MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

Risk Acceptance Criteria: Overview of ALARP and Similar Methodologies as Practiced Worldwide

White Paper

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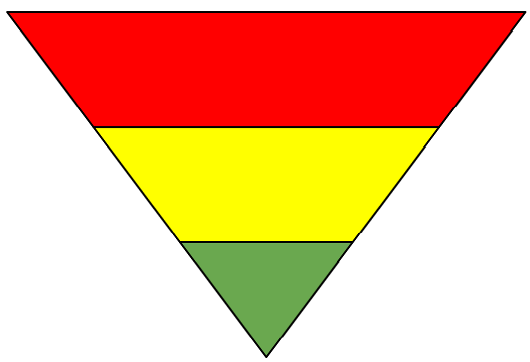

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
CBA	Cost Benefit Analysis
CCPS	Center for Chemical Process Safety
CSB	Chemical Safety and Hazard Investigation Board
DNV	Det Norske Veritas
EPA	Environmental Protection Agency
EU	European Union
FERC	Federal Energy Regulatory Commission
HSE	Health and Safety Executive
ILO	International Labour Organization
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NPD	Norwegian Petroleum Directorate
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PHMSA	Pipeline and Hazardous Materials Safety Administration
QRA	Quantitative Risk Assessment
RAC	Risk Acceptance Criteria
RAGAGEP	Recognized And Generally Accepted Good Engineering Practices
SFAIRP	So Far As Is Reasonably Practicable
SWA	Safe Work Australia
VROM	Volkshuisvesting, Ruimtelijke Ordening en Milieu

EXECUTIVE SUMMARY

The Deepwater Horizon oil spill catastrophe in 2010 initiated the discussion of adoption of a performance-based safety regulation in the U.S.A. chemical and oil and gas industry, especially for offshore operations. ALARP, known for *as low as reasonably practicable*, the most popular performance-based safety regulation, is not a very well understood concept as risk acceptance criteria in places like the United States where it is not mandated. One of the reasons might be that the performance based or safety-case regulations are not practiced in similar manner worldwide. They have subtle differences that contribute to the confusion. Moreover, the legal structure and practices may interpret the risk decision making differently in different countries. The main objective of this white paper is to present a few performance-based regulations and their differences hoping it will improve the understanding of the concept of ALARP or similar methodologies practiced in different parts of the world.

The success of implementation of ALARP is dependent on an existing robust process safety structure in the industry and a strong regulatory structure. Therefore, the focus was placed on countries where process safety has achieved a mature state through the interaction of academic, industrial and regulatory institutions. Another important aspect that guided this study was the availability of literature and other regulatory standards and guidelines in English. After careful consideration, documents available from four countries were analyzed: Australia, the Netherlands, Norway and the United Kingdom. Also considered were guidelines from the European Union (EU), the US Nuclear Regulatory Commission (NRC), the US Federal Energy Regulatory Commission (FERC), the US Pipeline and Hazardous Materials Safety Administration (PHMSA), and the Center for Chemical Process Safety (CCPS), although neither the European Union nor the United States mandated the ALARP or similar methodologies.

A questionnaire was used to extract necessary information from the documents gathered from the regulatory agencies that mandate ALARP or similar principles in the respective countries. The questionnaire includes what are the risk acceptance terminology used for performance-based regulations and if they are mandated, what are individual and societal risk values used in the risk acceptance criteria, how qualitative or quantitative is the methodology, what are the underlying principles (basis of individual risk calculation, disproportionality factor, implied cost of averting a fatality) behind the cost-benefit analysis, what practice area ALARP is applied to, what are the driving criteria for the risk assessment, and how the legal system of the country affected the formulation and implementation of ALARP.

In all four countries considered, ALARP or similar principles are mandated. Australia, Norway and the United Kingdom use the terminology ALARP, whereas the Netherlands uses another terminology ALARA for *as low as reasonably achievable*. Safe Work Australia (SWA) uses a separate terminology as SFAIRP for *so far as is reasonably practicable*. Whether the countries use the same terminology or a different one, they are not defined exactly the same, they are subject to interpretation by the legal system and its precedence, and hence, they are applicable to only for the practice area they are intended for.

	Australia	Netherlands	Norway	UK	USA
Terminology used	ALARP/ SFAIRP	ALARA	ALARP	ALARP	N/A
Applicability (industry)	Offshore/ Onshore process	Housing, land use planning, and environment	Offshore	Onshore and offshore workplace	Nuclear radiation
Mandated or not mandated	Mandated	Mandated	Mandated	Mandated	Not mandated
Regulatory body	NOPSEMA/ SWA	VROM	NPD	UK HSE	N/A
Type of risk assessment recommended	Qualitative or quantitative	Quantitative	Qualitative or quantitative	Semi-quantitative	N/A
Principle of cost-benefit analysis	Company determined	Geographic location	Standard guided	Regulatory model	N/A
Mechanism to document	Safety case			Safety case	N/A
Risk Criteria	Individual and societal provided, but not mandated	Individual and societal	Individual	Individual and societal	N/A

Individual and societal risk criteria, driving criteria of the ALARP principle, type of industry where it has been mandated, recommended quantitative or qualitative approaches for risk estimation and associated uncertainty, and cost-benefit analysis as adopted in these four countries have been compared. The analysis showed a wide variation in mandated approaches. However, the goal of the underlying principles of the regulations and standards is to minimize risk wherever possible when it is economically and/or technically feasible.

To understand how the companies are using risk acceptance criteria especially ALARP, a brief survey was conducted among the member companies of the steering committee of the Mary Kay O'Connor Process Safety Center. It is evident from the survey that although there is not clear guidance on the establishment of the risk acceptance criteria from the US regulatory agencies (*e.g.*, EPA, OSHA, PHMSA, FERC), more than half of the participating companies indicated that they use some form of risk acceptance criteria in making risk management decisions. Some of the companies use the concept of ALARP. Although the survey is not statistically representative, nonetheless, it shows the industry is well aware of the concept of ALARP used elsewhere in the world.

Finally, the objective of the white paper is <u>not</u> to justify the utilization of the ALARP concept in the United States, rather it is to better understand the ALARP concepts used across the world, and understand their limitations and benefits. So, in due time, if the discussion arises whether to adopt ALARP or not, this will enable process safety experts to make a more informed decision about its application.

1. INTRODUCTION

1.1 Background

After the Macondo incident (CSB, 2016) in 2010, there have been a number of discussions made comparing the performance-based and the prescriptive-based regulatory systems for the chemical and oil and gas industries. Attempts have been made to explain the benefits of each system over the other (Barua, 2016; Jain, Reese, Chaudhari, Mentzer, & Mannan, 2017). In a performance-based system, companies establish performance goals that often include risk acceptance criteria. They are held accountable by the criteria as if they were part of the regulation. Risk estimates of the companies or operations are compared with a specific risk acceptance criteria or goal, which can be a numerical value or defined as, *as low as reasonably practicable* (ALARP).

The term ALARP arises from the United Kingdom (UK) legislation, which requires "Provision and maintenance of plant and systems of work that are, *so far as is reasonably practicable*, safe and without risks to health" (United Kingdom Parliament, 1974). The phrase, *so far as is reasonably practicable* (SFAIRP), in this and similar clauses are interpreted as leading to a requirement that risks must be reduced to a level that is ALARP. For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. The original ALARP principle, defined by the UK Health and Safety Executive (UK HSE), arises from the fact that infinite time, effort and money could be spent in an attempt of reducing a risk to zero, but doing so is not practicable, nor desired from society. It should not be understood as simply a quantitative measure of benefit against the detriment. It is more of the best practice of judgement for the balance of consequence due to risk taken and societal benefit.

