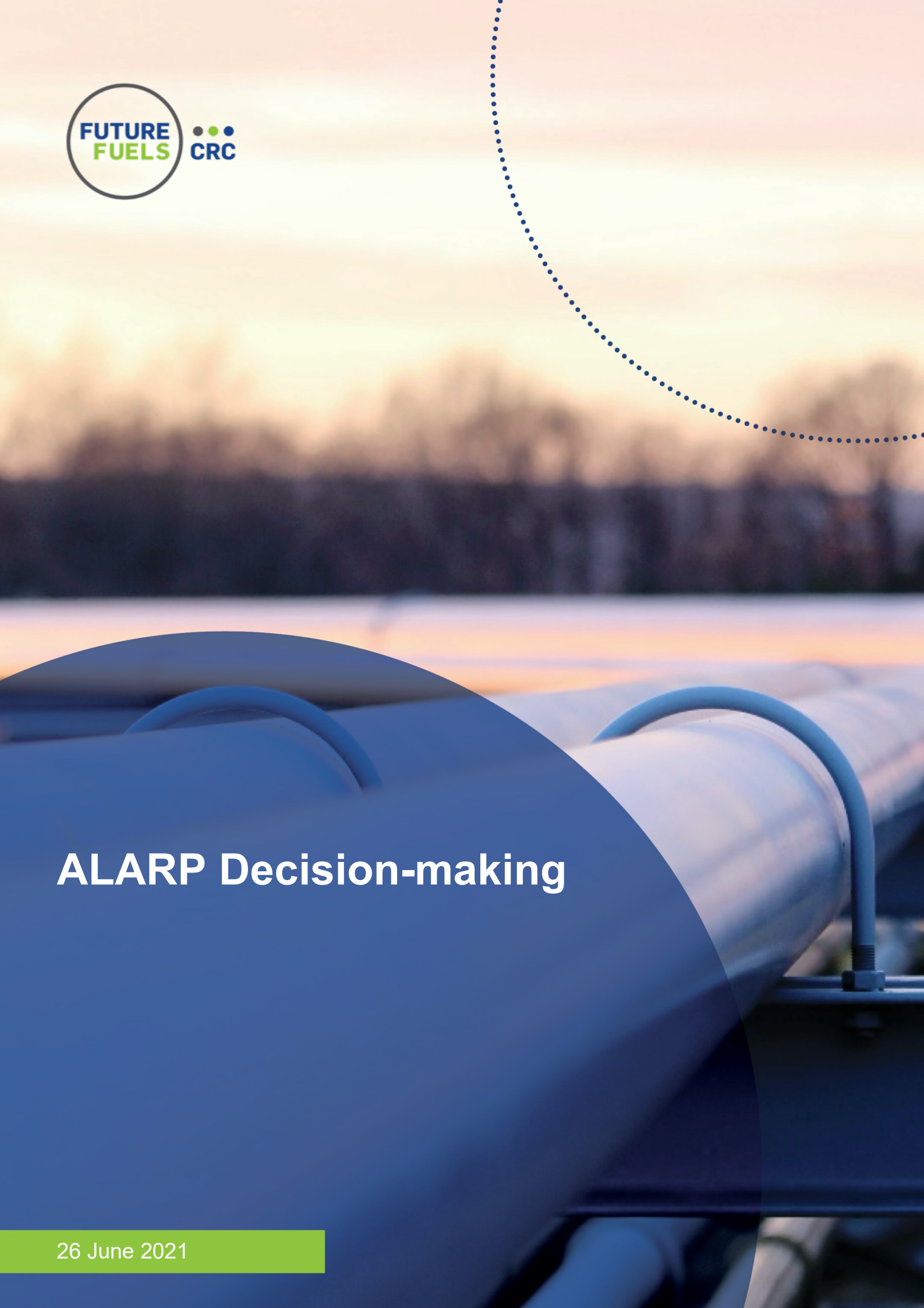

ALARP Decision-making

26 June 2021

Project number: RP2.3-05

ALARP Decision-making

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Project Information	
Project number	RP2.3-05
Project title	ALARP Decision-making
Research Program	Research Program 2 – Social Acceptance, Public Safety and Security of Supply
Milestone Report Number	Interim report (no milestone)
Description	This interim report covers the literature review and interview phases of the project. It details specific suggestions for updates to AS/NZS 2885.6 and provides the basis for the next phase of the project – developing additional guidance and/or a decision-making tool to support users regarding decision making in accordance with the ALARP principle.
Research Provider	RMIT University
Project Leader and Team	Jan Hayes, Nader Naderpajouh, Sarah Holdsworth, Ron Wakefield, Janice Wong (all RMIT)
Industry Proponent and Advisor Team	Richard McDonough (GPA), Craig Bonar (APA), Susan Jaques (Sage), James Czornohalan (Epic), Chris Liew (APA), Scott Mitchell (APA), Mieka Webb (SA DEM), Michael Jarosz (SEA Gas)
Related Commonwealth Schedule	This project is part of output RP2.3 but does not correspond to any existing milestone.
Project start/completion date	5 January 2021
IP Status	Confidential
Approved by	Richard McDonough
Date of approval	26 June 2021

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Summary of Report

The principle that risk should be reduced to a level that is as low as reasonably practicable (ALARP) is fundamental to risk management in the pipeline sector and a basic foundation for the relevant standard - AS/NZS 2885.6 Pipeline Safety Management (the standard).

This interim report details the results of the first two phases of a project to investigate whether the requirements regarding ALARP in the standard remain aligned with best practice and also to understand if and how the requirements of the standard regarding ALARP are currently being implemented by the pipeline industry.

A literature review covering new or revised industry/regulatory guidance material, academic publications since January 2017, and legal judgements grounded in the concept of 'reasonably practicable' found that there have been no major changes in the interpretation of ALARP inside or outside the pipeline sector since the standard was issued in 2018. The standard therefore remains broadly consistent with best practice. The review did, however, identify 28 recent insights regarding demonstration of ALARP. Many of these minor issues are worthy of consideration by the committee that will be convened to update the standard in the coming year to determine if minor adjustments to the standard to take these points into account would be improvements.

Twenty-five industry experts in the field of risk management were also interviewed. Of these, eleven were operating company personnel, four were regulators and ten were consultants who work on safety management studies. The interviews resulted in another 13 suggestions for specific changes to AS/NZS 2885.6.

The findings from interview reveal that there are three primary ways in which formal ALARP demonstrations are being done in the pipeline sector.

1. By guided discussion as part of SMS validation workshops. These discussions sometimes draw on the questions in Appendix I but are also strongly driven by precedent i.e. controls are adopted in line with current industry practice for similar situations.
2. By engineering analysis often using a combination of LOPA and structured responses to the questions in Appendix I. This method combines both quantitative and qualitative aspects and requires judgement to determine the final outcomes based on assembled evidence.
3. Relying on quantification of risk and use of cost benefit analysis. This work produces quantitative results that are given to decision makers as input to their decision making.

The intent of AS/NZS 2885.6 was for users of the standard to adopt the second method but this is not completely understood in industry. Those who have adopted the first and third methods are generally of the view that their work meets the requirements of the standard. In some cases, this would seem to be a somewhat optimistic assessment. Given that the second option has grown up largely since 2018, the overall uptake of this methods is perhaps as expected and not a bad position for the industry to be in.

The research did not identify any company that has adopted the High Consequence Recognition process as set out in Appendix H of the standard. Having said that, the industry conversations around this issue have been influential and many cases were reported where summaries are produced with a senior management, rather than technical, audience in mind and senior managers are more actively engaged in the results of safety management studies as a result.

Given that the requirements for ALARP set out in the standard are used by a relatively small number of people, it is perhaps surprising that there is so much variation. This is partly driven by a small number of influential consultants who all have their own ways of doing things and use their expertise to support companies across the sector. Some follow the requirements of the 2018 version of the standard closely whereas others have not updated their practice to take the revised requirements into account.

Ensuring that safety-related risk management processes remain robust is important in a future fuels environment. Existing threats to pipeline integrity are generally well understood in industry but the introduction of hydrogen introduces significant new uncertainty. There are many other FFCRC research projects underway to resolve a wide range of technical knowledge gaps regarding introduction of hydrogen into systems designed for natural gas. It is important in this environment to ensure that decision making frameworks are robust so that public safety remains the key priority of the sector.

The next phase of the project is development of a decision support tool and/or additional guidance for the industry regarding application of ALARP. This report provides a detailed discussion to support making a choice about the form such guidance/tool should take. This requires further discussion with the industry advisory team once the content of this report has been reviewed.

1. Introduction

The pipeline sector puts significant effort in to managing the potential for high consequence, low frequency accidents. For transmission pipelines, the framework for these activities is set out in AS/NZS 2885 Part 6 Pipeline Safety Management (the standard). The requirements guide important decisions and significant expenditure.

New requirements were developed between 2014 and 2018 and included in the current version of the standard issued in 2018. The scope of this research is to investigate the experience of industry in implementing these requirements with a view to determining how safety decision making could be further improved, particularly in the context of future fuels.

High Consequence Recognition (HCR)

The standard requires that senior management (in the form of the Licensee) are aware of the potential consequences of pipeline failures in high consequence areas and details of controls in place. Appendix H of the standard contains more advice on how this requirement might be met. The research has investigated:

- How have users of the standard responded to this new requirement?
- What has been the impact of implementing the new requirement?

Formal demonstration that risk is As Low As Reasonably Practicable (ALARP)

The requirement that risk is ALARP is a longstanding one, but the new version of the standard included specific guidance regarding how to formally demonstrate that risk is ALARP for those cases where such a formal demonstration is required (AS/NZS 2885 Part 6 Appendix I). The research has investigated:

- Who is using the formal ALARP process and how are they using the results?
- Is the new guidance useful? How can it be improved, particularly in the context of future fuels?
- Does the process support informed decision making?
- In practice, is there evidence of gaps in process, gaps in understanding and/or misconceptions when compared to best practice?
- What are the practical challenges when applying “formal demonstration of ALARP” to situations where multiple stakeholders are involved (e.g. developers)?

This interim report describes the comprehensive review of recent literature on use of the ALARP principle in the pipeline sector and other hazardous industries. It also reports on fieldwork interviews to investigate the above questions with 25 pipeline sector experts (operating company personnel, consultants and regulators) who regularly use the ALARP principle in their work. The report draws together suggestions for consideration by the relevant standards committee in preparing the next revision of the standard. This report also forms the basis for the next stage of the project, focused on additional guidance regarding application and use of the ALARP principle.

Demonstration of ALARP remains an exercise grounded in professional judgement. The next phase of this research project will also investigate the potential benefits of expanding the paper-based checklist into a more sophisticated decision-making tool. Options include the Choosing by Advantages method or a method based on Layers of Protection Analysis. Such a structured tool has the potential to make decision making more transparent thus leading to better decisions and facilitating communication on risk issues with internal and external stakeholders (including regulators, land use planners and developers).

2. Literature Review

A literature review has been completed to identify studies about ALARP since the end of 2016 (when the literature was gathered to support production of AS/NZS 2885.6). The following types of documents have been searched in this literature review:

- New or revised industry/regulatory guidance material,
- Academic publications since January 2017, and
- Legal judgements grounded in the concept of 'reasonably practicable'.

The review focuses on both decision-making processes and criteria linked to the concept of ALARP and 'reasonably practicable'. In each case, we have initially searched specifically for pipeline sector materials. However, because the related references to pipelines are very limited, information from other sectors that may provide useful lessons for the pipeline sector has also been collected and reviewed.

2.1 Published guidance material

The first part of the literature review is to identify new and updated guidance material on ALARP and risk-based decision making issued by relevant industry and regulatory bodies. A range of such documents were identified in the last review and used in preparation of AS/NZS 2885.6. These have been reviewed for any relevant new material. In addition, the review has identified new guidance material that has also been assessed for relevant lessons.

2.1.1 Updates to previously considered guidance material

Guidance material on risk-based decision making and application of ALARP has been produced by regulators in several jurisdictions and several sectors. Industry associations sometimes also produce such documents. A range of these was considered in producing AS/NZS 2885.6 Appendix I. These are shown in Table 1 below, along with their current status and key additions/changes since the earlier versions.

Table 1: Guidance material from previous review and current status

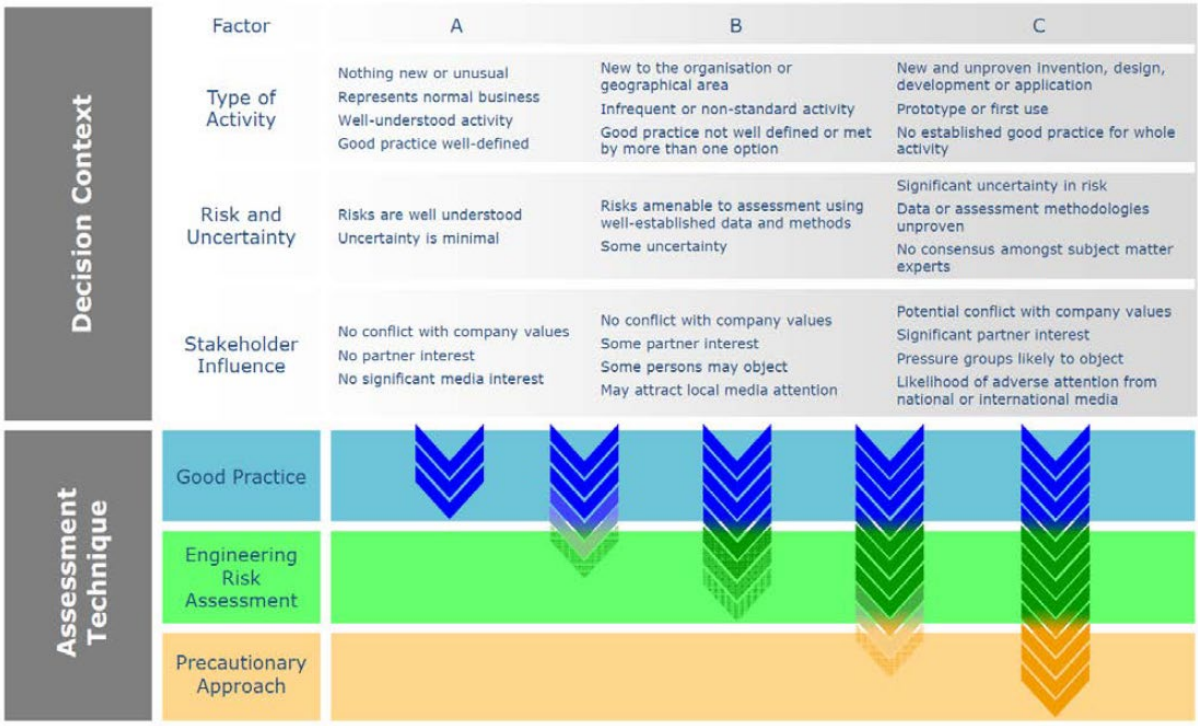
Item used in previous review	Current Status
Australian Standard	
AS/NZS ISO31000:2009 Risk Management – Principles and guidelines	The standard was updated in 2018. It remains significantly high level and as a result the sections on risk criteria and risk treatment do not contribute to this project.
Offshore Oil and Gas Sector	
UK Offshore Operators Association (UKOOA) A framework for risk-related decision support, Issue 1, May 1999 UKOOA is now branded as Oil & Gas UK.	Issue 2 was released in July 2014. A comparison of the documents shows that the overall model is similar and appears unchanged in overall intent with the exception of a stronger focus on use of the precautionary principle for cases where uncertainty is very high. Some specific practical points about ALARP demonstration have been added: • Beware of interdependence between options, i.e., don't assess options individually but incrementally, where appropriate. • Don't use 'reverse ALARP' to justify removing safety measures.

	• Use real field experience and data in preference to generic data or assumptions. • Beware of risk transfer – options that move risk from one part of the system to another. • Beware of the impact of uncertainty on results. If in doubt use the precautionary principle, rather than relying on risk assessment.
National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), Guidance Note ALARP, Rev 4, December 2012	This document was last updated on 24/6/20. The core concepts remain unchanged as are factors for selecting or rejecting control measures. The primary change in the content is introduction of the precautionary principle. Duty holders are advised to use the precautionary principle to demonstrate ALARP if the uncertainty in risk determination is so high that decisions cannot reasonably be made on the basis of risk. One possible case for this is new technologies where the frequency of failure cannot reasonably be estimated. The document also includes the new version of the decision support framework from the Oil and Gas UK document (see above) which also introduces the precautionary principle.
HSE Offshore Information Sheet No 2/2006 Offshore installations (Safety Case) regulations 2005, Demonstrating compliance with relevant statutory provisions	This seems to have been replaced by a series of web pages available from here: https://www.hse.gov.uk/managing/theory/index.htm The content is largely unchanged.
UK Health and Safety Executive, Reducing risks, protecting people (r2p2), 2001	Still available on the UK HSE web site - unchanged.
Workplace Health and Safety	
Safety Institute of Australia, OHS BoK, Chapter 8.2 Principles of OHS Law, 2012	This is now chapter 9.2 Work Health and Safety Law in Australia dated 2019. The changes appear to be formatting, removing some time-sensitive comments and updating the bibliography to reference more recent material. There is no additional relevant material for this project.
Safe Work Australia, How to determine what is reasonably practicable to meet a health and safety duty, May 2013	This document is still available of the Safe Work Australia website and has not been revised.
Major Hazard Facilities	

Worksafe Victoria, Guidance Note, Requirements for Demonstration (major hazard facility), April 2011	This document was last updated in July 2020. The changes appear to be formatting, removing some time-sensitive comments and updating the bibliography to reference more recent material. There is no additional relevant material for this project.

