Public Safety in the Pipeline Industry:
An Engineering Practice Guide

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Our Responsibility to Society

Society rightfully expects that pipeline systems carrying hydrocarbons will create no harm to either members of the public or to the environment. For our industry to meet that expectation requires diligence on the part of both individuals and organisations.

Engineering practice plays a significant role in delivering that expectation for our industry, both through the actions of the engineers themselves and through the actions of the organisations employing or working closely with engineers.

Many different organisations are directly or indirectly involved in pipeline engineering practice, including:

- Regulatory agencies that enforce compliance with various Acts and Regulations.
- Standards Australia which, with the assistance of expertise from our industry, develops and publishes minimum standards for design, construction, testing, operation and maintenance of pipeline systems.
- APGA, which has developed a detailed definition of competencies required of pipeline engineers.
- Those who own and operate pipeline systems and directly employ engineers.
- Those who supply engineering and related technical services.
- Those who supply equipment and contracted services to support the industry.

Pipeline engineers have a professional obligation to hold paramount the safety of the public, but the organisation holding the Pipeline Licence has the legal responsibility for safety and is therefore the ultimate decision-maker.

The Pipeline Licence confers on organisations an obligation to maintain pipeline system integrity so as to prevent harm to the public and the environment.

AS/NZS 2885.6 (Pipeline safety management) requires “the Licensee” (effectively senior management) to be aware of both the potential consequences of pipeline failure and the measures in place to minimise those consequences.

Pipeline engineers exercise their professional responsibility by providing all relevant information and advice so that public safety is at the forefront of decision-making.

To minimise the threat of harm to the public from pipelines, Pipeline Licensees, their engineers and their contractors must work together cooperatively.

This Engineering Practice Guide has been prepared to assist in that cooperation between individual pipeline engineers and the organisations that employ those engineers.

1 Public Safety in the Pipeline Industry: An Engineering Practice Guide

1.1 Scope

This practice guide applies to engineers who work in design and operation of high-pressure energy pipelines and associated facilities, and to those who employ those engineers. Pipeline engineering is a profession which means that pipeline engineers are bound together by much more than simply a common occupation. Professions are characterised by a collective body of knowledge, an education process, standards for admission to the profession, standards of conduct, a recognised status and collective values. One key value of the pipeline engineering profession is that ***public safety is paramount***.

This document forms part of the pipeline engineering body of knowledge in support of that value. The content aims to support excellence in engineering practice (i.e. how work is done) when it comes to decisions, actions and behaviours that impact public safety. In particular, it seeks to support pipeline engineers' ability to identify situations that can impact public safety and to analyse how public safety might be affected, so that the organisation can respond effectively.

Public safety is particularly important for pipeline engineers because the organisations employing them are responsible for infrastructure that is often not isolated from the general public as is the case for some other kinds of industrial facilities. By their very nature and purpose, pipelines are required to exist within the community and not remote from the community. Pipeline infrastructure has the potential to impact members of the public who may be simply walking down the street or going about their everyday work.

The aim of this practice guide is to support pipeline engineers to act with professional responsibility when it comes to public safety, even in the face of pressures from other individuals, their own organisation, from contractors or from clients. Most organisations will wish to support their engineers in this and so the guide starts with a section that describes how organisations create an environment that encourages their employees to act with professional responsibility.

This practice guide also sets foundational principles for formal engineering management systems, recognising the importance of both informal and formal processes in fostering an outcome that meets best engineering practice and prioritises public safety outcomes. This document does not address technical issues but will influence the way in which technical issues are assessed and resolved by individuals and teams.

The principles set out in this Practice Guide are completely consistent with the requirement to reduce safety-related risks linked to identified threats to a level that is as low as reasonably practicable as set out in AS(/NZS) 2885. As the examples in this Practice Guide illustrate, many decisions made by pipeline engineers in their everyday professional practice have safety implications yet sit outside formal risk management frameworks. Taking professional responsibility is essential to achieve the best public safety outcomes, regardless of the technical context or specific process requirements.

1.2 Codes of ethics

Some pipeline engineers are members of professional bodies such as Engineers Australia or the Institution of Chemical Engineers and, as such, are bound by various professional codes of ethics. What follows has significant overlap with professional practice requirements based on ethical principles, but it does not replace any code of ethics. Ethics in a professional context comprises moral principles governing all professional behaviour, whereas this practice guide addresses only those behaviours that directly impact public safety outcomes.

1.3 Further reading resources

References are included at the back of this guide for further reading material on organising for safety, engineering practice, the disaster case studies discussed in this guide, and relevant Energy Pipelines CRC research reports.

