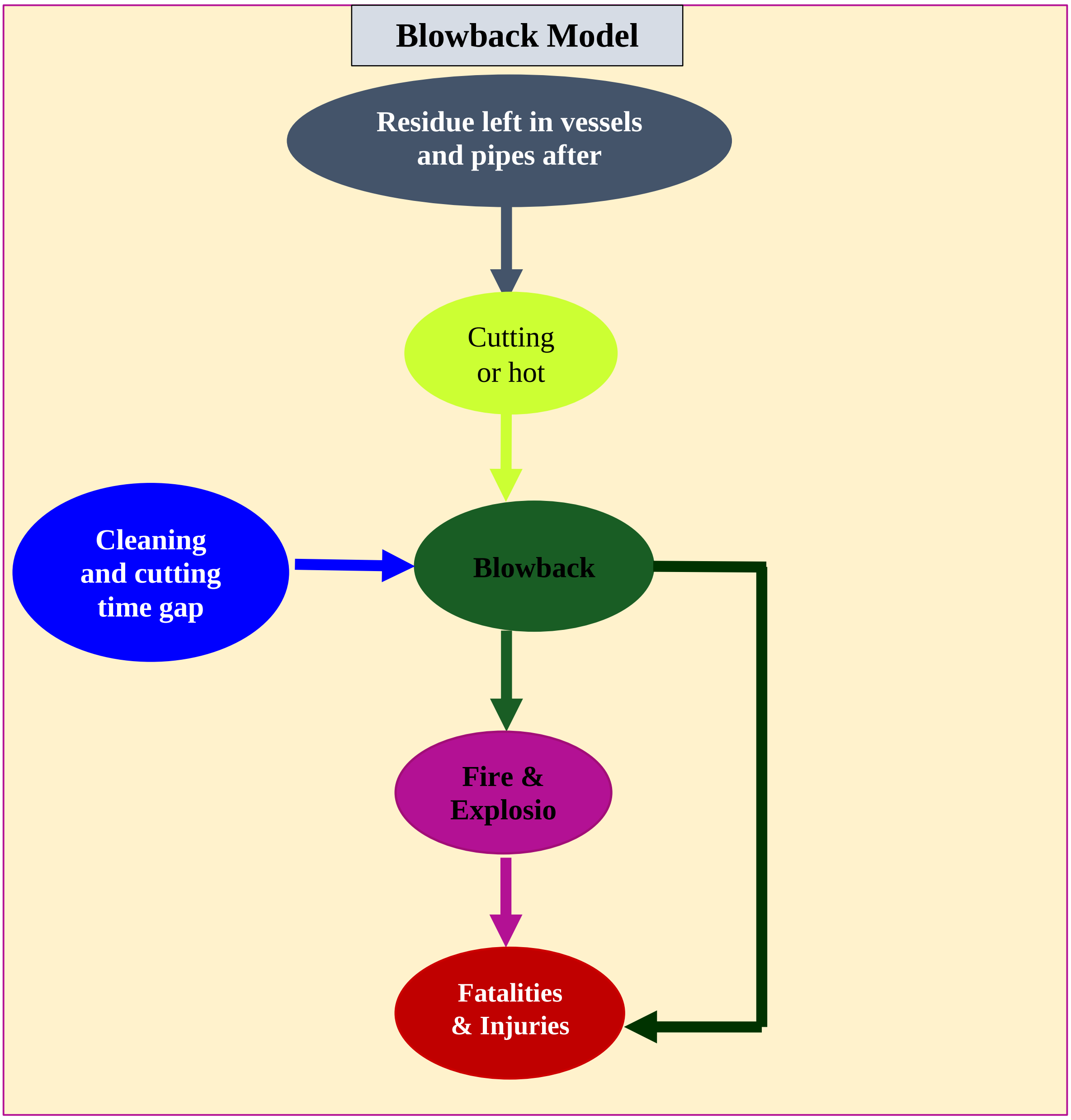

Figure 4-9 BN model for Blowback

4.3.6 Summarized BN model

Figure 4-10 shows the summarize Bayesian network model. It represents the all main hazards that can happen during decommissioning of offshore installations. It also shows that how these hazards can be raised and what can be the consequences of these hazards.

