Managing Risks through ALARP in Offshore Oil and Gas Operations

by

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Abstract

This thesis explores risk management techniques and the various methods that are available to aid in the determination of risk. It highlights both quantitative and qualitative risk management tools and focuses on Newfoundland and Labrador's local oil and gas industry. The concept of maintaining risk levels to As Low As Reasonably Practicable (ALARP) throughout the lifecycle of a facility is a focal point of this thesis.

Some of the more significant Major Accident Events (MAE) of the past are highlighted with a focus on the effects those MAEs have had on the local oil and gas industry. In particular, the actions leading up to and during the Piper Alpha disaster are reviewed. Exploration of the aftermath of the Piper Alpha and the effects both it and the Ocean Ranger disaster have on the Canadian and Newfoundland regulatory regime are discussed.

The permanent Newfoundland and Labrador offshore oil and gas assets/facilities are highlighted; The unique requirements some of these facilities are currently facing, as the assets age and transition into a period of extension of the original design life, are explored. With age, there are new hazards and differing risks to the overall facility. Aging mechanisms, as they pertain to safety systems, and the determination of service life, are explored.

Since the late 1980s, the Canada-Newfoundland Labrador Offshore Petroleum Board (C-NLOPB) regulates local offshore installations through a suite of regulations and guidelines. The current regulatory regime is somewhat prescriptive in that, for the large part, it dictates how an Operator is to achieve regulatory compliance. It is the intention that the regulatory framework is to transition from a prescriptive based regulatory regimen to a hybrid approach where goal-based regulations are preferred through the Frontier and Offshore Regulatory Renewal Initiative (FORRI).

FORRI is a federal/provincial government partnership initiative focusing on regulations in all offshore administrative areas in Canada. FORRI intends to modernize the regulatory framework to performance-based requirements, reduce redundancy across multiple regulations, bring standards up to date, and enable a more efficient and effective regulatory regime. FORRI intends to eliminate five existing regulations and integrate them into one new framework regulation.

The proposed policy intention for the Framework Regulations is reviewed against the current suite of C-NLOPB regulations. The more substantial differences concerning Technical Safety design are presented as a gap assessment. The assessment is not intended to be an exhaustive listing; however, the aim is to highlight some of the more prudent changes potentially affecting the discipline of Safety and Risk and associated design.

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List of Symbols, Nomenclature, or Abbreviations

ALARA	As Low as Reasonably Achievable
ALARP	As Low as Reasonably Practicable
ALE	Asset Life Extension
BP	British Petroleum
CA	Certifying Authority
CAN-NL	Canada-Newfoundland and Labrador
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
COF	Certificate of Fitness
COGLA	Canada Oil and Gas Lands Administration
CSA	Concept Safety Analysis
HMDC	Hibernia Management and Development Company Ltd
ETA	Event Tree Analysis
FORRI	Frontier Offshore Regulatory Renewal Initiative
FPSO	Floating Production Storage and Offloading
FRC	Fast Rescue Craft
FTA	Fault Tree Analysis
GBS	Gravity Based Structure
GCM	Gas Conversion Module
HSE	Health and Safety Executive
HSE	Health, Safety, Environment
IRPA	Individual Risk Per Annum
LEP	Life Extension Project

MAE	Major Accident Event
MODU	Mobile Offshore Drilling Unit
NLPD	Newfoundland-Labrador Petroleum Directorate
OA	Operations Authorization
PFP	Passive Fire Protection
PPE	Personal Protective Equipment
PS	Performance Standard
QRA	Quantitative Risk Assessment/Analysis
SCE	Safety Critical Element
VSL	Verified Service Life

1 Introduction

1.1 History

The offshore oil and gas industry has a deep-seated history locally, in Newfoundland and Labrador. First oil was discovered in 1979 after approximately 13 years of exploratory drilling on the Grand Banks in the Jeanne d'Arc Basin. (Higgins, Oil Industry and the Economy, 2009). The Newfoundland and Labrador oil and gas history is one that has been marked with both great successes and devastating tragedies. The industry has grown, developed, and changed throughout the last 40 years with new discoveries, new facilities, and new regulatory regimes.

As the industry grows and learns from the successes and failures of the past, the understood risk tolerance may also change. This thesis explores various risk management methods with a focus on the principle of As Low As Reasonably Practicable (ALARP) and how a risk tolerance level may change throughout the facility lifecycle.

1.2 Objectives and Scope

This thesis explores various risk management processes with a focus on the local oil and gas industry of Newfoundland and Labrador. It attempts to highlight the most influential major accident events (MAEs) of the past to understand the effect they have had on the current safety practices and the industry regulatory regime.

It details the current local offshore production facilities to highlight the facility lifecycle, focusing on the aging facilities and the risks associated with Asset Life Extension (ALE).

A review of upcoming changes proposing regulatory renewal initiative, known as the Frontier Offshore Regulatory Renewal Initiative (FORRI), is undertaken to highlight some of the more significant changes concerning safety in design.

1.3 Research Objectives

There are several objectives of this thesis, all of which focus on the collection of data, review and critical analysis of that information and the summarization of findings into a useful technical work.

The first objective is to research and document established theories and methods of risk management and present the most commonly used techniques in the oil and gas industry.

The second intention is to collect information on past MAEs in the oil and gas industry and analyze the causation factors following the accident investigations. The thesis critically analyzes the Piper Alpha disaster and details lessons learned from the tragedy. It presents the linkages from past MAEs and the role the Piper Alpha disaster has played on strengthening the safety culture and regulatory regime in the oil and gas industry.

The concept of ALARP is a focal point of this thesis and is critically analyzed throughout. A further objective of this thesis is to highlight the risk reduction measures/quantitative risk reviews that are mandated under the current local regulatory regime and typically employed during the design of an offshore facility to ensure risk levels are ALARP. Furthermore, this thesis aims to demonstrate that new hazards may develop, or existing hazards may be modified as a facility ages and associated risks must be reevaluated to ensure they remain ALARP.

The final objective of this thesis is to analyze the upcoming regulatory changes that will affect the local oil and gas industry as FORRI comes into force. The thesis highlights the most significant regulatory implications that may impact the technical safety design of an offshore facility through a regulatory gap analysis. The concept of ALARP will be further embedded into local regulatory regime with FORRI.

1.4 Research Scope

The scope of the current study is from the oil and gas perspective with emphasis on the local Newfoundland and Labrador offshore environment. While the research may be applicable to other hazardous activities and geographical areas, this has not been explored under this scope of work. This work focuses on the concept of ALARP and risks that are managed through the lifecycle of a facility.

1.5 Thesis Structure

This thesis consists of the following seven chapters:

Chapter 1 provides background information, the objective and scope of the thesis, as well as the thesis structure.

Chapter 2 provides an introduction to risk management principles pertaining to the offshore oil and gas industry. It includes definitions and information on various types of risk management/assessment tools available.

Chapter 3 reviews major accident events of the past and how past tragedies shape the safety performance of the current industry.

Chapter 4 analyses the Piper Alpha disaster with respect to risk management. It explores the learning from the Cullen Report and how it has influenced the regulatory regime.

Chapter 5 includes methods of risk evaluation/studies usually undertaken during the design of an offshore installation, including requirements of the C-NLOPB Installation regulations and the classification of safety critical elements.

Chapter 6 reviews aging platforms/installations and the requirement for asset life extension. It discusses requirements for validating risk levels and changes to risk profiles with respect to ALARP and the precautionary principle.

Chapter 7 highlights the current regulatory regime for local offshore installations and upcoming regulatory changes.

2 Safety and Risk Management

2.1 General

Safety and risk management are of paramount importance during the design, construction and the operational lifecycle of offshore installations. Particularly for offshore Newfoundland and Labrador, platforms are aging, and regulatory regimes are being updated.

To effectively manage risk, a structured risk management system must be employed. With respect to the safety of offshore installations, risk management is founded upon the proper identification of existing and foreseeable major hazards.

There are different aspects to process safety and risk management; however, they hinge on the identification of hazards to assessing the risk and then mitigating/managing the risk.

Risk is simply a measure of the occurrence of a potential loss. With respect to process safety, risk is measured based on the likelihood of the hazardous event occurring and the consequence or impact of that event. (Modarres, 2006) Safety is the freedom from the unacceptable risk.

A typical risk management procedure would include the following steps:

Risk Assessment – Determining the magnitude of the risk and whether it requires treatment. This involves three sub-steps:

> **Risk Identification –** Identifying where, when, why, and how events could occur or circumstances could exist that could cause harm or loss.

Risk Analysis – Determining consequences, existing controls, and likelihood and hence the level of risk. This analysis should consider the range of potential consequences, including escalation, and how these could occur.

Risk Evaluation – Comparing estimated levels of risk against the risk tolerance criteria, enabling decisions to be made about the extent and nature of risk mitigation required and associated priorities.

Risk Treatment – Developing and implementing cost-effective strategies and action plans for mitigating risks.

2.2 Risk Analysis and Evaluation

Risk analysis is a means of establishing the event's potential losses/consequences and estimating the likelihood or frequency of such an event. There are various methods used to evaluate risk; however, all forms assess the hazards or threats that may lead to an undesired consequence. While practices vary based on the company or risk analyst, the worst credible consequences are typically considered. During a risk analysis, the full scope of consequences should be evaluated, and they are often prioritized in the following order:

1. Injury to the public or workforce
2. Damage to the environment
3. Damage to assets and incurred cost

The event can have consequences in all three categories. In particular, where the asset damage and incurred cost consequences are greater than the health, safety, and environmental risk (HSE), the HSE risk should be considered separately.

These risk assessment methods can be generally categorized into two broad categories: quantitative and qualitative. However, it is important to note that in practice, many risk evaluation methods are a hybrid of both quantitative and qualitative methods.

2.2.1 Quantitative

Quantitative methods of risk evaluation are generally based on a statistical analysis of past hazardous events. Quantitative risk evaluation uses a ***mathematical scale*** to determine both the probability of an event occurring and the severity of the consequences.

There are various quantitative methods in which risks may be presented; one of the most common is the Individual Risk Per Annum (IRPA). For each hazardous event outcome, IRPA can be calculated as follows:

$$\boldsymbol{IRPA =} \quad \textit{Frequency of hazardous outcome event} \times \textit{Probability of fatalities} \times \textit{Proportion of year an individual is exposed to the hazard}$$

Equation 1: Individual Risk per Annum Formula

Alternatively, risks may be presented as group risk, which is the measure of the risk to society. The Health and Safety Executive defines group risk as "the relationship between frequency and the number of people suffering from a specified level of harm from the realization of specific hazards." Group risk is utilized when there is a concern of multiple individuals being affected simultaneously by an event. Group risk is often expressed in terms of an F-N diagram. (Health and Safety Laboratory and the Health and Safety Executive , 2009)

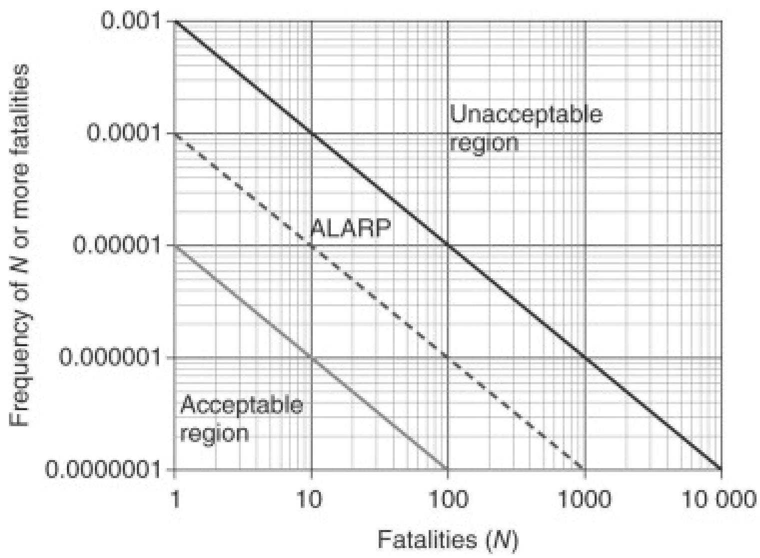

Figure 1: Typical F-N Curve (S.Tesfamariam, 2013)

2.2.2 Qualitative

Conversely, qualitative methods are customarily subjective risk assessments and are primarily based on the knowledge of those directly involved in the evaluation. Qualitative methods use a relative scale to determine the probability of an event occurring and the severity of the consequences.

Risks associated with qualitative risk assessments are often presented by means of a risk matrix. (Khan, Rathnayaka, & Ahmed, 2015) A risk matrix is a two-dimensional presentation of the likelihood of occurrence and severity of consequence. In practice, risk matrices vary from company to company based on risk tolerances. Typically, risk matrices range from 5x5 to 7x7 and at a minimum result in low, medium, and high risk.

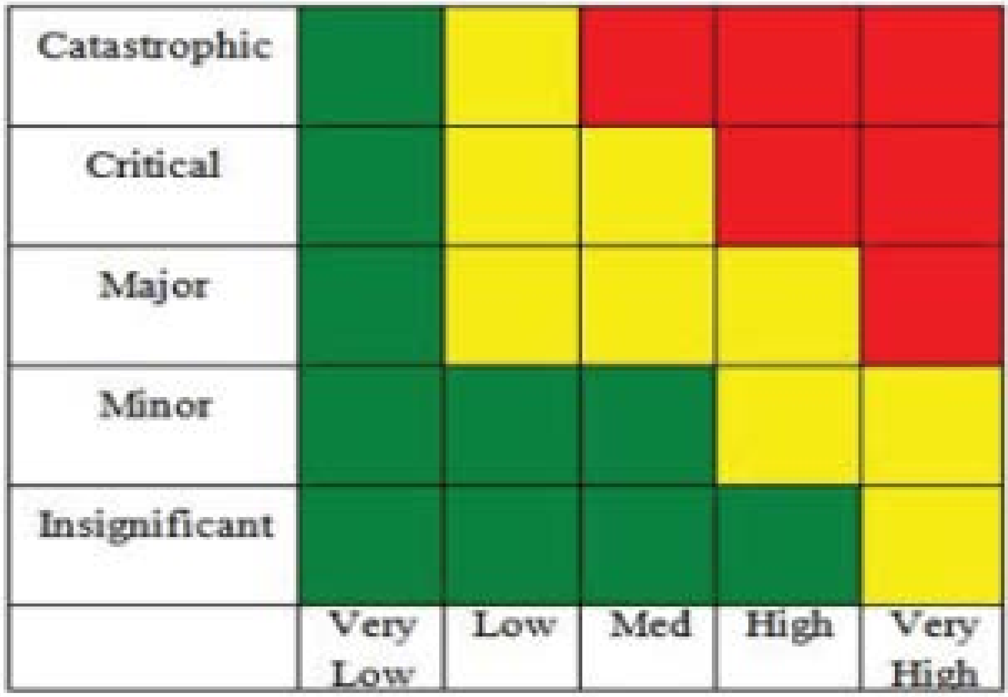

Figure 2: Generic Risk Matrix

Initial risk ranking is generally recorded without controls and safeguards considered to establish the initial unmitigated risk.

Risk treatment aids in the reduction of the likelihood of an event by adding safeguards and/or improving detection of the hazards. All risk treatment actions should be specific, measurable, and realistic. Considering risk treatment plans, these existing and/or suggested safeguards/mitigation measures are utilized to generate a residual risk.

With the addition of suitable provisions and safeguards, the risk should be reduced such that the residual risk is within the ALARP range and is tolerable.