As seen in Table 1, the only revised guidance material that provides items for consideration in the context of this review comes from the offshore oil and gas industry. The new decision support framework from Oil & Gas UK is shown in Figure 1, emphasising the need for a precautionary approach in cases where uncertainty is high.

Figure 1: Decision Support framework (from Oil & Gas UK and reproduced by NOPSEMA)



The changes to the NOPSEMA guidance and the Oil & Gas UK decision support framework will be further considered for application to the Australian pipeline context.

2.1.2 Newly identified guidance material

A Google search has showed other guidance material published within the last five years that is of potential interest as shown in Table 2 below, starting with the ESV guidance published since the last review. Apart from the ESV material, nothing new has been identified that relates specifically to pipelines or other hazardous linear infrastructure.

Table 2: New guidance material since 2016

Guidance	Key points re ALARP
Pipeline industry	
Energy Safe Victoria, Energy Infrastructure Safety Management Policy, December 2019	For the gas industry, this guidance supports compliance with safety case requirements under the Gas Safety Act 2005, which requires gas companies to minimise hazards and risks to people and property as far as practicable (AFAP). The guidance acknowledges that compliance with AS2885 is the mechanism to do this (thus avoiding the legal ambiguity around this issue at least in Victoria – see section 2.3.1 below). As a policy-level document, it does not provide specifics on how AFAP is to be demonstrated.
Energy Safe Victoria, Safety Management Plan Preparation and Submission for Pipelines, July 2019	This guidance describes how to prepare a compliant Safety Management Plan (SMP). As such, it focuses on operational pipelines. The relevant legislation requires that risks to the public and environment are minimised as far as is reasonably practicable (AFARP). The document cross references AS 2885. The guidance requires companies to make a demonstration that risk has been minimised AFARP, but leaves open the method of doing this.
Nuclear Sector	
UK Office of the Nuclear Regulator, Guidance on the Demonstration of ALARP, November 2020	This document refers heavily back to the HSE web site (see Link in Table 1). There are six other principles given regarding use of ALARP in decision making: • Affordability is not a legitimate consideration, although cost is. • ALARP cannot be used to argue against fulfilling statutory duties • ALARP must consider all risks and ensure any interactions / conflicts are taken into account. • Ensure ALL options are considered. Don't address only cheap options. Conversely don't simply consider (and reject) gold-plated options. • No grandfathering – ensure existing facilities are compared to current standards and gaps considered in the ALARP process. • ALARP demonstration should be fit for purpose. Higher risks deserve more measures than lower risks.

	• If doing Cost Benefit Analysis (CBA), gross disproportion is likely to be required by the courts for all real risks. The appropriate factor is likely to be about 3 for workers and about 10 for the public[1].
Dam safety	
Vic DELWP, Guidance Note on dam safety decision principles, March 2015.	Duties on dam owners are similar to those of pipeline licensees. This guidance emphasises the following points: • Affordability is not a legitimate consideration, although cost is. • Implementation of new risk reduction measures required to reduce risk to ALARP can be staged for practical reasons, but measures should be installed "As Soon As Reasonably Practicable" (ASARP). • ASARP considerations can balance equity and efficiency. • Uncertainty must be assessed so the impact on decision making is understood.
Offshore oil and gas	
WA DMIRS, Petroleum safety and MHF – guide, ALARP demonstration, February 2020	This document states: 'ALARP demonstrations are an objective test. ALARP is an engineering tool to demonstrate meeting legal obligations and broadly tolerable risk targets need to be referenced.' This seems rather out of step with other published guidance. It also draws heavily on the Oil &Gas UK document listed in Table 1 and has a lot in common with the NOPSEA guidance material also listed in Table 1.
Irish Commission for Energy Regulation, ALARP Guidance, November 2017	This document draws heavily on UK HSE material and includes the Oil & Gas UK decision framework diagram. It includes the following specific points on demonstration of ALARP: • ALARP demonstration should include discussion of items NOT implemented as well as ones that are implemented. • Care should be taken to address option dependence where appropriate. • A range of possible consequences and their specific frequencies should be considered, not just worst cases. • When assessing cost of a measure, only costs directly associated with the measure should be included. Deferred production is not a cost. • Realistic assessment of remaining life must be used. • What is defined as good practice may change over time and assessments may need to be repeated to take this into account.

[1] The guidance emphasises that this has not yet been clearly tested in court and so cannot be guaranteed to be adequate in the event of an accident and prosecution.

	• Reverse ALARP is not allowed, i.e., using a reverse ALARP argument to remove safety measures. • Use real data rather than generic where possible. • Care should be taken regarding risk transfer from one group to another.

2.1.3 New lessons from guidance material

Numerous new guidance materials have been published in the last five years, showing that the ALARP principle remains best practice for risk-based decision making. None of these represent a major departure from the concept of ALARP as considered in 2016.

The following points summarise issues emphasised in the specialist guidance from sectors other than pipelines:

- Beware of interactions / conflicts / interdependence between risk reduction options, e.g., assess options incrementally, where appropriate, and not individually.
- Reverse ALARP is not allowed, i.e., using a reverse ALARP argument to remove safety measures.
- Use real field experience and data in assessing risks and in considering risk reduction options in preference to generic data or assumptions.
- Beware of risk transfer – options that move risk from one part of the system to another with no actual reduction in risk overall.
- Beware of the impact of uncertainty on results. If in doubt use the precautionary principle, rather than relying on risk assessment.
- Affordability is not a legitimate consideration, although cost is.
- ALARP cannot be used to argue against fulfilling statutory duties.
- Ensure ALL possible risk reduction options are considered. Don't address only cheap options. Conversely don't simply consider (and reject) gold-plated options.
- No grandfathering – ensure existing facilities are compared to current standards and gaps considered in the ALARP process.
- Implementation of new risk reduction measures required to reduce risk to ALARP can be staged for practical reasons, but measures should be installed "As Soon As Reasonably Practicable" (ASARP). ASARP considerations can balance equity and efficiency.
- ALARP demonstration should include discussion of items NOT implemented as well as ones that are implemented.
- A range of possible consequences and their specific frequencies should be considered, not just worst cases.
- If doing Cost Benefit Analysis (CBA), gross disproportion is likely to be required by the courts for all real risks. The appropriate factor is likely to be about 3 for workers and about 10 for the public[2].
- When assessing cost of a measure, only costs directly associated with the measure should be included. Deferred production is not a cost.
- Realistic assessment of remaining life must be used.
- What is defined as a good practice may change over time and assessments may need to be repeated to take the updates into account.

[2] The guidance emphasises that this has not yet been clearly tested in court and so cannot be guaranteed to be adequate in the event of an accident and prosecution.

These are to be considered in the context of pipeline risk management and the existing guidance in AS/NZS 2885.6 to determine what is relevant and potentially useful and whether those points are addressed sufficiently in the current version of AS/NZS 2885.6 (see Section 2.4.).

2.2 Academic literature

The next step of the literature review is to search for use of the ALARP concept in academic literature, since previous work was informed by the literature up to 2016. As such, a Scopus search was conducted for the term 'ALARP'. This returned 642 items (mostly conference papers (388) and journal articles (212)). Of these, the earliest dates from 2012, with 168 items published from January 2017 to January 2021. The synthesis of literature is presented in the next section based on the results of the search.

2.2.1 General industry / sector use of ALARP

The ALARP principle remains topical in the process industries with recent articles published on how to apply ALARP to unmanned offshore installations (Vinnem, 2021), managing cargo in offshore supply vessels (B. Liu, Jin, Zhao, Song, & An, 2020), operation of subsea pipelines (Aldara, Artana, & Ariana, 2020), facility siting (Ashiofu, Bruce-Black, & Dyer, 2020), floating LNG storage and regasification (Lee, 2020) and selecting the best option for a clean fuels project (Benintendi, De Mare, & Nesticó, 2018).

Use of the concept continues to expand both geographically and across sectors. Given its origins in English law, much of the published commentary on ALARP is in the UK and Australian publications, but recently use of typical quantitative risk acceptance criteria for demonstration of ALARP has been proposed for the Indian chemical industry (Roy & Kshirsagar, 2021) and research has been published on demonstration of ALARP via Safety Cases in Cuba (Ilizástigui Pérez, 2020).

Moving outside the process industries, the concept has been widely adopted with applications varying as widely as building construction (Maselli & Nesticò, 2021; Tan, Weinert, Joseph, & Moinuddin, 2020) designing roads to withstand landslides (Winter & Wong, 2020), wind turbine design (Mehmood, Qureshi, & Kristensen, 2020), management of waste slag (S. Liu, Chai, Du, Luo, & Xiao, 2020), commercial fishing vessels operating in the EU (Nuñez-Sanchez, Perez-Rojas, Sciberras, & Ramos Silva, 2020), avionics design (Jiang, Zhao, Wang, & Ren, 2020), fire safety engineering (Van Coile, Jomaas, & Bisby, 2019) and pesticide handling in Selangor (How, Abdullah, & Othman, 2017).

2.2.2 ALARP in the pipeline industry

Discussion of the concept in the pipeline sector is growing with seven papers drawing on the concept since 2017 including our own work presented at IPC in 2018 (Carroll & Hayes, 2018; Gong, Niu, & Bai, 2020; Mullins, Doyle, & Taylor, 2018; Nemeth, Hassanien, & Leblanc, 2018; Nidd, 2017; Pei, Wang, Luo, & Luo, 2018; Zhang, Qin, & Wang, 2018).

Three engineers from ROSEN UK presented on using classic QRA for assessment of pipeline risk at the flagship process safety conference in the UK (Mullins et al., 2018). Their presentation of ALARP is entirely quantitative, i.e., based on FN curves and Cost Benefit Analysis (CBA). The paper includes a worked example, demonstrating that for the test case marker tape and slabbing are justified, but pipeline isolation valves are not justified as the cost is grossly disproportionate to the risk benefit. The somewhat unsatisfying overall conclusion is that risk is still in the ALARP region so more measures such as increased depth of cover must be considered but these are not worked.

Gong et al. (2020) have sought to establish quantitative societal risk acceptance criteria (represented by lines on an FN curve as in the UK) for Chinese gas distribution systems by plotting US Department of Transport data for pipeline incidents on an FN curve and then using the concept of ALARP to postulate what should represent tolerable risk. This second step is presented as highly mathematical, but as the paper says, 'acceptability criteria are essentially a political decision' (Gong et al., 2020, pg 7). While the criteria proposed are generic for all gas distribution systems, the authors state 'it will be better to work out specific criteria for different pipelines with different pipeline specs, location and operative conditions' (Gong et al., 2020, pg 7). Their method does not seem to provide useful guidance for us. The earlier paper by Pei et al. (2018) is very similar in approach seeking to establish numerical risk criteria for Chinese transmission pipelines. Both papers claim to be establishing criteria in accordance with the ALARP principle (include additional risk reduction measures unless the cost is disproportionate to the benefit gained), but we would not recognise the way they go about this as useful. Zhang

et al. (2018) have developed a maintenance optimisation system, again using numerical application of the concept of ALARP. These three Chinese papers demonstrate how widespread use of ALARP has become in engineering risk-based decision making linked to numerical modelling.

The other pipeline-related papers are conference papers and their full text is not publicly available. Therefore, assessments given here are based on the abstracts only. Phillip Nidd, a principle at Dynamic Risk in Houston may be known to some Australian industry colleagues. The abstract of his presentation at the 2017 Pipeline Pigging and Integrity Management Conference in Houston (Nidd, 2017) states that ALARP 'is in reality "how we do business" ' and 'to achieve an acceptable ALARP level of risk, pipeline operators must as a minimum undertake specified actions in compliance with regulation'. Both these statements when applied to the US pipeline industry tend to suggest he is not using ALARP in the same way as it would be used in Australia[3]. In addition to the paper presented at the International Pipeline Conference in 2018 by Francis Carroll and Jan Hayes (Carroll & Hayes, 2018), the conference included a second paper drawing on the concept of ALARP. Nemeth et al. (2018) presented a paper about how to generate reliability targets so that predicted probability of failure can be compared to an integrity permissible probability of failure. In common with most of the engineering application of ALARP, the paper appears to be numerical in its use of the concept.

In the context of future fuels, Casson Moreno, Papasidero, Scarponi, Guglielmi, and Cozzani (2016) analyse accidents in biogas production showing that the number of accidents in the sector is climbing faster than the increase in biogas production. They suggest that the risk profile is non-negligible and more typical of the ALARP zone, i.e., where more should be done, provided that the cost is not disproportionate to the benefit. Their overall conclusion is that there is a need for better industry-specific safety standards, an improved safety culture and increased risk awareness in the biogas production sector. The paper does not provide any new insights into the concept of ALARP.

2.2.3 ALARP demonstration methods in the engineering literature

When it comes to how to demonstrate ALARP, the focus in the engineering literature remains on quantification. The papers cited above rely on calculation of numerical values for costs and benefits followed by application of numerical risk acceptance criteria in order to demonstrate that risk is ALARP. This trend is despite the warning of many authors noting issues with this method in the past. Most recently Vinnem (2021) notes that the qualitative component of ALARP evaluation is equally important 'but this is often a challenge to achieve, as the quantitative element is very often dominant' (pg 3). In their study of QRA methods for offshore fixed production platforms, Wang, Ong, Wood, Zou, and Abdul-Rahman (2020) warn that quantitative ALARP tools are insufficient to effectively manage risk and that application of past lessons learned achieves a better outcome. Miller (2018) notes that he abandoned QRA in his professional practice in favour of a qualitative well-reasoned argument on the basis that (amongst other things), 'QRA had not produced any safety insights, it simply put a number on things that were already understood' (pg 1). In a later paper (Miller, 2019), he suggests that the uncertainty associated with QRA calculations is perhaps why such calculations have never been used in court as part of a defence against prosecution after an accident. He claims that a well-reasoned argument (similar in form to the one encouraged by AS/NZS 2885.6 Appendix I) is the best form of defence. It must be noted that he is not a lawyer.

There has been a small number of papers published that focus on conceptual and methodological issues associated with ALARP that are reviewed next. Bryant, Croft, and Cole (2018) note that in some regulatory regimes, the requirement that risk is ALARP applies to total risk, in addition to each risk individually. This is particularly relevant in industries and for facilities where hazards vary widely and so risk can still be quite high even if each individual risk is addressed. Langdalen, Abrahamsen, and Selvik (2020) make a similar point in their article on the need for systems thinking in relation to ALARP judgements. One aspect of systems thinking is to see the whole and considering interactions. This is consistent with the approach currently promoted in AS/NZS 2885.6 Appendix I and is also reinforced by the legal case review below. Another aspect of systems thinking is to ensure that interactions between hazards (including the impact of common controls) are considered.

[3] US pipeline regulation does not require risk to be reduced to a level that is low as reasonably practicable but rather for companies to comply with prescriptive requirements. Where risk assessment is used, it tends to be in order to prioritize expenditure (for example), rather than to allow comparison with external risk criteria. Neither of these is consistent with the way ALARP is used in Australia and the UK.

In periodic safety reviews, many actions may be identified that contribute to demonstration that a risk is ALARP. Bounds (2017) proposes a method for prioritisation of actions into four categories based on an estimate of the risk frequency. Time frames for implementation range from urgent (immediate), one year, three years, and no restriction. This point can be considered and added to the decision support system although it is not part of decision making per se.

In a nuclear industry journal article, Hurst, McIntyre, Tamauchi, Kinuhata, and Kodama (2019) summarise the ALARP principle and its application for an international audience. The background and the way in which they propose that 'ALARP thinking' is used throughout a project lifecycle is entirely consistent with AS/NZS 2885.6. The article also includes four ideas about how the judgment that risk is ALARP can be made and justified. These are:

- Consider where the proposed risk controls fall on the hierarchy of controls. Risk control arrangements where most of the effort is low on the hierarchy (i.e., linked to PPE or use of discipline to apply safe systems of work) can likely be improved by application of controls higher on the hierarchy.
- Make sure a wide range of options are considered so that it can be demonstrated that the best one(s) is/are selected.
- Consider industry standards but also relevant good practice, i.e., what is the accepted practice for dealing with this risk nationally and internationally? If this approach is not adopted, why not?
- Recognising that given the uncertainties involved, Cost Benefit Analysis (CBA) is at best a supporting argument in ALARP judgments.