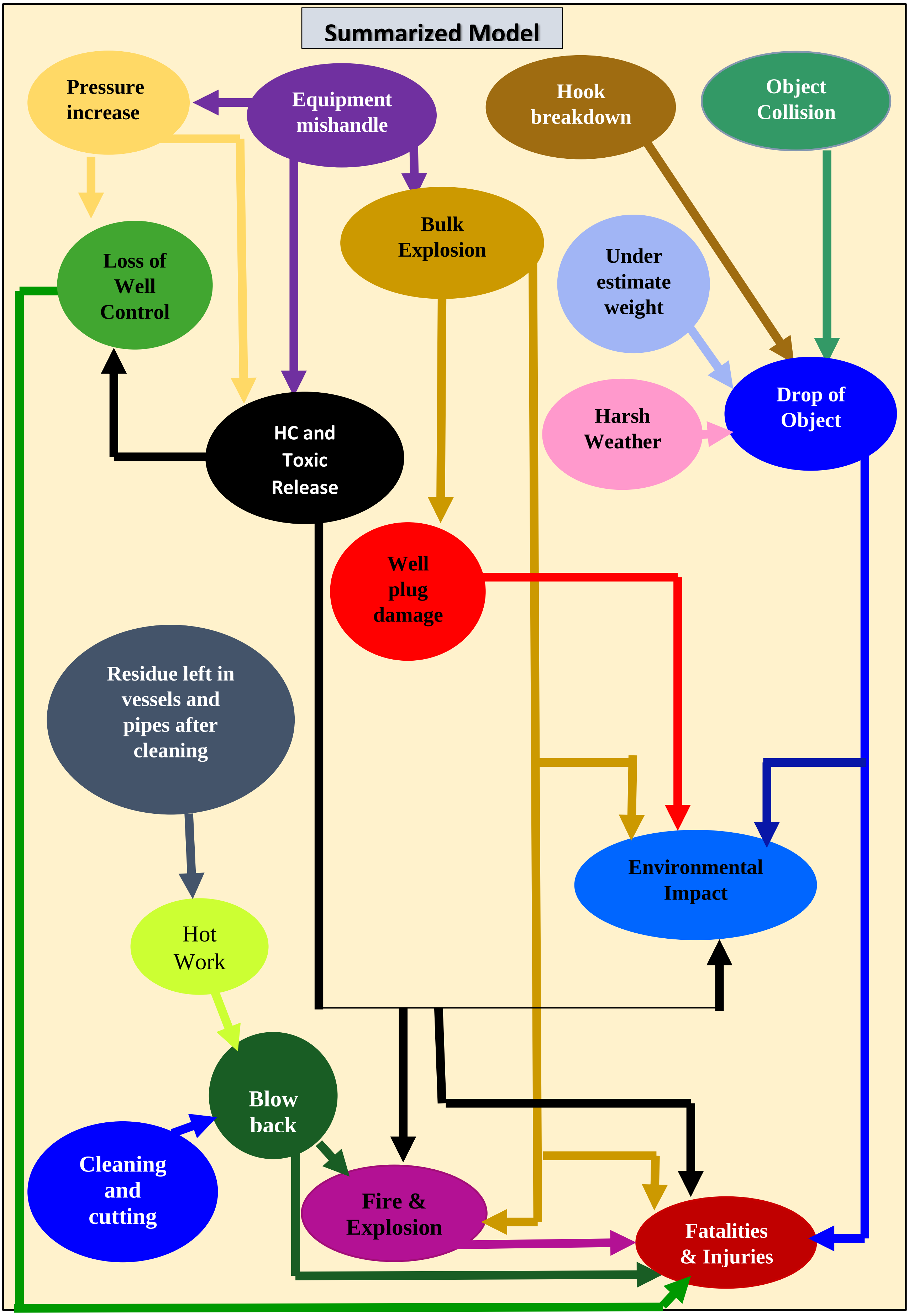

Figure 4-10 BN model for main hazards during decommissioning

4.3.7 Limitation of the Bayesian models

To determine the cause and main consequences of decommissioning hazards Bayesian models has been developed. The probability of occurring of each hazard is based on the subjective / knowledge based probability. However, the model has not the capability to show the strength of knowledge from which the probability has been executed.

4.4 Uncertainty Assessment

Since uncertainty is the main component of risk, therefore there is a need to assess the uncertainties related to risk analysis process. Uncertainty consideration helps in the decision-making process, as information about the strength of knowledge and sensitivity support in making a decision.

4.4.1 Strength of knowledge

Uncertainty about the occurrence of events and their consequences depend on the strength of knowledge. If the strength of knowledge is strong about the occurrence of any event, it means it has low uncertainty. To assess the strength of knowledge Aven (2013) suggest following conditions:

- *The knowledge is week if one or more of these conditions are true:*
- *The assumptions made represents strong simplifications.*
- *Data are not available, or are unreliable.*
- *There is a lack of agreement /consensus among experts*.
- *The phenomena involved are not well understood; models are nonexistent or known/believed to give poor predictions*.

However, on the other hand, the knowledge is considered strong if all of the following conditions are true:

- *The assumptions made are seen as very reasonable*.
- *A great deal of many reliable data is available*.
- *There is broad agreement/consensus among experts.*
- *The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.*

The strength of knowledge can be classified as a medium for cases in between.

4.4.2 Sensitivity

If uncertainty is reduced, then it is not essential that risk will be reduced accordingly. It is because of sensitivity. If the model is not sensitive to changes, then results can have little uncertainty. Sensitivity can be graded according to Berner & Flage (2016) as:

***Minor sensitivity**: Unrealistically large changes in base case values needed to bring about altered conditions.*

***Moderate sensitivity**: Relatively large changes in base case values needed to bring about altered conditions.*

***Significant sensitivity**: Relatively small changes in base case values results in altered conditions.*

4.4.3 Assumption deviation risk

The assumption deviation risk is another method to assess the strength of knowledge. According to Aven (2013), assumption deviation risk is "*the risk related to the deviation from the condition/states defined by the assumption made*". To assess this risk Aven suggest following consideration:

- *The magnitude of the deviation.*
- *The probability (subjective) of this magnitude to occur.*
- *The effect of change on the consequences C.*
- *An overall judgment of the strength of the background knowledge.*

Berner and Flage (2016) suggest using the Table 4-3 assess the uncertainty assumptions.

Table 4-3 *Setting faced when making assumptions in risk assessment*

Belief in deviation from assumption	Sensitivity of risk index wrt to assumption	Strength of Knowledge	
		Strong	Moderate / Weak
Low	Low	Setting 1	Setting 2
	Moderate / High	Setting 3	Setting 4
Moderate / High	Low	Setting 3	Setting 4
	Moderate / High	Setting 5	Setting 6

Aven (2013) four consideration also covering this table, belief in deviation, the sensitivity of risk and strength of knowledge.

4.5 Risk treatment

The purpose of this step is to identify the options for treating risk that has been analyzed. From previous sections, we have determined the significant hazards, their causes, and consequences of decommissioning projects. Now this step describes the treatment options for these hazards. General options that are available for risk treatment are shown in Table 4-4 that can be applied individually or in combination according to demand.