Outside the UK, the ALARP principle is used in a few places. However, it may not have the exact same implications as in the UK, as "*reasonably practicable*". Often the discrepancy arises from the local culture and past historical practices. For example, the Netherlands standard of *as low as reasonably achievable* (ALARA) does not employ the concept of gross disproportionality. In Australia the implementation strategy is different. The objective of this paper is to provide a representative survey of how ALARP and similar concepts are applied worldwide and to highlight the similarities and differences among the criteria and how they are adopted worldwide. For the rest of the paper, the term ALARP has been used to represent the regulatory applications of the ALARP principle and other similar risk acceptance criteria.

1.2 Definition of risk and types of risk

In general term, risk is defined as the possibility of loss of any kind, and it can be interpreted in many ways depending on the practice area. In the context of chemical process industry, risk is understood as a measure of the negative effects that a hazard or a set of hazards could have on people, assets or environment. Risk takes both the probability of occurrence as well as the magnitude of consequences into account. In other words, risk can be expressed as product of the likelihood of a hazardous event and the severity of the impact. Calculated risks take on meaning only when used against a predefined risk ranking. The acceptability or tolerability of the risk must be defined objectively as well as based on the values suggested by the society or mandated by the regulatory agencies. Calculated risks can thus be compared to standardized risk criteria to assess the efficacy of safety measures. However, the ambiguity present in the risk analysis and risk evaluation process makes it difficult for decision making regarding the safety measures and risk acceptance (Rausand, 2015). Rightfully, ISO 31000 (2009)/ ISO Guide 73:2002 defines risk as the '*effect of uncertainty on objectives*'. The decision also involves risk of individual worker who is voluntarily present in the facility or people from the surrounding community on whom risk is involuntarily imposed.

Individual risk is defined as *the risk to a person in the vicinity of a hazard in terms of nature of injury, the likelihood of injury and the time period over which it occurs* (CCPS, 2009). Societal risk on the other hand is a measure of the risk to a group of people and is expressed in terms of the frequency distribution of multiple casualty events (CCPS, 2009). Whereas individual risk provides a perspective on process risk from an individual's point of view, societal risk provides a perspective of the risk affecting a group of people in the surrounding community from a potentially catastrophic event. Societal and individual risks are different sides of the same coin and both are necessary in assessing the benefits of risk reduction and judging the acceptability of risk.

The most common forms of presentation of individual risk include risk contour plots and individual risk profiles. Similarly, societal risk is represented in the form of F-N curves. The details of both types of risk are provided in CCPS guidelines (CCPS, 2009). Risk can also be classified as being voluntary risk or involuntary risk. Voluntary risk results from hazards of activities in which the person(s) participate, whereas involuntary risks result from hazards of activities in which no prior consent has been given. Generally, voluntary risk and individual risk go hand in hand, while societal risk is viewed as involuntary. Risky activities and operations may be considered acceptable or tolerable depending on whether they are voluntary or involuntary and there is a corresponding effect on the design and operation of various types of facilities.

1.3 Risk tolerance and risk acceptance

Risk management is about balancing between the benefits from risk being reduced versus probability of consequences from risk not being addressed. Risk events, when presented can be simplistically viewed as either broadly acceptable or tolerable or broadly unacceptable. Generally, there is a range presented between acceptable and unacceptable risk. This range is known as tolerable range and widely depends on the practice area, culture of the society, and regulatory principles of the country *etc*. The risk in this tolerable risk zone is not acceptable, however, for many cases significant resources and/or technology and/or know-how are required to reduce the risk further, and bring it into a broadly acceptable zone. UK HSE defines it as, *The zone between the unacceptable and broadly acceptable regions is the tolerable region* (UK HSE, 2001). Risk tolerance is the willingness to bear a certain risk to obtain certain benefits with the confidence that the risk has been controlled, is being reviewed, or will be reduced in the future. Risk acceptance refers to consent and to accept the level of risk present in an activity assuming no changes in the risk control mechanisms. However, the usage of the term risk acceptance should not be interpreted as implying or giving license to avoid implementing necessary preventive, mitigation, and response barriers in order to eliminate and control activities with significant levels of risk.

1.4 Establishment of risk acceptance criteria

Risk acceptance criteria (RAC) is the basis of decision making about accepting risk. Regulatory agencies across the world adopted different approaches to establish the risk acceptance criteria. In general, the criteria can be classified according to three 'pure' criteria. Regulators have either used these 'pure' criteria on their own or have used them as building blocks to create new criteria. They are (UK HSE, 2001):

Equity-based – notion is that all individuals have unconditional rights to certain levels of protection. This often converts into fixing a limit to represent the maximum level of risk above which no individual can be exposed. If the risk is above this maximum limit and further control measures cannot reduce the risk, the risk is deemed as unacceptable.

Utility-based – this approach measures risk reduction against cost. It compares the monetary value of benefits (*e.g.,* statistical lives saved, life-years extended) with the cost of prevention measure of a particular risk. It also requires a particular balance to be maintained between the two.

Technology-based – approach reflects the idea that application of state-of-the-art technology gives an acceptable level of risk.

Another principle that is used along with the aforementioned approaches is the precautionary principle, resulted from the work of the Rio Conference, or "Earth Summit" in 1992 (Rausand, 2015). The principle 15 of the Rio Declaration 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, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*". The approach suggests where there is lack of scientific certainty or higher uncertainty in risk assessment, precaution should be considered to avoid irreversible damages.

It is expected that risk related decision making should be made with sufficient certainty and understanding of the both the likelihood and consequence of an event occurring, which led to *uncertainty assessment*. Where this is not the case, a precautionary approach should be taken in decision making regarding risk management.

There are several risk acceptance criteria developed world-wide based on the approaches and principles described above such ALARP from the UK, SFAIRP from Australia, ALAP, and ALARA from the Netherlands. Although each of the principles seem similar, there are subtle differences among the methods and each method can be interpreted differently based upon the context. To clarify the differences between the different concepts, common definitions will be stated. However, not every country or body of law will have the same definition for each concept, even if they use the same terminology.

Risk acceptance criteria are needed to make judgements about the tolerability of the risk level and to help decide if additional risk reduction is required. An organization should have a sound understanding of how it is going to use the risk criteria before developing them. Risk estimated using any method only has significance when it is compared to specific risk acceptance criteria. They give experts and management the ability to decide if risk is too high or low for a given hazard.

1.5 Definition of the ALARP principle

The ALARP principle is a form of risk acceptance criteria used in the UK by HSE. It is a process by which organizations weigh risk against the resources needed to implement the corresponding risk-reduction measures. The overall process by which risk management is performed under the UK HSE, ALARP is as follows:

1. Identify the hazards
2. Decide who might be harmed and how
3. Evaluate the risks and decide on the precautions
4. Record significant findings
5. Review risk assessment and update if necessary

According the UK HSE, the objective of ALARP is to provide a process for duty holders to determine risk acceptance so that the sacrifice that they must endure to reduce risk comparable to the total risk involved. The primary focus of ALARP is on identifying the acceptability of risk, a task which largely resides in step 3 of the overall process. Under ALARP, risks are divided into three regions: broadly acceptable risk, intolerable risk, and tolerable if ALARP risk, as shown in Figure 1.1 (HIDCI5A, 2019).

The legal definition of ALARP was given by Lord Justice Asquith in Edwards vs. National Coal Board (1949) case. This judgment introduced the concept of gross disproportionation, stating that there must be a consideration of the risk and the sacrifice to reduce the risk, and that if the sacrifice is in gross disproportionation to the reduction in risk, then the duty holder discharges the onus on them.

In a few cases, existing good practice is sufficient to determine whether a risk is ALARP. Good practice is defined as standards that satisfy the law for a particular case. Good practice must be agreed upon by discussion between the stakeholders, which can include employers, trade associations, other government departments, trade unions, health and safety professionals, and suppliers.