These authors also note that ALARP assessments are made at a particular point in time and the assessment may change over time as industry practices change. What is considered acceptable now, may not be acceptable in the future and can be updated accordingly.

Pike, Khan, and Amyotte (2020) have compared ALARP and the Precautionary Principle (PP) as criteria for decision making regarding public safety. They make the case that the PP should apply in cases where the level of uncertainty is too high to conduct any credible assessment of risk. They note that when using the ALARP principle for decision making, 'if there is more that can be done, then the presumption is that those responsible for the industrial activity will implement these further measures, but this needs to be confirmed by going back to first principles to compare the risk with the sacrifice involved in further reducing it'. They also note that following the ALARP principle does not completely eliminate risk. The logical conclusion to this is that 'we have to expect the risk arising from a hazard to be realised sometimes and for harm to occur, even though the risk is ALARP. This is an uncomfortable thought for many people, but it is inescapable.' (Pike et al., 2020, pg 163) In the pipeline case, both AS/NZS 2885.6 and the relevant legislation assume that credible risk assessment is possible and so the ALARP principle applies.

Syed and Lawryshyn (2020) have developed a multi-criteria decision model for physical asset management but the paper focuses mostly on the way the model itself works, rather than how the factors that must be included in the model are to be defined. It has much in common with the highly quantitative use of ALARP described earlier.

2.2.4 ALARP in legal literature

Scopus does not index law journals and given that ALARP is originally a legal concept we have also searched various legal databases for new material in this area. The Proquest Criminal Justice database returns 13 peer reviewed papers for the period of 2017-2021 that use the term 'reasonably practicable'. None are relevant. The search simply reveals that this expression is used in legal areas as diverse as retaining people under mental health regulations, anti-money laundering, reporting child sexual abuse and aviation security. Searching for 'ALARP' reduces the results to three items which are also not relevant to the current context. Similarly, a search using HeinOnline (another well respected legal database) revealed only four published articles in the period in question. The only one relevant to safety (Ladkin, 2019), addresses practical use of the functional safety standard IEC 61508 and how this links to the legal requirement of a duty of care. He notes that '[v]arious efforts have been made to turn ALARP into an engineering scientific procedure, but this author regards such efforts, while helpful to engineers who need to understand the principle, to be potentially misleading - the arbiter of ALARP is not some engineering assessor but an English court of law. ALARP is a constraint on safety-critical system engineering, but it is not an engineering-scientific procedure' (pg 55). In our case, we are clearly dealing with Australian courts but the point remains valid.

A further search of specifically Australian material via auslii.edu.au (the open access legal database of the Australasian Legal Information Institute) also found little published material of relevance. One article in the Journal of the NSW Bar Association about the circumstances of the MH17 aircraft shoot down over Ukraine makes the point that Malaysian WHS law (which is apparently very similar to the Australian law) requires that taking all reasonably practicable steps to reduce risk includes identifying all 'real risks' (more on this is presented in the case discussion below). In the view of the author, the fact that eight other airlines had stopped overflying the area because of concerns about risk associated with Russian missile activity in the area, mean that Malaysian Airlines likely did not meet the requirements of Malaysian WHS law by continuing to fly over Ukraine and thereby expose passengers to this risk (Chitty, 2016). In Chitty's view, the changed context of flying over Ukraine is something that the airline should have known and taken into account in flight planning.

This lack of attention in the legal literature on the subject of demonstration of 'reasonably practicable' in a safety context (or any others) is unexpected. Given the extent to which industry debates the questions of "how the term is best applied to decision making" and "what it means in practice", it is surprising that there is no legal debate on this subject, or at least not one in the academic legal literature.

2.2.5 Recent lessons regarding ALARP demonstrations

The review of academic literature reveals no major changes in the ALARP demonstration methods in the last five years with a continued focus on quantification despite continued ambivalence about the utility of such methods, even from those who support using them. In summary, the literature review suggests undertaking the following checks of the current guidance in AS/NZS 2885.6 to see if changes are warranted:

- Ensure that the hierarchy of controls/safety by design is emphasised in decision making about the overall acceptability of groups of controls.
- Ensure that the AS/NZS 2885.6 process promotes consideration of options so that there are clear reasons for selection of a specific option.
- Does AS/NZS 2885.6 say enough about the relevant industry practice and the need to consider what others are doing?
- Is Cost Benefit Analysis (CBA) couched as a supporting approach and not a determinant of the answer?
- Is the role of current and future non-engineering / environmental factors (such as future land use) covered sufficiently?
- Does AS/NZS 2885.6 say enough about interactions between threats and possible common controls?
- Do current methods cover assessment of ALARP overall, rather than for single hazards? Is there any gap?
- Should guidance on suggested implementation timing based on effectiveness / impact of measure (for assessments on operational systems only) be included?

These are to be considered in the context of pipeline risk management and the existing guidance in AS/NZS 2885.6 to determine what is relevant and potentially useful and whether those points are addressed sufficiently in the current version of AS/NZS 2885.6 (see Section 2.4).

2.3 Legal sources

The following is based on a close reading of relevant judgments and other legal documents, but it should be considered that none of the research team is a lawyer. The opinions passed are based on our extensive experience in the subject field, but this does not constitute legal advice.

The regulatory guidance material mentioned in Section 2.1 aims to support industry in making ALARP decisions, but what is reasonably practicable is ultimately highly context-specific and a matter of judgment. The ultimate test of the quality of decision making is the performance of the system, i.e., absence of major accidents, but the ultimate *legal* test would be in court if an accident were to occur. With that in mind it is useful to review legal judgments from past cases to see what conclusions have been drawn regarding what constitutes reasonably practicable decision making.

2.3.1 Reasonably practicable in pipeline legislation

Before turning to cases, it is important to understand how AS/NZS 2885 and specifically the ALARP requirements of AS/NZS 2885 link to legal compliance requirements.

The legal situation regarding interpretation of ALARP in pipeline law is complex. As we have highlighted previously[4], the requirement for risk to be reduced as far as reasonably practicable has been incorporated differently in the pipeline legislation in each state. Table 3 reproduced below from EPCRC report RP4-26 demonstrates this issue across the states.

Table 3: References to 'reasonably practicable' in Australian pipeline legislation (reproduced from EPCRC report RP4-26, Table 8, Victorian GSA reference added)

Jurisdiction	Primary reference to 'reasonably practicable'
VIC	"A licensee must manage any pipeline operation so as to minimise as far as is **reasonably practicable** hazards and risks to the safety of the public"[5]. And "A gas company must manage and operate each of its facilities to minimise as far as **practicable** hazards/risks to public safety and property damage."[6]
SA[7]	"…must ensure that any identified risks are eliminated or reduced so far as is **reasonably practicable**".
QLD[8]	"A formal safety assessment must … state ways to control risks associated with the operating plant to … as low as is **reasonably practicable**".
WA[9]	"The formal safety assessment is a risk assessment that … identifies the measures that are necessary to reduce risks to a level that is as low as is **reasonably practicable**."
NSW	—

Of particular note, is that these requirements related to 'reasonably practicable' sit outside the framework of AS/NZS 2885.

The previous EPCRC work also noted the links between pipeline legislation and AS/NZS 2885, noting:

> *AS2885 is specifically referenced in the relevant regulations in all states except Western Australia. In WA, a pipeline operator is required to nominate which standards the pipeline complies with, and we are assured by WA regulators that if AS2885 were not the nominated standard then the regulator would want a specific reason to be given as to why this was not to be used. As such, AS2885 forms a key aspect of the legislative framework for pipelines in Australia and review of the technical safety requirements under Australian legislation requires consideration of AS2885 plus the relevant state legislation.*

Details are included in Table 4, reproduced from EPCRC report RP4.26.

Table 4: References to AS 2885 in Australian Pipeline Legislation (reproduced from EPCRC report RP4-26, Table 7)

Jurisdiction	Primary reference to AS2885
VIC[10]	A pipeline must be constructed and operated in accordance with AS2885

[4] These issues were canvassed extensively in Energy Pipelines CRC project RP4-26 Economic and Technical Regulation.
[5] See: *Victorian Pipelines Act 2005*, Part 9, Clause 124
[6] See: *Victorian Gas Safety Act 1997*, Section 32
[7] See: *South Australia Petroleum and Geothermal Energy Act 2000*, Division 10, Clause 86A(6)
[8] See: *Queensland Petroleum and Gas (Production and Safety) Regulation 2004*, Clause 700.
[9] See: *Western Australia Petroleum Pipelines Act 1969*, Division 2, Clause 7.
[10] See: *Victorian Pipelines Regulations 2007*, Clause 21.

Jurisdiction	Primary reference to AS2885
SA[11]	"the design, manufacture, construction, operation, maintenance, testing and abandonment of pipelines … must be carried out in accordance with the relevant requirements of AS2885."
QLD[12]	AS2885 is listed as a mandatory standard for "design, construction, operation and maintenance of transmission pipelines".
WA[13]	"The safety case for a pipeline operation must specify the principal Australian and international standards that apply in relation to the operation and plant used in connection with the operation."
NSW[14]	"A licensee must ensure that the design, construction, operation and maintenance of any pipeline … are in accordance with … AS2885."

Tracing the requirement to reduce risks to ALARP (or other formulations of 'reasonably practicable'), except in NSW, it appears that there are two sets of requirements that must be met in order to comply:

- Those imposed by AS/NZS 2885 (and so required by legislation indirectly), and
- Those imposed by the relevant legislation directly.

While the first requirement is clearly the same across Australia, the second requirement varies in every state. The pipeline industry would surely argue that compliance with AS/NZS 2885 is a large part of how duty holders (licensees) meet their requirement regarding reasonably practicable under legislation and so the two requirements essentially collapse into one but none of the Acts or regulations state this explicitly[15]. In practice, we will not know if this argument is accepted unless and until it is tested in court and even then, the outcome will be state-specific.

The subject of this review is how ALARP should be demonstrated to meet the requirements of AS/NZS 2885, which aims for best practice in managing risk to the public from transmission pipelines. This is not necessarily the same as meeting legal requirements for risk management.

2.3.2 Comparison with WHS legislation

Putting aside the question about whether the meaning of 'reasonably practicable' in pipeline legislation is the same as ALARP in AS/NZS 2885, we have continued with the legal review. Prosecutions under pipeline legislation are rare. This means that to draw on interpretations of the meaning of ALARP and 'reasonably practicable' from judgements, we need to look beyond the pipeline legislation. The cases drawn on in the next section include concepts of reasonably practicable in relation to safety taken from the Workplace Health and Safety law. The question then arises as to how relevant such cases are when it comes to the pipeline sector and so whether they provide useful guidance in efforts to meet the specific requirements of pipeline legislation and to avoid prosecution. The answer is complex because the term 'reasonably practicable' arises in different ways in different legislation and different states.

First, to compare 'reasonably practicable' in WHS law and pipeline law, the following extract from the Victoria Occupational Health and Safety Act (2004) shows how WHS law treats 'reasonably practicable'. This draws on the Model WHS Act and the wording is common across states due to agreements to harmonise WHS law. "Reasonably practicable' is embedded in the duties of defined individuals and some guidance is given on what it meant.

[11] See: *South Australia Petroleum and Geothermal Energy Regulations 2013*, Division 3, Clause 29.
[12] See: *Queensland Petroleum and Gas (Production and Safety) Regulation 2004*, Schedule 1, Part 2.
[13] See: *Western Australia Petroleum Pipelines (Management of Safety of Pipeline Operations) Regulations 2010*, Clause 12.
[14] See: NSW Pipelines Regulation 2013, Division 2, Clause 10.
[15] The only exception identified is in the Victorian Energy Infrastructure Safety Management Policy where compliance with AS2885 Parts 1 and 3 is explicitly stated as meeting the requirements of the Gas Safety Act 1997 and associated regulations to reduce risk 'as far as practicable' (AFAP). The Policy further states that ALARP and other formulations of 'reasonably practicable' as included in Victorian pipeline legislation should be taken as being equivalent to AFAP.

20 The concept of ensuring health and safety

(1) To avoid doubt, a duty imposed on a person by this Part or the regulations to ensure, so far as is reasonably practicable, health and safety requires the person—

(a) to eliminate risks to health and safety so far as is reasonably practicable; and

(b) if it is not reasonably practicable to eliminate risks to health and safety, to reduce those risks so far as is reasonably practicable.

(2) To avoid doubt, for the purposes of this Part and the regulations, regard must be had to the following matters in determining what is (or was at a particular time) reasonably practicable in relation to ensuring health and safety—

(a) the likelihood of the hazard or risk concerned eventuating;

(b) the degree of harm that would result if the hazard or risk eventuated;

(c) what the person concerned knows, or ought reasonably to know, about the hazard or risk and any ways of eliminating or reducing the hazard or risk;

(d) the availability and suitability of ways to eliminate or reduce the hazard or risk;

(e) the cost of eliminating or reducing the hazard or risk.

From Occupational Health and Safety Act 2004 (Vic)

In WHS law, there is then a single framing of 'reasonably practicable' that applies in all states.

Turning to pipeline legislation, in Victoria, the Pipelines Act 2005 frames general duties and the definition of 'reasonably practicable' in very similar terms as can be seen in the following extract.

124 Duties of licensee for safety and environment protection

A licensee must manage any pipeline operation so as to minimise as far as is reasonably practicable—
(a) hazards and risks to the safety of the public arising from the pipeline operation; and
(b) hazards and risks to the environment arising from the pipeline operation.

Penalty: In the case of a natural person, 240 penalty units;
In the case of a body corporate, 1200 penalty units.

125 What is reasonably practicable?

For the purposes of this Division, regard must be had to the following matters in determining what is (or was at a particular time) reasonably practicable—
(a) the likelihood of the hazard or risk concerned eventuating;
(b) the degree of harm that would result if the hazard or risk eventuated;
(c) what the person knows, or ought reasonably to know, about the hazard or risk and any ways of eliminating or reducing the hazard or risk;
(d) the availability and suitability of ways to eliminate or reduce the hazard or risk;
(e) the cost of eliminating or reducing the hazard or risk.

From Pipelines Act 2005 (Vic)

The issue is that there is not such close alignment between WHS law and pipeline law in all states as we have shown in the previous section. Nevertheless, we have examined WHS cases for any insights they might have regarding ALARP.

2.3.3 The form of safety prosecutions

The final issue before turning to the judgments themselves is to understand the form of charges laid relating to accidents. It is important to understand that companies are not prosecuted because they have had an accident in the sense that this is not what they are charged with. The definition of 'reasonably practicable' can be very important when it comes to the potential for prosecution after an accident, but in the specific, not the general. Using WHS law as an example, offences are risk-based, not outcome-based and so experiencing a fatality at work is not an offence. This is clear when reading the law but was also set out in an Appeals Court case, which explains 'the prosecution need only establish that there was a risk to employee health and safety, the measures identified as necessary [i.e., included in the charges] would have eliminated or reduced the risk (as the case may

be) and it was 'reasonably practicable' in the circumstances for the employer to have taken those measures.'[16] An obvious example is that companies may be prosecuted for not guarding dangerous machinery before anyone has been injured. In practice, prosecutions are rarely mounted unless someone has died, but this outcome is not the basis of the charges laid.

This means that while an accident may trigger the political will to mount a prosecution, in fact, as explained in this Appeals Court decision, 'the occurrence of the accident is of evidentiary significance only, to the extent that it may bear upon the existence of the risk to health and safety, the likelihood of the risk eventuating, the gravity of the consequences if it did; and hence, whether all reasonably practicable steps had been taken to eliminate or reduce the risk. Any exploration by counsel of the circumstances of the accident is for the sole purpose of establishing, or refuting, its evidentiary significance.'[17]

The same style of risk-based offences certainly applies in the Victorian pipeline legislation (see boxed text above which lists the penalty for breaching the relevant duty). Legislation in some other states take a different approach to what constitutes an offence, e.g., following the Varanus Island incident, Apache was charged with 'failing to maintain a pipeline in good condition and repair' – and outcome-based, rather than risk-based offence[18]. In practice, if a pipeline accident were to occur, the relevant authorities would have to make a decision regarding which, if any, legislation should be used to formulate charges against the parties involved. This is likely to be very specific to the circumstances, not only the state in which the accident occurred but also who was involved. If a third party breached a pipeline while working, for example, charges might be laid under WHS law rather than the relevant pipeline act. No doubt lawyers could find other options too that we have not considered.