2.3 Precautionary Principle

The simplest form of the precautionary principle can be described by the statement "better safe than sorry" or the notion to "err on the side of caution." The principle puts the burden of proof on the maker of a product and/or process to prove that it is safe rather than the public to prove potential harm. (Blank, 2020)

There is some debate on the precise origins of the precautionary principle as the concept is not novel. Most literature credits the precautionary principle stemming from environmental debates and movements of the 1960s and 1970s. In particular, the German concept known as *vorsorgeprinzip* (foresight principle). This principle was forged into German environmental law, and in 1987 at the International Conference on the Protection of the North Sea, it entered into international law. (Epstein, 2019)

There are varying definitions of "precautionary principle"; however, most noteworthy is that posed under Principle 15 of the Rio Declaration of 1992, which stated:

> *In order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there are threats of serious or irreversible damage, full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*

The principle is ambiguous and leaves open for interpretation as to the appropriate "measures." (Cole, 2005)

In 1998 clarification of the definition was offered at the Wingspread Conference in Racine, WI, USA, which stated:

> *When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.*

The precautionary principle is an avenue to aid in applying safeguards against potential serious harm or consequence in the face of scientific uncertainty. Uncertainty may be in regards to the nature of potential consequences or the likelihood of its occurrence. Safeguards or precautionary measures may be preventative or anticipatory in nature. (Hayes, A. Wallace, The Precautionary Principle)

2.4 ALARP

Risks can not be entirely eliminated but can be mitigated and managed. Mitigating and managing risks to an acceptable level is fundamental to the ALARP principle.

The ALARP or As Low As Reasonably Practicable Principle is a method of quantifying risk levels. The principle originated in the United Kingdom but is now a commonly used method of risk management worldwide. The ALARP principle is not prescriptive but rather puts the onus on duty-holders to systematically determine tolerable risk.

ALARP has been defined by the Court of Appeal in its judgment in Edwards v. National Coal Board, [1949] 1 All ER 743 as: "'Reasonably practicable' is a narrower term than 'physically possible' … a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it is shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them." (Health and Safety Executive, 2020)

The ALARP principle is intended to allow duty holders to evaluate known hazards against the potential consequence by assessing applicable safeguards. It is intended to balance the need for additional safeguards against the reduction in the overall risk profile. The term ALARP is generally used to describe a state where all reasonable risk treatment options have been used to reduce risk to people and the environment to as low as reasonably practicable. (Pike, 2020)

There is no set standard risk tolerance or prescriptive number to quantify the point at which risk level reaches ALARP and will vary from company to company. The ALARP principle is based on the reduction of risk through the addition of safeguards or levels of protection until the benefit of doing so is grossly disproportional to the time, cost or effort.

Typically, in practice, ALARP means:

- Compliance with good/best industry practice, and
- Where good industry practice is not available, to:
    - Identify potential barriers to reduce the likelihood of the consequence.

- Incorporate those where cost is proportional to the risk reduction benefit.
- Discard those whose cost is disproportionate to the reduction in risk.

The ALARP principle is often best described using the ALARP triangle:

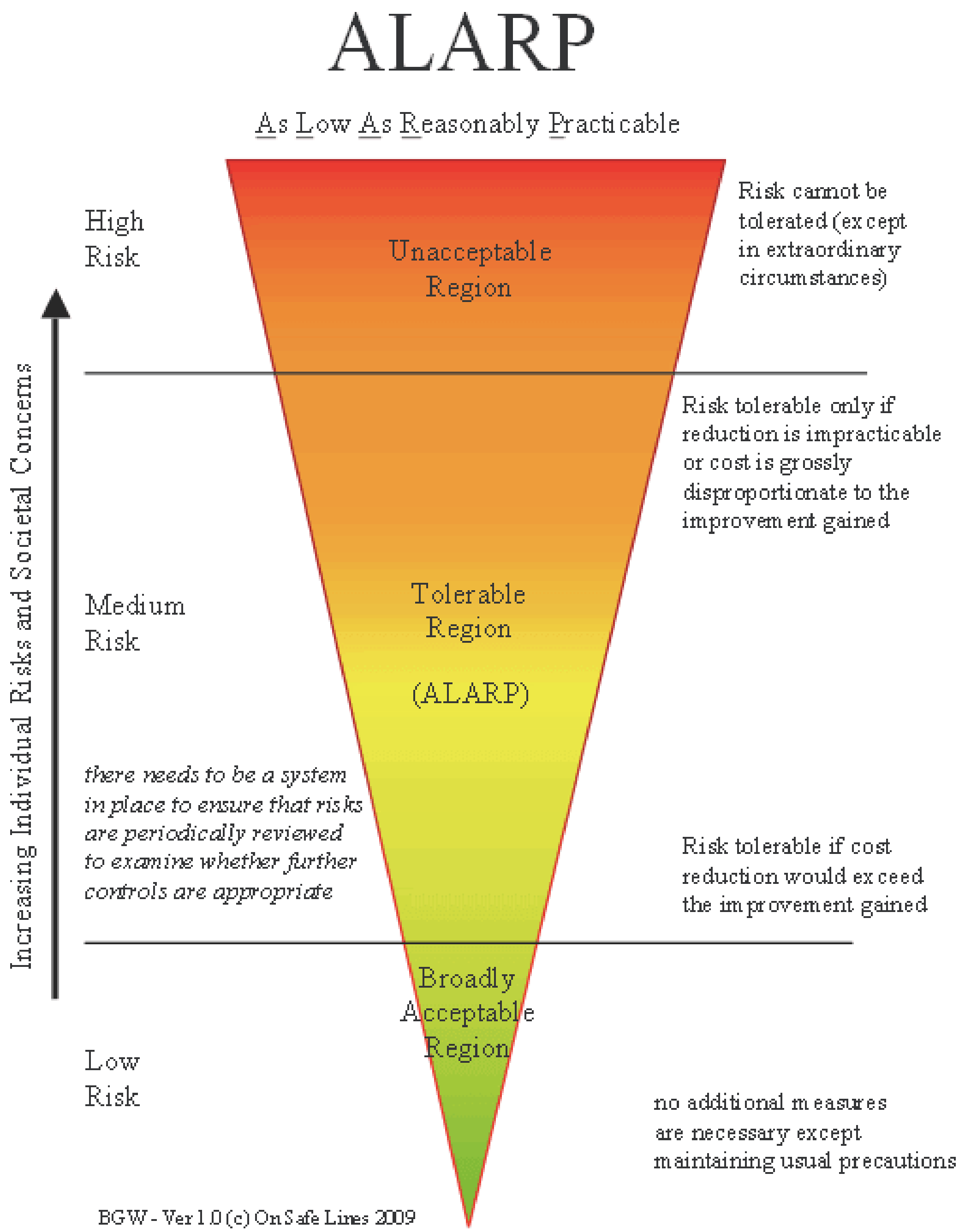

Figure 3: ALARP Triangle (Welch, 2009)

ALARA stands for “As Low as Reasonably Achievable” and is synonymous with ALARP and is a term often used outside of the UK. For the purposes of this paper, ALARP is the preferred terminology.

2.5 Risk to Personnel

Individuals' risk levels are generally grouped into three distinct categories: broadly acceptable, conditional/tolerable, and unacceptable.

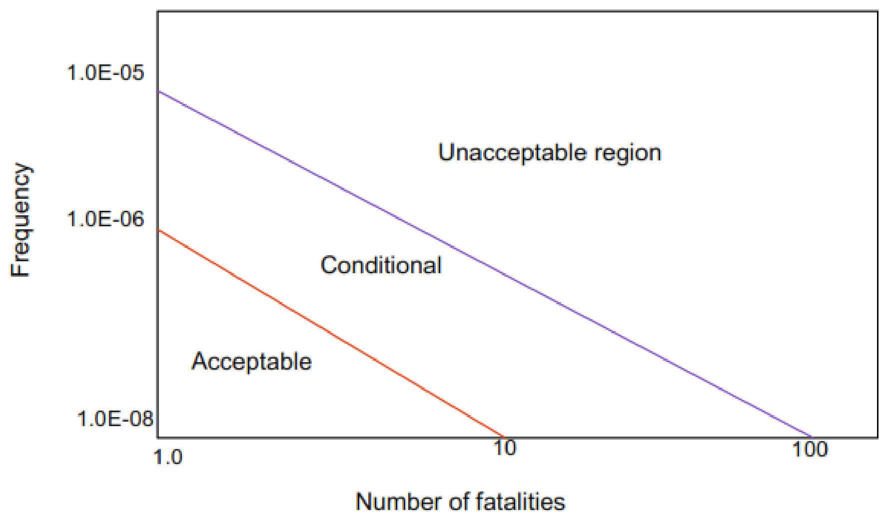

Figure 4: Acceptance Criteria for Frequency of Number of Fatalities

Hazardous events that may occur and/or affect individual personnel with a frequency of less than 1.0E-06/year are generally considered “broadly acceptable.” Noting, however, that risk tolerance levels change from company to company as all will have slightly differing risk tolerance. These risks are considered to be low enough such that further risk reduction methods are not required and/or justified. Like all hazardous events and associated risks, “broadly acceptable” risks should be monitored to ensure risk levels do not rise outside the acceptable range.

Hazardous events that way occur and/or affect individual personnel with a frequency of greater than 1.0E-06/year and less than 1.0E-05 are generally considered conditionally acceptable. These risks are deemed tolerable if it can be demonstrated that the risks have been reduced to ALARP.

Hazardous events that may occur and/or affect individual personnel with a frequency of greater than 1.0E-05 are generally considered conditionally unacceptable. Events falling within the unacceptable range must have additional controls and mitigation measures put in place to reduce the risk to an acceptable level.

To establish target levels of safety achievable for a facility, numerous safety studies must be employed. Typically, these studies may include hazard identification studies such as HAZIDs and MAE Bow-tie assessments as well as evaluation studies such as Fire and Blast analysis, Temporary Refuge impairment, Dropped object study, Radiation and Exhaust studies, Emergency Escape Evacuation Rescue study, and a Quantitative Risk Assessment.

2.6 Risk Reduction Techniques

2.6.1 Inherently Safe Design

In the hierarchy of risk management or risk reduction techniques, an inherently safe design is of the highest importance. In an inherently safe design either the hazard is eliminated or the magnitude of the hazard is reduced such that the consequences are tolerable. An inherent safe design is generally established by utilizing four strategies:

1. Minimize – involves minimizing the hazardous quantity and/or energy of a system to drastically reduce or eliminate the consequence of an event.

2. Moderate - involves modifying the event or material such that it is less hazardous and/or severe.
3. Substitute – involves the substitution or replacement of a hazardous item, material, or process with one that is less hazardous.
4. Simplify – involves the simplification of a process to help reduce or eliminate human error. (National Academy of Engineering, 2004)

2.6.2 Safeguards

A safeguard is an element of design that either aids in the prevention against the hazard or mitigates the level of severity of the consequences of a hazardous event. Safeguards, also referred to as barriers, can generally be classified into two broad categories: preventative barriers and mitigating barriers. (Crowl & Louvar, 2011)

Figure 5: Preventative and Mitigating Barriers (Crowl & Louvar, 2011)

A preventative barrier or safeguard is a proactive control against a threat, i.e., it prevents an initiating event from proceeding to an undesired event or incident. In contrast, a mitigating barrier is a reactive control that aids in minimizing the consequence of an initiated incident or hazardous event.

According to Crowl and Louvar, there are generally four accepted categories of risk reduction strategies: inherent, passive, active, and procedural. (Crowl & Louvar, 2011)

2.6.2.1 Passive

Passive barriers may be either preventative or mitigating however, they do not require activation to aid in the reduction of risk. Typical passive barriers on an offshore installation would include barriers such as passive fire protection, bunding, blast/firewall, and decks.

2.6.2.2 Active

In the simplest form, active barriers require an automated activation or response, often triggered by a process change or upset. Active barriers include fire and gas detection systems, firewater and deluge systems, emergency shut down valves, etc. (Borisevic, Greenfield, & Potts, 2016)

2.6.2.3 Procedural

Procedural barriers are not automatic and require human intervention to trigger a response. In the hierarchy of safety barriers, procedural barriers are the least desirable as they rely on manual operations and can be prone to human error. Procedural barriers may include opening and/or closing of manual valves, emergency response plans, and activation of manual call points.

2.7 Risk Evaluation Methods

2.7.1 Fault Tree Analysis

A fault tree is a logical method of identifying the potential ways that hazards may lead to an accident, known as a top event. Logic functions are utilized in the fault tree from a top-down approach, working backward towards the various scenarios that could have resulted in the accident or top event. (Crowl & Louvar, 2011) The fault tree visually displays the interrelationships between the top event/accident and the causes for this event.

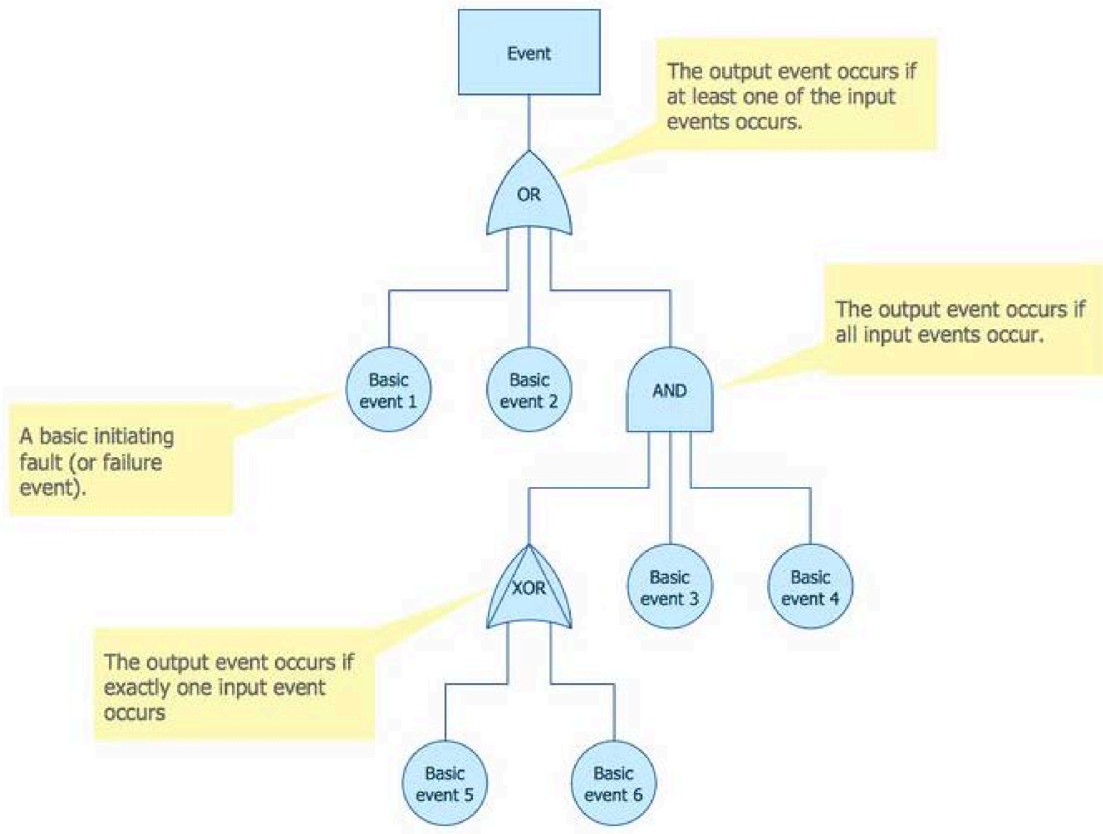

Figure 6: Fault Tree Sample (CS Odessa Corp., 2020)

There are various components used in a creation of a fault tree with different symbols, labels, and identifiers, as shown below:

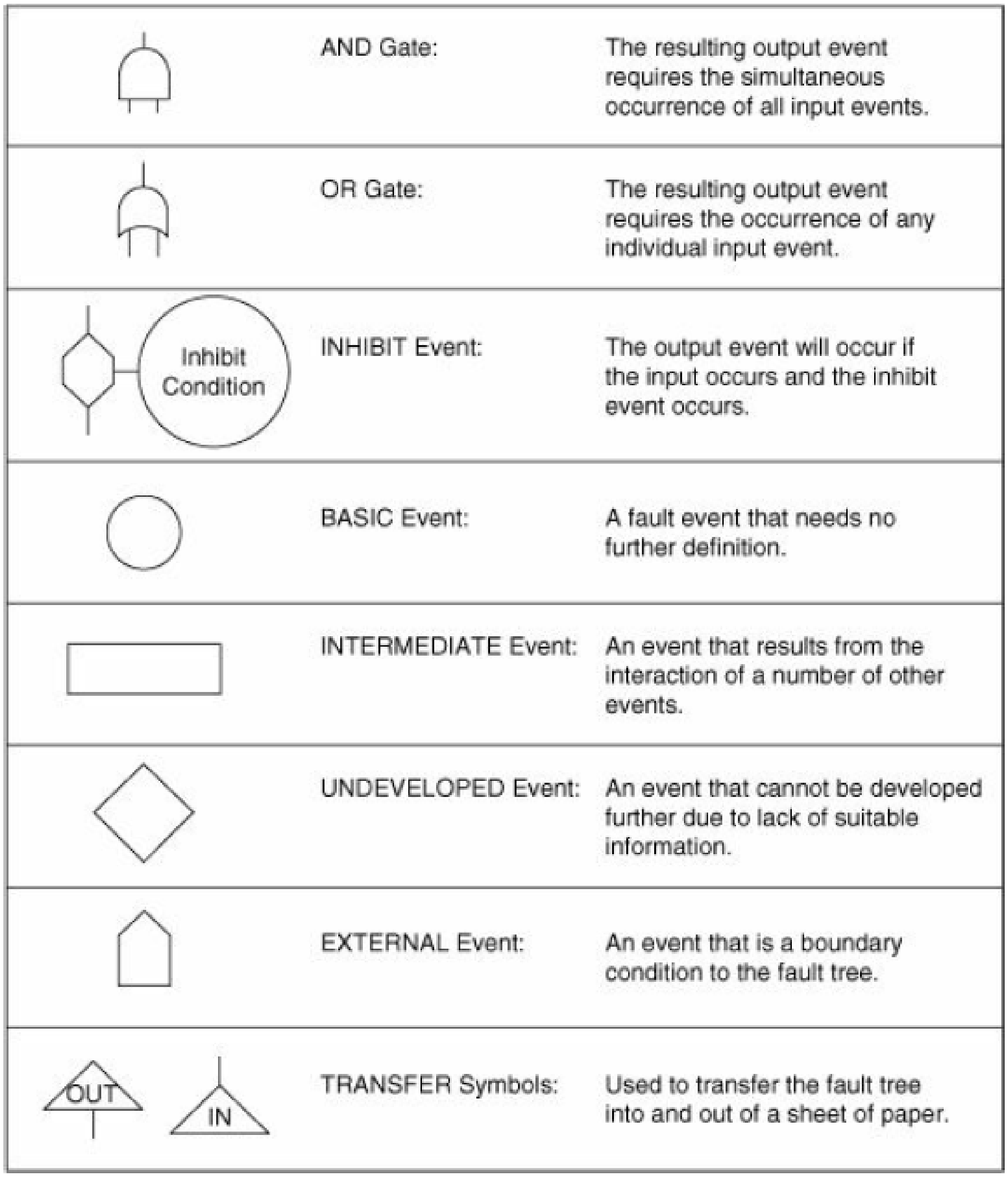

Figure 7: Fault Tree Identifiers and Symbols (Crowl & Louvar, 2011)

Utilizing known probabilities for the basic events, the top event's likelihood can be quantitively determined in the fault tree analysis. Alternatively, fault trees can be utilized qualitatively to determine the minimum cut set for the top event. (Adedigba, 2017)

2.7.2 Event Tree Analysis

Complementary to the fault tree analysis is an event tree analysis. An event tree analysis evaluates the potential consequences leading from an initiating event. It employs a “forward-thinking” process whereby analysis begins with the initiating event and the factors leading to a final consequence are analyzed based on the success or failure of the evolved safety functions. (Crowl & Louvar, 2011)

Event trees typically utilize Boolean logic gates (i.e., yes/no, on/off) and progress left to right to quantitively determine the probability of a consequence given the known probability of the initiating event and the success/failure of each system node (safety function). (RRC Training, 2010)

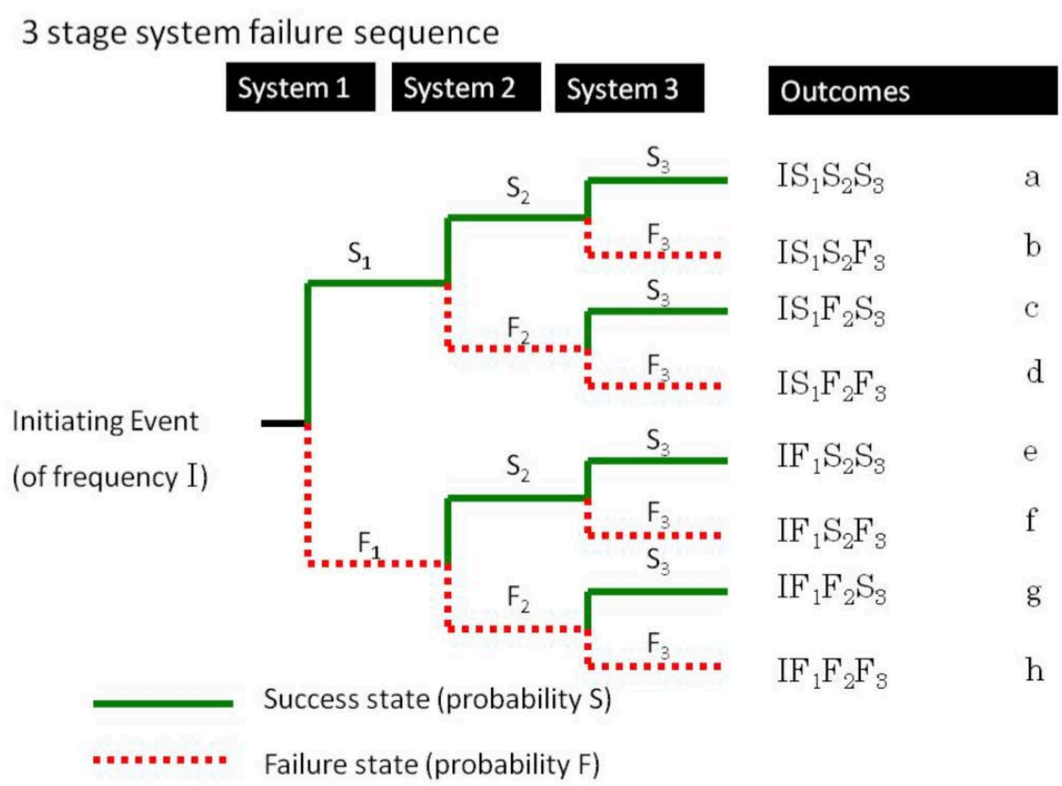

Figure 8: Sample Event Tree (RRC Training, 2010)

2.7.3 Bowtie Diagram/Analysis

The bowtie hazard analysis technique combines the concepts of both Fault Tree Analysis and Event Tress Analysis. (Kim, 2015) The diagrams below illustrate how both analysis techniques fit together to form a bow-tie diagram. The FTA is represented to the left of the "Event" and the ETA is represented to the right of the "Event".

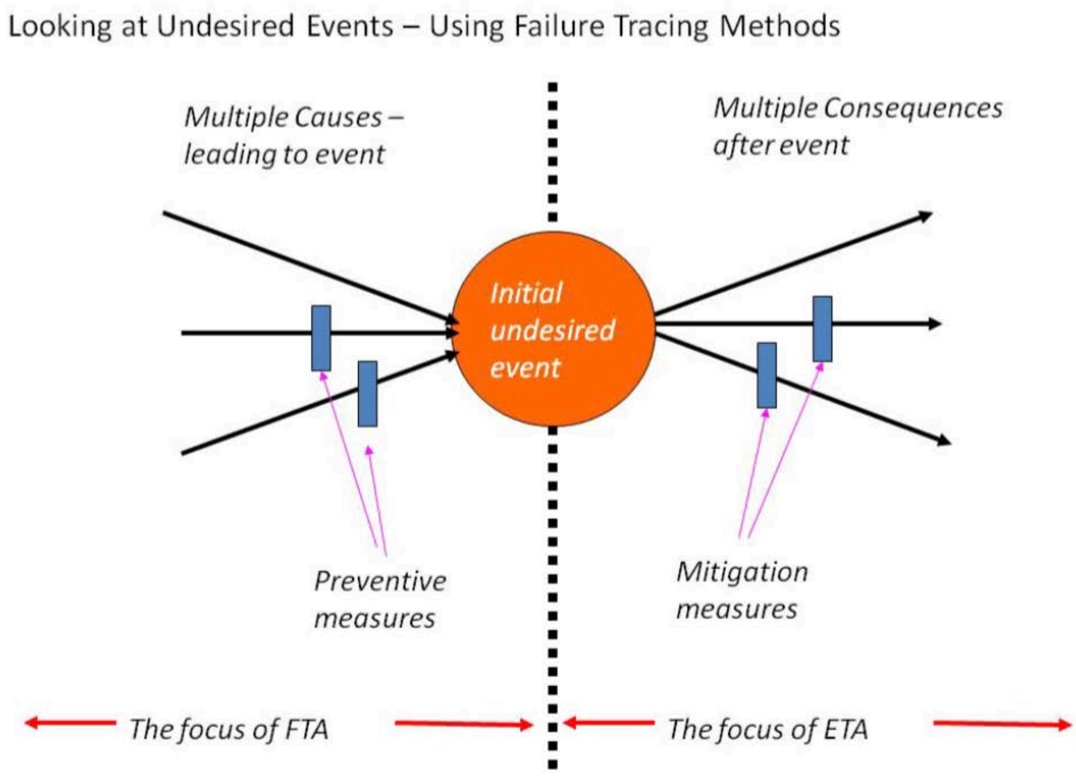

Figure 9: Fault Tree and Event Tree Relationship (RRC Training, 2010)

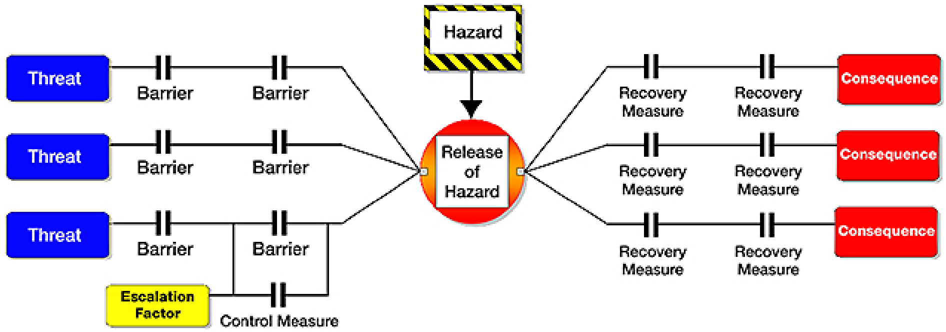

Figure 10: Bow-tie Analysis of FTA and ETA (Cholamandalam MS Risk Services Limited, 2020)

The bowtie diagram clearly illustrates the factors "leading to" and the consequences "leading from" the hazardous event. It pictorially demonstrates the relationship between hazards, threats, potential consequences, and the prevention and mitigation barriers between them. It is a risk assessment tool that is a transparent and easily accessible method of documenting and presenting information and linking risk back to the management system.

2.7.4 Swiss Cheese Model

The Swiss Cheese Accident Causation Model is a risk management tool developed by James T. Reason in 1990. The model was used to demonstrate how active and latent errors/failures contributed to an accident. Active errors are those such as unsafe acts that can be directly linked to an accident; whereas latent errors are contributory factors that may lie dormant for some time until they contribute to the accident.

Each slice of cheese in the model represents a safety barrier relevant to the hazards or accident. Holes in the cheese represent errors or failures, either active or latent. Within the Swiss Cheese Model, each error or failure is seen as required however insufficient individually to cause the accident. When there are exposed vulnerabilities in each safety barrier, i.e., holes in the slices of the cheese line up, an accident will occur.

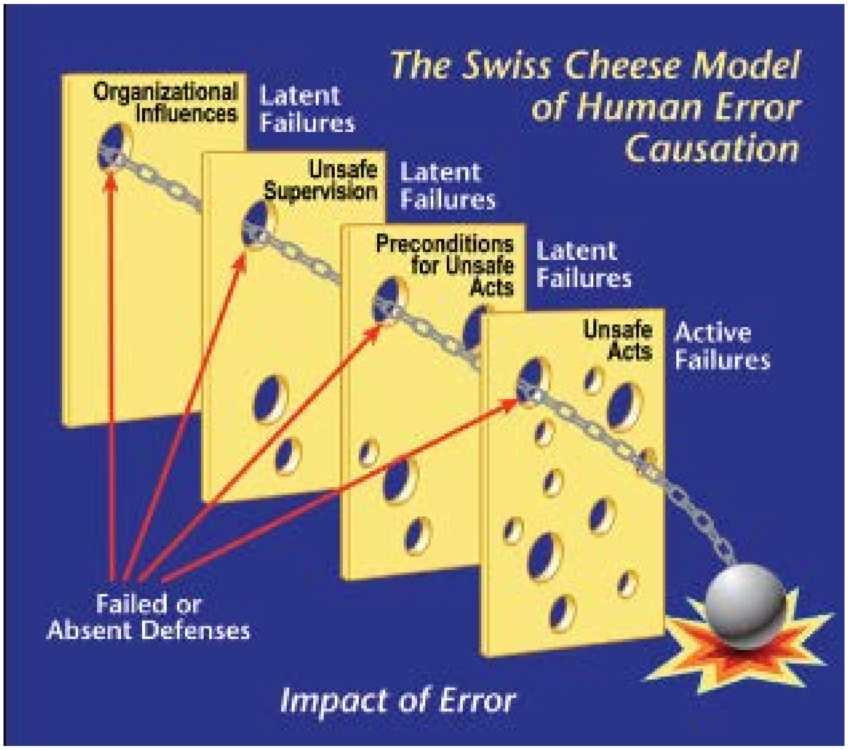

Figure 11: The Swiss Cheese Model of Human Error Causation (Albert, 2013)

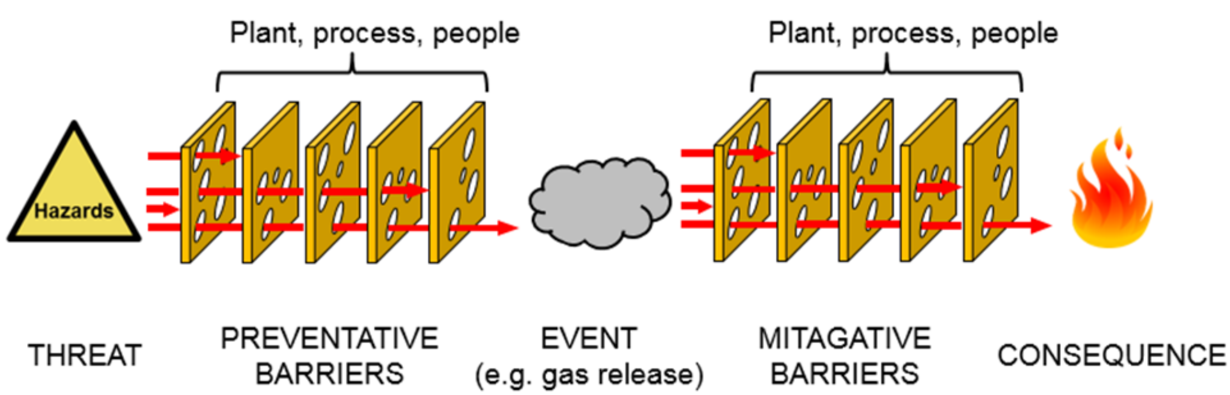

Figure 12: Swiss Cheese Model Highlighting Barriers

2.7.5 Safety Critical Elements

Some barriers are considered Safety Critical Elements (SCE). In general terms, an SCE is any component, system, or an integral part of an installation whereby:

- its failure could cause or contribute substantially to a major accident, or
- its purpose is to prevent or limit the effects of a major accident.