Table 4-4 *General risk treatment options* (University, 2013)

Avoid the risk	Not to proceed with the activity or choosing an alternative approach to achieve the same outcome. Aim is risk management, not aversion.
Mitigate	Reduce the likelihood - Improving management controls and procedures.
	Reduce the consequence - Putting in place strategies to minimise adverse consequences, e.g. contingency planning, Business Continuity Plan, liability cover in contracts.
Transfer the risk	Shifting responsibility for a risk to another party by contract or insurance. Can be transferred as a whole or shared.
Accept the risk	Controls are deemed appropriate. These must be monitored and contingency plans developed where appropriate.

In decommissioning projects, we try to mitigate the risk but if we failed to reduce the consequences at specified level then “Avoid the risk” options can be used. In “Avoid the risk” option alternative approach would be considered to receive the same outcome, for example in decommissioning activities instead of completely removal the whole structure partial removal can be considered after gaining approval from authorities.

This section will represent the mitigation techniques for hazards that have been identified in risk analysis and risk evaluation steps. Bayesian network models in the previous section describing the cause and relationship between these hazards. The information from all these stages leads to grasping out the treatment techniques. The treatment options for main hazards during decommissioning projects are given below:

4.5.1 Risk Treatment for Loss of Well Control

Loss of well control can occur during plugging and abandonment of wells. The main reason for the loss of well control is the change in internal and external pressure difference as shown in Figure 4-5 in the previous section. This figure shows that how the loss of well control can happen and its effect.

The treatment to this hazard will require at first to focus on initial step of plugging. During plugging process water needs to be filled in the well bore for cleaning purpose before applying the sealing. There is a need to monitor the pressure gauge during all the process; then the emergency plan should be implemented to stop the process immediately or shifting on alternative option to control the increased pressure.

There is also need to consider the options that if barrier system fails or pressure gauge failed to measure the reading then what are other alternative options and plans. If the loss of well control occurred then how the process can be controlled, what are an emergency plan and routes to escape out? The answer is that blowout preventer is used for this purpose that controls the volume and pressure of the fluid and can close the well bore in the case of emergency. Either the blowout preventer can control the well, but there is still need to prepare for any emergency situations. All emergency escape routes should be clearly specified and well known to all workers. They should be properly trained to get out from dangerous situations.

The next step is to seal the well. It demands proper techniques because there is a danger that sealing can break up and well can start leaking in future. To avoid any leaks in future, a good quality cement should be used. Proper sealing prevents the fluid or gas to penetrate from one surface to another. However, the significant variation in downhole temperature and pressure can influence the cement integrity and cause debonding. (SLB, 2001). As a result, fluid starts to flow and can damage the casing. Leaking and emission of CO_2 after plugging is also dangerous for the environment and marine life. The solution of this problem is that instead of using the ordinary Portland cement, advanced flexible cement should be used for plugging. Advanced flexible cement provides long-term cement integrity, and it resists stress cracking and micro annulus or channel formation. (SLB, 2001)

4.5.2 Risk treatment for bulk explosion

Bulk explosion can occur during cutting of conductors and piles. The most common technique for these cuttings is explosive cutting. Figure 4-6 in the previous section shows how bulk explosion can occur during cutting of conductors and piles. It also shows the bulk explosion impact on the environment and persons.

To avoid this proper hazard planning, engineering and scheduling are required. If all the specification of the installation like diameter is known correctly and equipment are handled properly, then there are 95% chances that there will be no explosion. (CETS, 1996).

Another option to make the explosive cutting process safe is the use of ROVs (Remotely Operated Vehicle) for underwater cuttings. However, the use of ROV makes the process complicated and costly. There would be required to add different configurations in ROV to perform various tasks as each platform has unique size and shape.

It depends on the location, specification, and documentation of the installation that which option will be more suitable. If the installation specification is missing or has significant uncertainties, then ROV option will be preferred for safety purpose.

4.5.3 Risk treatment for drop of objects

Objects can fall during lifting and cutting operations. Figure 4-7 of BN models shows the main reasons for a drop of objects and their consequences. In the light of this model risk treatment procedure should be like that it can diminish the factors that are causing the drop of objects.

Since the main reason for the drop of objects is platform or ship collision so it requires that there should be made some danger zones where there is a chance that lifting object can collide with the platform, and these danger zones should be restricted for lifting operations. To avoid the hook breakdown during lifting operations, hook stability and lifting capacity should be accurately known. The weight of the object that is going to be lifted should also be known. Longer pipes should be cut into manageable pieces before lifting to avoid any breaking and collision because corrosion can weaken the strength of the material and increased the risk of breaking with a longer length.

The severe weather condition can also be dangerous for lifting operations. For example, if there are high wind and waves then it can disturb the stability of the object, and there is a danger that it can fall. So weather conditions should also be considered for lifting, and lifting could be postponed if there is a severe risk of falling objects due to poor weather.

In addition to these precautions, there is a need to make proper plan and procedures to lift the objects. Lifting crew had proper training and license to carry out the job. They should be prepared for any emergency situation and know that how they can proceed in such condition.

4.5.4 Risk treatment for HC and Toxic releases

The release of hydrocarbons and toxic material is standard during cleaning and disposal activities. The removing of drill cutting piles or mounds before lifting the structure also releases toxic material. Figure 4-8 of Bayesian model shows the major activity for the release of hydrocarbon and toxic release.

The main risk from hydrocarbon and toxic release are that the person involves in cleaning, disposal and removing activities can be affected by a hazardous material. They can experience a lack of oxygen and fire or explosion.

There is a need to examined the type of chemicals and hydrocarbons before starting the cleaning and cutting activities at any installations. Some old platforms have dangerous material like asbestos. Therefore, an extra protection is required for working on these platforms.