2 Organising for safety

Individual professional engineers are responsible for their actions and need to be able to collaborate effectively with colleagues. Nevertheless, organisations can make things easier by surrounding engineers with effective systems, processes and collective informal practices as they work. The following sections of the practice guide address the two main aspects of organising for safety:

1. Establishing a culture that facilitates safety-oriented behaviour in individuals.
2. Setting up the management system to facilitate safety-oriented practices.

Addressing both aspects effectively will support engineering professional practice that makes public safety paramount throughout all activities.

2.1 Safety-oriented culture

The five principles for embedding public safety consideration in pipeline engineering practice described in Section 3 focus on individual behaviours. Organisations can make this easier by having processes and systems in place that support and reward these behaviours. The organisations that are best at this are known as High Reliability Organisations. Key aspects are described below.

2.1.1 Reward the right behaviours

Professionals are motivated by both intrinsic and extrinsic rewards. Intrinsic rewards stem from professional and personal values. Extrinsic rewards come from company systems and include remuneration, bonus payments, prizes, promotion, and praise of various kinds. Companies will consistently get the behaviours they want from their employees when intrinsic and extrinsic rewards are aligned.

Research shows that people will do the right thing if structures and incentives aren't pointing them in the other direction. In many companies, pipeline engineers at all levels will receive part of their remuneration in the form of a bonus payment. Well-designed bonus schemes reflect the importance of public safety by linking individuals' bonuses to what they do to ensure public safety. This includes both short-term and long-term bonus arrangements.

Other types of rewards are also important, so organisations should be sure to publicly praise and promote those who do well when it comes to consideration of public safety.

2.1.2 Advocate for safety in outsourced work

Rewarding desired behaviours also applies to contractors. Best practice ensures that contractor engagement requirements including scopes of work, specifications, contractor evaluation and selection processes, and that contract terms and conditions are all aligned with client expectations for behaviour from contract workers to support excellent public safety outcomes.

Effective mechanisms include a focus on relationship contracting instead of risk transfer, so that the client and the contractor mutually understand expectations for protecting public safety and make adequate provisions in contract pricing. Also important is full transparency in back-to-back clauses of sub-contracts when chains of contractors are used to ensure that sub-contractors are advised of, and bound by, client expectations in the same manner as the head contractor, and that responsibilities are clearly allocated to each of the parties.

Best practice in contracting for achieving safe outcomes may also include use of pain-share gain-share mechanisms which genuinely reward achievement of safety performance targets including both lead and lag indicators.

Engineering practice can also be significantly influenced by project contracting strategy:

- Strategies such as engineering, procurement and construction management (EPCM) in which the engineering services are directly engaged by the client are more likely to deliver expected outcomes in all areas including safety and system integrity, and engineers expressing concerns are more likely to be heard.
- Strategies such as engineering, procurement and construction (EPC) in which the engineering services are engaged by a construction contractor, often on a fixed-price basis, are more likely to limit opportunities for engineers to raise concerns and expect to have them addressed.

Further, strategies which attempt to fix lump-sum pricing too early on the basis of limited engineering and technical definition are more likely to end up facing pressures to cut costs and reduce functionality as the engineering detail is further developed. This has the potential to distract attention from public safety as the paramount priority.

2.1.3 Have the right structure so bad news can travel up

Engineers, as do all professionals, like to demonstrate to the boss that everything is under control. This is seen as a reflection of competence. The problem comes when everything is not under control and the means to fix the problem are beyond us. In cases such as this, it is important that bad news can travel up in an organisation to the level where action can be taken. Speaking up for safety – which includes safety of the asset as well as the people – needs to go all the way to the top. Formal roles and responsibilities and reporting lines can have a major impact here. Defining appropriately experienced and well-regarded individuals as technical authorities for specific systems can also support public safety excellence.

2.1.4 Encourage and act on hazard reporting

Also important is how organisations respond to bad news. Reporting of problems and errors is more likely to occur when people can see that action is taken and they are praised for highlighting issues and pointing out where things did not go according to plan. Reporting is less likely in organisations where reports are ignored, or the information given is used punitively for the reporter or others.

A culture in which mistakes are seen as opportunities for learning is sometimes called a just culture. In organisations willing to implement a just culture, punitive action is taken only in the case of negligence or deliberate misconduct.

Often this is well-handled for personnel hazards; the same attention is warranted for asset hazards.

2.1.5 Create opportunities to share stories

Time is money and everyone is busy with short-term priorities but problems can be avoided if organisations build into work plans time and structures for sharing stories that act to reinforce knowledge about safety matters and desired professional practice. Some examples of how this can be done are:

- A lunch and learn session about a recent incident.
- A monthly reading group of reports and books regarding major disasters.
- Time built into operational training sessions to discuss recent incidents of professional interest.
- An online 'on this day' popup that shares stories of past events that occurred on the same date.