The C-NLOPB Drilling and Production Guidelines define an SCE as "components and systems of an installation that prevents incidents or mitigates the effect of an incident including a pollution event..."

The regulator further defines an incident as:

> *any event that causes*
>
> *(i) a lost or restricted workday injury,*
>
> *(ii) death,*
>
> *(iii) fire or explosion,*
>
> *(iv) loss of containment of any fluid from a well,*
>
> *(v) imminent threat to the safety of persons, an installation, or support craft, or*
>
> *(vi) pollution;*
>
> *any event that results in a missing person; or*
>
> *any event that causes:*
>
> *(i) the impairment of any structure, facility, equipment or system critical to the safety of persons, an installation or support craft, or*
>
> *(ii) the impairment of any structure, facility, equipment or system critical to environmental protection.* (C-NLOPB, 2017)

The key requirement for Safety Critical Elements is that they must be suitable. SCEs and the associated Performance Standards are currently a requirement of an Installation's Safety Plan under the current C-NLOPB regulatory regime. The SCE performance standard is a vehicle for describing the requirements that safety-critical elements should satisfy throughout the lifecycle of an installation.

The performance standard describes:

- components that make up the safety-critical element
- functional requirements/what it is supposed to achieve
- assurance activities on how it will be achieved

In practice, the performance standard aids in establishing the health of an SCE and helps identify potential impairments or shortcomings of a system in operation.

3 Major Accident Events

3.1 Major Accident Hazards

A major accident hazard can loosely be defined as a source of danger that has the potential to cause personnel fatality, significant damage to the asset, or major environmental consequences. Proper hazard identification is the first step in a strategic risk management plan.

The characterization of major accident hazards and the subsequent events can differ on each facility; however major accident events typically include:

- A fire, explosion, or release of a dangerous substance involving death or serious injury to one or more persons on the installation
- Any event involving major damage to the structure of the installation or the loss of stability
- The collision of a helicopter with the installation
- Environmental loading/iceberg impact
- Any other event arising for a work activity involving death or personnel injury to five or more persons

The methods of controlling major accident hazards in current and future installations rely heavily on learning from past major accidents. Some of the most noteworthy major accidents in the oil and gas industry include:

1. Ocean Ranger
2. Piper Alpha
3. Deepwater Horizon

3.1.1 Ocean Ranger

The Ocean Ranger was an offshore semisubmersible drilling rig (MODU). The rig was the largest of its class and was owned by Ocean Drilling and Exploration Co (ODECO). During the early 1980s, the Ocean Ranger was under contract with Mobil Oil Canada Ltd., drilling exploration wells for the Hibernia oil field off the Grand Banks of Newfoundland.

Figure 13: The Ocean Ranger Drilling Rig, 1980 (Higgins, Response to the Ocean Ranger Disaster, 2018)

On February 15th, 1982, approximately 170 nautical miles off the coast of St. John's, the Ocean Ranger capsized and sunk, taking with it the lives of all 84 crew members. The date marks one of the most tragic major accidents in local and international marine history.

The below figure depicts the probable orientation of the Ocean Ranger on the night of the accident.

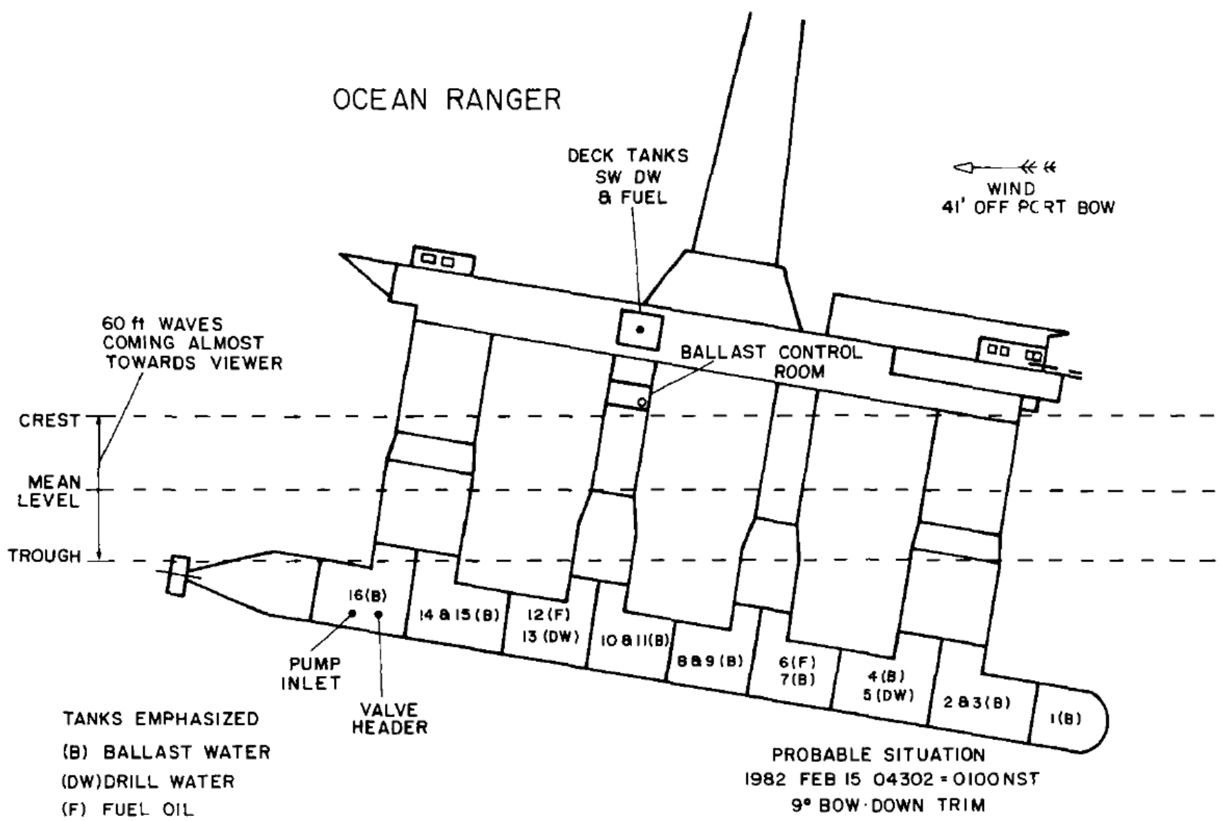

Figure 14: Ocean Ranger Probable Orientation on February 15, 1982. (Heising & Grenzebach, 1989)

Following the tragedy, the federal and provincial government appointed the Royal Commission to conduct an investigation into the Ocean Ranger Disaster. The investigation aimed to determine the potential causes of the tragedy, why there were no survivors, and to gather learnings on how to avoid similar marine disasters in the future. (Higgins, Response to the Ocean Ranger Disaster, 2018). The Royal Commission completed a qualitative assessment that concluded that the capsizing could be attributed to severe weather, numerous design fails, and human error. The Royal Commission noted the following contributing factors:

1. The ballast control room was ill-positioned, located in the third column below the lower deck, which was only 28 ft. above mean water level. This was considered a major design flaw as the location was susceptible to water ingress in the event of severe weather.
2. There were no means of protection from the possibility of water ingress for the ballast control console and its components.
3. The Ocean Ranger ballast room was outfitted with four portlights to allow the operator to view operations and monitor vessel draft. During the storm, the crew failed to close the deadlights (covers) on the portholes.
4. The Royal Commission also noted that the crew had insufficient training and understanding of the ballast control system's functioning in an emergency situation. (Heising & Grenzebach, 1989)
5. There was inadequate lifesaving equipment aboard the rig and the crew lacked sufficient training in its use.
6. Rescue operations were poor and crew aboard the standby vessel, which was located too far from the Ocean Ranger to timely aid in the evacuation, were insufficiently trained, and did not have the appropriate tools for rescue operations.

Stemming from this tragedy was the recognition of the regulatory shortcomings of Canadian and Newfoundland oil and gas operations. The regulatory framework at the time was complex. Three agencies governed the industry: the federal government through COGLA (Canada Oil and Gas Lands Administration), the provincial government through the NLPD (Newfoundland-Labrador Petroleum Directorate), and the United States Coast Guard. None of the agencies adequately monitored or enforced their standards and guidelines due to the regulatory framework's overly complicated nature.

The Royal Commission published 66 recommendations regarding why the Ocean Ranger sank with no survivors and an additional 70 recommendations on how to increase worker safety in offshore operations. (Higgins, Response to the Ocean Ranger Disaster, 2018).

The Ocean Ranger disaster paved the way for the beginning of tighter safety and rescue equipment requirements, increased oil and gas worker training as well as aided in the development of a single regulatory body. The Canada-Newfoundland Offshore Petroleum Board was established in 1985, later renamed Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). (Higgins, Response to the Ocean Ranger Disaster, 2018).

3.1.2 Piper Alpha

The Piper Alpha was a fixed oil production platform located in the North Sea’s Piper oilfield, covering 12 square miles (31 square kilometers). The Piper Alpha was located approximately 120 miles (193 kilometers) off the coast of Aberdeen, UK, in approximately 474 feet (144 meters) of water. (The Maritime Executive, 2018). The field was discovered in 1973, and shortly after, the platform was built modularly by McDermott Engineering and Union Industrielle d'Entreprise (UIE) of Cherbourg and mated in 1975. (Wikipedia, 2020). As an oil-only facility, it began producing in 1976 operated by Occidental Petroleum (Caledonia) Limited with a design throughput of 40,000 m3/day (250,000 barrels per day) of oil. (Shallcross, 2013).

Figure 15: The Piper Alpha Platform (Center for Chemical Process Safety of the American Institute of Chemical Engineers, 2012)

Figure 16: Piper Field (Macleod & Richardson, 2018)

On July 6, 1988, a day in history was marked with tragedy and disaster. The Piper Alpha platform experienced a series of catastrophic explosions and fires, destroying the platform and taking with it the lives of 167 personnel. (Center for Chemical Process Safety of the American Institute of Chemical Engineers, 2012). Marked with great tragedy, the Piper Alpha disaster is one of the most defining Major Accident Events in history for the oil and gas industry. It was the world's largest offshore oil disaster, affecting 10% of the UK oil production and financial losses estimated at £2 billion ($3.5 billion Canadian). (Macleod & Richardson, 2018)

The Piper Alpha tragedy, including its effect on the regulatory regime, is further discussed in Section 4.

3.1.3 Deepwater Horizon

The Deepwater Horizon was a deep water, dynamically positioned, semi-submersible mobile offshore drilling unit. It was built in 2001 and owned by Transocean and then leased to BP. The rig was capable of operating in water up to 2400m with a maximum drill depth of 9100m. (Wikipedia, 2020)

In 2010 the Deepwater Horizon began drilling an exploratory well at the Macondo Prospect in the Gulf of Mexico off the coast of Louisiana. On August 20th, 2010, a tragic well blowout occurred, resulting in the escape of hydrocarbons and subsequence explosions and fire on the rig. The fire continued for 36 hours until the rig sank. The event resulted in the death of 11 crew members and injury to 17 more. The event also had a significant environmental impact, as the well continued to flow for 87 days. (BP, 2010). The Deep Water Horizon oil spill was the largest spill in the United States' history, spilling almost 5 million barrels of oil into the sea. (Graham, et al., 2011)

Figure 17: Deepwater Horizon Semi-submersible Drilling Rig (Wikipedia, 2020)

BP conducted an internal investigation following the accident to determine the potential causes of the incident and to aid in the prevention of similar further events. Like all disasters, no single action was the cause, and the report listed eight key findings:

- The annulus cement barrier did not properly isolate the well hydrocarbons.
- The shoe track barriers did not isolate the hydrocarbons.
- A negative-pressure test that was conducted prior to temporarily abandoning the well was inaccurately accepted. The test is used to verify the integrity of mechanical barriers such as shoe track and casing barriers.
- The drill crew did not recognize the influx until hydrocarbons were in the riser.

- The chosen well control response actions, to divert fluids to the mud gas separator, failed to regain control of the well.
- Diversion to the mud gas separator resulted in gas venting onto the rig.
- The fire and gas system did not prevent hydrocarbon ignition as it was found that hydrocarbons had migrated outside electrically classified areas.
- The BOP emergency mode did not seal the well. (BP, 2010)

Outside of BPs internal investigation, in May of 2010, the president of the United States created an independent National Commission to investigate the Deepwater Horizon disaster. Their mission was to determine the causes of the tragedy, improve the ability to respond to oil spills, and make recommendations to increase the safety of offshore oil and gas operations. (Graham, et al., 2011)

The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling concluded that, like most major accidents, the loss could have been prevented. It stemmed from a series of mistakes on the part of BP, Transocean, and Halliburton that were viewed as "systematic failures in risk management that place in doubt the safety culture of the entire industry." (Graham, et al., 2011). The commission faulted the industry and government for being ill-prepared for risks associated with drilling in increasing water depths and pioneering these new deepwater depths. The Commission called for increased regulatory oversight into planning and operations and increased enforcement for oil and gas operations, in particular deepwater drilling. Additionally, the Commission recognized the laws, regulations, and practices concerning minimizing the environmental impact of a spill were insufficient for deepwater drilling in conditions such as in the Macondo Prospect. (Graham, et al., 2011)

The former members of the Commission, in 2020, stated that the U.S. Congress had not implemented most of the recommendations in the final report. The Commission did recognize that the industry had improved well containment capability. (Pallardy, 2020)

4 Piper Alpha - Influence on Regulatory Regime

Following the Piper Alpha disaster, the United Kingdom Secretary of State called for a public inquiry to investigate the circumstances surrounding the accident, the proposed causes, and recommendations to avoid similar accidents in the future. The Public Inquiry into the Piper Alpha Disaster, which has come to be known as the Cullen Report, was issued in 1990 and written by The Honorable Lord Cullen.

The following figure shows the Piper Alpha platform, associated platforms, and Flotta Oil Terminal.