Proper planning and management can minimize the severe effect from toxic release. Therefore, to perform these activities, there is a need that persons should be well trained and prepared for any emergency situation. Protective clothing, proper equipment, and specialized logistics for cleaning and handling disposal are required. Strict control of ignition sources and inventory is mandatory to reduce the risk of fire and explosion.

4.5.5 Risk treatment for Blowback

Blowback can occur during cutting, welding or hot work on pipes and vessels. Figure 4-9 of Bayesian model in the previous section shows the main reasons of blowback during these activities.

After cleaning the vessels and pipes, there is a chance that there can be some residue left that can cause blowback. Therefore, the plan for cutting and welding on pipes and vessels should be made to keep this situation in mind. Workers should be prepared for any emergency situation, and they have proper clothing and mask for their protection.

A technology with a sensitive sensor for chemical detection can be used to make sure the amount of residue left in pipes and vessels. In the market, chemical detective sensors are

available that can help to detect the quantity of residue that has been left. A new chemical detective sensor that is using the nanotechnology is under development. It will be capable of detecting a slight amount of chemical too. When the quantity of residue left is known, then, it will be easy to treat the hazard either by more cleaning or more protection.
Another solution to treat this hazard is the use of remotely operated vehicle for cutting and welding activities. But this solution can be expensive and will not be applicable in congested areas.

The general risk treatment for main decommissioning hazard has been specified. So the next step is to monitor and review the complete process.

4.6 Monitor and Review

The result of risk management process should be monitored and considered so that if any change happens or any new information or technology up gradation receive then plan can be updated according to new situations. Monitoring and reviews are critical because

- It keeps the analysis and assessment up to date.
- It decides that current risk treatment is enough, or there is a need to do more detail risk analysis.
- It ensures that all process have been completed within required cost, time and resources.

For decommissioning projects monitoring and review is an important step. It demands that each stage of the risk management process should be documented properly. These documents should specify the data sources, experiment, results and reasons for treatment options.

Risk management process for the decommissioning project has been proposed in this section Now the next chapter will outline a case study on the decommissioning project and how this proposed risk management process possibly implemented to ensure better risk management of the decommissioning project.

5 Chapter 5 – Case Study-Leman BH field

5.1 Introduction

In this chapter decommissioning program of the Shell, Leman BH field is considered as a case study example. The objective of this case study is to investigate the risk management plan for the Leman field in comparison to new risk process described in chapter 4.

Leman BH field is located approximately 50 km east of the Norfolk coast and 62 km west of the UK/Netherlands median line. The operator of the Leman field is Shell U.K. The decommissioning program of the Leman field is currently under consideration of The Department of Energy and Climate Change (DECC) and is waiting for approval.

The Leman BH field is connected via bridge to Leman BT as shown in Figure 5-1. The Leman BT gas transportation platform was installed in June 1970 and the Leman BH living quarter platform was installed in February 1981 (Shell, 2015).

Figure 5-1 Leman BH and Leman BT field (Shell, 2015)

The main characteristics of the Leman BH field are given in Table 5-1. (Leman BH, 2015)

Table 5-1 Characteristics of Leman field

Field Name	Leman BH
Production Type	Living Quarter
Water Depth (m)	35.7

Type	Fixed Steel Jacket (4 legs)
Topside Weight (Te)	990 (excl. bridge) 1039 (including bridge)
Jacket Weight (Te)	566

5.2 Decommissioning program

According to decommissioning report of Leman field (Shell, 2015), following decommissioning program has been proposed for topside, jacket and bridge removal.

Table 5-2 *Decommissioning Program for Leman BH field*

Selected Option	**Proposed Decommissioning Solution**
Topside	
Complete removal, onshore dismantling, recycling and disposal.	Prepare topside for lifting by removing or securing any loose materials or equipment. Remove the topsides by Heavy Lift Vessel (HLV) and transport onshore for dismantling.
Jacket	
Complete removal, onshore dismantling, recycling and disposal.	The piles will remain in jacket structure and be cut from the inside of the pile 3meters below the seabed. HLV will remove the jacket and piles and then transport them onshore for recycling.
Bridge from Leman BH to BT	
Complete removal and recycle	*Remove the linking bridge during the preparation phase by crane of the work accommodation jack-up vessel. The bridge will be transported onshore for dismantling and recycling.*

To follow this proposed decommissioning solution, a proper risk management process is required to avoid any hazard situation. According to Leman BH report (Shell, 2015a), risk management plan for the Leman BH field is developed according to Shell Health Safety

Security Environment and Social Performance (HSSE-SP) control framework. Therefore, the main points of the Shell HSSE-SP framework have been discussed in next section.

5.3 Shell risk management framework

The main points of Shell framework that will be discussed in this thesis are:

1. Risk definition
2. Risk acceptance criteria
3. ALARP principle
4. Risk Assessment Matrix (RAM)

1. Risk definition

The Shell HSSE-SP control framework define risk as "A combination of the probability of an event and its consequences" (Hoem, 2014).

2. Risk Acceptance Criteria (RAC)

The Shell control framework does not state any general risk acceptance criteria, but it defines an upper limit for an acceptable risk. Specific risk criteria changes according to location and regions, therefore, Shell framework defines the acceptance criteria according to the location of the field. For example, the risk acceptance criteria for Draugen field is shown in Table 5-3.