2.2 Safety-oriented management

2.2.1 Context

Pipeline engineering usually occurs in one of two contexts:

- Design and construction of a new pipeline or modifications to an existing pipeline, required to comply with AS/NZS 2885.1.
- Operation and maintenance of an existing pipeline, required to comply with AS 2885.3.

(AS 2885.0 and AS/NZS 2885.6 apply in both cases.)

Operation and maintenance work is required to be done within a pipeline management system (PMS) the content of which is specified in some detail by AS 2885.3.

Design and construction work does not have mandatory requirements for a management system. This Engineering Practice Guide recommends good practices for the management of all pipeline engineering work. This Guide puts emphasis on design and construction but is also applicable to operation and maintenance. These guidelines are consistent with, but not identical to, the AS 2885.3 PMS requirements.

The recommendations of this Engineering Practice Guide should be considered, documented and disseminated to all members of the engineering team, not necessarily all in one document but included somewhere appropriate within existing management system documentation.

This section can serve as a checklist, and engineering management should take responsibility for ensuring that all of the following have been addressed collectively by the relevant parties with no gaps or overlaps.

2.2.2 Stakeholders

Pipeline engineering can involve several different parties, particularly on large projects or pipeline systems, including at least the following:

- Licensee, who has legal responsibility for the pipeline (usually but not necessarily the owner, and not necessarily the operator either).
- Owner, who may also be the operator or may be a relatively passive investor.
- Operator, who may be the owner or a contracted operating organisation.
- Engineering consultant(s), who provide engineering services (particularly design) to a variety of clients on a contracted basis.
- Suppliers and fabricators, who must undertake some elements of design relevant to their products for any buyers.
- Construction contractor(s), who undertake construction engineering to complete their scopes of work, again for many clients.
- Service providers, who deliver specialised technical services such as pipeline inspection.

Each of the above would normally have their own in-house systems for management of their engineering functions.

In the following guidelines “client” is used to refer to the organisation that commissions the engineering work. For a new pipeline this will usually mean the owner. For an existing pipeline it will usually be the operator. In some cases, the client and the engineering team will both be within the one large organisation. In all cases, the ultimate responsibility lies with the Licensee, who may or may not be the client.

2.2.3 Engineering policy statement (or values statement)

Principle: For safety to be paramount that vision should be formally documented and promulgated.

All engineering teams should work under a clearly stated policy for community/public safety, security of supply, environment and workers’ health and safety.

Such statements should align with other relevant client policy statements such as those for quality assurance, health and safety, etc.

The engineering policy statement should be made available to all engineers on the project.

2.2.4 Management structure

Principle: Failure to adequately define roles and responsibilities may lead to gaps or conflicts in responsibility and failures of communication, with possible safety implications.

The engineering team should have a clearly defined structure appropriate to the size and complexity of the engineering task.

Responsibilities, accountabilities and authority levels should be clearly defined for all engineering areas.

Interfaces with similar structures for sub-contract and supplier engineering teams should also be clearly identified.

2.2.5 Technical Authority

Principle: To avoid conflict of interest, review of engineering work and advocacy for technical decisions that influence safety should be fully independent of considerations of cost and schedule.

The client management structure should include someone nominated as the Technical Authority, an individual who accepts responsibility for engineering and technical completeness and accuracy of the engineering work (including safety aspects). If the client organisation lacks the level of expertise required for the Technical Authority position, then it should retain a suitable expert.

The Technical Authority should be fully independent of other management positions responsible for commercial project delivery goals such as cost and schedule.

All engineering personnel should be at liberty to raise engineering concerns with the Technical Authority without fear of repercussions or threat of termination. The Technical Authority and the engineering personnel should work cooperatively through the issues that have raised concerns so that they can be addressed. If the issues cannot be resolved and a decision is made to proceed without change, the engineering personnel should receive a written management justification for not taking action.

If management declines to accept the recommendations of the Technical Authority, then the Technical Authority should request and receive written justification for the rejection of the advice.

2.2.6 Competence

Principles: Unsafe outcomes may result if work is done by people and organisations who are not fully competent in the matters for which they are responsible. Self-assessment of competence can be inadequate. There is no substitute for knowledge and experience.

Public safety and pipeline engineering competence are closely related:

- APGA has a framework for demonstration of competency in pipeline engineering: the Pipeline Engineering Competency System, (PECS).
- APGA has also worked with Engineers Australia to have Oil and Gas Pipeline Engineer recognised as an area of engineering practice for listing on the National Engineering Register (NER).