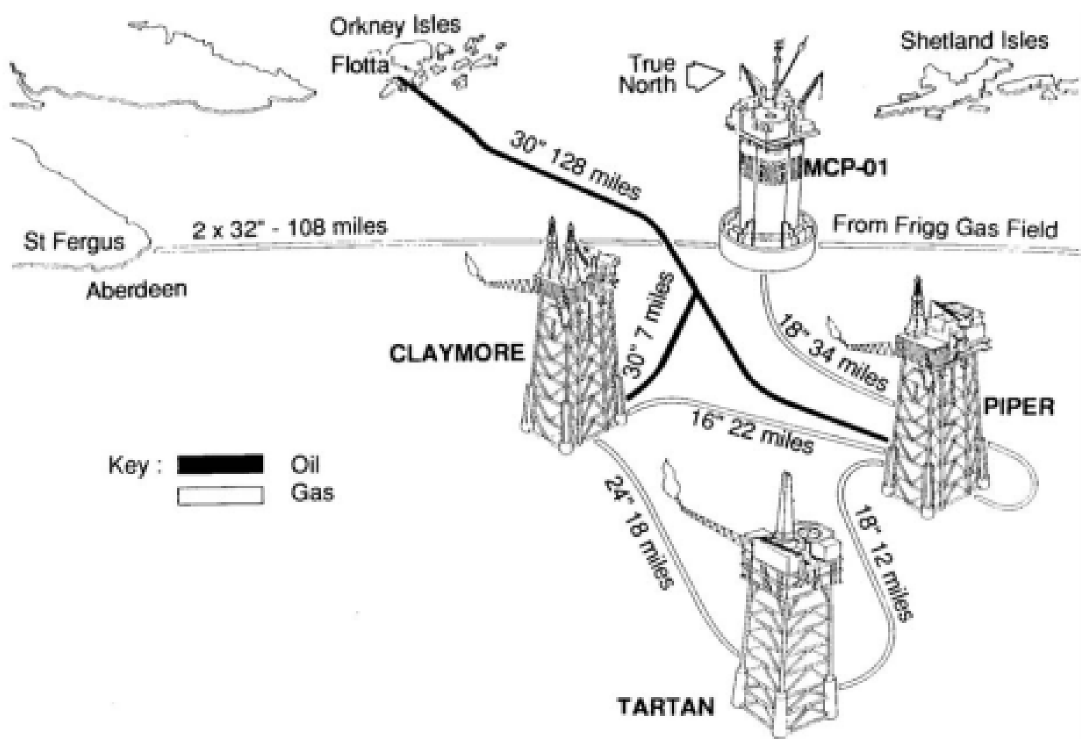

Figure 18: Piper Field Pipeline Connections (Cullen, 1990)

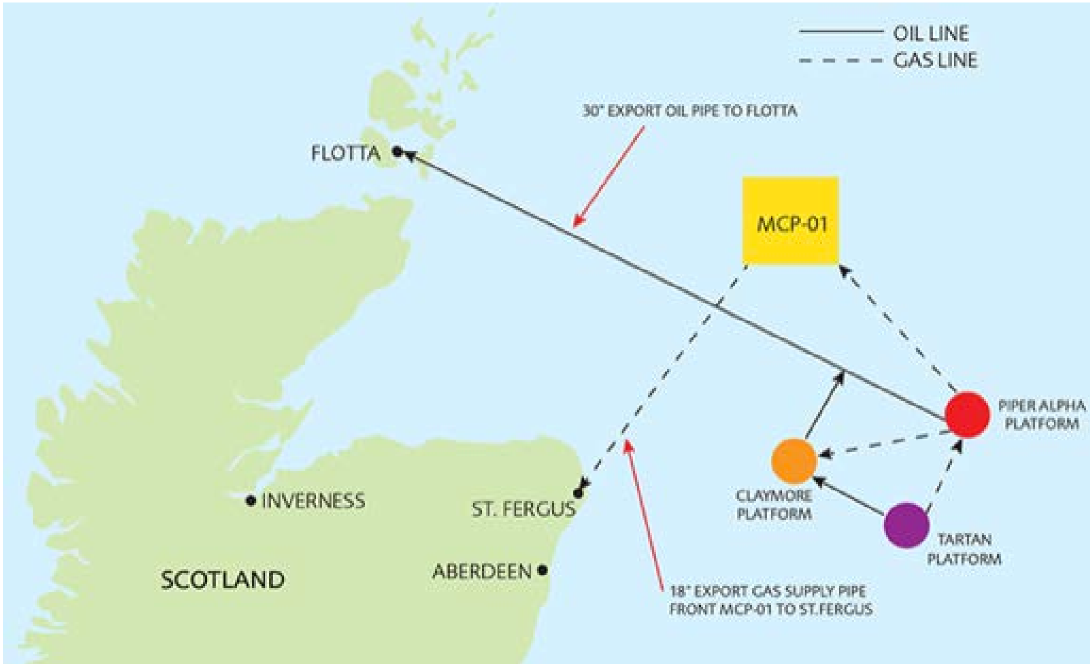

Figure 19: Piper Field (Macleod & Richardson, 2018)

The platform was originally an oil-only production platform with 32 well slots. The oil, gas, and water produced were separated on the platform by the main production separators. Two booster pumps were used to pump the oil to the oil export line, then to the Flotta Oil Terminal. (Shallcross, 2013). The water was further treated and then routed to the overboard discharge line. Initially, the gas was compressed and sent to flare.

The platform consisted of four main production areas or modules, modules A-D, located at the production deck level. Module A housed the wellheads, Module B housed the production separators, Module C the gas compression plant, and Module D contained the electrical plant and miscellaneous facilities. On top of the deck was the drilling deck housing the drilling and mud modules. The living quarters were on the top deck with a helideck above. (Cullen, 1990).

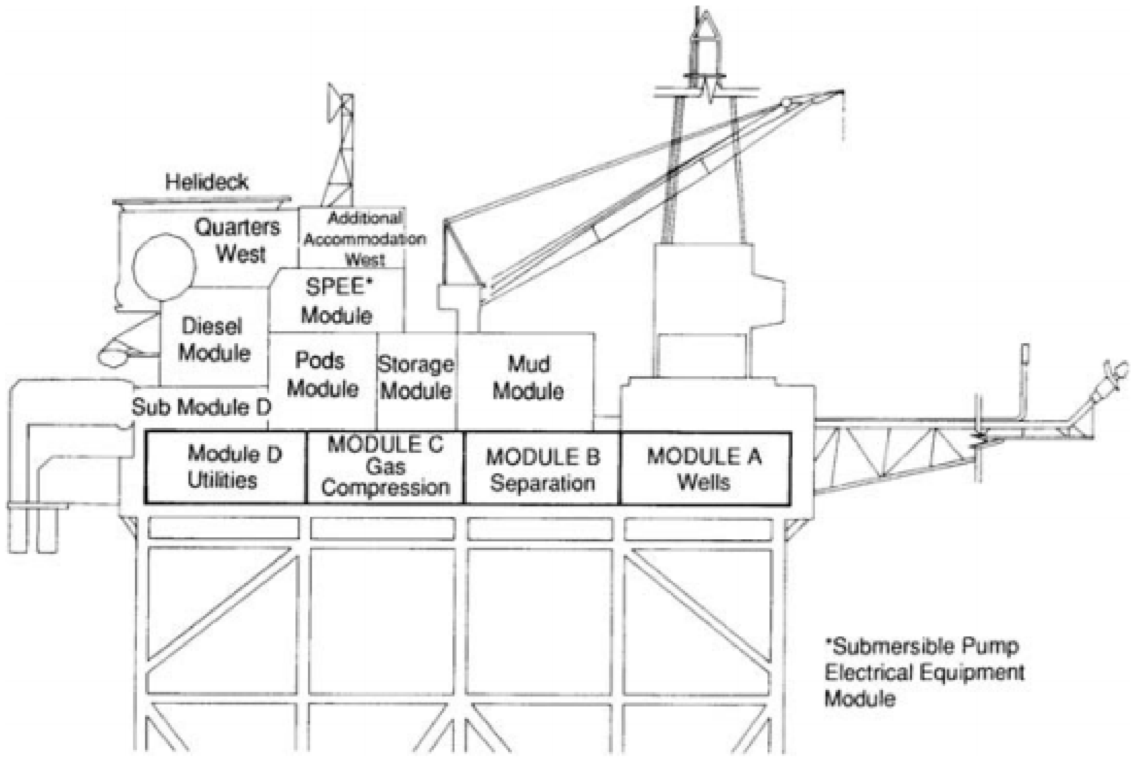

Figure 20: Piper Alpha Platform – West Elevation (Cullen, 1990)

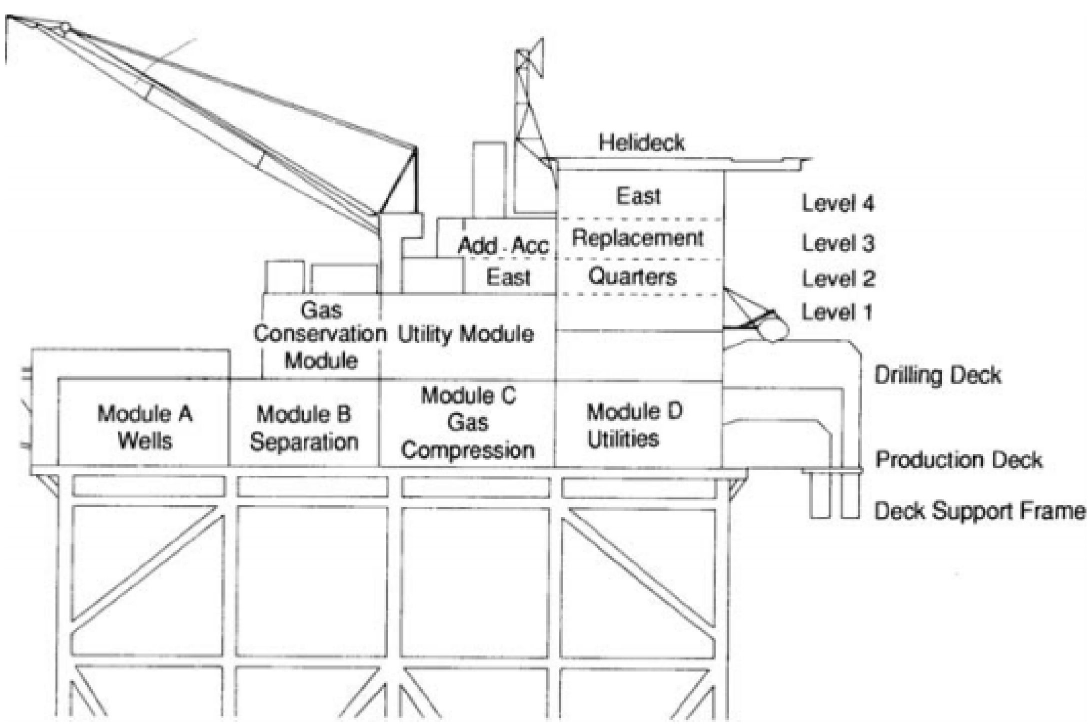

Figure 21: Piper Alpha Platform – East Elevation (Cullen, 1990)

In 1978, in order to comply with changing Government policy, means of exporting gas off the platform were required. This meant that the gas was purified and pumped to the MCP-01 gas compression platform where it was intermingled with gas from the Frigg field before it was pumped to the British Gas collecting plant at St. Fergus. (Cullen, 1990). To enable the gas exportation, the Piper Alpha was first retrofitted with a gas dehydration unit and a Joule-Thomson (JT) expansion valve. Further modifications were made in 1980 with the installation of improved facilities for drying and expansion of gas as well as a distillation column to remove gas from the condensation. With the improved facilities for the drying and expansion of gas, the first gas dehydration unit was removed in 1983. The location of the Gas Conversion Module (GCM) is visible in the figure above. The original design of the Piper Alpha physically distanced the production side of the platform, the most hazardous side, from the personnel and control spaces. The GCM now occupied space adjacent to personnel occupied critical control spaces.

In the processing stream, the separated water and hydrogen sulphide (H_2S) were removed in molecular sieves, and the gas was compressed and then cooled by expansion. The heavier fractions of gas (propane) were condensed as a liquid and the remaining gas (methane) was exported. A large vessel that was connected to two parallel condensate pumps (A and B) collected the condensate and injected it into the oil for export to Flotta. (Macleod & Richardson, 2018)

Operating without the use of the GCM was known as Phase 1 operations; operating with the use of GCM was referred to as Phase 2 operations. According to the Cullen report, the Piper Alpha was operated in Phase 2 from December 1980 until July 1988, with the exception of the period from April to June 1984, as well as the few days leading up to the accident.

4.1 History of Events

- At approximately 22:00 on July 6, 1988, the initial explosion occurred on the Piper Alpha's production deck.
- Fire immediately followed at the West face of Module B, including a fireball.
- Fire spread to Module C and downward. Dense smoke engulfed most of the upper portions of the platform.
- Series of smaller explosions followed the initial explosion.
- Emergency systems failed to operate, including firewater and deluge systems.
- 226 personnel were on board and three maydays were sent out, including a call to abandon the platform.
- Due to the immense smoke and fire, personnel were unable to evacuate by helicopter or lifeboat.
- At approximately 22:20, there was a rupture of the Tartan gas riser, causing another major explosion.
- The Cullen report notes that a message was sent from The Piper Alpha to the Tharos platform that read: "People majority in galley area. Tharos come. Gangway. Hoses. Getting bad."
- At approximately 22:45, firewater monitor spray from the Tharos platform reached the Piper Alpha however the gangway was not landed.
- At 22:50 rupture of the MCP-01 riser occurred, causing another catastrophic explosion.
- This explosion started the structural collapse, caused the Tharos to pull back, men to jump from parts of the platform, and destroyed the Fast Rescue Craft (FRC), taking the lives of those of most onboard.

- At 23:20 the Claymore gas riser ruptured, causing further explosions and further collapse of the platform. More men jumped from the platform at the pipe deck level, some of whom were survivors.
- By 00:45 the center of the Piper Alpha had collapsed with the risers and gas pipelines torn apart.
- That night the Piper Alpha has 62 survivors (one of whom later died in hospital) and one survivor of the Sandhaven FRC crew. The disaster took the lives of 165 Piper Alpha crew members along with the lives of 2 FRC crew members. (Cullen, 1990). Of those deceased, 109 deaths were attributed to smoke inhalation, 13 due to drowning, 11 due to burns and miscellaneous injury, 4 of unknown causes, and 30 bodies were never recovered. (Macleod & Richardson, 2018)
- It took over three weeks for the fires to be extinguished, with the Piper Alpha's remains finally sinking on March 28, 1989. (Macleod & Richardson, 2018)

4.2 Findings

The Cullen report concluded that the most probable source of the initial explosion was a concentration of condensate (propane) in Module C. It has found that on July 6, 1988, condensate pump A was isolated under permit for required maintenance. Under a previous and separate permit the pressure safety relief valve associated with Pump A had been removed and blind flange put in its place; the blind flange was not pressure or leak tested.

As per Macleod and Richardson, “At about 21.45 on 06 July 1988, condensate pump B tripped. Shortly afterward, gas alarms activated, the first-stage gas compressors tripped, and the flare was observed to be much larger than usual.”

It was likely that as pump B had tripped, operators would have restarted pump A as they would have been unaware of the missing pressure relief valve due to the nature of the Piper Alpha work permit system. Upon restart of pump A, condensate leaked from the unsecured blind flange. It is believed that 30kg of condensate over 30 seconds of leakage caused a hydrocarbon gas cloud to form. When this flammable cloud found its ignition source, the initial explosion and fire occurred. (Macleod & Richardson, 2018) (Cullen, 1990)

Following the Cullen Investigation, several contributing factors related to the design, operation, emergency response, training, and safety culture were found to formulate the root causes of the disaster;

- Management of change system was flawed and/or lacking. There were very poor design choices during the retrofit of the platform for gas exportation. The process safety design failed to recognize and/or effectively mitigate against the new hazards and risks (fire and blast) associated with the processing of gas for export. The new GCM module was physically located adjacent to the control room and below the accommodations module, electrical power supply, and radio room. Explosions badly damaged the control and radio rooms, severing communication. (Cullen, 1990)
- The platform's fundamental safety design lacked in fireproofing/passive fire protection and lack of blast walls. With the addition of the gas module, the increased risk of explosion was not realized and/or mitigated against as there was no protection from blast overpressure.
- The permit to work system and shift change-over procedures were found to be flawed. The permit to work system largely relied on informal communication. Permits were filed by

trade, rather than system or location, with suspended permits residing in the Safety Office rather than the Control Room. At shift changeover, crews often did not discuss suspended permits. The permit to work was a flawed system; operators were unable to see the status of all components of a safety-critical system. In addition to the inadequacy of the permit to work procedure for the Piper Alpha, the Cullen Report also noted that there was inadequate training on the system, resulting in a procedure that was not complied with nor monitored.