Table 5-3 Field specific RAC for acute oil and condensate spill to sea (Hoem, 2014)

Consequences Categories	Recovery Time	Intolerable probability per year	ALARP probability per year	Negligible probability per year
Minor	1 month-1 year	2×10^{-2}	2×10^{-2} - 2×10^{-3}	2×10^{-3}
Moderate	1-3 years	5×10^{-3}	5×10^{-3} - 5×10^{-4}	5×10^{-4}
Significant	3-10 years	2×10^{-3}	2×10^{-3} - 2×10^{-4}	2×10^{-4}
Serious	>10 years	5×10^{-4}	5×10^{-4} - 5×10^{-5}	5×10^{-5}

3. ALARP Principle

The ALARP (As Low As Reasonably Practicable) principle for the shell is shown in Figure 5-2. Risk will be intolerable if it is above the RAC values. If the risk is in between 50 to 100% of the RAC values, it will be in ALARP region A, and in ALARP region B if values between 10-50%. Below the RAC values the risk will be considered as negligible. (Hoem, 2014)

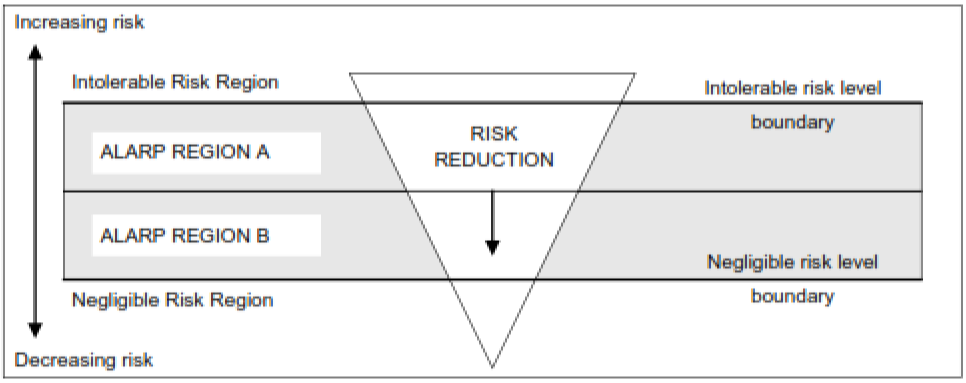

Figure 5-2 ALARP (Hoem, 2014)

4. Risk Assessment Matrix (RAM)

The Shell risk assessment matrix to determine the environmental impact of Leman field decommissioning projects are shown in Table 5-4. This matrix is used to identify and manage the level of different environmental impact. It has a magnitude (severity), consequences and likelihood (probability) of any hazard to occur. The likelihood criteria for Shell risk assessment matrix is shown in Table 5-5.

Table 5-4 Shell risk assessment matrix (Shell, 2015a)

Magnitude	Environmental Impact	Stakeholder Concern	Likelihood (frequency, duration or probability)				
			A	B	C	D	E
0	No effect	No public interest	VL	VL	VL	VL	VL
1	Slight /negligible effect	Individual concerns	VL	VL	L	L	L
2	Minor effect	Local concerns	VL	L	L	M	M
3	Moderate effect	Regional concerns	L	L	M	M	H
4	Major effect	National concerns	L	M	M	H	H
5	Severe effect	International concerns	M	M	H	H	H

Table 5-5 *Likelihood criteria (Frequency /duration or probability* (Shell, 2015a)

Likeli-hood	Planned Operation (frequency/duration)	Accidental Event – Unplanned (probability)
A	One off event over lifetime of development for < 24 hours	Never Heard of in the Industry - Extremely remote $< 10^{-5}$ per year Has never occurred within industry or similar industry but theoretically possible
B	One off event over lifetime of development over several days duration OR Once per year for <24 hours	Heard of in the Industry - Remote 10^{-5} - 10^{-3} per year Similar event has occurred somewhere in industry or similar industry but not likely to occur with current practices and procedures
C	Regular over less than 3 years OR Intermittent over more than 3 years	Has happened in the Organisation or more than once per year in the Industry - Unlikely 10^{-3} - 10^{-2} per year Event could occur within lifetime of 10 similar facilities.
D	Continuous emission or permanent change over less than 5 years OR Regular over more than 3 years	Has happened at the Location or more than once per year in the Organisation - Possible 10^{-2} - 10^{-1} per year Could occur within the lifetime of the development
E	Continuous emission or permanent change over more than 5 years	Has happened more than once per year in the Location - Likely 10^{-1} - >1 per year Event likely to occur more than once on the facility

By using Shell matrix, the potential impacts for Leman BH field are shown in Table 5-6.

Table 5-6 *Potential Aspect and Impacts for Leman BH field* (Shell, 2015a)

	Atmosphere	Benthos	Fish/Shellfish	Birds	Marine Mammals	Conservation Sites	Commercial Fisheries/ other users of the sea	Shipping (Traffic)	Water / land contamination	Onshore Communities
Physical presence (HLV, support vessels)		M	L			M	L	VL		
Energy use/Atmospheric emissions (Offshore and onshore)	VL					VL				VL
Noise generation (underwater noise)			L		L					
Accidental Events (Collisions/spills/dropped objects)		L		L		L	L	L	L	VL
Waste generation (Offshore and onshore)									L	L

5.4 Comparison of Shell framework with proposed risk management process

The main points of the shell risk management framework have been discussed in the previous section. Now this section will examine theses points in the light of new risk perspective as discussed in Chapter 4 and presented by Aven (2013) in the Figure 5-3.

Figure 5-3 New risk perspective (Aven, 2013)

1. **Risk definition**

According to PSA (2016), risk can be defined as the "*consequences of activity with associated uncertainties.*" Aven (2013, p5) define risk as a hazard, consequences, and related uncertainties. On the other hand, Shell risk definition describe the risk by using only probability and consequences. It has no information about the associated uncertainties.

2. **Risk Acceptance Criteria and ALARP**

The overall Norske Shell risk acceptance criteria and ALARP principle are according to Norwegian HSE regulation. (Hoem, 2014). However, by using this predefined risk acceptance criteria, there is a need to focus that risk should be reduced to level as low as reasonably practicable.