Tender documents seeking proposals for supply of pipeline engineering services should emphasise that tender evaluation will strongly favour proposals which offer nominated personnel who can demonstrate relevant competencies via the PECS and are listed on the National Engineering Register as an Oil and Gas Pipeline Engineer.

Any organisations electing not to offer or engage pipeline engineers with PECS and NER competencies should be able to demonstrate clearly that in-house competency assessment and training to an equivalent level has been implemented for their pipeline engineers.

Proof of pipeline engineering competency should be subject to periodic audit.

Competent and experienced supervision and oversight are critical to any engineering practice. At least some of the full-time supervision and management positions in a pipeline engineering team should be filled by individuals who have many years of directly relevant experience.

2.2.7 Resourcing

Principle: Unsafe outcomes may result from engineering work that is compromised by lack of time or resources for proper deliberation, review and checking.

The pipeline engineering team should be provided with adequate resources across the required range of competencies for the task at hand to deliver a pipeline system that will be safe in operation and will meet societal expectations for the entire operating life.

2.2.8 Planning and communication

Principle: Detailed documentation of the engineering activities clarifies expectations and ensures that important steps are not missed. All engineering projects regardless of size should be undertaken in accordance with a written engineering execution plan.

As well as the client engineering organisation, all consultants, sub-contractors, suppliers and service providers involved in engineering should prepare a written engineering execution plan.

The client should ensure that the various engineering execution plans for the entire project are complete with no gaps or overlaps.

To achieve optimum pipeline engineering outcomes, clients need to provide engineers with a clearly written understanding of the standard of work/design/functionality expected for the finished pipeline system and facilities. Such instructions should clearly identify requirements for redundancy of critical components and for maintainability of equipment and should avoid vague terminology such as “in accordance with good practice” which can be subject to interpretation.

2.2.9 Engineering quality assurance (checking and verification)

Principle: Safety requires thorough checking and verification of engineering outputs because all people make errors, no matter how careful and well-intentioned.

Each party to a project should have a written engineering quality assurance (QA) plan within the overall project documentation, possibly as part of their engineering execution plan. Each engineering QA plan should address QA as well as audit plans and demonstration of compliance with AS (/NZS) 2885.

The client should review the QA plans of sub-contracted services and suppliers collectively to check for gaps.

Engineering QA plans should include requirements for assessing the validity of software outputs. In addition to normal calculation checking processes this should include checks that assumptions underlying the software are valid for the specific calculation and, depending on the criticality of the outputs, may require check calculations by other software or methods.

Independent verification of the engineering team outputs is recommended for major or technically complex projects. Such verification should be done by a competent and experienced third party reporting only to the Technical Authority. This ‘fresh eyes’ review provides increased confidence that the output represents engineering practice appropriate to the task.

In conjunction with the recommendations around QA checks and reviews, it is important that individual engineers accept and welcome that their work will be checked by others. There is no benefit to the project or outcome when an engineer avoids or criticises reviews of their work.

3 Professional engineering practice to promote excellent public safety outcomes

3.1 Individual practice principles

The following sections describe key principles of individual professional practice that support excellence in public safety.

These principles are:

- Talk about public safety.
- Focus on the long term.
- Speak up for safety.
- Think beyond compliance.
- Work only within your area of competence.

Several examples are then provided showing how this principle impacts the day-to-day work of pipeline engineers. Each section concludes with a disaster case study example demonstrating why this principle is important for public safety.

Engineering is a collaborative profession. Little engineering work is done by a lone individual. Reflecting that, many of these individual practice principles are about how pipeline engineers can work most effectively for public safety in day-to-day interactions with colleagues, managers, clients and contractors.

3.1.1 Talk about public safety

Talking about public safety and, in particular, the consequences of engineering decisions is the first public safety principle. A key factor in applying professional responsibility when making choices in pipeline engineering work is to make the direct link between many of the tasks done and the real potential for disaster. Especially for work done away from the worksite, it is easy to forget about innocent bystanders and become complacent or even careless. Unless engineers can actively imagine that their work may have consequences, this possibility can quickly fade from attention. Talking about public safety keeps awareness high.

Pipeline engineers should talk openly about the potential public safety impact of their work by taking opportunities to remind themselves and others (including all levels of organisational management and contractors) that decisions have real-world consequences. Taking a step back and talking in plain language about why it's important to get things right can have a direct and positive impact on public safety.

Routinely talking about public safety also makes it easier to take a firm stand when needed (see Section 3.1.3 below).

Examples for discussion

Example 1

Situation

Ron is checking a colleague's design calculations and finds an error. His colleague is annoyed as he feels the error is minor, work is behind schedule and the time to make the necessary changes will push the work schedule further behind. He suggests to Ron that he should just sign off the calculations without any changes so they can all move on. What should Ron do?