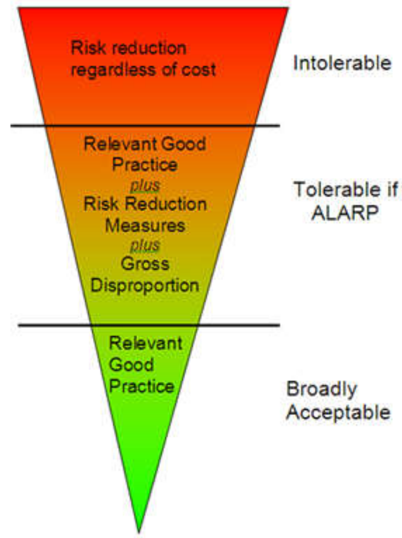

Figure 1.1 ALARP carrot diagram example given by UK HSE COMAH

However, in many other cases, there is no agreed upon good practice. In such cases, further examination must be done based on the first principles. This can be either qualitative or quantitative, depending on the situation. When the cost is clearly grossly disproportional to the reduction in risk, a qualitative analysis may suffice. However, when there is a high degree of hazard or if there is a novel or complex situation, where the cost and risk are not clearly grossly disproportional a semi-quantitative or quantitative cost-benefit analysis must be performed based on the first principles. Higher consequence cases would require more certainty within the analysis and would be held to a higher degree of rigor. Such a cost-benefit analysis would not constitute an ALARP case on its own but would also require a demonstration that good practice has been followed to the furthest extent possible. Furthermore, the depth of such an analysis would have to match the importance of the risk. If the risk has been reduced to the tolerable region, then no more risk reduction is necessary.

In general, ALARP as defined by the UK HSE puts the burden of responsibility on duty holders to find every reasonable safety measure, but also gives them the flexibility to decide whether such measures are necessary based upon a flexible but stringent methodology of analysis. The rigor of the analysis is not high unless there is a high degree of hazard, or if the case is complex or novel. Even when cost benefit analysis is required, a high degree of rigor is not always necessary. ALARP, as defined by the UK HSE is a well-established methodology for determining the acceptability of risk.

2. REVIEW OF RISK MANAGEMENT PRINCIPLES

2.1 Risk management process and assumptions

The responsibility of implementing a risk management plan differs from culture to culture, and there are different methodologies for implementing risk management, but the core tenets of risk management remain the same throughout most cultures. The responsibility of implementing such a risk management framework lies primarily between the government, the duty holders, the operators, and society as a whole. Since risk acceptability is a subjective matter that varies based on the perception of society as a whole (Melchers, 2001), the government, operators, and society should be involved in the process of deciding risk acceptability. But the duty holder is ultimately held responsible for the assessment, analysis, and management of risk (Abrahamsen, 2018; Ale, Hartford, & Slater, 2015).

Figure 1 shows a generalized framework for risk management that can utilize risk acceptance criteria, including ALARP. There may be variations in how each step is implemented, and the order by which they are implemented, but each step is necessary for a complete risk management plan.

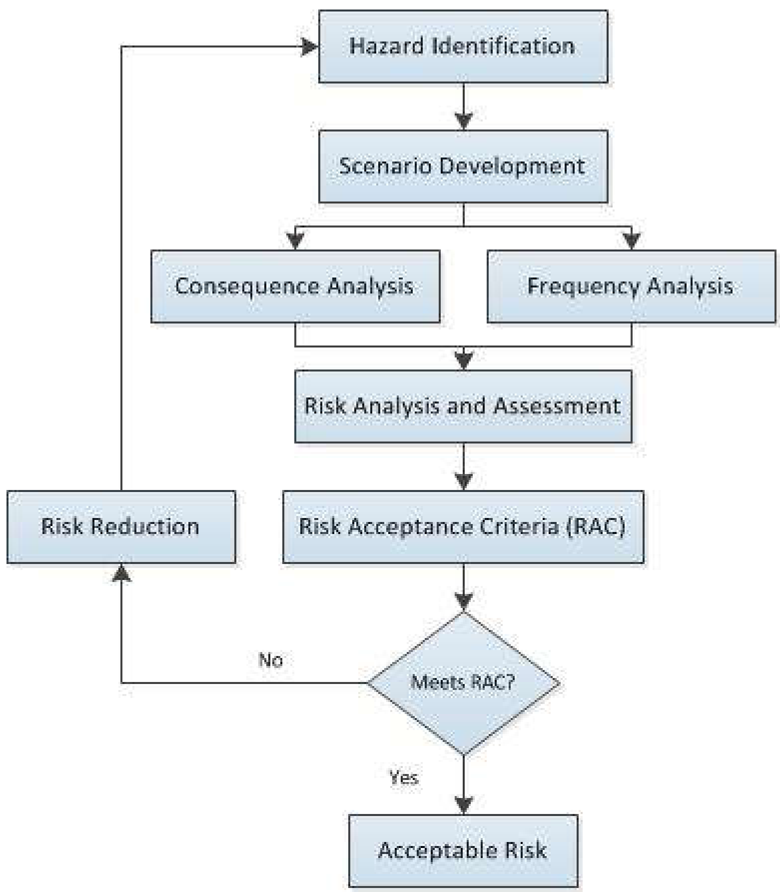

Figure 2.1 Assessment of risk and application of the ALARPs principle in risk management

Criteria for decision-making in risk management are typically categorized into three different approaches (Klinke, 2002; Yasseri, 2005): rights-based, technology driven, and utility-based. The rights-based approach allows many involved parties to discuss with each other in roundtables, apply their own risk acceptance criteria, and reach a decision that is acceptable to all of them. This approach only allows risks to be imposed on people if voluntary consent is given. However, it is very difficult to get every side to meet together and agree on what is acceptable, and is thus is primarily only used for new technologies. The technology driven approach focuses on the technical feasibility of risk-reduction and other safety measures. If an available technology can be feasibly used to reduce risk, then it must be implemented. This can sometimes be more expensive than necessary, and can lead to the use of untested and unviable technologies. ALARA is typically performed as an application of the technology driven approach. The utility-based approach weighs the preferential value, or the cost and benefit, of the possible outcomes against each other. Utility-based approaches examine cost-benefit analysis, cost-effectiveness, bounded cost, and multi-attribute utility. ALARP is typically performed as a utility-based cost-benefit analysis with a bounded level of risk.

The utility-based approach has problems of its own. Klinke (Klinke, 2002) defines three challenges that can undermine the validity of risk assessment in risk-informed decision-making to be complexity, uncertainty, and ambiguity. Complexity is the difficulty in identifying cause and effect links between failure modes, safety measures, and the resulting consequences. Interactions between different nodes, feedback loops, time delays, and other complicating factors cause complexity to increase. Uncertainty is made of distinct components such as measurement errors, ignorance, and indeterminacy. Uncertainty reduces the validity of the estimated cause and effect chains, and decreases the confidence in the result. Ambiguity refers to the different interpretation of the same data that results in different valuations of the same facts. Ambiguity is a difficult phenomenon to study and quantify because it is based on cultures and context, and varies even between individuals. Rausand (Rausand, 2015) defines ambiguity based on linguistic, contextual, and normative ambiguity, and outlines a stepwise procedure for approaching ambiguity in risk assessment.

2.2 Uncertainty in risk estimation

There have been different techniques adopted in risk assessment to estimate the uncertainties both in frequency of occurrence and event severity (Fenton & Neil, 2012; Markowski, Mannan, Kotynia, & Siuta, 2010). However, the methodology of how uncertainty information may be applied in risk acceptance decision making is somewhat unclear in ALARP guidelines. Baybutt notes that ALARP is *not intended to address uncertainties in risk estimates* but instead to focus on reducing risk to a *de minimis level* (Baybutt, 2014). This means uncertainty can be dealt with by risk distributions and other methods of uncertainty analysis, or utilizing the precautionary principle. The precautionary principle requires action when the lack of scientific certainty makes measuring likelihood improbable. This lack of scientific uncertainty cannot be a reason for delaying cost-effective safety measures. The obligation to implement safety measures increases with increasing risk and uncertainty. Clearly, ALARP at its core, demands a more cautionary approach and therefore leans towards the use of the precautionary principle when uncertainty is large or less quantifiable (Abrahamsen, Abrahamsen, Milazzo & Selvik, 2018; Baybutt, 2014). In essence, use of the precautionary principle results in a conservative estimate detailing a worst-case scenario. The assumptions from this worst-case scenario are often manifested as safety factors in practice (Baybutt, 2014).