3. **Risk Assessment Matrix**

The Shell risk analysis is based upon the general risk acceptance matrix. The shell risk matrix consists of hazard consequence and their probabilities. The probabilities for future events in the matrix are derived from historical data and experience.

However, the strength of knowledge upon which these probabilities are based upon has not been included in Shell risk matrix. Acceding to Aven (2016) risk can be described by ($C^{\backslash}$, Q, K) here $C^{\backslash}$ are specific consequences, Q is the measure of uncertainty associated with $C^{\backslash}$ (usually probability), and K is the background knowledge that supports $C^{\backslash}$ and Q. So according to new risk perspective risk matrix should include uncertainties that we have regarding probabilities.

Secondly, the surprising events are not covered by the Shell risk assessment process. Aven (2013) defines unexpected events also called black swans in two categories: unknown unknown's means that these events are not known to the scientific community and unknown known events means that they are not known within the industry but are known outside the industry or somewhere else.

Shell risk assessment matrix assigning a very low probability to the events where historical data is unavailable by defining a column "never heard of in the industry" see Table 5-5 Therefore, there are chances that these events can be untreated because of low probability value. As it can be seen from figure 5.4 that very low probability has been assigned to accidental events without describing the uncertainties associated with these values.

5.4.1 An example

5.4.1.1 *Problem*

A drop of the object can occur during decommissioning of Leman BH field.

5.4.1.2 *Shell risk analysis*

Shell risk analysis describes that due to a small number of lifts and after complete engineering analysis we can assign very low probability for this event to occur. They are not providing any information about the related uncertainties with these values.

5.4.1.3 *Proposed risk management process*

If we followed the risk management process described in Chapter 4, then we get all necessary information for decision support. Figure 4-7 shows the Bayesian models for dropped of objects. If we assign a probability to each factor that can cause the drop of an object like hook breakdown, underestimate weight, object collision, breaking due to corrosion and harsh weather then we will get the probability for a drop of the object. After that, uncertainty assessment will be carried out to find the uncertainties related to probability values.

In Table 5-7 probability has been assigned to each cause by using the information provided in Leman BH (Shell, 2015a) report. In the next column, conditional probability for object fall has been found in a way that if for example hook break down occur then what is the probability that object can fall and vice versa. After that, the strength of knowledge and sensitivity related to probability values has been found.

Table 5-7 Drop of object probability estimation for Leman BH field

Causes	Probability of cause	Object fall Conditional Probability		Strength of knowledge	Sensitivity
Hook breakdown	0.005-0.004	Yes No	0.6 0.2	Medium	Moderate
Underestimate weight	0.003-0.002	Yes No	0.7 0.3	Low	Moderate
Object collision	0.005-0.004	Yes No	0.5 0.2	Low	Moderate
Braking due to corrosion	0.02-0.01	Yes No	0.8 0.2	Low	Moderate
Harsh weather	0.1-0.2	Yes No	0.8 0.2	Medium	Moderate

If we apply now the Bayesian formula mentioned in section 4.3 for above values, then we can calculate the probability of a drop of the object based on all these causes in the table. These calculations have not been done here because the purpose is to show the information that we get by applying this proposed method. After knowing the subjective probability and the strength of knowledge and sensitivity related to the probability, it will be easy for the decision maker to make preventions for such events.

5.5 Pros and cons of following Shell risk control framework for Leman BH field

The advantages and disadvantages of following the Shell risk management control framework for decommissioning of Leman BH field are described below:

5.5.1 Cons

- Since Shell risk analysis process does not explain background knowledge on which the probabilities are based upon, therefore it can mislead the decision maker about the corrective actions to minimize the hazards.

- As Shell risk analysis process is not covering the surprising (Black Swan) type of events, therefore occurring of these events can be dangerous during decommissioning process.
- Leman BH platform is located in the area where a large number of offshore oil and gas activities are already happening. Therefore, the decommissioning operation with general shell risk management framework can be unsafe.
- Shell risk analysis matrix assigning very low probabilities for the occurrence of any accidental events like dropped of objects and vessel collision see figure 5.4 without describing the associated uncertainties with these values. Therefore, there is a chance that proper safety implementation can be ignored because of these small values.

5.5.2 Pros

- The Leman BH field does not have any wells and pipelines and it never been used for hydrocarbon storage as it is a living quarter platform. Therefore, there is a low probability that any dangerous situation occurs. Thus, it can be expected that the Shell risk management framework can work in such conditions.
- Vessel collisions on Leman BH field can be minimized by using Shell risk management policies. As the Shell guard vessel consists of radar and communication equipment so any vessel in the decommissioning area can be detected and informed prior.
- Hazardous material like fluorescent tubes containing mercury, batteries, and other radioactive material will be sent onshore for recycling or disposal. It will be good for the marine environment.
- Single lift method has been proposed for topside and jacket removal by Shell framework which can minimize the noise and will be less time consuming.

5.6 Results

In the light of the consequences for the Shell framework for Leman BH field, we can say that Shell framework will not be entirely safe for the decommissioning phase. The proposed risk management process for decommissioning can prevent and mitigate the safety issues in a better way for Leman BH field decommissioning.

It is recommended therefore that risk management process proposed in Chapter 4 should be followed for the decommissioning o

6 Chapter 6 – Discussion & Conclusion

6.1 Safety challenges

As there is limited offshore decommissioning data for risk management, identification of safety challenges in this thesis is mainly based on the common observation. In this thesis, all platform types are considered to explain the safety issues. For a particular kind of platform and water depth, these safety issues can be different.