Discussion

As a professional engineer with responsibility for checking the work of others, Ron cannot simply sign off and ignore the error. Ron must clearly demonstrate to his colleague the potential consequences that the error introduces into the system using plain language. For particularly serious errors, that could include asking his colleague if he would like to live next to the facility if it is constructed with this error in the design.

If agreement cannot be reached, or Ron becomes aware that the colleague simply got someone else instead to sign off the calculations with the error, he should bring the matter to the attention of management.

Example 2

Situation

Helen is a construction supervisor. She has been asked to review a training package for new members of the construction crew. She finds it focuses completely on the need for compliance with occupational safety procedures and doesn't mention any serious public safety outcomes that could occur. What should she do?

Discussion

Helen should ensure that the training clearly sets out the procedures covering the work and she should also ensure that the potential consequences of not following the procedures are also clearly included. She should do her best to help workers understand the link between their activity and preventing a serious accident that may affect more than just the work crew. Helen should recommend written additions to the training package to give effect to clearly communicating the consequences.

Disaster case study 1

The 1907 collapse of the Quebec Bridge is a seminal event in Canadian engineering, partly because the project was set to take out a double world record – longest cantilever span and longest bridge span. Instead, it is now remembered for causing the deaths of 75 workers.

Three organisations held key responsibilities regarding the design and construction of the bridge. The Quebec Bridge and Railway Company (QBRC) was the project proponent and ultimate owner. Although the company had a strong desire to build this iconic structure, it was in significant financial difficulty from the beginning of the project and cost was the key consideration. Phoenix Bridge Company (PBC) was appointed as bridge designer and the eminent consulting engineer Theodore Cooper was also appointed by QBRC to assist on the project. PBC's bid for the design was very competitive because it was an experienced bridge designer in an era of mass-produced bridges. The organisation took pride in the way work had been routinised so that much of the design could be done by draughtsmen, rather than requiring bespoke calculations by specialist engineers. This might have worked well for standard designs but literally contributed to disaster in a situation requiring a specialist design. Bridge expert Theodore Cooper had the job of overseeing the design

and construction. This expert near the end of his career apparently saw the bridge as his professional legacy but was also constrained in the detailed oversight that he put into the project. QBRC may also have realised the various technical failings of the design if it had engineering expertise in house. Unfortunately, its chief engineer was a railway engineer with no experience of such major structures as the Quebec Bridge. The design produced by this organisational arrangement had major failings that became apparent during construction.

The Royal Commission into the bridge failure effectively blamed two individuals, Theodore Cooper and PBC's lead designer, Peter Szlapka. But why did two experienced engineers effectively let such a disaster happen? We cannot know for sure, but it seems that no-one involved with this project imagined that the unique structure could fail. Any rational consideration of the likelihood of failure would have led to changes, especially as the structure began to deform during construction. Rather than see bending members as a sign of imminent collapse, the responsible engineers decided that work should continue. It seems no-one on the project was thinking about safety – no one could seriously imagine that the structure they were building could, in fact, collapse if their work was wrong.

Disaster case study 2

In 2018, a pedestrian bridge under construction at Florida International University in Miami collapsed during the middle of the day killing one construction worker and five motorists. The worker was on the bridge at the time and the motorists were in their cars stopped at the traffic lights underneath the partially constructed bridge.

Before it failed, the partially constructed bridge consisted of a single concrete truss spanning approximately 174 feet and weighing approximately 930 tons which had developed numerous wide and deep structural cracks. The investigation found that the supervising design engineer, the construction contractor and the statutory inspector were all aware of the cracks but failed to realise their significance. In fact, they found that the cracks did not present any safety concerns.

Analysis following the collapse showed that formal checking of the design did not include checking for structural integrity at each construction stage and so failed to identify a lack of redundancy in the design in this partially constructed state.

Despite the nature and extent of the cracking and the lack of redundancy of the bridge design, none of the engineers involved in construction understood the potential for collapse. The lead design engineer, construction engineer or inspection engineer could have articulated the need to close the roadway below the bridge while the integrity of the structure was secured but all three failed to link their work to the potential for public deaths.

Disaster case study 3

On 25 July 2010, during a routine shutdown, Enbridge's diluted bitumen (dilbit) pipeline failed near Marshall, Michigan.