- Fire pumps were placed in manual mode as the Piper Alpha placed personnel safety above process safety. They chose to leave the fire pumps in manual mode to protect divers from potential injury due to the suction of the pumps. The risk management was flawed in that the MAE potential was not realized or prioritized. With the fire pumps placed in manual mode for the majority of the time, the only way to activate the pumps was local. During the disaster, the smoke and fire intensity was too great for the crew members to reach the pumps.
- The firewater system was poorly maintained on the Piper Alpha. The sprinkler and deluge heads were blocked, which would have greatly hindered this system's effectiveness if the firewater pumps had activated and the ring main was intact from the blast.
- The Piper Alpha had access to a large hydrocarbon inventory as it was interconnected with Claymore, Tartan, and MCP-01. The export oil from the Piper Alpha joined with oil from Claymore and Tartan into a single line to Flotta. The other platforms delayed show-down, continuing to produce after the initial explosion. Additionally, the emergency shut-down valve on the Piper Alpha export line failed to fully close, allowing oil to reverse flow from the connected platforms adding more fuel to the fire.

- The Piper Alpha's primary method of evacuation was meant to be by helicopter, but due to the dense smoke, helicopters were unable to land. In addition to the unavailability of evacuation by helicopter, not a single lifeboat or life raft was successfully launched during the attempts to abandon the platform. The Piper Alpha had very poor emergency response planning and evacuation training of their crew.
- There was a lack of safety culture regarding management oversight, whereby previous incidents were ignored, and opportunities for improvements were pushed to the side. (Cullen, 1990)

The Cullen Inquiry resulted in 106 recommendations, all of which were accepted and acted upon. Of the 106 recommendations, 57 were to be overseen by the Health and Safety Executive (HSE), operators of installations were responsible for 40, 8 were directed at the entire industry, and the remaining for the Standby Ship Owners Association. (Oil & Gas UK the voice of the offshore industry, 2008).

The recommendations included improvements to the permit to work management systems, modifications to emergency shutdown valve placements, subsea isolation systems, mitigations for smoke hazards, improved escape and evacuation systems, and the requirement for formal safety assessments. The most influential recommendation from the Cullen report was the establishment of new safety regulations. The need for stronger safety and risk management regimes was recognized globally, and legislation (in the UK) was put in place to help aid in the prevention of future disasters. These regulations would require all duty-holders (owners/operators) of every installation operating in UK waters to submit a safety case for acceptance by the HSE. (Oil & Gas UK the voice of the offshore industry, 2008)

In the UK, The Offshore Installations (Safety Case) Regulations came into force in 1992. The safety case is a comprehensive document that details the way in which a duty- holder intends to control the major accident hazards on the installation and describes the methods that will be used for managing health and safety. The Safety Case regulations require that all hazards are identified and appropriate controls are put in place such that the residual risk is ALARP, therefore implying that a QRA is required. (Vinnem & Røed, 2019)

This legislation promoted a global shift in safety culture and the need for stronger regulations. While legislation varies based on the location, the general requirement today remains the same - hazards must be identified, and risks must be assessed to ensure they are as low as reasonably practicable. The Piper Alpha tragedy and the subsequent findings played a crucial role in the regulations and guidelines enforced locally, offshore Newfoundland.

5 Local Offshore Requirements and Regulations

5.1 Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB)

In 1985, the Canada-Newfoundland and Labrador Atlantic Accord Implementation Act was signed between the federal and provincial governments, allowing for the formation of the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). The C-NLOPB was given the authority to regulate the Newfoundland and Labrador Offshore oil and gas industry. Such authority was derived from Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act, R.S.N.L. 1990, c. C-2 and the Canada-Newfoundland and Labrador Atlantic Accord Implementation Act, S.C. 1987, c.3 (Accord Acts). This allowed the C-NLOPB to oversee offshore operator activity to ensure compliance with legislative and regulatory requirements, including offshore safety, environmental protection, resource management, and industrial benefits. (C-NLOPB, 2020)

The C-NLOPB regulations have been developed and have been continuously evolving with new learnings and better practices.

Newfoundland Offshore Area Oil and Gas Operations Regulations (SOR/88-347) were registered on June 30, 1988, after being published in the Canada Gazette on February 13, 1988. (C-NLOPB, 2014)

The Newfoundland Offshore Petroleum Installations Regulations (SOR/95-104) were officially registered in 1995 after publication in the Canada Gazette in 1994. (C-NLOPB, 2020)

Similar to the UK Safety Case regulations, the C-NLOPB Installation Regulations (2020) require every installation to complete a Concept Safety Analysis (CSA). The CSA is to be submitted as a part of the development plan application process. The CSA quantitatively evaluates risk to life and the environment and evaluates those risks against agreed target levels of safety. The CSA is developed in the early stages of a project to form the preliminary quantitative risk assessment (QRA) of the potential major accident hazards affecting the platform. As the CSA is a preliminary study, it often provides recommendations of improvement for development into later states of a facility. The C-NLOPB Installation Regulations, Section 43, Concept Safety Analysis for Production Installations, defines the details required and states:

> *43 (1) Every operator shall, at the time the operator applies for a development plan approval in respect of a production installation, submit to the Chief a concept safety analysis of the installation in accordance with subsection (5), that considers all components and all activities associated with each phase in the life of the production installation, including the construction, installation, operation and removal phases.*
>
> *(2) The* ***concept safety analysis*** *referred to in subsection (1) shall*
>
> *(a) be planned and conducted in such a manner that the results form part of the basis for decisions that affect the level of safety for all activities associated with each phase in the life of the production installation; and*
>
> *(b) take into consideration the quality assurance program selected in accordance with section 4.*

(3) Target levels of safety for the risk to life and the risk of damage to the environment associated with all activities within each phase of the life of the production installation shall be defined and shall be submitted to the Chief at the time the operator applies for a development plan approval.

(4) The target levels of safety referred to in subsection (3) shall be based on assessments that are

(a) quantitative, where it can be demonstrated that input data are available in the quantity and of the quality necessary to demonstrate the reliability of the results; and

(b) qualitative, where quantitative assessment methods are inappropriate or not suitable.

(5) The concept safety analysis referred to in subsection (1) shall include

(a) for each potential accident, a determination of the probability or susceptibility of its occurrence and its potential consequences without taking into account the plans and measures described in paragraphs (b) to (d);

(b) for each potential accident, contingency plans designed to avoid the occurrence of, mitigate or withstand the accident;

(c) for each potential accident, personnel safety measures designed to

(i) protect, from risk to life, all personnel outside the immediate vicinity of the accident site,

(ii) provide for the safe and organized evacuation of all personnel from the production installation, where the accident could lead to an uncontrollable situation,

(iii) provide for a safe location for personnel until evacuation procedures can be implemented, where the accident could lead to an uncontrollable situation, and

(iv) ensure that the control station, communications facilities or alarm facilities directly involved in the response to the accident remain operational throughout the time that personnel are at risk;

(d) for each potential accident, appropriate measures designed to minimize the risk of damage to the environment;

(e) for each potential accident, an assessment of the determination referred to in paragraph (a) and of the implementation of the plans and measures described in paragraphs (b) to (d);

(f) a determination of the effects of any potential additional risks resulting from the implementation of the plans and measures described in paragraphs (b) to (d); and

(g) a definition of the situations and conditions and of the changes in operating procedures and practices that would necessitate an update of the concept safety analysis.

(6) The determinations and assessments required by paragraphs (5)(a) and (e), respectively, shall be

(a) quantitative, where it can be demonstrated that input data is available in the quantity and of the quality necessary to demonstrate reliability of the results; and

(b) qualitative, where quantitative assessment methods are inappropriate or not suitable.

(7) The plans and measures identified under paragraphs (5)(b) to (d) shall be designed to ensure that the target levels of safety as defined pursuant to subsection (3) are met.

(8) The operator shall maintain and update the concept safety analysis referred to in subsection (1) in accordance with the definition of situations, conditions and changes referred to in paragraph (5)(g) to reflect operational experience, changes in activity or advances in technology. (C-NLOPB, 2020)

Newfoundland Offshore Petroleum Drilling and Production Regulations SOR/2009-316 came into force June 1, 2009. (C-NLOPB, 2014). Within the regulations are the regulations surrounding the "Application for Authorization." Section 6, Application for Authorization, states:

The application for authorization shall be accompanied by

(a) a description of the scope of the proposed activities;

(b) an execution plan and schedule for undertaking those activities;

(c) a safety plan that meets the requirements of section 8;

(d) an environmental protection plan that meets the requirements of section 9;

(e) information on any proposed flaring or venting of gas, including the rationale and the estimated rate, quantity and period of the flaring or venting;

(f) information on any proposed burning of oil, including the rationale and the estimated quantity of oil proposed to be burned;

(g) in the case of a drilling installation, a description of the drilling and well control equipment;

(h) in the case of a production installation, a description of the processing facilities and control system;

(i) in the case of a production project, a field data acquisition program that allows sufficient pool pressure measurements, fluid samples, cased hole logs and formation flow tests for a comprehensive assessment of the performance of development wells, pool depletion schemes and the field;

(j) contingency plans, including emergency response procedures, to mitigate the effects of any reasonably foreseeable event that might compromise safety or environmental protection, which shall

(i) provide for coordination measures with any relevant municipal, provincial, territorial or federal emergency response plan, and

(ii) in an area where oil is reasonably expected to be encountered, identify the scope and frequency of the field practice exercise of oil spill countermeasures; and

(k) a description of the decommissioning and abandonment of the site, including methods for restoration of the site after its abandonment. (C-NLOPB, 2014)

With reference to the safety plan, Section 8, states:

8) The safety plan shall set out the procedures, practices, resources, sequence of key safety-related activities and monitoring measures necessary to ensure the safety of the proposed work or activity and shall include

(a) a summary of and references to the management system that demonstrate how it will be applied to the proposed work or activity and how the duties set out in these Regulations with regard to safety will be fulfilled;

(b) a summary of the studies undertaken to identify hazards and to evaluate safety risks related to the proposed work or activity;

(c) a description of the hazards that were identified and the results of the risk evaluation;

(d) a summary of the measures to avoid, prevent, reduce and manage safety risks;

(e) a list of all structures, facilities, equipment and systems critical to safety and a summary of the system in place for their inspection, testing and maintenance;

(f) a description of the organizational structure for the proposed work or activity and the command structure on the installation, which clearly explains

(i) their relationship to each other, and

(ii) the contact information and position of the person accountable for the safety plan and of the person responsible for implementing it;

(g) if the possibility of pack sea ice or drifting icebergs exists at the drill or production site, the measures to address the protection of the installation, including systems for ice detection, surveillance, data collection, reporting, forecasting and, if appropriate, ice avoidance or deflection; and

(h) a description of the arrangements for monitoring compliance with the plan and for measuring performance in relation to its objectives. (C-NLOPB, 2014)

The C-NLOPB, in conjunction with the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB), issued guidelines to aid operators in understanding the Safety Plan requirements and the Board's expectations for regulatory compliance. As per the regulations, a Safety Plan must accompany an application for an operations authorization. In 2011 the Safety Plan Guidelines were issued. (National Energy Board, 2011)

It should be noted that the Safety Plan Guideline makes reference to the concept of ALARP; while guidelines are not regulations, they represent the Board's expectations. With respect to hazard identification, evaluation, and risk management, The Safety Plan Guidelines state:

While the concept 'as low as reasonably practicable' (ALARP) is not discussed in the Regulations, this concept has been used for a number of years by industry and numerous agencies in considering safety matters and reduction of risk. Industry may demonstrate incorporation of ALARP into their risk reduction and associated mitigating measures *through a number of means, including a combination of qualitative analysis, quantitative analysis and good industry practice.*

6 Newfoundland and Labrador Offshore Oil and Gas Facilities

6.1 Local Offshore Oil and Gas Facilities

There are currently four production facilities offshore Newfoundland: Hibernia platform, Terra Nova FPSO, SeaRose FPSO, and Hebron platform.

6.1.1 Hibernia

The first oil field of discovery was the Hibernia field, found in 1979, approximately 315km off the East coast of St. John's, on the Grand Banks in the Jeanne d'Arc Basin. Owned by the Hibernia Management and Development Company Ltd (HMDC), the Hibernia platform development began in 1986. Hibernia is a gravity-based structure with both drilling and production facilities. The topsides consist of drilling, production, and utility facilities, as well as living quarters for approximately 185 people. The gravity-based structure, which supports the topsides from the ocean floor, has the capacity to store 1.3 million barrels of oil. The construction of the platform began in 1991 and once it was towed to the field had its first oil in 1997. The Hibernia platform is still producing with an annual production rate of 220,000 barrels per day. (HMDC, 2020)

6.1.2 Terra Nova FPSO

The Terra Nova field is located approximately 350kms southeast of Newfoundland and was the second-largest oil discovery on the Newfoundland Grand Banks. The field was first discovered in 1986 by then Petro-Canada. The Terra Nova is a Floating, Production, Storage, and Offloading vessel, 292.3 meters long and 45.5 meters wide. The FPSO can accommodate approximately 120 people and can store 960,000 barrels of oil. The FPSO was built in 2000 and began production in 2002. The Terra Nova FPSO is operated by Suncor Energy, with Suncor Energy owning the majority of interests along with ExxonMobil, Equinor, Husky Energy, Murphy Oil, Mosbacher Operating and Chevron Canada. (Suncor, 2020)

6.1.3 SeaRose FPSO

The White Rose oil field is located approximately 350kms east-southeast off the coast of Newfoundland, located in the Jeanne d'Arc Basin. The field was discovered in 1984 with an estimated 440 million barrels of recoverable oil. The White Rose oil field is produced by the SeaRose FPSO, which is 267 meters in length and 46 meters wide. The FPSO can accommodate approximately 90 personnel and has a cargo capacity of 148,200m^3 of liquids. The FPSO was built in 2004 and began producing in 2005 and is operated and owned, in the majority, by Husky Energy. (Ship Technology, 2020)

6.1.4 Hebron

The Hebron oil field is located approximately 340kms off the southeast coast of St. John's in the Jeanne d'Arc Basin. The field was discovered in 1980 with an estimated 700 million barrels of recoverable oil. Development of the Hebron Platform began in 2010 with the commencement of the Front End Engineering and Design (FEED). The platform is a gravity-based structure with both drilling and production facilities. The topsides of the platform began fabrication in 2013 and consists of drilling, production, and utilities facilities as well as living quarters for approximately 220 people. The GBS stands 122m with a base diameter of 130 meters and can store approximately 1.2 million barrels of oil. The platform is operated by its majority-owned shareholder ExxonMobil Canada Properties. Other shareholders include Chevron Canada Limited, Suncor Energy Inc., Equinor Ltd., and Nalcor Energy - Oil and Gas Inc. The Hebron Platform began hook-up and commissioning in 2016 and had its first oil in 2017. (The Hebron Project Office, 2015)

6.2 Asset Life Extension

Each of the facilities is required to have and maintain a safety plan, as per the requirements of the C-NLOPB as a condition of the facilities Certificate of Fitness (COF) and Operations Authorization (OA). As each of the facilities is subject to ongoing regulatory oversight by the C-NLOPB, the COF and OA are regularly renewed.