During identification of safety issues, it is important to point out that these safety issues are going to appear more often on older installations than others. They have missing documentation for initially installed equipment and their design. Missing documentation increases risk during the removal process of decommissioning phase. Therefore, one possible suggestion is that operators and authorities give focus on this issue and establish a database for storage of initial design and other documentation related to the fields. The relevant information that database needs to store for decommissioning is initial platform design, quality of used material, construction defects and platform modification record. If the operators are going to sell their platform to the other party, then the operator should transfer such information to new stakeholders.

The second main reason of occurring these issues is that the most operators are using the same risk management process as for installation. Regulatory authorities are not emphasizing to operators for the establishment of decommissioning risk management process. As decommissioning is quite a different process as compared to installation. Therefore, a risk management process proposed in this thesis give a good reasonable input for having separate risk management process applicable to decommissioning phase.

Another reason of accident and fatality during offshore decommissioning is the lack of experienced and trained persons. Therefore, there is a need to conduct the discussion session in which the skilled persons share their knowledge and bad experience with the untrained workers and facilitate them to overcome the hazards in future. In Norway, mostly operator companies are already practicing by giving a contract to service companies with specialized experience within offshore decommissioning.

6.2 Risk management process

This thesis proposes risk management process to carry out decommissioning activities that are safe and environment-friendly. This risk management process is based upon the general risk management steps. These steps are modified according to the requirement of offshore decommissioning. The decommissioning safety issues make the basis for the proposed risk management process. The risk analysis phase uses Bayesian network which is a better approach for analyzing the cause and consequences of different hazards related to offshore decommissioning. In this thesis, only the main causes and consequences related to each hazard has been identified. The cause and effect analysis can be extended and be different based on safety challenges for each and every particular case. Secondly, the use of Bayesian models have some limitations as they are not providing the strength of knowledge associated with the probability values. As the Bayesian model is not taking the strength of knowledge into its results, the thesis mention to do uncertainty assessment of the Bayesian model results as the next step.

There has been proposed mitigation techniques for identified hazards. The mitigation techniques are based on provided risk analysis results and their uncertainty assessment. Uncertainty assessment of Bayesian model results helps to determine severe issues and which issues to prioritize in risk treatment phase. The use of modern technology like remotely operated vehicle and nanotechnology sensors are recommended to treat the decommissioning risk.

6.3 Implementation of proposed plan

Shell Leman BH field has been selected for a case study, and the comparison is made between Shell risk control framework and suggested risk management process for particular points like risk definition, risk acceptance criteria, and risk assessment matrix. For these particular points, it is found that Shell framework is not providing all necessary information for safety implementation because Shell framework using general risk assessment matrix to analyze the hazards and not giving any information about the strength of knowledge and sensitivity associated with the probability values.

If the strength of knowledge is weak, then it means that high uncertainty is related to probability values, and it will force the decision maker to make safety arrangements to avoid any dangerous situation. But if the decision maker will be unaware about the uncertainty associated with probability value they can ignore the safety measurements in case of low probability values.

Therefore, the risk management process proposed in the thesis applied to identify the hazard for Leman BH field, and the proposed process is providing better information as compared to Shell framework for safety implementation in offshore decommissioning.

6.4 Final conclusion

- Decommissioning activities are expected to increase in upcoming years, and therefore safety hazards during decommissioning activities need to be addressed. There is also need to establish and prepare a risk management process before starting any decommissioning activity. This thesis research is focusing on these needs for decommissioning industry. It has identified the critical safety challenges during decommissioning activities, and the risk management process has been proposed to handle these challenges.
- The proposed risk management process is specifically for risk management of offshore decommissioning activities. This risk management process determines the cause and consequences of each hazard by using Bayesian network. Uncertainty assessment procedure like the strength of knowledge and sensitivity analysis of risk analysis results provide the useful information to decision makers. In addition, mitigation techniques for identified hazards have been suggested.
- Implementation of proposed risk management process on Leman BH field shows that it is providing better management and mitigation procedure for the safety issues. The decision maker is getting useful information by using this proposed risk management process.
- Environmental challenges during decommissioning are also considered that how decommissioning activities can impact the environmental and marine life.
- Offshore decommissioning is relatively new industry compares to oil and gas exploration and production phase. As less amount of data is available , it is even more important to consider the uncertainty assessment. Therefore , as this thesis used , it is very important to use the strength of knowledge for doing any kind of risk analysis related to decommissioning activities.
- Therefore, we can say that it can be utilized as a guiding document to prepare risk management process for offshore decommissioning before starting any decommissioning activities.

6.5 Future work

- In future more detailed Bayesian models (to analyze the cause and consequences of decommissioning hazards) can be made, and the value of probabilities can be calculated for individual hazard using real data.
- A particular type of installation can be considered to determine the safety issues, and the comparison can be made between general and specific type.
- There are still some issues for offshore decommissioning that need to be addressed in future like cutting methods, cleaning procedures, lifting techniques and cost issues.

7 Chapter 7 – References

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8 Appendix A

Platform Types

There are a large number of platforms and structures across the North Sea. Each structure has its unique size, type and structure. Therefore, to understand the decommissioning process and removal methods, there is a need first to know about the kinds of platforms. "*An offshore platform is a large structure which has the facilities to drill wells, to extract and process natural gas and temporary storage capacity until the product brought to shore for refining.*" (Wiki, 2013). Most of the platforms also have the house facilities for workers. Platforms can be fixed structure to the sea floor or floating production