The primary focus of this review is to ensure that the best decisions are made and that accidents do not occur. It is with this objective in mind (rather than a mindset of how to avoid prosecution) that the following review of judgments regarding past accident cases is undertaken.

2.3.4 Relevant cases

In searching for interpretations of ALARP or other phrases using 'reasonably practicable' in a safety context, both WHS and pipeline cases and associated judgements have been reviewed.

Starting with legal cases linked to pipeline law, the first point of note is that offences under pipeline legislation are generally heard in the relevant state magistrates court and magistrates court proceedings are not generally transcribed. This means that the only cases available for study are those that have come before higher courts. For simple prosecutions under a pipeline act, detailed legal commentary is only likely to be available if there has been an appeal or similar matter which has been heard in a higher court. Having said that, only higher courts are likely to offer interpretations of terms such as ALARP so those judgements are of most interest to us anyway.

Starting with the main act covering technical regulation of transmission pipelines in each mainland state, Table 5 shows available judgments that refer to the relevant act.

Table 5: Documented court judgments citing pipeline legislation

State	Act	Cases that cite the Act
SA	Petroleum and Geothermal Energy Act 2000	22 cases listed. All native title-related in the Federal Court of Australia
VIC	Pipelines Act 2005	4 cases listed: One native title One civil case regarding a damages claim following a liquids line leak (not linked to ALARP).

[16] DPP v Vibro-Pile (Aust) Pty Ltd [2016] VSCA 55, clause 6
[17] DPP v Vibro-Pile (Aust) Pty Ltd [2016] VSCA 55, clause 99
[18] As described below this prosecution was not successful.

		Two cases regarding pipeline licences.
NSW	Pipelines Act 1967	9 cases listed Five regarding council disputes. Three regarding mine subsidence One pollution prosecution (not linked to reasonably practicable).
WA	Petroleum Pipelines Act 1969	50 cases listed 3 administrative and tax matters 10 linked to Apache and the Varanus Island pipeline failure 37 native title.
QLD	Petroleum and Gas (Production and Safety) Act 2004	103 cases listed covering a wide range of issues. Only one is safety related.

This summary demonstrates that there are few cases relevant to this project. Looking at the WA cases, of the ten judgements linked to Apache and Varanus Island, many are administrative (e.g., arguments over Freedom of Information and jurisdictional matters) or commercial matters (various companies taking civil action against Apache due to loss of gas supply). The Department of Mines and Petroleum (WA) prosecuted Apache Northwest, (and co-licensees Kufpec and Harriet) in the Magistrates Court of Western Australia for the alleged offence that, being the registered holders of a pipeline licence under the Petroleum Pipelines Act, they failed to maintain the pipeline in good condition and repair. Ultimately, the prosecution was withdrawn because of technical legal matters, so there is nothing of relevance to ALARP to be gained from legal proceedings as a result of this accident.

Looking at the single Queensland case that cites the Petroleum and Gas (Production and Safety) Act 2004 and is safety-related, we find that it is not pipeline-related. An operator of a coal seam gas facility was successfully prosecuted for not having a safety management plan (SMP) in place that complied with the Act. A worker fell from a partially assembled drilling rig. The charge was that the SMP was not adequate because 'it did not identify at what stage the crew were to install the stairs and hand rails and, therefore, did not achieve an acceptable level of risk.'[19] The sentence handed down was appealed, hence the appearance of this case in the Industrial Court of Queensland. Again, it was the worker injury that triggered the prosecution, although the charge itself is not directly related to the injury but to the way systems of work have been managed. Looking at the criticism of work practices, the available details are thin but perhaps the guilty plea from the operator indicates that risk management was indeed poor.

Since there is little to be gleaned from cases related to pipeline legislation, the review now turns to workplace health and safety legislation. Again, simple prosecutions occur in the Magistrates Court in each state, but many cases appear in higher courts as a result of appeals and other related legal proceedings. Here, there is much more information to draw on. There are 352 judgements available classified as related to duties under work health and safety law. This is too many to review for the purposes of this review, so the list has been sorted by court (superior to lower) and separately by most cited (high to low). The top 10 judgements have been reviewed in both lists (although there is a high degree of overlap between the lists).

The first key point is that assessment of what is 'reasonably practicable' must always be context specific. One judgement relates to an accident where a rigger was killed when an incorrectly assembled pile driving machine

[19] Du Preez (Commissioner for Mine Safety and Health) v Parhusip [2017] ICQ007 270 IR 402 clause 10

fell. The machine was erected with some critical bolts missing. The machine operator claimed that they had discharged their responsibilities regarding 'reasonably practicable' measures to be taken to reduce risk because the manual for erecting the machine said that all bolts were to be installed. The court found that this was not the case as the consideration was not just what was written but 'the critical issue was whether there were systems in place to ensure that the instructions in the manual were read, understood, and followed in practice'[20]. In addition to arrangements for training, the company should also have considered 'risks associated with tiredness, inadvertence, inattention and haste'[21].

In a somewhat similar finding, the High Court of Australia found that a school did not meet its duty of care to a teacher by considering the manual handling risk associating with erecting a display in a school[22]. The court found that it should have been clear that this was only part of the overall activity and the process of taking the display down again and the associated manual handling risk should also have been considered. Again, the emphasis is on considering how risks play out in practice, rather than simply on paper. Another case cited by this one and several others makes the point that companies are required to consider 'real' risks[23]. A risk 'which is not far-fetched or fanciful is real and therefore foreseeable'. Further, 'if a risk is one which a reasonable man would brush aside as farfetched, then it is not a real risk'.

Another case is particularly relevant to duties of designers. In this case, an appeal before the Supreme Court of South Australia, an injured worker who fell during construction of a fume extraction system, sought to gain compensation from Lurgi who designed the system[24]. In a split judgement, one judge found that Lurgi's duty to reduce risk so far as is reasonably practicable extended only to their work on the design. In a majority decision, it was found that Lurgi's duty extended beyond the design itself and that the designer has an obligation 'to take into account foreseeable departures from the design in the erection of the structure'. Again, the emphasis is on how work is done in practice, rather than in theory.

The top ten most cited cases are all about the division of responsibilities in chains of contractors indicating a new trend in modern work practices and the impact it has on safety.

Finally, a text search for 'as low as reasonably practicable' brings up no results as does a search for ALARP, indicating that judgements using these terms (if any) have been made at a Magistrates Court level only and so are unreported. Searching for 'so far as [is] reasonably practicable' and 'safety' brings up 142 judgments. Sorting by court and by most cited and reviewing the top 10 cases in each list (as described above), does not provide any new relevant judgements.

2.3.5 Lessons from legal sources regarding ALARP

A close reading of the legislation shows that the relationship between ALARP in AS/NZS 2885.6 and meeting legislative requirements for risk reduction is not straightforward. In summary:

- Meeting the ALARP requirements of AS/NZS 2885 is a separate question from meeting legislated requirements to reduce risk, in that legislation in most states requires both and does not explicitly link the two.
- Getting a firm legal view on how the two are linked would require this to be tested in court and the result is likely to be quite specific to the circumstances of any given case, including which jurisdiction is involved.
- Despite this uncertainty, reducing risk to ALARP may be a key aspect of charges that could be laid in the event of an accident, depending on the state in which the accident occurs.

When it comes to making ALARP judgements that are likely to stand up to legal scrutiny after an accident, a review of the past cases suggests some key factors to be considered, such as:

[20] DPP v Vibro-Pile (Aust) Pty Ltd [2016] VSCA 55, clause 53
[21] DPP v Vibro-Pile (Aust) Pty Ltd [2016] VSCA 55, clause 53
[22] Deal v Father Pius Kodakkathanath [2016] HCA 31
[23] Wyong Shire Council v Shirt [1980] HCA 12 146 CLR 40
[24] Silvak v Lurgi (Australia) Pty Ltd 2001 HCA 6, 205 CLR 304

- Don’t rely on what procedures say for knowledge of what happens in the field – try to get as much information as possible about actual field practices not just in relation to what risks/threats exist but also in relation to how controls function.
- When designing new systems, don’t assume that everyone will follow procedures. Take into account that sometimes people are tired, forgetful, unmotivated, etc., and the system should still function safely, i.e., not injure them.
- Think broadly about risks and ensure all related activities are included in your considerations, not just the primary task.
- What others do in similar situations is knowledge about a given risk that must be taken into account in deciding whether more could be done.

None of this is ground-breaking, but it serves to remind us that risk assessments are not a box ticking exercise. Every case must be considered individually and decided on its merits.

These lessons are to be considered in the context of pipeline risk management and the existing guidance in AS/NZS 2885.6 to determine what is relevant and potentially useful and whether those points are addressed sufficiently in the current version of AS/NZS 2885.6 (see Section 2.4).

2.4 Summary of Literature Review findings

The review of literature detailed above revealed a total of 28 recent insights on demonstration of ALARP. A summary listed is provided in Table 6, along with comments regarding whether each item is currently addressed in AS/NZS 2885.6 and whether any changes are recommended.

Many items are already covered, and others may be less relevant for pipelines than in the process industries but there are several good points that are worthy of inclusion as additional notes in the standard.

Table 6: Proposed actions based on literature review insights

Insight from literature review	Currently covered in AS2885?	Proposed action
1. Beware of interactions / conflicts / interdependence between risk reduction options, e.g., assess options incrementally, where appropriate, and not individually.	Implied by section 3.3.1 and partly addressed in the Appendix I questions but not covered strongly. An example of this may be where liaison and signage direct people to use DBYD. These things need to be carefully considered so that we don't "double up" when applying risk reduction factors.	If this is an issue for pipeline risk controls, then it should be more comprehensively addressed in Part 6 and also in the structure of our tool.
2. Reverse ALARP is not allowed i.e. using a reverse ALARP argument to remove safety measures.	Not covered.	Add a sentence to section 4.2 along the lines that reverse ALARP (i.e. showing that the incremental risk increase associated with removing an existing risk control is small and so the control is NOT justified) cannot be used for existing pipelines and existing controls.
3. Use real field experience and data in assessing risk and in considering risk reduction options in preference to generic data or assumptions.	Hinted at in several places but not stated very explicitly.	Add a point to the list in section 5.5.1 of information to be considered in SMS validation to say 'field data / experience regarding the nature of threats or the effectiveness of controls'. Note also in Appendix I that real field experience should be used to answer the questions in I4, not generic information.
4. Beware of risk transfer – options that move risk from one part of the system to another with no actual reduction in risk overall.	Not covered except by question e(iii) in I4.	Add a note to section 3.6.1.
5. Beware of the impact of uncertainty on results. If in doubt, use the precautionary principle, rather than relying on risk assessment.	Uncertainty is covered on in Appendix I section I4.	Consider including something on this in the body of Part 6. Note the UK Oil &Gas material on this topic.

Insight from literature review	Currently covered in AS2885?	Proposed action
6. Affordability is not a legitimate consideration, although cost is.	Not stated explicitly, but cost is listed as a consideration.	Add a note to Appendix I.
7. ALARP cannot be used to argue against fulfilling statutory duties.	Not stated explicitly. Covered by Part 0?	Not required for the standard.
8. Ensure ALL possible risk reduction options are considered. Don't address only cheap options. Conversely don't simply consider (and reject) gold-plated options.	Section 4.2 lists some 'gold plated' options that must be considered for existing pipelines. Does this encourage people to ignore cheaper options? Is anything more required?	Sub-committee to discuss.
9. No grandfathering – ensure existing facilities are compared to current standards and gaps considered in the ALARP process.	Covered in Part 0	Nothing further required.
10. Implementation of new risk reduction measures required to reduce risk to ALARP can be staged for practical reasons, but measures should be installed As Soon As Reasonably Practicable (ASARP). ASARP considerations can balance equity and efficiency.	Mentioned specifically in Table 3.4 and section 3.6.3.	Nothing further required.
11. ALARP demonstration should include discussion of items NOT implemented as well as ones that are implemented.	Required by Section 4.2	Nothing further required.
12. A range of possible consequences and their specific frequencies should be considered, not just worst cases.	Covered by Section 3.4.1 Note 1.	Nothing further required.
13. If doing CBA, gross disproportion is likely to be required by the courts for all real risks. The appropriate factor is likely to be about 3 for workers and about 10 for the public	Not included.	Sub-committee to discuss.
14. When assessing cost of a measure, only costs directly associated with the measure should be included. Deferred production is not a cost.	Not included. This is an upstream O&G issue and so not relevant.	Nothing further required.
15. Realistic assessment of remaining life must be used.	Not included.	Add to Appendix I4 questions.
16. What is defined as good practice may change over time and assessments may need to be repeated to take this into account.	Not addressed explicitly.	Consider adding this as an objective for periodic assessment in section 5.5.1.

Insight from literature review	Currently covered in AS2885?	Proposed action
17. Ensure that the hierarchy of controls/safety by design is emphasised in decision making about the overall acceptability of groups of controls.	Mentioned in Section 3.3.1 Note 1.	Add a note to section 3.6.1.
18. Ensure that the AS/NZS 2885.6 process promotes consideration of options so that reasons for selection of a specific option are clear.	Explicitly required by section 4.2.	Nothing further required.
19. Does AS/NZS 2885.6 say enough about relevant industry practice and the need to consider what others are doing?	Only addressed in the Questions in I4.	Add a note to section 3.6.1. This is not as straightforward as it may seem as some unhelpful precedents have been set.
20. Is cost benefit analysis couched as a supporting approach and not a determinant of the answer?	Yes, only addressed as a few questions in Appendix I4.	Nothing further required.
21. Is the role of current and future non-engineering / environmental factors (such as future land use) covered sufficiently?	Yes, listed as inputs to SMS validation in Section 5.	Nothing further required.
22. Does AS/NZS 2885.6 say enough about interactions between threats and possibly common controls?	Nothing included on this.	Add a note to section 3.6.1.
23. Do current methods cover assessment of ALARP overall, rather than for single hazards? Is there any gap?	Nothing included on this.	Consideration of overall risk could be added as a find step in the process.
24. Should guidance on suggested implementation timing based on effectiveness/impact of measure (for assessments on operational systems only) be included?	See Item 10.	
25. Don't rely on what procedures say for knowledge of what happens in the field – try to get as much information as possible about actual field practices not just in relation to what risks/threats exist but also in relation to how controls function.	See Item 3.	
26. When designing new systems, don't assume that everyone will follow procedures. Take into account that sometimes people are tired, forgetful, unmotivated etc and the system should still function safely i.e. not injure them.	Covered by controls fail approach in Section 3.7.	Nothing further required.

Insight from literature review	Currently covered in AS2885?	Proposed action
27. Think broadly about risks and ensure all related activities are included in your considerations, not just the primary task.	Covered by Question e(xv) In Appendix I	Nothing further required.
28. What others do in similar situations is knowledge about a given risk that must be taken into account when deciding whether more could be done.	See item 19.	

3. Fieldwork

The next stage of the project was to interview key stakeholders regarding their recent experience using the ALARP principle and the new requirements for High Consequence Recognition.

3.1 Method

The primary target population for the interviews is experts in pipeline sector risk management processes. The purpose of the interviews is to build an understanding of how the new requirements about recognition of high consequence events and formal demonstration that risk is as low as reasonably practicable (ALARP) that were introduced in the 2018 version of AS/NZS 2885 Part 6 Pipeline Safety Management have been received, how formal ALARP demonstrations are being done across the industry, and what additional guidance would improve the quality of ALARP decisions.

Interview participants were recruited by direct invitation to pipeline engineers known to the research team as a result of a decade of previous research with this group. The industry advisory group and some interviewees also suggested other people for the research team to approach.

Thirty four invitations were issued. Twenty five interviews were undertaken by video call (since the project was undertaken during the COVID-19 pandemic with travel restrictions in place). Interviewee demographic information is shown in Table 7.

Table 7: Interviewee demographic details

	Number of interviewees	Proportion of interviewees[25]
Gender		
Male	22	88.0%
Female	3	12.0%
Discipline		
Mechanical / Materials	18	72%
Process / Chemical	3	12%
Civil / Structural	4	16%
Electrical / Instrumentation / Systems	0	0%
Employing organisation		
Operating company	11	44.0%
Regulatory agency	4	16.0%
Consultant / contractor	10	40.0%
Experience		
< 5 years	0	0%
5 - < 10 years	2	8%
10 - < 20 years	10	40%
20 - < 30 years	7	28%
30 years or more	6	24%
Total	**25**	**100%**

[25] Percentages may not add up to 100% due to rounding.

In addition to the experts described in Table 7, it had been our intention to interview some senior owner/operator executives who are pipeline licensees and so may be recipients of the high consequence recognition statements. Despite multiple emails, no one in this group made themselves available for interview. As such, their views are not represented in what follows.

Interviews were conducted in a semi structured way with the conversation significantly driven by the responses of interviewees. Conversations were guided by the following questions:

1. What is your current role?
2. Can you tell us about your professional background and what has led you to be in that position?