Three of the four facilities offshore Newfoundland are aging and coming upon their original design life. New oil discoveries, further reserves, and facility extensions are urging owners and operators to extend the life of their existing facilities past the original design life. As facilities age, there are new hazards and differing risks to the overall facility. As an asset ages, the facility must be reviewed to determine the service life of all safety-critical systems. Aging mechanisms, asset integrity, and modifications to the facility must be reviewed and revalidated. Asset history and performance must be thoroughly reviewed and understood. Inspections, failure analysis, recorded incidents, and industry information with respect to similar assets and individual components should be analyzed to determine the overall integrity of the piece of equipment. (C-NLOPB, 2019)

The C-NLOPB issued ALE guidance intended to aid operators in the successful completion of their respective Asset Life Extension (ALE) projects. The following figure depicts the suggested stages of succession:

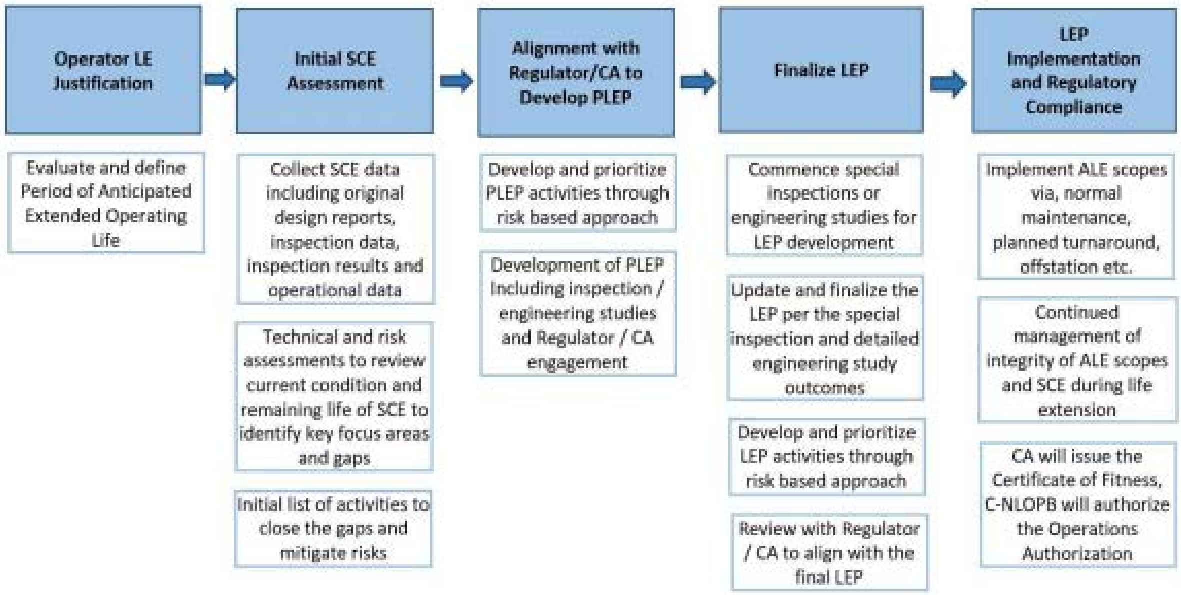

Figure 22: CAN-NL Offshore Area Process for ALE (C-NLOPB, 2019)

With respect to safety-critical systems and equipment, it is required that systems and securities be in place to ensure their reliability, availability, and sustainability during the facility's life. With an asset life extension project, decisions must be made on each of these systems to determine if components will be maintained, repaired, re-rated, or entirely replaced. The service life assessment does not only pertain to physical assets but also extends into software systems, maintenance regimes, skills, and training that may need to be adjusted or modified with an extended facility life.

The C-NLOPB has issued guidance and guidelines on the asset life extension program. Within the guidance, it notes the following considerations must be made when assessing the feasibility of extending a service life:

- Aging / deteriorations
- Fatigue

- Changes to environmental loads
- Hazard profile change of installation
- Process and well condition changes over time
- Installation modification
- Obsolescence
- Technology and knowledge advances
- Limitations of monitoring programs and techniques (C-NLOPB, 2019)

The initial safety-critical element assessment should begin with the collection of SCE data. This would entail the review of the original design basis documentation along with the operating, inspection, and maintenance history of the equipment. It should also include input from various functions supporting the asset to ensure procedural and human factors associated with any asset extension, not already captured by the maintenance system, are taken into consideration.

Secondly, a Verified Service Life must be established. A specified design or service life is intended to mitigate the operational failure of a piece of equipment due to time-dependent degradation mechanisms. In some cases, the service and/or design life of a piece of equipment may have been specified in the equipment's original design documentation. In other cases, service life must be established based on engineering judgment after assessment of the equipment condition, discussions with the original manufacturer, maintenance history, and current and predicted future operating conditions. At a minimum, the following systems should be assessed to establish the VSL of all SCEs and supporting systems:

- Structures

- Production Systems
- Marine Systems
- Pipelines and Subsea
- Drilling Systems
- Safety and Environmental Systems
- Wells
- Electrical Systems
- Pressure Systems
- Control and Instrumentation
- Mechanical Handling Systems
- Communications Systems (C-NLOPB, 2019)

Utilizing a piece of equipment beyond its service life reduces its reliability and increases the risk of failure and potential required maintenance. With the VSL of all SCE equipment established, a Preliminary Life Extension Plan (PLEP) must be developed to extend the VSL of all equipment and systems to the facility's new forecasted end of life. To mitigate this risk, a list of required upgrades, maintenance strategies, repairs, or replacements must be made to close established gaps in extending the VSL to the new end of life to ensure it remains fit for purpose. The established gaps will vary in magnitude and potential consequence and therefore overall risk. The PLEP should prioritize the established gaps based on a risk-based prioritization. (C-NLOPB, 2019)

With an established PLEP and alignment with both the C-NLOPB and the facility Certifying Authority (CA), the Operator can plan and establish the Life Extension Project (LEP). The LEP must include all the necessary actions/repairs/replacements to ensure the affected safety-critical systems are able to provide the necessary level of protection against the established Major Accident Hazards. This will include all items stemming from the previously completed/revalidated studies, inspections, as well as CA and regulatory input. (C-NLOPB, 2019)

As previously stated, each facility is subject to ongoing regulatory oversight, including the asset life extension period. Before the C-NLOPB renews an OA, the CA must issue a renewed COF. During the asset life extension phase, this includes a plan for the life-extension project which demonstrates that all necessary activities will be completed before the life-extension period.

The Safety Plan is one of the documents that must be updated and revised for aging facilities OA renewal. As per the C-NLOPB ALE guidance document, the following topics should be included:

- Defined timeframes of SCE inspections and risk assessments specifically for aging issues
- Structural integrity assessments
- ALARP demonstration
- Fire and explosion risk assessments
- Design parameter identifications
- Aging processes
- Changes in operating conditions and any performance standards that may limit the life of the installation, or of its SCE (C-NLOPB, 2019)

The Asset Design Life Extension Program Guideline issued by the C-NLOPB makes it clear that managing the risk of an aging platform, with respect to safety-critical equipment and processes, is of paramount importance. The previously completed risk analysis documents must be reviewed and revalidated, and changing and new hazards must be realized.

With respect to asset life extension for local offshore oil and gas facilities, the notion is somewhat new to the region as the facilities are only now approaching the end of their original design life. While a new concept for the local region, extending facility design life has been practiced in other regions. As asset life extension is not a novel notion, the concept of ALARP is more applicable than the concept of the precautionary principle.

While considering safety-critical and life-saving systems for an asset life extension project, it is important to critically review the past operating history, maintenance regimes, modifications to the original system design, equipment failures and/or modifications, obsolescence, and changes to regulatory requirements and industry best practice. Typical systems to be reviewed under an asset life extension program, with respect to safety systems, include but are not limited to:

6.2.1 Firewater Systems

It is imperative that firewater and deluge systems of offshore facilities are thoroughly reviewed to determine the current system status and identify the potential risk of increasing the service life. Any modifications to the original system design should be reviewed, monitored, and analyzed. Deluge testing results should be trended to aid in the understanding and analysis of the system operations. A thorough review of past fire pump maintenance, failures, and performance must be determined. Historical firewater pump output and pressure, as well as the pressure at the ring main(s) and individual deluge skids/valves should be reviewed to ensure they are within the design range. Any known additional future firewater requirements should also be considered in the assessment. Firewater piping corrosion reports must be reviewed to determine if repairs or replacements are required. Concerning firewater piping, corrosion under insulation should be considered. Original equipment manufacturers for major pieces of equipment should be contacted to determine if there any issues with equipment obsolescence for the perceived duration of the proposed life extension.

As the firewater system review is a multi-disciple engineering review, engineering judgment following systematic analysis must be utilized to determine the feasibility of extending the system service life. All potential risks of extending the service life must be identified such that mitigating measures may be put in place to ensure the system risk of failure is ALARP.

6.2.2 Foam Systems

In addition to the sentiments highlighted above under the firewater system review, there are increased requirements for foam systems to comply with changes to environmental practices. The industry is moving into more environmentally friendly foams, moving from a C8 to C6 fluorochemistry firefighting foam. Synthetic firefighting foams, including aqueous film-forming foam (AFFF), alcohol-resistant aqueous film-forming foam (AR-AFFF), and film-forming fluoroprotein foam (FFFP), utilize perfluorinated surfactants and low molecular weight polymers in their manufacturing. Perfluorinated surfactants contained in firefighting foams have almost exclusively been produced by the telomerization process, with these surfactants containing carbon chains ranging from C4 to C24 in length. It has been found that higher carbon changes (C8 and above) can break down in the environment to produce perfluoroctanoic acid (PFOA) or other perfluorocarboxylic acids (PFCAs) while shorter chain compounds have a lower potential for toxicity and bioaccumulation. (Tyco, 2016)

The foam manufacturing industry has moved from the production of C8 foam to C6 foam. For facilities that have not yet fully transitioned their firefighting foam systems to a C6 formation, they would be required to do so for asset life extension.

6.2.3 Passive Fire Protection (PFP) Systems

The primary objectives of PFP systems for offshore facilities, in general, are to prevent the weakening and collapse of primary, load-bearing, structural steel; to maintain the integrity and viability of the temporary refuge, escape routes, and evacuation systems; and to protect critical components and essential equipment/systems.

Fire-resistant coatings and coverings, fire/blast rated bulkheads, partitions and doors, and fire and blast rated pipe penetrations and cable transit seals typically form the basis of a passive fire protection system aboard an offshore installation.

Passive Fire Protection systems are susceptible to “physical aging” as opposed to “reliability-based” aging concepts. Physical aging corresponds to a slow, continuous process of degradation of the equipment properties and functions. (Health and Safety Executive, 2007). There are differing anomaly or failure types for PFP coating systems. The HSE provides guidance on the various anomalies:

Surface Cracking and Spalling – This can be a result of incorrect application, exposure to extreme weather and operating conditions, or general wear over time. Intumescent coatings generally have low ductility levels; when applied to vessels or surfaces that expand and contract with temperature, particularly on heated vessels, cracking tends to occur.

Water Ingress and Corrosion – This is generally due to a breakdown of the topcoat, deep cracking, and disbandment. If left over time, excessive corrosion under insulation will occur.

Disbondment – With disbondment, separation can either be between the PFP system layers or at the interface between the PFP and the protected surface. The coating is bonded to the steel substrate by adhesive force but the primary retention is provided by mesh, a physical retention mechanism. If the material loses its adhesion with the substrate the mesh allows the coating to maintain its fire protection capability. However, the corrosion rate of the steel mesh and support pins will accelerate if there is excessive moisture within the coating.

Chips and Gouges – This usually occurs due to physical exposures and contacts with sharp, abrasive objects.

Erosion – Typically, these occur at weather-exposed surfaces and at the extremities, for example, where wind speeds are high and harsh weather is common. (Health and Safety Executive, 2007)

6.2.4 Life-Saving Appliances and Rescue Equipment

In terms of an asset life extension review, life-saving appliances and rescue equipment generally refer to items such as lifeboats, davit systems, life raft systems, fixed escape systems, and fast rescue craft where a facility is outfitted with such. For items that may be easily replaced, such as throw-over life rafts, there is an existing predetermined service life and as such an assessment would not be required.

Lifeboats and fast rescue craft can have a service life that would exceed that of a facility if the equipment has been properly maintained and the equipment is not obsolete such that spare parts will remain available for the foreseeable future. With respect to survival craft, known issues with a particular model type or a manufacturer that is no longer supporting the equipment could necessitate a full replacement.

The goal of the system review is to determine the service life of the system and identify the changes and/or modifications that may be required to increase the useful life of the system to facilities updated end of life. In some cases, the service life may not be able to be extended, and a full system overhaul and/or change out may be required. Conversely, it may be found that the system is in excellent working order, with a verified service life past exceeding the facility end of life, and no modifications are required.

While offshore oil and gas asset life extension projects have been undertaken in other areas for some time, the concept has only recently been required locally for the offshore Newfoundland and Labrador facilities. It is of my opinion that the concept of ALARP ties more appropriately into an ALE project than that of the concept of the Precautionary Principle. But perhaps there should be learnings taken from both; Risk assessing the criticality of a suggested upgrade (as opposed to a do-nothing approach) can aid in the decision-making process on the future reliability, survivability, and availability of individual pieces of equipment or safety systems as a whole.

As we saw in 2020, unique challenges are facing the offshore oil and gas industry. A global pandemic has threatened many local oil and gas projects, and of noteworthy concern the asset life extension of the Terra Nova FPSO. While a global pandemic is an unexpected setback and one that would not be qualified within any risk assessment, perhaps one may hypothesize, at least with respect to timing, if perhaps PP could have been applied. There are always unknowns and novelties as we undertake a new process within a geographical region. While it is still my opinion that decisions, with respect to the extension for safety systems, should be made based on the principle of ALARP, if and when there is uncertainty, one should take precaution to ensure the owner has taken all necessary steps to protect the overall safety of the people, asset and environment.

7 C-NLOPB Current Regulatory Regime and Upcoming Regulatory Changes

As previously stated, the C-NLOPB regulates local offshore installations through a suite of existing regulations and guidelines. These regulations and guidelines have been issued and modified based on the authority derived from Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act. C-NLOPB regulations have been continuously evolving, with new regulations being added, since they first were established beginning in the late 1980s.

The current regulatory regime is somewhat prescriptive in that, for the large part, they dictate how an Operator is to achieve regulatory compliance. Changes are coming to the regulatory framework to transition from a prescriptive based regulatory regimen to a hybrid approach where goal-based regulations are preferred.

7.1 Frontier and Offshore Regulatory Renewal Initiative

The Frontier and Offshore Regulatory Renewal Initiative (FORRI) is a federal/provincial government partnership initiative focusing on regulations in all offshore administrative areas in Canada. FORRI was created through the Atlantic Roundtable initiative in 2005. (McNeil, 2019)

It is the intent of FORRI to modernize the regulatory framework not only to performance-based requirements but also to reduce redundancy across multiple regulations, bring standards up to date, and enable a more efficient and effective regulatory regime. In the development of performance-based requirements, the focus will be more on the regulatory goal rather than the means. This will allow the regulations to have more flexibility to incorporate changing practices, standards, and technology.

The current regulatory process has an overwhelming regime with respect to seeking approval for regulatory alternatives outside the current regulations' prescriptive requirements. FORRI intends to streamline the process and reduce the need for regulatory approval on the means of achieving a regulatory requirement/goal, thus reducing the administrative burden on the industry.

FORRI intends to eliminate five existing regulations and integrate them into one new framework regulation. These five regulations are:

- Operations Regulations
- Installation Regulations
- Drilling and Production Regulations
- Geophysical Regulations
- Certificate of Fitness Regulations (Government of Canada, 2020)

There are five major stages to regulatory development in Canada:

- Developing policy intent to inform the drafting of the regulations
- Drafting regulations
- Pre-publication in Canada Gazette I
- Public comment period on draft regulations
- Publication in Canada Gazette II (Government of Canada, 2020)

The publication of the FORRI into the Canada Gazette has been delayed and the pre-publishing of draft regulations into Part I of the Canada Gazette awaits, at which point, the public has an opportunity to comment on the draft regulations. Prior to coming into force, the final regulations will be published in Part II of the Canada Gazette. It is anticipated that draft regulations will be entered into Part I of the Canada Gazette sometime in 2021.