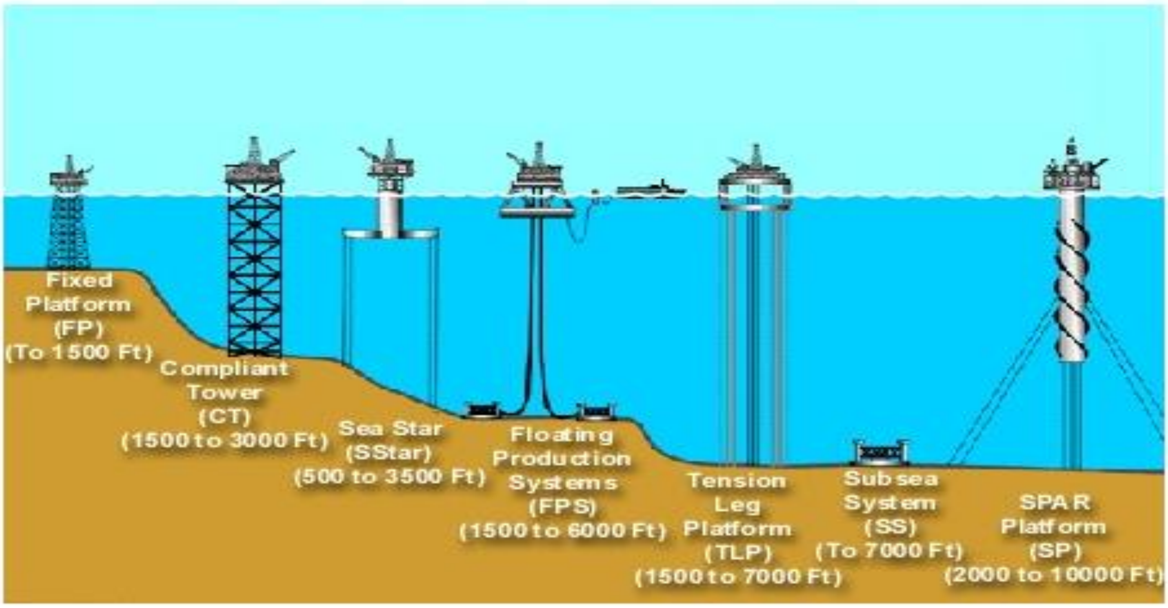

Figure 8-1 Platform classification (Maritime-connector, 2016)

1. Fixed platform

Fixed platforms have concrete or steel legs that attached with the seabed. These legs provide the support to the deck, production facilities, and workers quarters. The structures consist of welded tubular steel jacket that is piled into the seabed, concrete caisson, floating steel and floating concrete. Fixed platforms are extremely stable and are designed for very long term. The height of the platform depend on the water depth, and they can be installed in water depths up to 1,710ft as the water depth increases they become costly and not remain feasible economically. (Wiki, 2013)

2. Compliant towers

Compliant towers used the basic idea of fixed platforms, but they consist of slender and flexible towers of concrete and steel. They are designed to move parallel with the forces of wind and waves. These towers can operate in water depths ranging from 1,210 to 2,990ft. (Wiki, 2013)

3. Gravity based structure

Gravity based structure can be made of steel or concrete and are directly mounted on the seabed. It has a concrete base with one or more shafts to support the topside platform. This structure can withstand in a harsh environment by its weight. GBS platforms are largest structures as compared to other structures and have weights ranging from 3,000 to 1.2 million tons with a corresponding topside weight between 650 to 52,000 tons. The concrete gravity based structures that have been installed are Troll platform in water depth 994 ft. And the Hibernia platform has weight 1.2 million tons on land. (OGP, 2012). In order to install the GBS at the exact position, it is connected with either transportation barge or other barge with strand jacks. When it is assured that GBS will not move away from its target position than jack is released.

4. Jacket structure

These platforms are fixed on to the sea bed, and steel tubular structure supports their deck. This tubular steel structure is called a jacket. The height of the jacket can be in hundreds of meters with weight thousands of tons. They are installed directly on the seabed where water depth is not more than 1640ft. (Explorer, 2012).

Since the main focus of the thesis will be on the decommissioning of fixed platform like gravity based therefore other types of platforms like floating production system, tension leg platforms, and spar platforms has not been described here.

5. Floating production systems

The main type of floating production system is floating production storage and offloading system (FPSO). FPSO is a production facility that is generally ship-shaped and is used for storage of oil in the hull of the vessel. The storage oil is than transported to the shore periodically either by shuttle tankers or ocean going barges. FPSO have been also used to develop offshore fields in deep water around the worlds since late 1970s in North Sea, Brazil, Southeast Asian/ South China Seas, Mediterranean Sea, Australia and West Coast of Africa. (Security, 2011)

6. Semi-submersible platform

Semi-submersible is multi-legged floating structure with large deck and have pontoons of sufficient buoyancy that enable the structure to float. These platforms attached with chain, wire rope or polyester rope during drilling and production operations. They are capable to float from one place to another. Semi-submersible are used in water depths ranging from 200 to 10,000 ft. (Wiki, 2013)

7. Tension leg platform

A tension leg is a buoyant platform stand in place by mooring system. The conventional TLP is 4-column design which looks similar to semisubmersible. The installation process of tension leg completed in stages. The well will be drilled during the design and construction process of TLP. They are used in water depth up to 6,600 ft. Mini TLPs like Sea star and MOSES are relatively low cost and used in water depths ranging from 590 to 4,270 ft. (Wiki, 2013)

8. Spar Platform

A spar consists of a hollow cylindrical structure that has more conventional mooring lines as compared to TLP. It has three major systems, the conventional one piece cylindrical hull, truss spar and cell spar. Truss spar connects the upper buoyant hull (hard tank) to the bottom tank that has permanent ballast. Spar platform has more inherent stability than TLP, and it does not require mooring for an upright position. The main feature of the spar is that it can move in the horizontal direction by setting the mooring line, and it can also be placed itself at some distance from the main platform. Previously spars were used for oil storage and collecting oceanographic data, but now spar is being used for drilling and production.

The first production spar was Kerr-McGee’s Neptune held in 1,940 ft. in the Gulf of Mexico (Wiki, 2013).