2.3 Cost-benefit analysis (CBA)

Regardless of variations in risk acceptance criteria and ALARP within and among countries, most applications of ALARP and similar methodologies involve some form of cost-benefit analysis. The role of cost benefit analyses in ALARP process is evaluated by Aven and Abrahamsen (Aven & Abrahamsen, 2007). As stated, standard cost-benefit analyses should be used with caution as the net present value calculations to large extent ignore uncertainties and use of these procedures can be questioned. In an attempt to resolve the apparent conflict between ALARP and CBA, Lee and Aven examined the requirements that are being implied by the ALARP principle (Jones-Lee & Aven, 2011). CBA suggests a safety improvement only if cost does not exceed the resultant benefits. Whereas the ALARP concept demands duty holders reduce risk as low as reasonably practicable, improvement must be undertaken if costs are not in 'gross disproportion' to benefits. This results in costs exceeding the benefits substantially in some cases using a traditional analysis. However, CBA can be adjusted under an ALARP framework. This results in the use of the disproportionate criterion, the control is adopted unless the costs are grossly disproportionate to the benefits (Baybutt 2014; Ale, Hartford & Slater, 2015). As Ale *et al*. succinctly summarizes, ALARP guides how the information from a CBA is applied, rejecting the idea that cost be equal to the benefits, but instead some level of disproportionality must exist between the two (Ale, Hartford & Slater, 2015).

One of the biggest complicating factors in CBA is the valuation of the life that is at risk. There are many methodologies that have been adopted to measure the value of a life, but all of them have faced criticism for various reasons **and there is no agreed upon standard** (M. Rausand, 2011; Yasseri, 2005). Such methods include Value of a Statistical Life (VSL), Net National Product (NNP), Value of Averting a Fatality (VAF), Implied Cost of Averting a Fatality (ICAF), and Life Quality Index (LQI). ICAF and VAF are nearly identical concepts. While the valuation of life may be a necessary evaluation under CBA, ALARP strongly encourages any control that would decrease the risk to human life and health.

2.4 Use of quantitative risk assessment

While ALARP, ALARA, and similar methodologies are not the only methodologies for decision-making in risk management, they are useful tools. Taylor (Taylor, 2016) studied QRA reports of 92 plants with a total of 7,134 units years of experience, and found 26 major incidents occurred in these plants over 36 years. One of the top three lessons recommended by him includes "*Always make a detailed cost benefit or ALARP analysis*". He strongly suggested implementation of automated ALARP assessment of all possible risk reduction measures (Taylor, 2016).

Schofield (Schofield, 1998) highlighted the need to evaluate QRA results on the basis of the limitations in methods and techniques used, as well as uncertainties in failure data, objective knowledge and subjective ignorance. **This reinforces the need for the precautionary principle when dealing with large uncertainties** and adjusting a CBA with the disproportionality criterion. This results in "stronger weight being placed on uncertainties and the [precautionary] principle than is the case with" traditional cost benefit analysis (Abrahamsen 2018).

Further details on QRA and methods to identify, guard against and take decisions about low probability and high consequence events are available in the literature (Pasman, 2016). Regulatory schemes tend to favor a semi-quantitative analysis as the true benchmark level of *de minimis* risk which is difficult to quantify. Overall, ALARP requires a more case-by-case basis approach, as the details of each scenario will affect the management of risk, the potential regulatory impact of ALARP, and the techniques used to demonstrate that risks have been reduced to a minimum acceptable level differently.

2.5 Complexity in decision making

Variations in context across countries shapes risk acceptance criteria and the way that the principle of risk acceptance criteria has been influenced. Ale described how the implementation of policy on the control of major hazards is country-specific and is shaped by risk perception and existing legislation (Ale, 1991). The example of setting the cumulative risk threshold of 10^{-5} in the Netherlands is based on consideration of population density, chemical facility proximity, risk to human life, and risk to the environment. Melchers notes that the principle of risk acceptance criteria is complex and identifies several factors affecting it, most notably the extent of societal participation as factors in defining risk acceptance criteria and the corresponding regulations and guidelines (Melchers, 2001). Similarly, Ale notes that the political, legal and historical context also affects the application and development of the principle of risk acceptance criteria (Ale, 2005). Following development of risk acceptance criteria within individual countries, the principle informs stakeholders how resources are allocated. One example of this can be found in Bowles in which the principles of cost effectiveness and disproportionality ratio are used to evaluate risk reduction decisions for dam safety (Bowles, 2004). However, as noted by Schmidt, resource allocation can be negatively affected by inconsistent risk thresholds and significant variations exist both among and within countries (Schmidt, 2016).

3. REGULATIONS, STANDARDS, AND PRACTICES

3.1 Risk acceptance terminology used across countries and agencies

The ALARP principle is most useful when implemented in a country with an existing robust process safety structure. Each of the countries included in the assessment presented below was selected because it is a world leader in process safety, with strong process safety regulations and industry practices. Each organization/directive was chosen based on its importance to the process safety regulations and impact in its respective country. The selection of countries was also limited by the availability of literature in English. The countries and organizations and the terminology used that this work reviews are listed in Table 3.1 below.

Table 3-1 Overview of organizations and directives enforcing/recommending ALARPs

Country	Organization/Directive	Acronym	Terminology	Mandated
Australia	National Offshore Petroleum Safety and Environmental Management Authority	NOPSEMA	ALARP	Yes
	Safe Work Australia	SWA	SFRAIP	Yes
European Union	Seveso-III	Seveso-III	"all necessary measures"	No
Netherlands	Ministry of Housing, Spatial Planning and the Environment	VROM	ALARA	Yes
Norway	Norwegian Petroleum Directorate	NPD	ALARP	Yes
	Det Norske Veritas	DNV	ALARP	Yes
	Norsk Sokkels Konkurranseposisjon	NORSOK	ALARP	Yes
United Kingdom	Health & Safety Executive	HSE	ALARP	Yes
United States	Nuclear Regulatory Commission	NRC	Probabilistic Risk Assessment	No
	Federal Energy Regulatory Commission	FERC	-	No
	Pipeline and Hazardous Materials Safety Administration	PHMSA	-	No
	Center for Chemical Process Safety	CCPS	ALARP/ALARA	No

ALARP was first developed in the UK and therefore the UK HSE presents an excellent example of implementing the ALARP principle. The Health and Safety at Work Act specifies that all employers must demonstrate that employees operate under ALARP conditions (UK HSE, 2001, 2003, 2017, 2018). Plant work, hazardous chemicals, training, and maintenance are specifically referenced as activities that must be conducted with ALARP levels of risk.

In the Netherlands, companies are required by VROM legislation to demonstrate compliance with ALARA governmental criteria (VROM, 2012).

Norway requires all risk assessment to be demonstrated following certain standards. For instance, NORSOK standard Z-013 requires companies to comply with ALARP in the pre-engineering phase, detailed design phase, and when conducting special operations (NORSOK, 2001). According to the NPD, during the design of unmanned wellhead platforms, the risk is required to be "reduced to the lowest extent possible". While the legislation does not require the ALARP methodology to be used per see, the NPD requires that either the prescriptive NORSOK S-DP-001 standard be followed or the more risk-based ALARP methodology be used (Nielsen, 2016). Additionally, DNV recommended practices on shale gas require ALARP to be implemented in planning, implementation, and design of shale gas activities. This includes facility planning and selection of well pad components (Det Norske Veritas AS, 2013).