For operating company people:

3. How are high stakes decisions made in your organisation? Can you give us a recent example?
4. What's your role in that process?
5. Where does ALARP come into the picture? What does ALARP mean to you?
6. Do you use the guidance in AS2885?
7. Why? Why not? How have you found it?
8. Does the process support informed decision making?
9. Does the process work when there are multiple stakeholders involved, e.g., developers?
10. Examples in guidance
11. Who else in your organisation uses the process?
12. Who signs off on decisions and how is this recorded / documented?
13. Are you familiar with the requirements for high consequence recognition (HCR)?
14. Has the HCR approach improved decision making?
15. Would you like more guidance?
16. What do you think would further improve ALARP decision making?

For consultants and regulators:

3. How are high stakes decisions made by those you work with? Can you give us a recent example?
4. Do all organisations use the same approach, or does it vary?
5. Where does ALARP come into the picture? What does ALARP mean to you?
6. Do you use the guidance in AS2885? Do you see others using it?
7. Why? Why not? How have you found it?
8. Does the process support informed decision making?
9. Does the process work when there are multiple stakeholders involved e.g. developers?
10. From what you have seen, who signs off on decisions and how is this recorded / documented?
11. Are you familiar with the requirements for high consequence recognition (HCR)?
12. Has the HCR approach improved decision making?
13. Would you like more guidance?
14. What do you think would further improve ALARP decision making?

Interviews were recorded with permission and transcribed for analysis.

Ethics approval for the project was obtained from RMIT's Design and Social Context College Human Ethics Advisory Network in July 2020.[26] The study was regarded as 'low risk' because participants were not placed at any foreseeable risk. The only personal information collected about individual participants was their name, organisational position and contact details. All interview recordings and transcripts were assigned a project code and cannot be attributed to specific individuals. All interview data has been treated as confidential. No interview data has been discussed or published, or will be, which could identify an individual participant although in some cases others with knowledge of the pipeline sector may be able to guess the identity of participants given the relatively small pool of individuals involved.

3.2 Results

Application of the ALARP principle is situated within the broader framework of AS/NZS 2885 requirements. Many pipeline sector people are very proud of AS/NZS 2885 and enjoy working with it. This is true of people involved in the various Standards Australia subcommittees but also those in the industry more widely. Interviewees reported that the activities required under the standard fit well into a general process safety framework for those whose business extends beyond pipelines. It was also reported that the pipeline-specific details make the standard more useful than some process safety management frameworks that can include 'a lot of theory and all that' but can be lacking 'when it came to the nitty-gritty' (I18). In this way, AS/NZS 2885 fits in a broader risk management framework, but is more useful for pipeline engineers as it is more practical.

Participant interviews covered a broad range of topics related to ALARP and risk management in the pipeline sector more generally. Some people put use of ALARP into a broader context based on either the development of concepts regarding risk in the pipeline sector or how ALARP is used in other industries. Other interviewees focused more on the details of how ALARP is applied in practice. A broad range of themes from interview are canvassed in the following sections.

3.2.1 Pathways to ALARP

The requirement that risk is reduced to ALARP effectively means that ALARP is the risk acceptance criteria embedded in the standard. AS/NZ 2885.6 Section 4 states clearly that there are three pathways to demonstrating that risk is ALARP. These are:

a) The threat is controlled

b) The residual risk is assessed to be low or negligible

c) The residual risk is formally demonstrated to be ALARP.

The first pathway means that the identified threat is managed completely by engineering means as defined in other parts of AS/NZS 2885. These cases are not discussed further in this report.

Treatment of low and negligible risks is discussed further in Section 3.2.6.

Intermediate risks requiring formal demonstration that risk is ALARP are the most complex cases, effectively requiring more analysis to better understand the risk, its drivers and so how it might be further reduced. This is described in Section 3.2.2.

Normal practice is to do an SMS validation workshop, including a risk assessment. If any intermediate risk threats are identified, then a requirement for further analysis is triggered. People in workshops are aware of this aspect of the process and so at times, 'there's a lot of push by certain people sometimes to make it low, not intermediate' (I03).

It is a little difficult to see how this could be argued in some cases. Looking at the AS/NZS 2885.6 risk matrix (Table 3.3), any threat that can lead to catastrophic consequences (i.e. multiple fatalities) must pose a risk that is at least intermediate.

[26] RMIT University Human Research Ethics Committee Project No. 2021-24071-13435 approved 21 January 2021.

3.2.2 Methods for formally demonstrating ALARP

Threats that are assessed as posing an intermediate risk are required to go through a formal process to demonstrate that risk is ALARP. The standard is explicit on this, listing six factors that must be included in a formal ALARP assessment which must also be documented. These are:

- The current level of risk and justification for further risk reduction
- Additional or improved controls available for further reducing risk
- The reduction in risk resulting from each available control
- The cost of each control
- Any uncertainty in the analysis
- The reasons why controls have not been adopted.

Appendix I of the standard gives further guidance on how such an analysis may be done.

Despite this, practices regarding formal demonstration of ALARP vary quite widely.

In the past, analysis has been scant. As one regulator said, *'most companies, including the big ones, basically just had a one-liner 'Meets ALARP' and that was it. We've come to intermediate risk, but it's ALARP by nothing, no analysis at all.'* But times have changed and *'now, they are doing a lot better job because they actually are now reading the standard.'* (I03) As another interviewee described,

> *Years ago, ALARP assessments was everyone looked around the group, "You reckon that's as low as practicable?" "Yeah, can't think of anything else we can do." "Right, that's it, agreed, done," and that was the limit of it and then it was only cost-based analysis after that, only maximum justified spend and as the industry has moved along and improved, we've moved and improved with it. (I17)*

Many industry experts now use better processes for formal demonstration of ALARP, but this is not universally the case. Some key industry members seem to be of the view that the points listed above can be addressed by discussion in an SMS workshop and the recorded results constitute a formal ALARP assessment. Others are of the view that quantitative assessment is required in order to successfully address these issues. Despite no mention of Layer of Protection Analysis (LOPA) in the standard, one interviewee told us, *'Part 6 came out and it kind of reinforced using LOPA'.* The various ways in which formal ALARP assessments are being done is detailed further in the following sections.

3.2.2.1 Deemed to be ALARP

As described above, historically, intermediate risks were often dealt with in SMS validation workshops with ALARP decided by consensus without further analysis. This no longer meets the intent of the standard and yet some interviewees remain confused about this.

There remains a significant set of industry practices that aim to undertake ALARP assessment of intermediate threats by consensus in the original SMS validation workshop without further analysis. As one interviewee explained: '*I think the Standard recommends a separate workshop. In my experience that's problematic for us … but we normally discuss the ALARP pretty much right there and then. And we generally try to get a consensus – as much as possible a consensus of whether the participants think that is ALARP or not.*' (I10)

As one facilitator explained, *'it comes down to the mood in the room. It is – I reiterate to people when we're talking about ALARP it is a group decision, it is a consensus and that we have to – we have to address any dissenters. If a person doesn't feel that it's ALARP we have to back up and start all over again to go through the process – go through all the controls and really run it to ground.'* (I12) Another facilitator explained their practice *'I'm prepared in the workshop where it's obvious to everyone, there's agreement, consensus, even with my facilitation questions, a la Appendix I, … that everyone's in agreement that it's clearly ALARP, then we'll record that as much in the workshop.'* (I13)

Ultimately whether or not risk is ALARP is a matter of judgement. *"It's not hard science.'* (I11) As one interviewee explained, getting an appropriate outcome is dependent on having the right people in the room with the right attitude, *'Pretty easy to talk yourself out of things being credible. Pretty easy to talk yourself out of doing extra.*

You've really got to have the right people, the right mindset.' On the other hand, peer pressure in workshops can drive the outcomes too. One experienced facilitator was of the view that all it takes is one person in the workshop to insist that Intermediate risks must be further studied and cannot be simply deemed to be ALARP for further risk controls to be adopted on the spot. He reported seeing this behaviour on more than one occasion in workshops. In their view, insisting that more work is required on intermediate risks *'gives them pause to realise by not taking action we're not at ALARP. They know deep down in their bones that they're not and they know that a detailed review will bear that out and it'll just waste everyone's time, let's just put in the mitigation measures. I think that's been very helpful.'* (I18)

It is true that ALARP is ultimately based on judgment, but the standard encourages such judgments to be based on analysis, rather than opinion and assertion. It's difficult to know whether the practice of deciding that risk is ALARP in a workshop is a real issue leading to significant risk exposure. It may be possible that further analysis would reveal that there are significant risk issues to be addressed but it is perhaps more likely that analysis would assist in stripping out the many very conservative assumptions that are often embedded in pipeline risk assessments. The problem is that *'everybody just wants to get it done, and not actually do the real engineering to sort some of these problems out a bit.'* (I16) Without some additional engineering, decisions are not necessarily being made on an informed basis.

Some facilitators clearly do undertake ALARP workshops as part of SMS validation, but others do not take on such assignments. One consultant described how he responds to such requests:

> *And I say, well no we're not, because the whole point of the formal assessment, ALARP process, by token of the fact that you've got there, means you've got to do more work, and you've got to solve some difficult problems. And it's not something that we just deal with simply in a workshop as an add-on to the rest of the SMS workshop, it's an action that you guys have got to go and sort out afterwards. (I16)*

This practice should not be confused with the fact that some companies/facilitators encourage the use of ALARP validation workshops (as opposed to SMS validation workshops). These are seen as useful because *'you need input from everyone, you can't do the ALARP assessment in isolation. Because, you just need to understand whether what you're proposing is practical or not.'* (I05) These are important, but relatively small workshops. As one interviewee explained, *'there's probably no facilitator involved as well … just an engineering backroom exercise'* (I13). Another interviewee described their company practice in these terms.

> *And there might only be three or four people involved. We don't bring the field in and everyone else. And I think the last one that I was involved in, we brought in our principal engineer – our engineering manager in, so it was just the three of us. And we went through the LOPA and the rest of the spreadsheet, went through the questionnaire and came to a conclusion that we had demonstrated ALARP and that was documented in the risk register that was part of the SMS.* (I02)

There is apparently some residual confusion amongst some consultants and some operating company people about the requirements for formal demonstration of ALARP as required by the standard.

3.2.2.2 LOPA and other ALARP studies

The intention of AS/NZS 2885.6 is that formal ALARP assessments are engineering studies done based on data drawn from a wide range of sources. Many companies understand that. As one interviewee explained, *'I think that ALARPs tend to be done not in a workshop, they're written up by someone who puts it out for comment and discussion.'* (I15) As another interviewee pointed out *'a workshop is a terrible place to go into actual metadata … say, there's only an 8% chance that a leak will ignite.'* (I06)

Typically, one individual has the task of preparing the formal ALARP assessment but:

> *We need a lot of input from a lot of people. So, it is mainly engineering in terms of does it rupture, does it leak, what's the failure event, what's the failure frequency, chance of ignition, delayed ignition. So, we look into all that kind of stuff … we talk to [lands management] … and operations as well. What kind of size excavators do you expect to see out there? Do you see them with tiger teeth? … we're building at the moment, that metadata, so, at least we can back up our claims and say with confidence. (I06)*

Sometimes it is also relevant to consult with commercial people regarding spare pipeline capacity and the feasibility of reducing maximum allowable operating pressure (MAOP).

These studies are not trivial in the effort required. Even for relatively simple cases, *'each ALARP assessment might take at least a month to finish.'* (I05) This work is often done by operating companies in-house but is also sometimes contracted out, typically to the same consultants who also facilitate SMS validation workshops.

Many organisations draw together their considerations about the effectiveness of risk controls using a calculation based on a Layer of Protection Analysis (LOPA) approach. LOPA was developed in the process industries to determine the required reliability for instrumented systems, but the concept is simple as shown in Figure 2.

Figure 2: Typical steps in a pipeline LOPA

- Define threat to be considered
- Determine the base frequency of the hazard
- List layers of protection designed to prevent the hazard leading to consequences for people (these can be engineering systems, procedural controls, or environmental factors)
- Determine the probability of failure on demand (PFD) for each layer of protection
- Determine the final frequency of pipeline damage for this threat by combining the base frequency and all the PFDs.
- Re-evaluate risk based on the calculated frequency using the risk matrix.

LOPA is used in two main ways by the pipeline sector. Firstly, to assess in detail threats found in a workshop to pose an intermediate risk. LOPA can be used to refine understanding of risk and so get a better idea of where further risk controls might be useful. Secondly, LOPA is used to evaluate the effectiveness of risk controls in reducing risk. While the concept is simple, consultation with multiple parties and detailed analysis is often required to determine the best estimate for probability of failure on demand (PFD) for each risk control / layer of protection.

In terms of advantages of LOPA, as one interviewee explained, *'LOPA helps us inform where our likelihood is in a … bit more targeted sense than purely sitting in a workshop and going "Is this hypothetical or is it remote?"'* (I01)

LOPA provides a framework for examining the effectiveness of individual risk controls which is not always done well. As one company interviewee explained,

> *the interesting thing is I know that the [consultants that use LOPA], when people come up and they say, "Oh, we do patrols," they really try and probe them and work out how good they are. It's like I'm not sure everyone does that, because it's not really written down. …They think and probe, and really, do you really get out there once a week? Do you keep records? All these things.* (I20)

Another benefit of LOPA is that it allows easier comparison of options as this interviewee described:

> *I think it's to give a little bit of structure around the comparable benefits of options. It's very easy to say "This one's useful, that one's not useful", but with a semiquantitative method you can say that this one has this number, this one has that number, it's very clear what the difference is. So it helps to give visibility on that subjectivity of the usefulness of options. (I21)*

LOPA is not typically used on its own, but rather in combination with the questions in AS/NZS 2885.6 Appendix I, as one interviewee explained, *'LOPA as an assistance to determining frequency class for a qualitative risk assessment, yes. But not LOPA as equals ALARP.'*

When it comes to use of the Appendix I questions, approaches also vary. Some companies have adopted the list shown in Figure 3 verbatim. As one consultant reported, *'we've created a spreadsheet, and we've copied all the questions in Appendix I into that spreadsheet. And when we want to do ALARP assessment, for [companies] who don't have their own procedures, … we go through the list, and we answer each question one by one.'* (I05) This is not a workshop exercise based on off the cuff opinions, but an exercise in data collection and analysis.

Figure 3: ALARP demonstration questions reproduced from AS/NZS 2885.6 Appendix I

(a) Current level of safety risk:

- (i) Are the potential consequences of this event particularly severe?
- (ii) What is the level of safety risk to the public from the current arrangement from this THREAT?
- (iii) What is the level of safety risk to workers from the current arrangement from this THREAT?
- (iv) Does the risk change in the future?
- (v) If this is an existing facility, does it meet the standards that would be required for an equivalent new facility?

(b) Additional justification for further risk reduction:

- (i) Are there significant security of supply consequences for this event?
- (ii) Are there significant environmental consequences for this event?
- (iii) Are there significant reputational or other corporate reasons for wanting to reduce this risk further?
- (iv) Are external stakeholders aware of and objecting to this risk?

(c) Uncertainty

- (i) Do we understand the nature of the THREAT well?
- (ii) Is the risk assessment based on a comprehensive review of the history of this THREAT across the pipeline sector?
- (iii) Is the current and future land use/population well understood?
- (iv) Is the environment around the pipeline at this location well controlled?
- (v) Is this scenario novel or a standard industry situation?
- (vi) Are all industry standard methods of controlling this THREAT already in place?
- (vii) If either risk controls or activities that can lead to this threat are being subcontracted, how certain are we that those involved have the necessary expertise and have in place the systems, processes and procedures to ensure the work is carried out as we intended?
- (viii) Is there evidence that existing risk controls for this THREAT are effective, available when needed, reliable, will survive in an accident?
- (ix) Is there evidence that there are gaps in our knowledge about other risk controls for this THREAT?

(d) Reducing the risk

- (i) How might risk be reduced further?
- (ii) List as many ideas as possible for new controls or enhancements to existing controls then assess each one, starting with the one with the likely biggest risk benefit.

(e) Risk benefit of proposed control

- (i) What exactly is the proposed control?
- (ii) What is the benefit in terms of safety risk to the public from the proposed control?
- (iii) Is the risk benefit 'real' or does this control simply shift risk to another part of the system?
- (iv) Is the proposed risk control effective in all cases against this THREAT or it is designed to address only some cases?

(v) Is there significant uncertainty associated with the effectiveness of the proposed control?

(vi) Does the control reduce risk for other sections of the pipeline?

(vii) Is the proposed risk control reliable in all cases against this THREAT, i.e. will it work when called upon?

(viii) Is the proposed risk control available to be used in all cases when it might be called upon, e.g. could it be affected by the THREAT itself?