The pipeline was operated from a control room in Edmonton, Alberta, and at the time of the failure, operators were shutting down flow as part of routine procedure. Alarms went off in the Alberta control room but operators did not recognise them for what they were. A relatively small amount of dilbit was released at this stage. Hours later, operators tried to restart the line. Alarms again went off, but operators did not respond and continued pumping for an hour before they stopped, perplexed that they had not been able to re-establish flow at a point downstream from where, unbeknownst to them, the line had ruptured. During this time a large amount of dilbit was pumped out into a nearby river system. Two hours later, the operators tried again and pumped for half an hour, ignoring alarms. They were considering a third attempt to restart when word came through that a massive release had taken place.

The operations people failed to realise what was happening for many hours until they received complaints about the smell of the leaking oil. In hindsight, it's obvious that pumping without any

downstream flow could be caused by a massive leak, but at the time they were fundamentally unable to link their actions to the possibility of a pipeline failure.

3.1.2 Focus on the long term

The next public safety principle is that pipeline engineers must take a long-term view in safety decision making and recognise that failure may occur far in the future as a result of actions taken now. It is easy for the long-term implications of decisions to be lost in the face of pressure to meet short-term goals but pipeline engineers must always consider the interests of those people in the future who can be impacted by engineering decisions, even though they may be separated in time and space from the engineering work itself.

This principle applies in design but equally in operations and maintenance where today's decisions can impact innocent bystanders in decades to come.

Examples for discussion

Example 1

Situation

Joel is seeking to establish the location class for a new pipeline with a 25-year design life that runs through an area that may be subject to flooding in extreme cases, and so will require buoyancy control on the pipeline. The design team urgently needs detail on the pipeline weighting, but Joel has been told that, since it would take a one in 100-year flood to affect the pipeline, the project will not wait for the design of the extra flood mitigation. What should he do?

Discussion

Joel should do as much as he can to investigate future risk from natural events to ensure that the pipeline design takes the long-term safety of the public into account. He should ensure that those pressuring him to determine any mitigations from such events quickly understand that their choices now will directly impact public safety in future years and may cost the company much more in the long run if engineering changes need to be retrofitted, or damage is caused to the asset from a flooding event that potentially could have been foreseen even if it had a low probability of occurrence.

Example 2

Situation

Harry is reviewing a lifecycle cost estimate to be used for project economics calculations and notes that the annual allocation for inspections and maintenance drops off significantly in the latter years approaching the end of the design life of the pipeline system. Harry knows that in fact ageing infrastructure is likely to require more attention to such activities in order to ensure continued integrity and public safety, not less. What should he do?

Discussion

Pipeline system owners and their engineers should ensure that appropriate consideration is given to how the system will be maintained in the future in order to reduce the risk of future public safety impacts. Harry should review published literature to identify real life examples for other infrastructure in support of his position and discuss these with his management seeking changes to the lifecycle cost estimate to better reflect the likely future costs.

Example 3

Situation

Charlotte is preparing a project business case to connect an existing pipeline to provide gas to a new peaking power station. The project includes a new use of the pipeline for gas storage and is expected to change the operating profile from steady-state operation to a pack-and-deplete but maintaining the same maximum allowable operating pressure (MAOP). She has reviewed the existing defects in the pipeline and is comfortable there are none approaching a critical length based on the in-line inspection completed last year. However, she doesn't consider any other threats beyond those currently listed in the safety management study, as the business case is due for submission. She is also worried that the business case may not be commercially viable if there are limits on the operation. What should she do?

Discussion

Charlotte should consider whether the changes in operation will result in other threats in the future that may have an impact on the remaining life and accelerate a failure event. In this case, a change from steady-state operation to a pack-and-deplete operation will introduce a significant fatigue cycling load. This threat wasn't assessed in the safety management study (SMS) as the original pipeline design didn't consider fatigue cycling as a credible threat. She should ensure that changes in operation outside the original design basis and SMS are reviewed against all potential failure mechanisms introduced by the change, and that this is either investigated prior to the submission or be highlighted to be assessed as part of the project and the potential project impact.

Example 4

Situation

Max is designing a large high-pressure mains extension for an old pipeline to supply a growing urban fringe development, in a T1 location class. The existing mains doesn't have any pig launching facilities, so he decides to design the new pipeline without the ability for in-line inspection with short radius elbows and no pigging facilities, as this will be cheaper to construct and there will be fewer long lead materials to purchase. He doesn't consider it necessary to ensure the new section can accommodate in-line inspection tools, as the existing pipeline isn't fitted with a pig launcher and therefore the new section has the same risk profile. His construction manager rewards him for saving money on their project. Is this the right outcome?