Australia, through NOPSEMA, mandates the use of ALARP with offshore petroleum operations (OPGGS Regulations, 2009). Documents such as the well operations management plan (WOMP) or the Safety Case must be used to demonstrate that the titleholder has or will reduce risks to a level that is ALARP. However, for other operations, a process that is similar to ALARP called *so far as is reasonably practicable* (SFAIRP) is mandated by SWA (SWA, 2011a, 2011b, 2012a, 2012b, 2016). SFAIRP examines potential risks and determines which precautions are reasonable based on disproportionality, which is judged by the high court's common law. Whereas ALARP looks at the risks and reduces them until they are acceptable, SFAIRP looks at all available safety precautions and determines whether they are reasonably practicable based on a judicial standard rather than a legislative framework. Although the intention is the same, to reduce the risk to *as low as reasonably practicable*, the methods are not the same and the results are unlikely to be the same (Robinson, 2014).

In the European Union, member states are required to take *all necessary measures* to maintain the health and safety of their workers and the public, but determining the necessary measures is left for the member states to decide [EU, 2012]. Many states choose to implement one of these necessary measures to varying degrees. Additionally, the Seveso III directive is applicable to member states who then develop guidelines and legislation for companies operating within their territories (EU, 2012). It does not recommend the ALARP principle specifically.

In the United States, ALARP is not mandated. However, the Pipeline and hazardous Materials Safety Administration used the term *as low as reasonably achievable* regarding the contamination control of radioactive material (DOT, 2014). The NRC also mentioned that ALARA to be used in developing a radiation protection program in order to ensure the protection of workers and the public from unsafe doses of radiation (NRC, 1991).

Of the countries and regions analyzed, the primary countries that mandate ALARP for the chemical and oil and gas industries are Australia, the Netherlands, Norway and the United Kingdom and as such the subsequent discussion will focus on these countries.

In the countries which ALARP or similar principles are mandated, there are differing penalties applied for failing to follow the regulations, both in the design and operational phase. According to the UK Health and Safety at Work etc. Act 1974, the penalty for failing to follow the ALARP regulations is a fine or a prison sentence of up to two years (United Kingdom Parliament, 1974). In Australia, failure to follow safety case regulations to prove ALARP is applied in the form of penalty units, which are a monetary fine to the company (OPGGS Regulations, 2009). These fines go up to 80 penalty units, per offense, which translated to $16,800 as of July 2017. Failure to pay the fine may result in jail time, but there is no direct penalty of imprisonment for failure to implement ALARP. Due to its civil law structure, the Netherlands provides guidelines to local municipalities, but does not mandate specific penalties for failing to follow them. They leave that to local municipalities, and so penalties for failing to meet ALARA criteria vary from municipality to municipality (RIVM, 2009). While Norway's Act 29 No. 72, Relating to Petroleum Activities, imposes similar penalties to those of the UK HSE, it does not directly specify that ALARP must be used to demonstrate safety. The guidelines do reference NORSOK and DNV documents which recommend determining risk acceptance via ALARP but this does not mean failing to use the ALARP principle results in a penalty.

3.2 Individual risk and risk acceptance criteria

There is significant variation in the individual risk acceptance thresholds worldwide. Not all countries have established individual risk acceptance criteria. For the countries that use the thresholds, values for the individual risk acceptance criteria can be found in the literature (CCPS, 2003). Differences were also observed in the extent to which these individual criteria are mandated and these are summarized in Table 3.2.

The individual risk of employees working in facilities in the United Kingdom is reflected within regulations; however, individual risk criteria for employees is absent in the Netherlands. It is important to mention that the Netherlands does mandate individual risk criteria on 'vulnerable objects' - buildings such as schools, hospitals and offices which may be situated in close proximity to the facility. This results in individualized risk criteria or inanimate structures but not for human beings, a stark difference from the UK. In Norway, the application of individual risk criteria is limited to shale gas production but not for other industries. An assessment of the health and safety of employees is required, as well as assessment of the environmental and societal impact. Lastly in Australia, companies are given a goal-setting requirement to meet individual risk criteria and as such are given flexibility in how to accomplish this; this implementation resembles the UK in setting a general requirement for individual risk.

Table 3-2 Individual risk criteria of different countries

Country	Organization/ Directive	Mandated/ Recommended
Australia	NOPSEMA	Neither
	SWA	Neither
Netherlands	VROM	Mandated*
Norway	NPD	Mandated under HSE framework
	DNV	Not mandated, but references NORSOK
	NORSOK	Mandated by certain standards
United Kingdom	HSE	On-site risk is mandated

3.3 Societal risk and risk acceptance criteria

A mandated calculation of societal risk, like individual, is not universal. Each of the countries studied had a different approach to regulating societal risk acceptance criteria, which ranges in a gradient from mandating societal risk as necessary, to focusing almost entirely on risk to individual workers' health and safety and not on societal risk. Values for the societal risk acceptance criteria for the countries that use the thresholds can be found in the literature (CCPS, 2009).

The UK HSE regulations stand at one end of the spectrum, mandating specifically that both individual and societal risk be considered in order for a risk assessment to be valid (UK HSE, 2001). Meanwhile, the Netherlands has societal risk criteria specified for its industries and holds businesses to them. However, these risk criteria are primarily advisory, and can be waived by authorities, given sufficient justification (VROM, (V&W), & (BZ), 2012). Although Norway's framework HSE does not explicitly mention a need to assess societal risk, NORSOK standards on risk and emergency preparedness advise that risk-based cost-benefit analysis should be performed. This risk-based CBA analysis includes societal risk and indicates cost and benefits are most widely applicable in a societal context (NORSOK, 2001). Finally, Australia's risk guidelines provide no mention of societal risk in both in the offshore industry regulated by (NOPSEMA, 2017), and onshore in the chemical industry regulated by SWA (Safe Work Australia, 2011a, 2011b, 2012a, 2012b, 2016).

Table 3-3 Societal risk criteria of different countries

Country	Organization/ Directive	Mandated/ Recommended
Australia	NOPSEMA	Not Mandated
	SWA	Not Mandated
Netherlands	VROM	Mandated
Norway	NPD	Standard for Unmanned Wellhead Platforms
	DNV	Recommended Practice for Shale Gas
	NORSOK	Standard for Offshore
United Kingdom	HSE	Mandated

3.4 Approaches demonstrating risks reduced to ALARP

Generally, companies are not restricted to either quantitative or qualitative approaches and are given some flexibility in demonstrating that risks have been reduced ALARP; however, as mentioned above, quantitative methods require significantly more resources and the literature on implementation details is meager.

The UK HSE advocates a semi-quantitative approach involving the use of a disproportion factor to determine whether the costs of a risk reduction measure grossly outweigh the costs which introduces some measure of subjectivity. In order to determine if a risk is ALARP, the UK HSE allows one of two approaches to be used. A company may either decide by good practice, or decide based on first principles (UK HSE, 2003). Deciding by "good practice" is a methodology similar to *Recognized and generally accepted good engineering practices* (RAGAGEP) in the United States. This methodology involves adhering to approved, written codes of practice, guidance, and standards. Alternative codes may be used, but they must consider both individual and societal risks, cost and benefit, and practicality of control measures. Where possible, they must maximize the use of inherent safety, risk-avoidance, and the control of risk at source using physical engineering controls, while minimizing the need for procedural controls and personal protective equipment. Finally, the good practice must clearly define the scope of the code, guidance, or standard, and for what contexts it is relevant. Deciding on first principles involves a more rigorous cost-benefit analysis and should be done only if deciding by good practice is insufficient or if there is no relevant good practice to follow. More rigors must be applied for situations with higher consequences.

An example of cost-benefit analysis that was given by the UK HSE is given in Table 3.4 (UK HSE, 2018). The expected number of different types of injuries was determined based upon consequence analysis. A cash value was assigned for the prevention of each of these injuries. The likelihood of such a consequence and the lifetime of the plant were defined. Each of these was multiplied together to determine the total amount of money that would be reasonable to spend on lowering the risk to zero. A disproportionation factor (of ten in the example) was assigned and multiplied the total benefits of $9283 to get a total value of about £93,000. A reasonable amount of money to spend on reducing risk would be approximately £93,000, according to the UK HSE example. This disproportionation factor must be determined by the situation, and no method was prescribed to determine the disproportionation factor.