(ix) Is the proposed risk control likely to be impacted by the same THREAT that it is designed to mitigate?

(x) Is the proposed risk control a standard industry practice, or something novel?

(xi) Is there a plan in place to monitor effectiveness?

(xii) Has this proposal been benchmarked against practices of others? If so, what do others think of this proposal?

(xiii) Is the control dependent on other things in order to function?

(xiv) Are there other tangible or intangible benefits of this control?

(xv) Are there risks associated with the proposed control itself?

(f) Cost of proposed control

(i) What is the cost of the proposed control (capital and operating)?

(ii) Is this proposed control an industry standard approach to managing this THREAT?

(iii) Is the proposed control more expensive than it would be for a similar new pipeline?

(iv) Is the proposed control justified on a pure cost/benefit analysis basis?

The questions have generally been well received. *'We definitely use that 20-question process'* (I20), although one interviewee warned about going into too much detail in the standard.

> *I think the series of questions are good. … [they] are useful in the sense that it gives you a starting point and you can turn your mind to the sort of things you need to cover. That's the positive side of it. The negative side is people just go down through the series of questions and switch their brain off, which I think we've got to be careful. So, I think it's very good to have these series of questions just to turn your mind to making sure you've covered things. But I'd be reluctant to have it to a level of detail that people just use it as a recipe.* (I09)

Some risk experts have produced their own version such as this consultant who told us *'obviously the list in Appendix I is fairly long and we looked at trying to combine a few of them under a few very - I'm trying not to use the term 'generic' - but questions that were similar to another question got combined into one.'* (I17) and one operating company suggested that *'the 2885 sort of questions at the back did help, but we don't use them every time we do an ALARP now'* (I21). Similarly, others claim to use the ideas but not the details: *'We haven't – we haven't prepared a checklist, but I think the high-level concepts are there.' (I10) and 'I don't think we actually read it word by word each time we do an ALARP, but I'd say largely we would be following it and compliant.'* (I15) It seemed in interviews that there might be some consultants who had not actually read Appendix I until it was pointed out to them.

Overall, most feedback about Appendix I was positive as it facilitates the process of framing the judgement, although it must be acknowledged that there is still engineering judgement required to come to a firm conclusion.

> *I think it is good in the sense that the standard now has some framework on what to do and how to do an ALARP. It's still subjective. … Really ideally, you've got to go into it with an open mind, the formal*

> *ALARP assessment, you don't really want to go into it if someone's already made their mind up. You don't want anyone going to it with any pre-conceived ideas. Yeah really. I think it's good, it's just it is subjective. I'm not sure if you can ever really get around that.* (I22)

3.2.2.3 Cost Benefit Analysis

At the end of the day, decisions regarding risk reduction and ALARP must justify expenditure. As one interviewee noted, *'these entities are commercial entities. … so eventually they come back to the cost to benefit analysis in terms of reducing the risk to a further level [from] where it sits at the moment.'* (I14)

Having said that, the previous focus on numerical cost benefit analysis and calculation of maximum justifiable spend was seen as unsatisfactory. Cost benefit analysis is mentioned in Appendix I as something that can support (but not dictate) the decision-making process. As another interviewee explained, *'What I'm finding is … the industry is looking to move away from a purely cost benefit analysis approach to focus more on the likelihood of failure and trying to get the likelihood of failure down as low as reasonably practicable.'* (I01)

Despite this move to a broader analysis of costs and benefits, some interviewees still believe that quantification of cost and benefit is the way to go:

> *They might go into one part of it and discuss how much each different control would cost. But they may not quantify the risk reduction achieved by that control. And then relate that back to the cost. Sometimes they do and sometimes they don't. I think that's something that is often missing in ALARPs in general. (I08)*

Another interviewee found the Appendix I questions ultimately unsatisfactory because they do not drive a firm conclusion.

> *We have used those questions to answer whether the risks have changed and what we can do in order to improve the risks and so forth. I think we have used that and I think – but it's still, again, all those questions – I mean, they do come to a point where you just have to quantify it eventually because qualitatively we all will come to a point that there is a risk or there is a risk I mean where we have to do something about it. It's a point where we have to come up with like a cost benefit analysis.* (I19)

This residual attachment to cost benefit analysis is discussed further in Section 3.2.10.1 in the context of providing additional guidance.

3.2.2.4 Conclusions

In summary, there are three primary ways in which formal ALARP demonstrations are being done in the pipeline sector.

1. By guided discussion as part of SMS validation workshops. These discussions sometimes draw on the questions in Appendix I but are also strongly driven by precedent, i.e., controls are adopted in line with current industry practice for similar situations.
2. By engineering analysis often using a combination of LOPA and structured responses to the questions in Appendix I. This method combines both quantitative and qualitative aspects and requires judgement to determine the final outcomes based on assembled evidence.
3. Relying on quantification of risk and use of cost benefit analysis. This work produces quantitative results that are given to decision makers as input to their decision making.

The intent of AS/NZS 2885.6 was for users of the standard to adopt the second method but this is not completely understood in industry. Those who have adopted the first and third methods are generally of the view that their work meets the requirements of the standard. In some cases, this would seem to be a somewhat optimistic assessment. Given that the second option has grown up largely since 2018, this is perhaps to be expected and not a bad position for the industry to be in.

3.2.3 Benefits of formal ALARP demonstration

It is important to see the 2018 requirements in the context of the history and evolution of risk management in the pipeline sector. Prior to introduction of risk-based approaches to pipeline design and operations, interviewees report that decisions were based on prescriptive approaches in which best practice was very conservative.

Explicit consideration of threats and the likely frequency of hazardous outcomes has allowed the industry to find ways to do things more cheaply without any significant increase in risk. The primary benefit of the use of ALARP was seen as being that it focuses attention on the highest risk areas. Conducting a formal ALARP assessment provides a way to summarise all the disparate factors that must be taken into account to make the right decision. Using this method provides a logical framework for discussion that is repeatable and defendable.

This is particularly important when it comes to justifying decisions about necessary risk controls to those outside engineering. Some interviewees have also found ALARP assessments to be an excellent communication tool with senior management. The structure of the process *'really helps because you've put a lot of justification behind [a request for additional expenditure on risk control], … it kind of really highlights to them that hey, whoa, hang on a second, I need to pay attention to this. So, it's been really good in that respect of things.'* (I06)

Formal ALARP assessments are useful with developers and other external stakeholders too

> *Outside the organisation it has helped in understanding where - so, if we have to do something, we have to do something and it kind of just spells it out to them and they're just like, "Okay, we have to do that." So, it does put an end to that discussion, which is really good and yeah, it just comes down to cost and who paid for it.* (I06)

Formal ALARP studies have been useful in justifying risk decisions to regulators since such studies provide *'a formal justification for the company's position on a particular threat.'* (I17)

Application of the ALARP principle can sometimes be seen as favouring addition of new controls, but at its best the process encourages a focus on effectiveness of existing controls, too. This is important as this interviewee summarises:

> *I suppose we think about this discussion about get legal review of the process, that we are putting up. That's not the issue, it's actually the forensic review of everything that you've said that's meant to be in place, it's the implicit assumptions in the risk assessment – it's not the risk assessment, it's actually how you are doing things that are actually, that deliver the accident, not that you've done a, how do you best guess in a risk assessment workshop, and said it's low.* (I16)

As another interviewee summarised, *'effectiveness of controls is where it's at. How good is this control really? Let's get to the bottom of it. Is it going to work?'* (I20)

Driving effort of effectiveness of controls would seem to be a good focus for the next revision of the standard.

3.2.4 Use of consultants and consultants' knowledge

A small number of expert consultants service the pipeline sector on matters regarding safety management studies and ALARP. Operating company interviewees were asked which consultants they use and all consultants active in this area were approached. All consultants who were approached for interviews agreed to participate. The ten consultants who were interviewed for this project, therefore, represent a very large proportion of the contracted work done in this field.

Consultants are used for three reasons:

- To provide additional skilled resources for larger organisations that prepare many SMS Reports.
- To provide expertise to smaller organisations who may need an SMS report to be prepared but do not have sufficient skills in house.
- To provide independent facilitation of SMS workshops involving third party development in particular.

The tasks undertaken by consultants vary too. Tasks include:

- Collecting information and preparing for an SMS validation workshop.
- Facilitating an SMS validation workshop.
- Writing the SMS Report following the validation workshop.

- Undertaking formal ALARP assessment for specific intermediate threats.

Company practices regarding the scopes of work that they contract out vary and the tasks that consultants are prepared to take on also vary. Of the tasks listed above, doing formal ALARP assessments is the one least likely to be given to a consultant. There is a fine line between making use of external expertise and taking ownership of the SMS process. Some companies tend to outsource much of the SMS process and others retain key aspects in house and use specific, independent expertise when necessary.

Consultants tend to each have their own tools (e.g., customised multi-worksheet spreadsheets) that they use to define the SMS process and record the results. The tools are developed based on the consultants' experience across multiple operating companies (and sometimes multiple sectors) and their reading of AS/NZS 2885. As such, consultants are very influential within the pipeline sector regarding safety management study matters in general, and ALARP requirements in particular. Some consultants run training regarding SMS matters, conduct audits on behalf of government and are active in standards committees. As individuals, they are highly influential and act as a catalyst within the industry.

Given the level of industry-wide influence of this consultant group and the variation in methods of ALARP demonstration as described in Section 3.2.2, perhaps it is time to bring the consultants together as a group to discuss best practice and the requirements of the standard.

Many consultants work for the pipeline industry and also for other stakeholders such as developers and planning agencies. Working for other stakeholders introduces specific challenges as discussed in the next section.

3.2.5 External interference issues

Many of the cases that require multifaceted risk decision making relate to new developments near existing pipelines and the risk controls that are justifiable to address the risk of external interference with a pipeline. Some cases are greenfield developments and others involve intensification, or special developments and activities around pipelines in urban areas. All involve challenges for consultants who take on SMS validation workshop facilitation and sometimes ALARP studies in these situations.

Some of the expert consultants act as facilitators for SMS validation workshops at the planning stage where state governments are considering release of new areas for residential housing development. This seems to occur most commonly in NSW. Consultants involved in such studies find them very satisfying as, at this early stage, it is relatively easy to apply inherent safety principles. One consultant described such a case in the following terms: *'All parties on board early, moving schools and town centres to get them out of the measurement length, which was fantastic.'* (I13)

At the other end of the spectrum are cases where financial commitments have been made for a specific change to land use near an existing pipeline before the risk implications are considered. New childcare facilities and changes to schools near existing pipelines seem to be particular cases in point.

When it comes to work being done by groups outside the pipeline company that impact company assets, most organisations have well-established internal requirements for what they think is necessary for risk to remain ALARP and the cost to parties wishing to construct new facilities near as existing pipeline can be significant. Sometimes, gas companies deliver this news themselves. As one pipeline company person explained,

> *We try and be upfront as much as possible, we try and tell them this is what you're going to have to do. If you want to build the road this is what's required. … So, yeah, we try and be upfront and rather it coming out of an SMS, I kind of know what needs to be done and tell them upfront … I think open[ness] and transparency is important because if they go into the SMS and just be like, "What the hell? What do you mean we have to realign the pipeline?" You're going to cause a lot of drama, unnecessary drama because it will be a big shock and a big cost that maybe they can't do. (I06)*

Other gas companies manage this situation differently and leave these decisions to be driven by an independent facilitator managing an SMS workshop. Scenarios addressed in this way include planning for activities that could damage a pipeline but also changes of land use that do not impact the pipeline directly but could result in worse consequences in a worst case scenario (such as addition of a childcare centre within the measurement length). In such workshops, risk decisions tend to be consensus-based and many cases were reported where gas company representatives require that slabbing be installed, reportedly even in cases where no credible threat

can be identified that would benefit from this control. Situations such as these tend not to be addressed by formal ALARP assessment, but rather decided in the workshop.

> *if we go through it in the workshop and during the workshop the pipeline owner says, "yes if … the concrete slabs are installed then we're comfortable," it doesn't need an ALARP because what more will you learn? They don't see any value in doing anything more because they've already come to that conclusion which is what I was saying way back that they kind of have precedence. (I12)*

Other companies will take the output of the SMS workshop which was done with the involvement of representatives of the developers, and then conduct ALARP assessments for intermediate risk threats in house. These are typically not shared with third parties, despite the fact that third parties are expected to pay for any additional risk controls that have been determined to be required. One company interviewee described the process like this:

> *We often have tough conversations with developers for what protection measures we're going to employ. We go through the SMS process, they're participating in that, so they get to see, come along on the journey and see that this particular threat comes up to intermediate level, so they've got some buy in, they understand how we got there. But the ALARP is still done by [the company] inhouse. So that causes them some frustration because then we come back to them and say "Hey, we think there's justified mitigation here is to do top slabbing say" and they'll say "Well how did you get to that?"*

> *We do have to take them on a bit of a tour of the ALARPs, but we never send them out. We never send those documents out into the public domain, because we don't want anybody holding us to task on how we did our assessment. We think it's thorough and robust and we don't need to have it challenged by third parties. So anyway I guess we do have that conversation with them, and we do give them a bit of a guide as to how we got to it, but we don't ask for their input. Their input was in the risk assessment to come up to the risk level and then how we have to mitigate it, it's not their call to make. (I21)*

Generally speaking, developers are expected to pay for any changes required to the pipeline and its ongoing management in order that the risk remains ALARP. One company person explained it this way:

> *In very rare circumstance if it's a not for profit or a small business or a private landholder, we might pay for it ourselves. But generally, if it's a land developer where they're making x million dollars and we don't share that profit, then we think it's appropriate that they pay for it, but yeah, as part of our agreement with them. Because independent of the SMS process, we also have a commercial agreement that gets in place as well to cover that off. (I21)*

This sounds like a negotiated outcome, but in fact the power dynamics at play can be significant. Typically, an ALARP assessment is a tool for a company to decide what they are willing to spend to reduce risk. Uniquely in these external interference cases, gas companies are deciding how another organisation's money should be spent.

> *I've been in situations where I've thought, if they thought that they had to pay for it, they wouldn't be doing it. And I think it's bullshit, we're doing this because we can get some – and I've seen examples where, I mean it's particularly odious character, but he was just using it to get other people to pay for upgrade to the pipeline. (I16)*

Several consultants expressed significant professional discomfort with having to manage situations like this. Some consultants try to avoid these types of assignments with one person explaining why in the following terms:

> *I'm in the middle of a sandwich because I'm being hired by the developer who just wants to build houses and yet I'm part of the pipeline industry and the pipeline company is saying we don't want them to build houses. But my client is the proponent that wants to build the houses or childcare centre … And so it tears me apart because I like these guys who are building their – being developers and they're being – they're being overwhelmed by the power of these big pipeline companies who can scare them with philosophies. … It's very awkward. It's very difficult. (I12)*

A close reading of the requirements of AS/NZA 2885.6 further highlights confusion and inconsistency in this area. Where developments such as a new school or childcare centre are proposed in existing T1 and T2 locations, the

Pipeline Licensee is already required to demonstrate that all risks are reduced to ALARP as part of the five yearly operational SMS review process. In both cases, according to Section 4.2, they are required to conduct a formal ALARP assessment when "an existing pipeline is in a HIGH CONSEQUENCE AREA and does not conform with current requirements for NO-RUPTURE and energy release rates". The only difference between T1 (or I) and T2 (or S) is that the energy release rate criterion is 10 GJ/s for T1 (or I) and 1 GJ/s for T2 (or S). The NO-RUPTURE criterion is the same for both. So, the only real driver for decision making is limiting the size of the hole in the pipe, which determines the energy release rate. This has the following implications.

New Developments in existing T2 Locations: If a formal ALARP assessment following a five yearly operational review has been done with all due diligence and robustness, and if a new school is proposed in an existing T2 location (so that the location class changes to T2-S), the threat profile doesn't change, and the consequence arguably doesn't significantly change (given the uncertainties in estimating consequence – but expected to be many fatalities (children or adults) and therefore Catastrophic), so the risk profile doesn't significantly change. So, if the risk was ALARP before the school is proposed, why is it not ALARP after the school is proposed?

New Developments in existing T1 Locations but no change in energy release requirements: New developments other than high rise development or schools or hospitals generally don't change the requirements for energy release rate (e.g. a new petrol station in an industrial estate, a small shopping development in a residential area). In this case the argument above for T2 locations applies.

New Developments in existing T1 Locations but new development results in Sensitive Use (S) and therefore more stringent energy release requirements: This is typically in a T1 location where a school, or aged care facility is proposed. If the maximum energy release rate exceeds 1 GJ/s (the requirements for a Sensitive Use (S) location), then there is an obligation to demonstrate the risk associated with a release >1 GJ/s is ALARP. In some cases, there may be a significant increase in consequence if the school or aged care facility is in close proximity / directly adjacent to the pipeline. But it is not necessarily true that the consequence will significantly increase. The threat profile does not change. The risk assessment in this case is based on minimising the size of the hole that can be made in the pipe. It seems most likely therefore, if a formal ALARP assessment following a five yearly operational review has been done with all due diligence and robustness, there will be some (or many) instances where no further controls are required (or at least imposed on a third party).