Discussion

Max should be designing new pipelines and modifications such that the design can accommodate future loading, passage and retrieval of in-line inspection tools, as recommended by AS 2885.1. He should ensure that decisions he makes in the design phase to save capital cost won't result in a pipeline that is more difficult to operate, inspect and maintain in the future. Max should review the existing mains section and investigate whether there are any sections that currently restrict passage of in-line tools. He should look for the opportunity to improve inspection arrangements for the overall pipeline, rather than base the design on the existing installation. The project could be an opportunity to extend the life of the overall pipeline system by adding inspection facilities and therefore saving replacement costs.

Disaster case study

Hurricane Katrina hit the Gulf Coast of the US in 2005, resulting in more than 1800 deaths and insured losses above US$40 billion. The potential for extreme weather damage to this area was well-known and there were measures in place that were designed to prevent, or at least minimise, this damage. In fact, there were 50 major breaches of the New Orleans and Southeast Louisiana Hurricane Protection System (HPS) because of the hurricane.

The HPS consists of a series of levee-flood walls, outfall canals and pump stations. The design basis of the Standard Project Hurricane was set in the 1960s and changed during the design and construction stage of the project to build the HPS. Completed design and construction work was not revisited following the changes in the design basis, leading to a system as a whole that was not fit for purpose. Changes in flood mitigation philosophy over time systematically increased the inherent risk in the whole system as new sections were added, but this was not understood. Some structures had suffered subsidence, meaning that they no longer met their original authorised level, but no action was taken to correct this problem.

When Hurricane Katrina struck, the system failed to protect the city. Aspects of the system failed in previously unknown modes so even an HPS with a comprehensive systematic design would have experienced some failures, but the damage to the system, and hence the flooding of the city, could have been much less. Multiple failures occurred because in some cases the design of the system proved to be inadequate and in other cases components failed to work as designed. In addition to levee-flood wall breaches, pump stations were largely inoperable as power supplies failed and no safe havens were provided for operators.

Overall, those responsible for the original design did not consider how all the components of the system would work together and impact people living and working in the New Orleans area into the future. Those with ongoing responsibility for the system over decades also did not consider how the system would function as a whole to mitigate risk, nor the level of residual risk remaining. Hurricanes are rare but very high consequence events which can make it difficult to appreciate the real-world implications of design decisions, but this case study graphically illustrates the impact of failing to effectively consider what might happen in the long term because of engineering work done now.

3.1.3 Speak up for safety

The next public safety principle is a requirement to speak up for safety.

In some cases after an accident, it is found that someone knew. Sometimes they tried to speak up and their concerns were ignored but there are also many cases in which people kept their concerns largely to themselves. That serves no-one's interests.

Senior members of the profession who work in design are especially obliged to stand up for safety when they decide whether to 'sign off' on drawings, reports and specifications at various critical points in a project. This has legal, as well as ethical, implications in some States and Territories.

Decisions regarding safety involve risk trade-offs. Should more time and money be expended to make additional safety improvements or is the current arrangement safe enough? This principle is not about seeking a perfectly safe system. It's about ensuring that safety considerations are heard and explicitly considered when decisions are made. If you have concerns:

- Articulate them early and often.
- Document them for the attention of your management and request a written response.
- Make a clear link to the specific undesirable outcome that you wish to avoid.
- Draw on evidence of past similar cases to support your argument.
- Propose potential solutions.

Speaking up can be hard, particularly when you know that the news will not be well received, but it is an important part of being a professional engineer to stand up for what you think is the right thing to do. Ultimately, all engineers need to accept that their responsibility and influence have limitations, but no organisation sets out to have an accident. Accidents happen because those making important decisions cannot imagine that an accident might happen because of their actions. Making that link – reminding the rest of the team and those higher in management of the safety implications of actions – may be all that is needed to change outcomes.

AS/NZS 2885 Part 6 includes specific requirements regarding the need for the Pipeline Licensee to be aware of the potential consequences of pipeline failure, the controls in place and the limits of those controls. This provides a regulatory framework that engineers may find useful to refer to when making public safety concerns known.

Examples for discussion

Example 1

Situation

Mark is a registered professional engineer working on a brownfield project for changes to a compressor station. The project manager insists that Mark should sign-off drawings as approved for construction even though some key vendor details impacting pressure relief are not yet available.

The client is also pressuring Mark to sign off on the drawings because they have a company project deadline to produce issued for construction (IFC) drawings which will not be met if Mark waits for the final information that he believes is necessary. What should he do?

Discussion

Approving drawing for construction has legal and ethical implications. Mark's starting position should be that the drawings will not be signed until he is satisfied that, in his professional opinion, all necessary information has been included. Mark might enlist his discipline lead or engineering manager in the discussion to support this position. They might draw on the implications of getting this wrong (i.e. leaks, explosions, fatalities or whatever is realistic) in describing the reason for their position. Plain language discussion about consequences can sometimes cut through bureaucratic language about deadlines, etc.