With the transition to FORRI, the applicable regulatory boards, i.e., C-NLOPB, will issue new guidelines to be utilized in conjunction with the new regulations. The guidelines will not be mandates but will aid in ensuring compliance. While the concept of the Certificate of Fitness will remain the same, with the implementation of the FORRI regulations, a certification plan will now be required. As the FORRI regulations are intended to move away from prescriptive requirements, including the standards a facility must meet, a certification plan will be required to outline the codes and standards a facility is designed against to meet the regulatory intent. This effectively implements the ALARP principle into the new regulatory framework as the planned measures each Operator will implement to meet regulatory compliance must be demonstrated. (McNeil, 2019)

In addition to the development of the Framework Regulations, the Atlantic Occupational Health and Safety Initiative is also working to revise and modernize the occupational health and safety regulations to enhance safety and environmental protection. (Government of Canada, 2020)

The proposed policy intention for the Framework Regulations is available for review. While not yet in force, early review of the regulatory updates is of paramount importance as differing regulatory requirements from the existing regime can have a great effect on offshore operations and future design.

The current policy intention for the Phase 1 of Framework Regulations contains the following sections:

Part 1 – Board Powers

Part 2 – Management System

Part 3 – Application for Authorizations and Approvals

Part 4 – Operator Duties (Government of Canada, 2016)

The current policy intention for the Phase 2 of Framework Regulations contains the following sections:

Part 10 – Evaluation of Wells, Pools and Fields

Part 11 – Measurements

Part 12 – Production Conservation

Part 13 – Terminations and Decommissioning

Part 14 – Submissions, Notifications , Records and Reports (Government of Canada, 2016)

The current policy intention for the Phase 3 of Framework Regulations contains the following sections:

Part 5 – Certificate of Fitness

Part 6 – Installation Analysis, Design, Construction and Maintenance

Part 7 – Systems and Equipment Design, Operation and Maintenance

Part 8 - Geoscience, Geotechnical and Environmental Operations

Part 9 – Support Operations (Government of Canada, 2017)

Phase 3 FORRI proposed requirements, Part 6, Installation Analysis, Design, Construction and Maintenance and Part 7, System and Equipment Design, Operation and Maintenance, were reviewed against the current C-NLOPB regulations noted below:

SOR/95-104 Newfoundland Offshore Petroleum Installations Regulation (C-NLOPB, 2020)

SOR/2009-316 Canada Oil and Gas Drilling and Production Regulations (C-NLOPB, 2014)

The following items noted are some of the more substantial differences with respect to Technical Safety design. The below items are not intended to be an exhaustive listing and aim to highlight some of the more prudent changes that affected the discipline of Safety and Risk.

7.1.1 FORRI Gap Assessment

7.1.1.1 FORRI 6.6 Fire, Explosion and Hazardous Gas Risk Assessment

FORRI 6.6 states, "the operator shall ensure that a methodical and comprehensive fire and explosion risk assessment, as well as a hazardous gas containment and risk assessment are carried out for every installation" (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019) however the current C-NLOPB regulations do not require such an assessment for the accommodations and/or Temporary Refuge. The proposed requirement displays the shift from a prescriptive design to a more goal-based design, echoing the requirements of the UK.

7.1.1.2 FORRI 6.7 Passive Fire and Blast Protection

FORRI 6.7 states that "The operator shall ensure that every installation is equipped with sufficient passive fire and blast protection and barriers…". Furthermore, it states a prescriptive requirement for H-120 fire-rated division for "external bulkheads of the Temporary Safe Refuge, accommodations, evacuation embarkation points excluding helidecks, and control rooms that are facing production or well heads; and the bulkheads that segregate the well head and production process areas from other areas of the installation." These prescriptive H-120 requirements are not a part of the current set of C-NLOPB regulations.

Additionally, the proposed FORRI regulations also require that all installations, at a minimum, meet the fire and blast requirements of a classification society regardless if it is intended to be a classed facility. Linkages to class society is a new requirement and not currently applicable under the C-NLOPB regulations; however, these requirements are often met in practice. (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019).

7.1.1.3 FORRI 6.8 Prevention and Mitigation of Major Accidents

A regulatory clause specific to the prevention and mitigation of major accidents is a new requirement that is not explicitly stated in the current C-NLOPB regulations. It states:

> *The operator shall ensure that the reliability and availability of every system, the failure of which could cause or contribute substantially to a major accident event or the purpose of which is to prevent or limit the effects of a major accident event, is demonstrated through formal and appropriate risk and reliability analysis techniques to identify required redundancies and measures to protect that system from failure.* (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019).

This clause points to a stricter requirement around the identification and design of Safety Critical Elements (SCE) as well as the generation of applicable Performance Standards (PS) that are referred to in the C-NLOPB Drilling and Production Guidelines. This somewhat new requirement for FORRI emphasizes the movement towards a goal-based regulatory process and the importance placed on the use of SCEs and PSs.

7.1.1.4 FORRI 6.19 Classification and Access to Hazardous Locations

FORRI 6.19 states:

> *(1) The operator shall ensure that every platform is divided into different hazardous areas according to the type of activities that will be carried out and according to the associated hazards; and that higher risk areas are segregated from lower risk areas, and from areas containing important safety functions.*
>
> *(2) The operator shall ensure that* ***hazard identification and risk assessments*** *are carried out for each area to identify hazardous areas in which an explosive atmosphere may occur.*
> *….* (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019).

The requirements of this section of FORRI are largely covered under Section 9 Access to Hazardous Areas of the SOR/95-104. However, FORRI has more emphasis on specific hazard identification and risk assessments. Again, moving away from our current regulatory regime's prescriptive requirements and moving into more goal-based requirements based on site-specific risk analysis and review.

7.1.1.5 FORRI 7.30 Fire, Gas Detection

FORRI within this section requires:

> *The operator shall ensure that every fire and gas detection system is designed, arranged, including location, number, and types of detectors, tested and maintained such that:*
>
> *a. they are based on the* ***Fire, Explosion and Hazardous Gas Risk Assessment*** *in 6.6 and that they will ensure that any such fire, explosive or toxic gas accumulation, or other foreseeable abnormal conditions related to hazards identified in the Assessment will be detected;*
>
> …
>
> *j. means to manually initiate fire and gas alarm shall be available at or near the office of the manager of the installation, at the control center, at every control station and* ***other defined locations throughout the facility identified in the Fire, Explosion and Hazardous Gas Risk Assessment*** *required under 6.6;* (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

As stated previously, the Fire, Explosion and Hazardous Gas Risk Assessment is a new scope for the accommodations area/Temporary Refuge. Additionally, defining "other" areas to manually initiate fire and gas alarms based on a fire and gas assessment would likely require an assessment in greater detail than what has been completed in the past. The emphasis on design and installation in accordance with the required Fire, Explosion and Hazardous Gas Risk Assessment differs from the current C-NLOPB regulations, which require fire and gas detection devices to be designed, installed and maintained in accordance with prescriptive requirements such as design to National Fire Protection Association (NFPA) 72 and American Petroleum Institute Recommended Practices

14C and 14F. (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019) (C-NLOPB, 2020)

7.1.1.6 FORRI 7.31 Ignition Prevention

Ignition prevention is a new section listed within FORRI, and it encompasses portions of various sections of the current C-NLOPB regulations. FORRI, Section 7.31 states:

> *1) The operator shall ensure that materials and equipment on an installation are arranged, at all times, to prevent ignition of combustible and explosive fluids, and that measures are taken:*
>
> *a. to prevent fire and explosion, including measures to prevent uncontrolled release or accumulation of combustible or explosive substances; and*
>
> *b. to prevent the ignition of such substances and atmospheres.*
>
> *(2) All mechanical and electrical equipment located in a* ***hazardous area identified in accordance with 6.19(2)*** *shall be suitably designed, rated, protected, ventilated and maintained for safe operation in their intended location.*
>
> *(3) All equipment that is not suitably rated for use in a hazardous area shall be operated only at a safe distance from any potential source of combustible or explosive fluids and shall be equipped with automatic and manual means of deactivation in the event of gas detection (deactivation includes shut off and de-energize).*
>
> *(4) Any equipment that is to remain active in the event of an emergency associated with gas release is to be suitably rated for operation as if it was located in a hazardous area.*

(5) The operator shall ensure that hot work is only carried out under a permit to work system that has pre-determined safe distances from wells and other sources of ignitable and explosive fluids and other risk mitigation measures identified through risk analysis to prevent ignition.

(6) The operator shall ensure that the requirements in this section are supported by ***comprehensive risk assessments*** *specific to the installation.*

(7) The operator shall ensure that cargo tank internal atmospheres are maintained outside the explosive limits and that such systems will be designed, equipped with sufficient barriers, alarms and redundancy to:

a. prevent risks to safety during all modes of cargo operations; and

b. ensure that personnel are made aware when such systems become impaired. (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

Like other portions of FORRI, this section is now more goal and compliance-based, putting more design priority on the use of risk assessment and reviews.

7.1.1.7 FORRI 7.32 Emergency Shutdown and Blowdown

This FORRI section is relatable to Section 18, Emergency Shutdown System, of the C-NLOPB Installation Regulations; however, it has been revised to include a more goal and compliance-based approach. It states that "The operator shall ensure that the emergency shutdown system design shall be based on a formal risk assessment and analysis." (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

Within this section of the proposed regulations, there are new requirements not currently present in the C-NLOPB regulations, such as specifying that cold venting cannot be included in the emergency depressurization and disposal of hydrocarbon inventory. Furthermore, it specifies that temporary equipment on an installation shall be integrated into the installation emergency shutdown system and adhere to the system logic.

7.1.1.8 FORRI 7.33 Fire Protection Systems and Equipment

The portion of FORRI relates to the requirement of ensuring that "all safe and reasonable measures are taken at every installation and operations site to control and extinguish or control fires as appropriate and to minimize any danger to safety or the environment that results or may be reasonably expected to result from the fire."

Again, this section relies heavily on installation-specific hazard assessments rather than the prescriptive requirements of C-NLOPB SOR-95-104, which notes various standards to which a fire protection system must comply. FORRI states, "The design and selection of fire protection systems and equipment, including suppression agents is appropriate for its intended use based on the Fire, Explosion and Hazardous Gas Risk Assessment required in 6.6." (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

FORRI section 7.33 (9) states that the “firewater system must be able to run continuously for a minimum of 18 hours”, this is a relaxed requirement from C-NLOPB SOR-95-104, which requires a period of 24 hours.

Additionally, prescriptive requirements surrounding the design of fire hydrant systems, Section 24 C-NLOPB SOR-95-104, are not present in the proposed FORRI requirements. It allows more room for engineering design and best practice and only states, “The number and position of the hydrants and/or fire hose reels shall be such that at least two jets of water, not emanating from the same location, may reach any part of the installation normally accessible. For areas where the use of hydrants and hose reels is impracticable portable fire extinguishing equipment may be provided.”

7.1.1.9 FORRI 7.36 Evacuation and Escape

This portion of the proposed FORRI regulations intents to “ensure that every installation has the most suitable and most effective facilities and technology practicable for safe and controlled emergency response during accidental events.” (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019) This section is more robust with respect to requirements of the design of the Temporary Refuge and provides more guidance in comparison to the current C-NLOPB regulations. The FORRI requirements are more goal-based, where the onus is on the operator to demonstrate temporary refuge, and evacuation systems are sufficiently designed against the installation-specific hazards and allow for safe evacuation based on the approved escape and evacuation studies.

7.1.1.10 FORRI 7.37 Lifesaving Equipment for Offshore Installations

The section of FORRI details the requirements of the Operator to "ensure every offshore installation is designed for and equipped with sufficient lifesaving equipment, survival craft and launching facilities safe evacuation of all personnel." (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

FORRI Section 7.37 is similar in nature to Section 22, Lifesaving Equipment for Installations, of C-NLOPB Petroleum Installations regulations. However, there are new explicit requirements in FORRI regarding the number and locations of evacuation stations. It states:

> *(3) The operator shall ensure that the arrangement and selection of the lifeboats is based on a formal Escape, Evacuation and Rescue Analysis that considers all of the major accidental events evaluated in the Quantitative Risk Analysis and that:*
>
> *a. each installation arrange for lifeboats in at least two separate locations; and, ensure that those locations, based on the installation's safety studies,*
>
> *including the escape and evacuation analysis, provide the optimal redundancy for evacuation from the installation for all foreseeable emergency scenarios;*
>
> *b. such lifeboats (and associated equipment such as launching mechanism) shall include features to maximize escape [from the installation];*
>
> *c. at least one location is adjacent to the temporary safe refuge; and*
>
> *d. provides sufficient capacity to accommodate the total number of persons on board if a lifeboat in any one location is lost or rendered unusable.* (Government of Canada; Government of Newfoundland and Labrador; Government of Nova Scotia, 2019)

There is a clear shift in the proposed FORRI framework regulations whereby the expectation is safety and risk-based decisions are to be formulated based on facility-specific safety-related studies and the established QRA.

7.1.2 FORRI Effects

As highlighted in the previous sections, the proposed regulatory updates represent a global shift from the current prescriptive requirements to more performance-based requirements. With respect to regulatory compliance, Operators will now be required to develop and submit a certification plan highlighting how an Operator meets, or intends to meet, a regulatory initiative rather than completing a regulatory compliance matrix.

This shift gives the Operator more flexibility on how they meet, or intend to meet regulation, and increases the need to prove their methods/design are effective and appropriate.

8 Conclusion

Newfoundland and Labrador has a long standing history in the oil and gas sector. Throughout the last 40 years, the local industry has seen many changes; new discoveries, new facilities, and new opportunities. Along with the successes, there have been accidents and tragedies. However, emerging from these accidents, the industry moved toward a more safety prominent culture with increased regulations and stronger risk management. The industry continues to grow and evolve, some of the existing facilities are aging and coming upon the end of their original design life. With aging, new hazards may immerge or old hazards may be modified. It is necessary to analyze risks as changes immerge throughout a facility's lifecycle to ensure risks remain tolerable and ALARP. Newfoundland's oil and gas regulatory regime is in the process of renewal and revitalization through the Frontier and Offshore Regulatory Renewal Initiative. It is the intention that the regulatory framework is to transition from a prescriptive based regulatory regimen to a hybrid approach with goal-based regulations. As FORRI allows for more freedom on how operators are to comply with the regulatory intent, it places strong emphasis on site specific hazard identification and risk analysis, effectively implementing the ALARP principle into the new regulatory framework.

9 Recommendations

This body of work, in its current state, can aid in the risk management practices of oil and gas operators. This thesis can also serve as an aid in the review of safety systems associated with facilities undergoing asset life extension. Additionally, with respect to upcoming regulatory renewal initiatives the identified gaps highlighted under Chapter 7 may allow operators an advance indication of potential impact on safety system design.

For future improvement of this work, it is recommended that the following items are expanded upon:

- With every MAE there are learnings and systemic factors which can be strengthened. The aftermath of some MAEs have a global impact, such as those highlighted in this thesis. Additional MAEs could be researched and analyzed to determine the associated lessons learned to highlight potential risk reduction techniques to be employed in future works.
- If appropriate data could be obtained, the completion of a case study would be beneficial in demonstrating the potential risks associated with asset life extension. Furthermore, mitigating measures could be identified to reduce the risks to ALARP.
- To further demonstrate the potential of technical safety and risk impacts of the regulatory changes associated with FORRI, a case study could be conducted. It should be noted that this assessment would likely contain proprietary information associated with a local facility.

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