Based on this assessment of the requirements of the standard, it is unclear why the common practice of requiring additional slabbing near new sensitive uses has arisen.

3.2.6 Regulatory issues

Given the range of views regarding ALARP, it is not surprising that this variation also extends to regulators. According to all interviewees, there is broad agreement between the regulators in most states about what is required to demonstrate that risk is ALARP but subtle differences sometimes create conflict.

According to interviewees, the issues on which there is disagreement have changed over time, but one current point of some contention comes from ESV. It is clear from ESV guidance material[27] that for risks that are assessed to be low or negligible, there is a requirement for the safety management study to consider what more can be done to reduce risk and if there are simple, inexpensive suggestions then they should be acted on. This is consistent with the concept of proportionality and is also consistent with the last paragraph of AS 2885.6 Appendix I section I3 which states:

> *It is not intended that achievement of a low or negligible risk rank means that further risk reduction is unnecessary. If there are additional readily available and cost effective risk reduction measures it would be inconsistent with the ALARP principle to ignore them solely because the risk is already low or negligible.*

[27] Energy Safe Victoria, Safety Management Plan Preparation and Submission for Pipelines, July 2019

Further, Section 4.2 of the standard itself states:

> *Notwithstanding that a risk has been determined to be low or negligible, if there are simple measures that could be taken to reduce risk further, then those measures should be adopted.*

Having said that, Table 3.4 regarding risk treatment actions states that the required action for low risks is to:

> *Determine the management plan for the THREAT to prevent occurrence and to monitor changes that could affect the classification.*

The required action for negligible risks is to:

> *Review at the next relevant SMS (for periodic operational review, LAND USE CHANGE, ENCROACHMENT, or change of operating conditions)*

As such, Table 3.4 does not explicitly call for consideration of additional risk controls for low and negligible risks. Some safety management studies have apparently been conducted without explicitly considering further risk reduction for low and negligible risks. This is a small item in the process if done at the time of the main study, but tricky to complete as an add-on to completed work, potentially requiring workshop groups to be reconvened. The finding provides even more incentive to get this right from the start.

3.2.7 Senior management awareness

Specific requirements were introduced to the standard in the 2018 revision regarding senior management awareness. AS/NZS 2885.6 Section 1.5.6 states:

> *The Licensee shall be aware of the potential consequences of pipeline failures in high consequence areas, the controls in place to mitigate these consequences and the limitations of the controls*

Appendix H gives more detail on the intent of this requirement and how it might be achieved. Earlier drafts of the 2018 revision advocated that a declaration signed by the licensee could be used, but this was not included in the final version of the standard.

Overall, awareness of these new requirements was low amongst interviewees. Many interviewees had no knowledge that this requirement exists but there were exceptions.

Some operating company specialists have thought about this requirement and tweaked existing company practices with senior management risk awareness in mind. There is a pre-existing requirement that the pipeline licensee signs off the SMS report. The new requirement has caused some companies to consider how this document communicates key messages to the licensee and some changes have been made. As one such interviewee said, *'I think we're kind of halfway house where the executive summary kind of ticks some of those boxes but not fully and there's no declaration which was kind of the intent if I'm putting the high consequence stuff together in the first place'* (I07)

One pipeline operating company has adjusted the sign off processes for their SMS reports to include a presentation of SMS results to the licensee that is essentially in line with what is suggested in Appendix H. Interviewees from this organisation emphasised that the presentations themselves were a good vehicle for senior managers to ask probing questions before signing off on SMS Reports. As one interviewee explained:

> *They ask a lot of questions about whether we've done enough about what the threats are, what we've done to mitigate those threats. Could we have done more? How that compares to the rest of the system especially if it's in a populated area.* (I15)

Another interviewee from the same organisation was of the view that such presentations have lasting benefit:

> *It works … really, really well. I find that the licensees and senior management actually, just in office watercooler chats, that they are aware of what's happening on the assets, you know the risk profiles of the different assets, far more than we used to 10 years ago, so I think it's definitely helped.* (I21)

Given the influential role played by consultants, their actions in relation to high consequence recognition are important too. Results from the interview suggest that a wide range of attitudes are present. There are three prevailing attitudes:

- Some consultants who are actively involved in producing SMS reports are completely unaware of the high consequence recognition requirements. These are likely a subset of the next group.
- Some consultants see their role as purely technical. They record their work in technical terms and have no knowledge and essentially no interest in how it is received in client organisations beyond their technical clients. In some cases, people such as this were aware of the new high consequence recognition requirement but essentially saw it as not relevant to them.
- A third group of consultants try to structure their deliverable to encourage and facilitate client compliance with the high consequence recognition requirements. This includes:
    - Writing SMS report executive summaries in plain language and including the information suggested in Appendix H.
    - Including a version of a declaration form prepared along the lines of Appendix H that their clients can chose to use.

Regarding improved executive summaries, one interviewee explained that previously this information *'was in the body of the report but it didn't smack you in the face in the executive summary. It was there in the body, it just wasn't explained in layman's terms. You had to go looking for it.'* (I17) As a result of the new standard requirements, this consultant now writes SMS Report executive summaries differently.

Another consultant who has changed his approach explained why:

> *I feel incumbent to, as an SMS facilitator, make [a declaration ready for the licensee to sign] a deliverable and offer it to them. … I think I'm getting traction with licensees understanding and agreeing for the need for it despite some of that legal pushback we had in the Part 6 public comment phase.* (I13)

Overall, it appears that the discussion about introducing this requirement into AS2885.6 and the words in the standard have had some impact, but it is not industry-wide at this stage. Regulators reported that their audit results also suggest that uptake of this requirement in industry has been low. As one regulator explained, *'they always argue that, "Here's our SMS report and it's all in there." So, in theory they can always demonstrate that. It's in the report and approved by the licensee.'*

We attempted to gather the views of licensees themselves as part of this research, but despite multiple approaches, no licensees made themselves available for interview.

3.2.8 Implications for future fuels

Most interviewees were of the view that the ALARP process is not impacted by industry moves to develop future fuels, i.e., the same considerations apply. Of course, this is broadly true but some interviewees reflected on contextual changes that may result.

When it comes to thinking about risk, several interviewees spoke about what they see as an acceptable level of risk. One interview described in some detail that it's not simply a matter of whether or not a pipeline leaks.

> *Many pipelines are in remote locations and leaks in that situation are more acceptable because fewer people may be impacted. Conversely industry moves to hydrogen may reduce the number of leaks that are seen as acceptable due to the wider flammability range of hydrogen compared to natural gas and so the increased potential for fire.* (I03)

Ultimately, it's a matter of *'whether the public thinks "hey look have the industry done enough or not to try to minimise the risk" '*(I10). Public expectations are important, and this changes so *'we've got to ask ourselves what's reasonably practicable today is not reasonably practicable in 10 years' time, in 20 years' time.'* (I10)

Managing hydrogen was seen by interviewees as largely a technical problem, but one that is not yet solved. As one interviewee explained, *'we don't know the risks or the consequences as well as we do with natural gas.'* (I08)

The perceived significant level of technical uncertainty means that more research is needed to understand how addition of hydrogen might impact pipeline properties (for example) and:

> *Once you've got that understanding you can feed that into your ALARP set of questions, into your framework and I think then you can come out with a sensible decision. I think if you went through the ALARP, the current ALARP framework, at the moment you wouldn't get very far because we don't know what hydrogen will do our pipe in detail, so we would just stop very early. (I07)*

Consideration of ALARP in decision making only increases the value of the work of the FFCRC in resolving such uncertainties.

3.2.9 Suggestions for specific changes to AS2885.6

All interviewees were asked for any feedback / suggestions about changes to AS/NZS 2885.6 that might be useful in the next update. Some people provided specific suggestions. The results are shown in Table 8 below.

Table 8: Interviewee suggestions for changes to AS/NZS 2885.6

Suggestion	Possible action
1. Include more on critical controls – which controls are critical? How is effectiveness defined and measured? (I08)	This was the subject of an Issue Paper in the last revision. NOTE that if LOPA is used, effectiveness is assigned to each control. Would need to be discussed by the sub-committee.
2. Emphasise the effectiveness of existing controls (not just new controls) in the formal ALARP process. (I08)	Review section 4 and Appendix I and tweak as necessary. Note that Appendix E also addresses effectiveness of procedural controls to some extent and could be updated on this topic.
3. Add an ALARP flowsheet based on AS/NZS 2885.6 section 4 and Appendix I[28]. (I08)	Sub-committee to discuss.
4. Include some numerical guidance to support cost benefit analysis: • Appropriate gross disproportionality factors. • Cost of a number life value. (I10)	Sub-committee to discuss.
5. Clarify what grossly disproportionate means. (I12)	Sub-committee to discuss.
6. Clarify the relationship between the five risk controls listed at the end of AS2885.6 section 4 (items A to E), and the formal ALARP assessment questions in Appendix I. (I13)	Sub-committee to discuss.
7. In AS/NZS 2885.6 section 4, are items A to E valid for all formal ALARP assessments? This list used to apply to item ii only, not items i, ii and iii. (I13)	Sub-committee to discuss.
8. In AS/NZS 2885.6 section 4, item E should refer to maximum credible hole size in addition to rupture. (I13)	Sub-committee to discuss.

[28] In particular this interviewee likes Figure 8.2 in the HSE guidance regarding LOPA in a COMAH context. https://www.hse.gov.uk/research/misc/vectra300-2017-r02.pdf

9. Ensure that all text (including Figure A1) is consistent on what action is required for low and negligible risks. (I14 and I16). See also report section 3.2.6.	Adjust figure and text in section 3 to be consistent with Section 4 and Appendix I which both state that simple additional controls should be added even for low and negligible risks.
10. Add a step requiring risk to be quantified (e.g. by LOPA) between the matrix risk assessment and the formal ALARP assessment for cases where the risk has been evaluated on the matrix to be intermediate. (I05)	This doesn't seem desirable as something to mandate. Sub-committee to discuss.
11. Look critically at the requirements for a safety management study plan (Section 5.4.1). This seems to be a useful idea, but is rarely actioned. Maybe leave text as is but emphasise to industry (I18).	Sub-committee to discuss.
12. Requirements regarding failure of threat controls can be ambiguous. An appendix with a worked example would be useful. (I18)	Sub-committee to discuss.
13. Clarify requirements for the secondary location class Crowd so that it is only a high consequence area if the crowd and the threat are present at the same time (I21)	Difficult to see what more could be provided given that there is a detailed note addressing this point already provided.

3.2.10 Views on additional guidance / tools

Given that the next phase of the project is to produce a tool and/or guidance material, interviewees were asked for their views on what would be useful.

3.2.10.1 Guidance on quantitative assessment

Many people use some form of risk quantification to support their formal ALARP demonstrations. This is often in the form of a layers of protection analysis (LOPA) approach used to confirm the frequency assessment that has led to an intermediate risk determination, to better understand the nature of the threat itself, and to provide a framework for assessing the effectiveness of possible additional risk controls. Many interviewees suggested that it could be useful to develop a basic LOPA tool or provide some worked examples of LOPA. As one interviewee said, *'I think it would be good to give a bit of guidance to the industry when you're going through all those factors about typical frequencies, I think that will help people rather than hurt them, and you don't have to use what's given to you as an example, but I think it would give good guidance.'* (I15)

Such a tool could set out what factors need to be considered for some typical intermediate risks and typical (or a range) of PFD figures. The downside would be if people simply copy the data, as well as the method. As one interviewee explained, *'Even if you've got a pipeline on opposites of the country, there's very good reasons for not assigning a standard risk reduction factor because of very local conditions. That's what bothers me, that people aren't going to actually think it through.'* (I16)

Others were of the view that LOPA is a standard industry tool and already available and so it is not something that the FFCRC should spend time on. This group were of the view that the question framework in Appendix I is something that is worth developing further, especially in presenting the results in a way that informs decision making. This school of thought is effectively leaning the project towards a Choosing by Advantages tool (even though they are not aware of this approach).

3.2.10.2 Use of examples

There has been some debate within the industry advisory group for the project about the benefits and drawbacks of providing worked examples in the form of published guidance.

Interviewees were asked about this and were overwhelmingly in favour of such examples being made available, but outside the standard itself.

Positive comments included:

> *'that's always a benefit if you can just walk through something' (I02)*
>
> *'I think some worked examples would be good' (I18)*
>
> *'definitely worked examples would be great, yep.' (I06)*
>
> *'I think sharing is a fantastic thing and not only third-party damage, it might be unpiggables and what we do there and with corrosion threats. I think the more we share, the better.' (I15)*

Carefully chosen examples showing cases that require changes in order for risk to be considered as ALARP were seen as a good way of communicating information about industry best practice.

The standard already explains the decision-making process generically and yet as this interviewee explains, some engineers are not comfortable with applying their judgement in specific cases.

> *one of the unfortunate things about engineering is that people are reluctant to use their judgement, their engineering judgement. And I don't know whether they can't because they haven't been trained to or they're scared. … they want to see something tangible. … as an engineer, you've got to use your judgement because every case is different. And the biggest risk we have is that people will run through a worked example and just duplicate and copy it because it's easy, and that's wrong. (I09)*

This issue is inherent in adult learning. As Dreyfus and Dreyfus (1986) explain, in the early stages of learning, adults follow generalised, context free rules feeling little responsibility for the outcome of their actions, only in their competence in following the rules. In the context of driving pipeline risk management processes, this means that less experienced engineers will focus on the process defined in the standard. When dealing with formal ALARP assessments, they will prefer that the defined process leads to a clear specific outcome.

As skill level increases, a competent person has a specific goal in mind and selects context-specific information that seems to be relevant to augment their decision making. A competent person still uses rules to determine how best to tackle the problem at hand and select the best course of action. Whilst the course of action is chosen rationally (i.e., by analysis and application of rules), the decision maker now feels responsible for the outcome. In the context of applying the safety management study process, this means that competent users will be aware of the process as defined in AS/NZS 2885.6 but will also draw on their experience of past risk assessments and actual field conditions to inform their judgement regarding ALARP.

This evolution from the abstract to the concrete decision-making contexts, reverses childhood learning sequences that require understanding of concrete examples before progressing to abstract reasoning. But specific examples are still needed for adults to build expertise. This means that those engineers with less experience in undertaking formal ALARP assessments can certainly benefit from having access to worked examples put together by more experienced colleagues.

The possible downside of providing examples is articulated by this interviewee. *'My concern would be, if you put a worked example, everyone would follow that worked example.'* (I05) As another interviewee warned, *'if they don't have the knowledge they're just going to copy and paste.'* (I06) This could be a problem if the examples provided can be misapplied. To address this, some of the following factors could be considered in formulating the examples.:

- Examples could show cases where additional expenditure is required. Copying this would then mean that 'lazy' companies spend more money on safety.
- Assumptions used in coming to a decision in example cases should be carefully listed and justified. This will make it easier for those who wish to rework the example for their own specific circumstances and for those who are reviewing a copied example and wish to challenge its application is a different environment.

- Examples could be included of what NOT to do in making an ALARP justification. This would need to be considered carefully but might be a way to articulate the logic of good decisions in contrast to poor ones.

4. Additional Guidance and Tools

There are various options available for the next stage of the project, i.e., there are various forms that a tool and /or guidance could take. Key options are discussed briefly below.

4.1 Layer of Protection Analysis (LOPA)

As described in Section 3.2.2.2, Layer of Protection Analysis can be used to determine the frequency of a given outcome from a specific threat and how the frequency might changes if different controls are in place.

In the next phase of the project, we could produce a basic LOPA tool for use by industry, which sets out the process and perhaps provides ranges for some of the common PFD figures needed to do LOPA calculations. We could also provide some worked examples. Having said that, LOPA is a standard risk management method already widely used in industry. There is a view that producing a LOPA tool is not good use of FFCRC research resources.

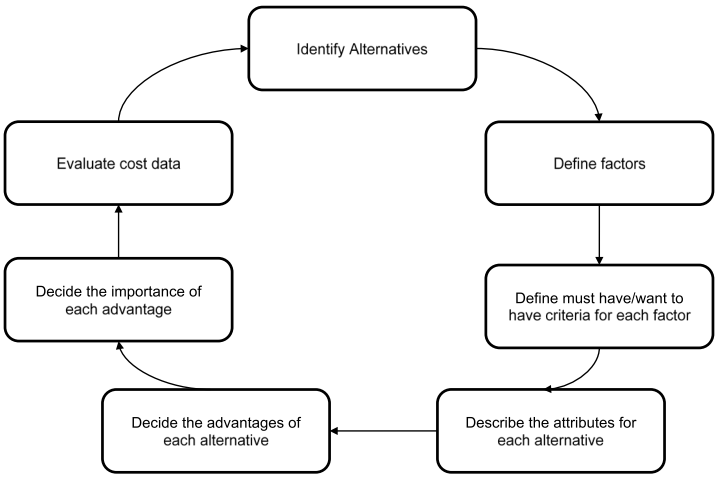
4.2 Choosing by Advantages

Another decision-making method that may be useful for industry in applying the questions in Appendix I to intermediate risk threats is Choosing by Advantages.