Table 3-4 UK HSE example of cost-benefit analysis

Injury	Expected # Injuries	Cash Value	Likelihood	Plant Lifetime	Estimated Benefit
Fatalities	20	x1,336,800	x 1×10^{-5}	x25 yrs	= 6684
Permanent Injuries	40	x207,200	x 1×10^{-5}	x25 yrs	= 2072
Serious Injuries	100	x20,500	x 1×10^{-5}	x25 yrs	= 512
Slight Injuries	200	x300	x 1×10^{-5}	x25 yrs	= 15
Total Benefits					£9283

Australian companies have a large degree of flexibility in showing how ALARP has been met. The methodology that is recommended, but not mandated, by NOPSEMA is to use a safety case to assess the initial risk, and to perform continuous improvement to ensure that the safety of the ongoing developments improves (NOPSEMA, 2015). A safety case is a document produced by the operator of a facility that identifies the facility's hazards, assesses the risks, identifies controls, and then confirms that the controls are implemented (NOPSEMA, 2018). To ensure continuous improvement, these steps are continued cyclically over the operation of the facility. The requirements specify that uncertainty must be considered in the assessment in order to demonstrate that the risk has been reduced ALARP, but do not require any specifically quantitative or qualitative approach.

In Norway, the NPD specifies that the ALARP principle must be examined in the design of offshore facilities and recommends that NORSOK and DNV standards be used. NORSOK and DNV standards list a number of required categories that must be considered when assessing risk, and specify that the risks must be reduced ALARP, but do not specifically give requirements as to how this is to be done.

In summary, **the three main methods that are either mandated or recommended to determine whether risks are ALARP are 1) good practices and standards, 2) cost-benefit analysis through first principles, and the 3) safety case**. Good practices involve following existing codes, standards, and accepted industry practices to ensure that the safety of a facility is acceptable. Cost-benefit analysis is a risk-based methodology that determines whether a risk is ALARP by weighting the cost of reducing risk against the risk itself. The safety case is a practice by which each individual hazard is examined, controls are implemented, and then over the operational time of the facility, hazards and controls are maintained so that the safety remains ALARP. Good practices are mandated in the UK, but none of the other approaches is mandated anywhere else.

3.5 Principles underlying the cost-benefit analysis regarding ALARP

Given that well-established methods of performing cost-benefit analysis exist, the focus of this section is on identifying the primary components and principles underlying the cost-benefit analysis as they pertain to ALARP and risk acceptance criteria. Principles that are both common to and different across the countries examined are discussed and an interpretation of the results of the cost-benefit analysis are also provided.

Underlying basis for individual risk calculation

The selection of the underlying principle is important because the level of risk calculated in the different countries for the same scenario could differ as a result of the basis for calculation. The underlying principle for individual risk calculations, where present, differs across the countries considered here. A summary of the basis for risk calculations is provided in Table 3.5.

Table 3-5 Underlying principle for risk calculations

Country	Principle
Australia	Company determined
Netherlands	Geographical location
Norway	Best-estimate
United Kingdom	Hypothetical individuals

In Australia, for safety case acceptance purposes, NOPSEMA will evaluate the operator's approach in terms of its robustness, transparency and appropriateness to the facility. The operator should therefore define the underlying rationale, criteria and decision-making basis for the case. The description must be convincing; this means that the rationale for deciding the completeness of the hazard identification and the adequacy of the measures employed should be supported and accompanied by all assumptions made and conclusions drawn. Where appropriate, it should present/summarize the results of supporting studies that have been performed. The description should demonstrate that the process was systematic which means that it followed a fixed and preestablished scope. Finally, the degree of analysis in support of the demonstration should be proportionate to the risk and to the complexity of the facility, hazards and the control measures.

Norway follows a "system-theoretic" approach to risk acceptance and total risk analysis. The calculation of risk is based upon available data for each system. In situations where data is scarce or unavailable, a conservative estimate is used. NORSOK does not prescribe a complete list of systems to be evaluated but does require careful documentation of each system that was assessed. Such documentation must include the objectives, scope, and limitations of the study, as well as assumptions made and uncertainties present. Furthermore, there must be a description of the system in question, in all phases of its use and in decommissioning. In this system, the risk to personnel, to the environment, and to assets must be considered.

Disproportion factor

Disproportionality factor is expressed as follows:

$$Cost/Benefits = \gamma ,$$

where γ is a parameter known as the disproportion factor. The UK HSE uses a factor of 10 in an "example" (UK HSE, 2018). NORSOK standards do not recommend any specific disproportion factor. However, a factor of 10 is used as an example (NORSOK, 2001). In Australia, both NOPSEMA and SWA use a disproportionation factor in their respective use of ALARP and SFAIRP. However, neither agency recommends any specific disproportionation factor. ALARA, which is used in the Netherlands, does not take into account a disproportionation factor. Instead, it relies on a more stringent risk estimation with lower uncertainty, as well as a potentially higher risk acceptability limit (Ale, 2005).

Implied cost of averting a fatality (ICAF) or Value of statistical life (VSL)

NORSOK standards do not recommend the use of any specific cost of averting a fatality, but do cite an official use of 5 MNOK ($0.64 million) per statistically saved life in a 1966 evaluation (NORSOK, 2001). NORSOK also suggests that an that the order of magnitude of a typical value of averting a fatality is 10 to 20 MNOK ($1.3 to $2.6 million). However, if a willingness to pay (disproportion) factor is used, then the cost to avert a single fatality can rise up to 100 MNOK ($13 million), or even higher.

3.6 Current industry practices

A survey was developed by the Mary Kay O'Connor Process Safety Center to gauge the usage of risk acceptance criteria and the ALARP principle in industry. The survey questionnaire is attached in Appendix A.

A total of nine companies responded to the survey consisting of seven operating companies and two consulting companies. Not all companies responded to every question. It is noted here that: (i) specific company names have been omitted for the sake of confidentiality, (ii) survey results are only analyzed quantitatively in the presence of complete data, and (iii) that the survey results only provide a general sense of current industry practices and are by no means necessarily reflective of the practices of the entire industry nor of the practice of any one company. Selected survey results are shown in Figure 3.1, Figure 3.2, and Figure 3.3.

Results from the other survey questions are summarized in Appendix B. Results involved 5-6 responses for these survey questions. It was seen that (i) usage of the concept of ALARP was not universal among surveyed companies; (ii) more respondents indicated usage of the same risk acceptance criteria globally and across different functions than otherwise; and (iii) that one surveyed company indicated consideration of voluntary risk, with the other surveyed companies considering either individual risk and/or societal risk.

Responses from surveyed operating companies on methods used to determine whether risk is ALARP included consideration of:

- *cost/benefit*
- *mix of cost/benefit and RAGAGEP*
- *continuous risk reduction* and *specific risk acceptance criteria, RAGAGEP, Subject Matter Expert (SME) judgment*
- *risk tolerability levels based on inherent and residual risk* with *risk above tolerable (medium) level requiring further risk assessment to establish whether we can accept the risk* and *risk treatment actions* to reduce *intolerable (high)* risk to *acceptable tolerable levels of medium or low*

Overall, the survey results indicated significant variability in the usage of risk acceptance criteria and the ALARP principle among surveyed companies. It is also reflected in the survey that although ALARP is **not** mandated in the United States for any onshore or offshore chemical and oil and gas companies, almost half of the companies are aware of ALARP as risk acceptance criteria, and utilize the ALARP principle in some fashion.