Choosing by Advantages (CbyA) is a form of multi-criteria decision-making (MDCM) approach that is focused on distinguishing solution alternatives based on their relative advantages (Yoon, Naderpajouh, & Hastak, 2019). The assessment is conducted considering the relative weights of the importance of each advantage (Murguia & Brioso, 2017). P Arroyo, Tommelein, and Ballard (2015) indicate that CbyA decisions are more straightforward for decision-makers than the common methods such as analytical hierarchy process (AHP), which use pairs of variables in order to determine the best alternative (Paz Arroyo & Molinos-Senante, 2018) . Furthermore, CbyA uses a visual interface that helps establish consensus among decision-makers in the context of the decision and current alternatives considering costs (Suhr, 1999). CbyA has also demonstrated a decrease in group decision-making time and dissatisfaction among stakeholders as compared with a weighted number procedure (Paz Arroyo, Mourgues, Flager, & Correa, 2018).

The overall process is depicted in Figure 4.

Figure 4: Steps in CbyA (adapted from (P Arroyo et al., 2015)



The CbyA consists of seven major steps:

- Stakeholders **select** alternatives that are expected to offer substantial benefits over other alternatives.
- They **need to select factors** that are able to distinguish selected alternatives.

- Stakeholders agree on the **parameters** for each factor. Factors can be used to measure the characteristics of alternatives. A criterion can be either a favourable (want) or a necessary (must) judgment rule. Alternatives that do not meet a must factor are not included in the subsequent steps.
- Stakeholders summarize the features (attributes) of **each option based on the factors** that can be: 1) demonstrated effectiveness in practice; (2) compatibility with existing process; (3) impact on risk reduction; (4) reliability; (5) practicality and ease of use; and (6) government policy and regulations.
- They determine the **least favoured attribute for each factor**, and then agree on the benefit of each alternative attribute compared to the least preferred (advantage), and
- They settle on the **value of importance** of each advantage (IofA). For these IofAs, stakeholders need to clearly state their priorities. First of all, they have to pick the supreme benefit, which is the most significant advantage of all. They use the supreme advantage to give an IofA scale, with the IofA with any least-preferred variable always having zero relative importance (the paramount advantage was assigned 100 IofAs). The preference of scale does not skew the calculation, and the stakeholders then use this scale to weigh additional advantages. The IofA is summed up with each option.
- Finally, stakeholders **analyse the cost data and choose alternatives** by comparing the IofA and relative costs.

In summary, Choosing by Advantages could be used to compare risk controls to decide which one(s) are justified according to the ALARP principle.

4.3 Worked examples v method

An overarching question is the extent to which the next phase of the work should produce a tool or examples.

The pros and cons of examples are discussed in Section 3.2.10.2. In summary, cases are good for learning, especially when novices who understand a process are trying to increase their practical expertise.

5. Conclusions

Referring back to the research questions in the introduction the results of the work to date are summarised below.

5.1 Use of the formal ALARP process

Both consultants and regulators report significant variation between pipeline companies when it comes to their level of maturity regarding risk-based decision making. The research has found that there are three primary ways in which formal ALARP demonstrations are being done in the pipeline sector.

1. By guided discussion as part of SMS validation workshops. These discussions sometimes draw on the questions in Appendix I but are also strongly driven by precedent i.e. controls are adopted in line with current industry practice for similar situations.
2. By engineering analysis often using a combination of LOPA and structured responses to the questions in Appendix I. This method combines both quantitative and qualitative aspects and requires judgement to determine the final outcomes based on assembled evidence.
3. Relying on quantification of risk and use of cost benefit analysis. This work produces quantitative results that are given to decision makers as input to their decision making.

The intent of AS/NZS 2885.6 was for users of the standard to adopt the second method but this is not completely understood in industry. Some large operating companies are using this method (but not necessarily in all parts of the organisation) and some influential consultants are also using this method. Those who have adopted the first and third methods are generally of the view that their work meets the requirements of the standard. In some cases, this would seem to be a somewhat optimistic assessment. Given that the second option has grown up largely since 2018, this is perhaps to be expected and not a bad position for the industry to be in.

5.2 Views on the new guidance

The new guidance added when AS/NZS 2885.6 was released in 2018 has been well received. Those who are not using it, in some cases simply have not read it.

The minority who have read it but find it unsatisfactory are looking for a quantitative tool to drive answers to risk-based questions which are fundamentally a matter of professional judgement.

The guidance mentions uncertainty. This is particularly relevant in a future fuels environment. Consideration of ALARP in decision making only increases the value of the work of the FFCRC in resolving technical uncertainties.

5.3 Support for informed decision making

Companies that have adopted methods for formal ALARP demonstration as promoted by the standard and the spirit of high consequence recognition in engaging senior management have seen increased support from senior management and so improved decision making.

5.4 Evidence of knowledge gaps

There is evidence of knowledge gaps.

As described above not all stakeholders are aware of the changes made in 2018, or their implications.

Other stakeholders have not really engaged with the Appendix I material because they are not confident or comfortable with the concept of decision making based on professional judgement and want a method that will calculate the result for them.

5.5 Applying ALARP to external interference cases

There are challenges when applying formal ALARP assessment methods in cases where the expenditure is not by the pipeline company. Given the power dynamics at play it is unclear how best to address this but a close reading of the requirements of AS/NZS 2885.6 suggests that in most cases, introducing a Sensitive Use

secondary location class into an existing area with a T1 or T2 primary location class should not change the argument about what risk controls are required.

5.6 High consequence recognition

No pipeline licensees were interviewed for this research as they did not make themselves available. Having said that, many interviewees deal with their company licensees regularly and so have views on the requirements for high consequence recognition introduced in 2018.

The research identified a small number of organisations that have thought seriously about the issue of senior management engagement with technical risks and have put in place processes that draw on Appendix H of the standard. Other organisations are as yet unaware of the requirements on this subject. Overall, the industry conversations around this issue have been influential and are increasing. Partly influenced by consultants, many cases were reported where summaries are produced with senior management, rather than a technical audience, in mind and senior managers are becoming more actively engaged in the results of safety management studies.

5.7 Specific updates to AS/NZS 2885.6

Suggestions for specific updates to AS/NZS 2885.6 have been collected from two sources.

Table 6 in Section 2.4 summarises items for consideration drawn from the literature review.

Table 8 in Section 3.2.9 summarises changes to the standard suggested by interviewees.

6. Implications and Recommendations for Industry

To be discussed with the industry steering committee following review of this draft report.

7. Next Steps and Future Works

Following review of this report, the overall direction of the next stage of the project regarding guidance / tool must be agreed.

Perhaps a way forward is to conduct a mock workshop using Choosing by Advantages and/or LOPA to test how these methods work in practice.

8. References

Aldara, D. R., Artana, K. B., & Ariana, I. M. (2020). *Risk Assessment of Subsea Pipeline due to Installation and Operation of Single Point Mooring (SPM).* Paper presented at the IOP Conference Series: Earth and Environmental Science.

Arroyo, P., & Molinos-Senante, M. (2018). Selecting appropriate wastewater treatment technologies using a choosing-by-advantages approach. *Science of the Total Environment, 625*, 819-827.

Arroyo, P., Mourgues, C., Flager, F., & Correa, M. G. (2018). A new method for applying choosing by advantages (CBA) multicriteria decision to a large number of design alternatives. *Energy and Buildings, 167*, 30-37. doi:https://doi.org/10.1016/j.enbuild.2018.02.031

Arroyo, P., Tommelein, I. D., & Ballard, G. (2015). Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. *Journal of Construction Engineering and Management, 141*(1), 1-8. doi:10.1061/(ASCE)CO.1943-7862.0000915

Ashiofu, A., Bruce-Black, J., & Dyer, J. (2020). Leveraging facility siting to optimize mitigation decisions. *Process Safety Progress, 39*(3). doi:10.1002/prs.12188

Benintendi, R., De Mare, G., & Nesticó, A. (2018). Upgrade the ALARP model as a holistic approach to project risk and decision management: A case study. *Hydrocarbon Processing, 97*(7), 77-82.

Bounds, A. (2017). *Implementation of improvements to achieve a risk that is as low as reasonably practicable (ALARP), as soon as reasonably practicable (ASARP).* Paper presented at the Risk, Reliability and Safety: Innovating Theory and Practice - Proceedings of the 26th European Safety and Reliability Conference, ESREL 2016, Glasgow; United Kingdom.

Bryant, P. A., Croft, J., & Cole, P. (2018). Integration of risks from multiple hazards into a holistic ALARA/ALARP demonstration. *Journal of Radiological Protection, 38*(1), 81-91. doi:10.1088/1361-6498/aa8e53

Carroll, F., & Hayes, J. (2018). *Effective Risk Management for In Service Pipelines: Achieving ALARP by Pressure Management and Slab Protection.* Paper presented at the Proceedings of the 12th International Pipeline Conference (IPC 2018), Calgary, Alberta, Canada, 24-28 September 2018.

Casson Moreno, V., Papasidero, S., Scarponi, G. E., Guglielmi, D., & Cozzani, V. (2016). Analysis of accidents in biogas production and upgrading. *Renewable Energy, 96*, 1127-1134. doi:10.1016/j.renene.2015.10.017

Chitty, D. (2016). Safety in the air begins with safety on the ground. *Bar News: The Journal of the New South Wales Bar Association, Winter*, 14-17.

Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over Machine*. New York: The Free Press.

Gong, Y., Niu, Z., & Bai, T. (2020). Societal risk acceptance criteria for gas distribution pipelines based on incident data from the United States. *Journal of Loss Prevention in the Process Industries, 63*. doi:10.1016/j.jlp.2019.104002

How, V., Abdullah, K., & Othman, K. B. (2017). Evaluate the decision of as low as reasonably practicable (ALARP) solutions for the safe use of pesticide among the pesticide handlers, paddy farm, Tanjung Karang, Selangor. *Annals of Tropical Medicine and Public Health, 10*(1), 36-43. doi:10.4103/ATMPH.ATMPH_73_17

Hurst, J., McIntyre, J., Tamauchi, Y., Kinuhata, H., & Kodama, T. (2019). A summary of the 'ALARP' principle and associated thinking. *Journal of Nuclear Science and Technology, 56*(2), 241-253. doi:10.1080/00223131.2018.1551814

Ilizástigui Pérez, F. (2020). Safety case process in Cuba: Transition from theory to practice. *Process Safety and Environmental Protection, 137*, 169-176. doi:10.1016/j.psep.2020.02.004

Jiang, Z., Zhao, T., Wang, S., & Ren, F. (2020). A novel risk assessment and analysis method for correlation in a complex system based on multi-dimensional theory. *Applied Sciences (Switzerland), 10*(9). doi:10.3390/app10093007

Ladkin, P. B. (2019). Duty of Care and Engineering Functional-Safety Standards. *Digital Evidence and Electronic Signature Law Review, 16*, 51-56.

Langdalen, H., Abrahamsen, E. B., & Selvik, J. T. (2020). On the importance of systems thinking when using the ALARP principle for risk management. *Reliability Engineering and System Safety, 204*. doi:10.1016/j.ress.2020.107222

Lee, S. (2020). Quantitative risk assessment of fire & explosion for regasification process of an LNG-FSRU. *Ocean Engineering, 197*. doi:10.1016/j.oceaneng.2019.106825

Liu, B., Jin, W., Zhao, J., Song, S., & An, W. (2020). *Research on risk assessment of offshore supply vessels carrying dangerous cargoes.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

Liu, S., Chai, B., Du, J., Luo, F., & Xiao, L. (2020). Risk post-assessment and management of a waste slag site under extreme scenarios. *Bulletin of Engineering Geology and the Environment, 79*(5), 2659-2677. doi:10.1007/s10064-019-01697-7

Maselli, G., & Nesticò, A. (2021) Cost-benefit analysis and investment risk assessment. threshold values according to the alarp logic. In. *Green Energy and Technology* (pp. 43-56).

Mehmood, S., Qureshi, A., & Kristensen, A. S. (2020). Risk mitigation of poor power quality issues of standalone wind turbines: An efficacy study of synchronous reference frame (SRF) control. *Energies, 13*(17). doi:10.3390/en13174485

Miller, K. (2018). *Quantifying risk and how it all goes wrong.* Paper presented at the Institution of Chemical Engineers Symposium Series.
Miller, K. (2019). *Constructing a legally sound demonstration of ALARP.* Paper presented at the Institution of Chemical Engineers Symposium Series.
Mullins, J., Doyle, A., & Taylor, K. (2018). *The role of individual and societal risk in the ALARP demonstration for pipelines (Paper 21).* Paper presented at the Institution of Chemical Engineers Symposium Series no. 163 (HAZARDS 28).
Murguia, D., & Brioso, X. (2017). Using "Choosing by Advantages" and 4D Models to Select the Best Construction-Flow Option in a Residential Building. *Procedia Engineering, 196*, 470-477. doi:https://doi.org/10.1016/j.proeng.2017.07.226
Nemeth, A., Hassanien, S., & Leblanc, L. (2018). *Updates on pipeline integrity reliability targets.* Paper presented at the Proceedings of the Biennial International Pipeline Conference, IPC.
Nidd, P. (2017). *ALARP and zero leak tolerance - Applications for the pipeline industry.* Paper presented at the Pipeline Pigging and Integrity Management Conference 2017.
Nuñez-Sanchez, M. J., Perez-Rojas, L., Sciberras, L., & Ramos Silva, J. (2020). Grounds for a safety level approach in the development of long-lasting regulations based on costs to reduce fatalities for sustaining industrial fishing vessel fleets. *Marine Policy, 113*. doi:10.1016/j.marpol.2019.103806
Pei, J., Wang, G., Luo, S., & Luo, Y. (2018). Societal risk acceptance criteria for pressure pipelines in China. *Safety Science, 109*, 20-26. doi:10.1016/j.ssci.2018.05.006
Pike, H., Khan, F., & Amyotte, P. (2020). Precautionary Principle (PP) versus As Low As Reasonably Practicable (ALARP): Which one to use and when. *Process Safety and Environmental Protection, 137*, 158-168. doi:10.1016/j.psep.2020.02.026
Roy, S., & Kshirsagar, R. (2021). Development of risk acceptance criteria in the Indian context. *Process Safety and Environmental Protection, 148*, 358-369. doi:10.1016/j.psep.2020.10.021
Suhr, J. (1999). *The choosing by advantages decisionmaking system*: Greenwood Publishing Group.
Syed, Z., & Lawryshyn, Y. (2020). Multi-criteria decision-making considering risk and uncertainty in physical asset management. *Journal of Loss Prevention in the Process Industries, 65*. doi:10.1016/j.jlp.2020.104064
Tan, S., Weinert, D., Joseph, P., & Moinuddin, K. (2020). Impact of technical, human, and organizational risks on reliability of fire safety systems in high-rise residential buildings—applications of an integrated probabilistic risk assessment model. *Applied Sciences (Switzerland), 10*(24), 1-31. doi:10.3390/app10248918
Van Coile, R., Jomaas, G., & Bisby, L. (2019). Defining ALARP for fire safety engineering design via the Life Quality Index. *Fire Safety Journal, 107*, 1-14. doi:10.1016/j.firesaf.2019.04.015
Vinnem, J. E. (2021). Assessment of risk tolerance for future autonomous offshore installations. *Safety Science, 134*. doi:10.1016/j.ssci.2020.105059
Wang, C., Ong, P., Wood, L. C., Zou, F., & Abdul-Rahman, H. (2020). Novel quantitative risk assessment interface for fixed offshore oil and gas exploration platforms. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 6*(2). doi:10.1115/1.4044809
Winter, M. G., & Wong, J. C. F. (2020). The assessment of quantitative risk to road users from debris flow. *Geoenvironmental Disasters, 7*(1). doi:10.1186/s40677-019-0140-x
Yoon, S., Naderpajouh, N., & Hastak, M. (2019). Decision model to integrate community preferences and nudges into the selection of alternatives in infrastructure development. *Journal of Cleaner Production, 228*, 1413-1424.
Zhang, P., Qin, G., & Wang, Y. (2018). Optimal maintenance decision method for urban gas pipelines based on as low as reasonably practicable principle. *Sustainability (Switzerland), 11*(1). doi:10.3390/su11010153

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