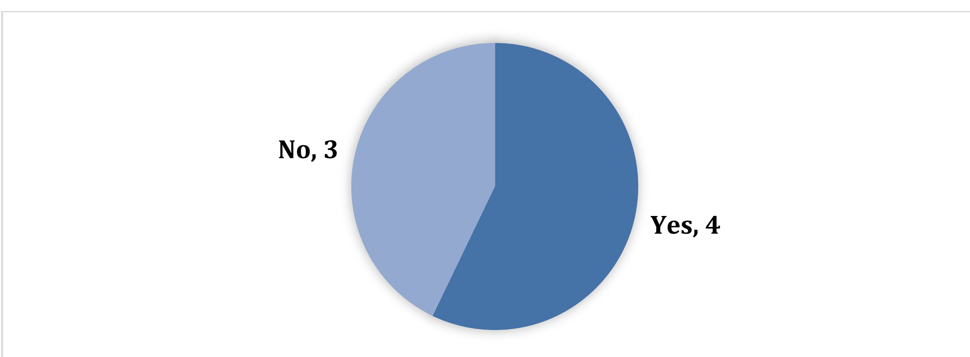

Figure 3.1: Four of seven operating companies answered positive when asked if they use any specific risk acceptance criteria in making risk management decisions

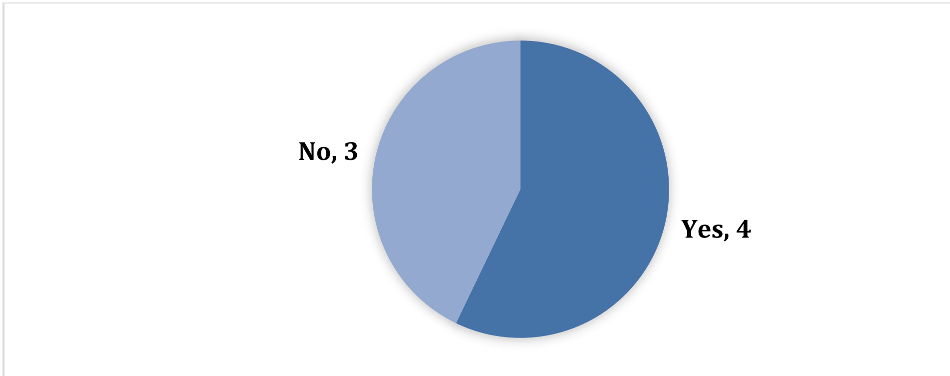

Figure 3.2 Four of seven operating companies replied positively when asked if they have a clear definition and specific criteria for risk acceptance

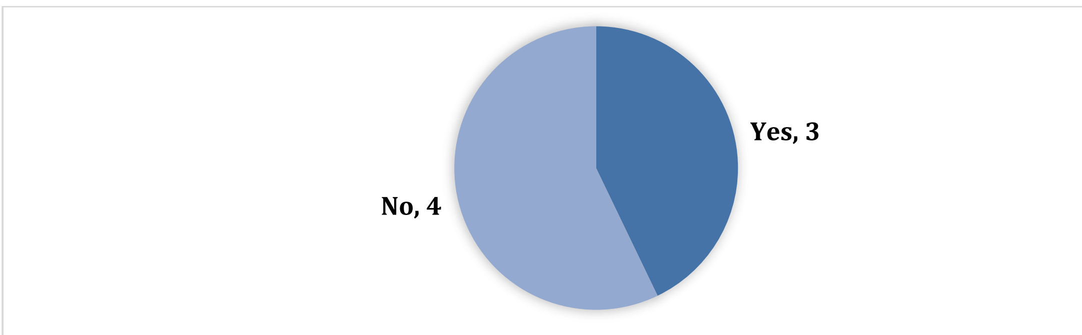

Figure 3.3 Three of seven operating companies replied positively when asked if their risk acceptance criteria changed over time

4. PARAMETERS AFFECTING THE RISK ACCEPTANCE CRITERIA

4.1 ALARP on different contexts

In order to fairly compare ALARP across multiple contexts, the industries that ALARP governs must be comparable. Table 4.1 examines the contexts of the industries governed by the organizations and directives examined in this work. The primary contexts examined are either general safety or petroleum safety. The United States is an exception, in which ALARP **is only mandated for nuclear waste**. Since the petroleum industry and nuclear waste disposal are not comparable, the United States NRC will not be used in the comparison with the other organizations in further sections.

In general, there are differences between ALARP criteria, and whether ALARP is used at all, based upon the context. Every country that was studied uses different criteria in different contexts, but generally no two countries are the distinguishing contexts the same. Some countries limit the application of ALARPs to specific industries (e.g. Australia NOPSEMA, Norway NPD), while others are more general (Australia SWA, UK HSE).

Table 4-1 Context in which the organization/directive govern

Country	Organization/Directive	Practice area
Australia	NOPSEMA	Offshore petroleum
	SWA	Australian work safety
European Union	Seveso-III	On-shore major incident hazards
Netherlands	VROM	Housing, Land-use planning, and environment
		Transportation is separate from other industrial activities
Norway	NPD	Petroleum on the Norwegian continental shelf
	DNV	International registrar and classification
	NORSOK	Petroleum on the Norwegian Continental Shelf
United Kingdom	HSE	Workplace Health, Safety, and Welfare in the UK
		Separate criteria for facility operations and land use planning
United States	NRC	Nuclear Regulations
	FERC	Evaluation of hydropower projects

One example of differing contexts and applications of ALARP is the contrasting categories that the Netherlands and the United Kingdom use to distinguish different types of risk. Both countries mandate the use of ALARP. However, in the Netherlands, transportation activities are distinguished as a separate risk category from other industrial activities. In contrast, in the UK transportation risks are aggregated into the risk category of the activities that the transportation action is active in (CCPS, 2009).

Furthermore, the United Kingdom's HSE distinguishes criteria based on the task being performed, having one criterion for facility operations and another for land use planning. In the Netherlands, the same set of criteria is used for both facility operations and land use planning. Another instance is in Australia, where a distinction is made between onshore and offshore contexts based on the different agencies that govern them.

Sometimes, the categories are the same, but the usage of ALARP differs. For example, the European Union's Seveso-III ALARP mandate applies universally for most hazardous material systems, but does not apply to pipelines, nuclear installations, and aviation safety (EU, 2012). However, this exception is made only if a separate document, ILO Convention No. 174, is ratified and followed. No mention of ALARP is made in ILO Convention No. 174. Therefore, ALARP is not mandated by the European Union for pipelines, nuclear installations, and aviation safety. This is in contrast to the United States, which only mandates ALARP for nuclear waste transportation.

4.2 Driving criteria for risk assessment

The establishment of risk criteria generally falls into two categories: prescriptive and goal-setting. Prescriptive approaches to the development of risk criteria involve the government mandate fixed risk criteria based on past experience, whereas goal-setting criteria represent aspirational criteria that may or may not be attainable but which allow the flexibility of exceedance.

Table 4-2 Are risk criteria prescriptive or goal-setting? What are their driving criteria?

Country	Prescriptive or Goal-Setting?	Driving Criteria	Legal System
Australia	Goal-Setting	Objective-Based	English Common Law
Netherlands	Mixed	Technology-Driven	Napoleonic (Roman) Law
Norway	Mixed	Standards-Based	Scandinavian-German Civil Law
United Kingdom	Largely Goal-Setting	HID Regulatory Model	English Common Law

The primary driving factor in Australia is the principle that the responsibility of protecting the health and safety of workers and the environment lies with the people and organizations that produce the risk. It is assumed that such people have the resources, motivation, and skills to manage risks, and thus should be expected to do so. Therefore, instead of following a prescriptive approach in which the government assumes it knows better than the industry, the industry is expected to follow high level regulatory requirements, but can decide on which methods they will use to do so. This methodology is called objective-based regulatory regime by NOPSEMA (NOPSEMA, 2017), and is the most goal-setting oriented criteria of the four countries listed.

The Netherlands focuses on a Technology-Driven approach. In this approach, the means by which a company uses in order to reach a risk acceptance limit is still left up to the company, but a risk acceptance level is set by the government. Companies are asked to reach or exceed this goal, regardless of their own risk acceptance criteria. If technology is not available to reach the goal, then the government may refuse to allow the company to build their facility (Ale, 1991). In this way, a partially prescriptive and partially goal-setting methodology is used to control risk.

Norway also uses a mixed approach to developing risk criteria. NORSOK prescribes a number of standards that companies are expected to follow in order to be considered in good standing. However, if the company can prove that a standard does not apply to their situation, then they can be exempt from it (NORSOK, 2001). Furthermore, DNV standards require companies to ensure that risk values are available for decision-making processes, and requires risk-management decisions to be made available for future decision-makers to manage changes in the process (Det Norske Veritas AS, 2013).

Likewise, the United Kingdom focuses on the goal-setting HID Regulatory Model (UK HSE, 2017), in which companies are expected to build a safety case for their respective hazards. Regulatory agencies check whether the safety case is appropriate for the hazard and provide guidance to the companies.

There are some links between the driving criteria for risk assessment and the prevailing legal system. The legal system affects the development of the risk acceptance criteria and how ALARP is assessed and decided. The prevailing legal systems for the countries are shown in Table 4.2. The main difference between the Napoleonic legal system practiced in the Netherlands and the Common law system practiced in the United Kingdom and Australia is that under Napoleonic law, expectations on ALARP that are not written into law may be non-binding whereas under Common law which relies on precedent, expectations on companies are often less explicitly expressed in legislation (Ale, 2005). This is consistent with the driving criteria for risk assessment in that in the Netherlands, risk criteria are mandated explicitly in line with the Napoleonic law paradigm. In the UK, an example of one important precedent is the 1949 Edwards v. The National Coal Board case which represents the first time that the notion of 'grossly disproportionate' entered into law and was pivotal in shaping development of the ALARP principle in the UK (Ref# Edwards v. The National Coal Board. All England Low Reports, 1, 747 OR NN, 1949. Edwards vs The National Coal Board (1949) 1 A11 ER 743).

Another consequence of the difference in legal systems is the magnitude of the difference between cost and benefit might be lower under Napoleonic law than under Common law in which the costs of risk reduction would have to be shown to be grossly disproportionate to the benefits (CCPS, 2009).

4.3 How quantitative is ALARP across the countries

The implementation of ALARP can be divided into three categories: qualitative, semi-quantitative, and quantitative. The extent to which ALARP is quantitative differs between the countries and is summarized in Table 4.3.

In the Netherlands, companies are required by law to use quantitative techniques to find the magnitude of risk present in their operations to show that they are below governmental thresholds (CCPS, 2009). The ALARP process is however not restricted to be quantitative across most contexts.

Table 4-3 Quantitative and qualitative approaches to ALARP

Country	Organization	Nature
Australia	NOPSEMA	Qualitative or Quantitative
	SWA	Semi-quantitative
Netherlands	VROM	Quantitative
Norway	NPD DNV NORSOK	Qualitative or Quantitative Qualitative Qualitative or Quantitative
United Kingdom	HSE	Semi-quantitative

In UK and for onshore operations in Australia (SWA), companies are expected to use semi-quantitative methods to show that risks have been reduced ALARP. These semi-quantitative methods take the form of quantifying the costs and the benefits of a risk reduction measure and then determining whether the costs are greatly disproportionate to the benefits. Some measure of objectivity can be introduced when determining the costs and benefits of a risk reduction measure through the proper use of standards; however, the disproportion factor introduces some subjectivity. Interpretation of what is 'grossly' disproportionate varies by context, industry and application. A nominal value of 10 for example for the disproportion factor may be considered to be high in the petrochemical industry but be considered appropriate in the nuclear industry where the extent of risk aversion is higher.

In Norway and for offshore operations in Australia (NOPSEMA), the extent to which ALARP is quantitative can vary. This variation between fully qualitative and fully quantitative can be across the lifecycle of a project in which the ALARP process becomes more quantitative as more information is obtained. Variation is also seen in the way that companies can demonstrate that risks have been reduced ALARP such as using a well operations management plan (WOMP).

5. KEY FINDINGS – HOW SAFE IS SAFE ENOUGH?

How safe is safe enough is more of a philosophical question than an engineering decision. The perception about safety and risk of a person varies with an individual's understanding due to education, experience and many more factors. Different societies developed different regulations and standards because of their norm, history, and culture. The purpose of the white paper was not to delve into such complex interplay of all such issues that contributed to the development of risk acceptance criteria of a country. Nonetheless, it is important to understand individual's and society's risk of acceptance or aversion towards certain technology or industry. Such understanding will probably not change the engineering assessment of risk and safety; however, it will be profoundly useful on risk communication. This white paper attempted to summarize the principles, regulations, and standards of a few countries (Australia, the Netherlands, Norway, and the UK), where ALARP has been practiced as risk acceptance criteria. objectively as possible. Relevant literature was studied and a survey was conducted on current industry practices regarding ALARP and risk acceptance criteria in the United States.

Comparison was made in this paper regarding the various country's mandates, individual and societal risk criteria, application in varying contexts, driving criteria, quantitative or qualitative approaches for risk estimation, uncertainty, and cost-benefit analysis. The results showed a wide variation in applications of the principles although at the bottom of all principles, regulations and standard, it is the same notion of risk reduction ensuring the safety of fellow workers and society at large.

A few key findings have been summarized below:

- A number of developed countries with mature process safety cultures are adopting, or have adopted, ALARP or similar principles as risk acceptance criteria.
- Although the underlying principles are similar, the application of the principles varies significantly.
- ALARP principles are often applied differently to various industries even within the same country
- Both qualitative and quantitative approaches have been applied for risk estimation
- All approaches recommend cost-benefit analysis, but there is no consensus on exactly how it should be done.
- There is no clear guideline on how to determine the disproportionality factor (in cost benefit analysis).
- Data is very scarce on how ALARP is practiced in industry.
- Although ALARP is not mandated in the United States, some US based companies practice ALARP principles, probably because of the global nature of the companies.

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APPENDIX A: Survey Questionnaire

Survey questions on risk acceptance criteria

- Type of Company completing this survey: [O-Operator, C-Consultant, R-Regulatory Agency, etc.]
  Answer format: Text input

- Does your company utilize risk acceptance criteria in making risk management decisions?
  Answer format: Yes/No

  If answer is YES,
  - Does your company utilize the concept of ALARP?
    Answer format: Yes/No

  - How do you determine if a risk is ALARP (e.g. cost/benefit, REGAGAP, *etc.*)?
    Answer format: Text input

- Do your company have a clear definition and specific criteria for risk acceptance?
  Answer format: Yes/No

  If answer is YES,
  - Is the same risk acceptance definition/criteria utilized globally and across different functions (oil and gas, chemicals, etc.) in your company?
    Answer format: Yes/No

- Does your company consider individual, societal, voluntary, involuntary risk?
  Answer format: Check boxes for individual risk, societal risk and voluntary risk

- Have risk acceptance criteria in your company changed over time?
  Answer format: Yes/No

APPENDIX B: Survey Results

Table B-1 Survey results

Company	Does your company utilize risk acceptance criteria in making risk management decisions?	Do your company have a clear definition and specific criteria for risk acceptance?	Have risk acceptance criteria in your company changed over time?
O_1	No	No	No
O_2	Yes	No	Yes
O_3	No	Yes	No
O_4	Yes	Yes	Yes
O_5	Yes	Yes	Yes
O_6	No	No	No
O_7	Yes	Yes	No
C_1	No	No	-
C_2	Yes	Yes	Yes

Table B-2 Survey results

Company	Does your company utilize the concept of ALARP?	Does your company consider individual, societal, and voluntary risk?	Is the same risk acceptance definition/criteria utilized globally and across different functions (oil and gas, chemicals, etc.) in your company?
O_1	-	Societal risk	-
O_2	Yes	Individual risk, societal risk	-
O_3	-	Individual risk	Yes
O_4	No	Individual risk, societal risk	Yes
O_5	Yes	-	No
O_6	-	-	-
O_7	No	Individual risk, societal risk, voluntary risk	Yes
C_1	-	-	-
C_2	Yes	Individual risk, societal risk	Yes