If power relationships are such that Mark feels he has no choice but to sign, he should ensure that his concerns and the consequences of getting it wrong are recorded in writing for the attention of his management, and that he has a way to update the drawings when the necessary information comes to hand.

Example 2

Situation

Leonie is a junior construction engineer working on a project to install a tie-in to an existing pipeline. In preparing for the mechanical work, she is present while the construction crew is excavating to uncover the pipeline. The project has lost several days due to bad weather, so work is running behind schedule. The digger driver decides that it will be faster to do the work if he digs across the pipeline rather than parallel to it. Leonie knows that this is against approved company procedures which are critical to its compliance with AS/NZS 2885. What should she do?

Discussion

Leonie should tell the construction supervisor that work can go ahead only in accordance with the approved design. She could also consider who might support her in implementing the approved company procedures in this instruction (pipeline operations personnel, her boss, etc.) and enlist their help.

If power relationships are such that Leonie feels unable to stop the work herself, she should immediately seek advice from others as above, but it is her professional responsibility to advise her employers that they should stop the work once she is aware of the problem.

Example 3

Situation

Paul is an operations supervisor on a pipeline network. An actuator on a critical pipeline shutdown valve has failed which means that the system cannot function unless the shutdown valve is locked open. The delivery of the necessary parts is estimated to be a week. What should he do?

Discussion

Since the shutdown valve is a safety-critical device the system should not run without something in place to replace it, even for only a week. Paul should shut down the system unless the consequences of shutting it down (for example, for security of supply) are worse than the consequences of an emergency with no functioning shutdown valve in place. If gas supply from the system is critical, he should ensure that alternative measures are put in place, for example, additional monitoring (physical or instrumented), possibly even staffing the valve.

Example 4

Situation

Kathleen is running a safety management study on a large gathering network. While doing the background work for the study, she finds that during the first three months of construction of this project, there have been two pipeline strikes because of unauthorised work. During the study workshop, it is discovered that a large construction camp has been constructed within the 12.6 kW/m2 consequence distance of two large pipelines that haven't been designed in accordance with the no rupture provisions of AS(/NZS) 2885. What should she do?

Discussion

It can be difficult to speak up, particularly when large sums of money or project schedules are involved. Kathleen should be sure to communicate this news upwards as specifically and clearly as she can. She should also request a response to concerns raised in writing. Referring to the high consequence recognition aspects of AS/NZS 2885.6 might also be useful.

Disaster case study 1

In the late 1960s, Ford Motor Company engineers were working on a new small car for release into the US domestic market. Design and production processes were accelerated due to market considerations regarding release of competing models from GM and overseas manufacturers.

Crash testing of the new Ford Pinto revealed that the fuel system was likely to be punctured in even a low-speed rear-end collision. Internal Ford documents show that this was known at least as early as 1970. As a result of the tests, engineers flagged to management that the car was potentially dangerous, and that the problem could be fixed with minor modifications to the design. Ford management's response was to conduct a cost-benefit analysis comparing the cost of making the design change with likely payout costs to victims of fuel fires if the design went into production unchanged. Given that production tooling had already begun, the conclusion was that it would be too expensive to make design changes at that stage. A cheaper option was to pay damages to victims if fires were to occur.

The Ford Pinto was released onto the market in 1971. Before long, a series of low-speed rear-end collisions resulted in fuel system failures and fires as the crash tests had predicted. The exact number of deaths and injuries is not known, but at least 23 victims and/or their families brought a series of civil cases for damages that Ford sought to settle out of court to protect its reputation. In 1977, the media became aware of the problem and a series of major newspaper articles brought the issue to the attention of the public. Car sales declined. In 1978, increasing negative publicity led to Ford conducting a voluntary recall of approximately one and a half million cars to make a minor

modification. The company also successfully defended three charges of reckless homicide brought in Indiana because of an accident in which three girls were burned to death in a rear-end collision involving a Pinto. While there might have been ethical questions to answer, the company was found not to have broken any laws.

This case vividly illustrates why it is important for decision makers to take engineers' safety concerns into account. Senior management at Ford apparently had no idea of the devastating impact on the victims, their families and the reputation of their organisation as a result of failing to take advice.

Disaster case study 2

Another well-known example in which engineers' safety concerns were ignored with catastrophic consequences was the loss of the NASA Space Shuttle Challenger on lift-off in 1986, killing the crew of seven astronauts.

The loss resulted from failure of o-ring seals in a joint on the solid rocket boosters that allowed hot gases to escape, impinging on the fuel tank and causing structural failure which then led to the shuttle breaking apart. The o-rings themselves failed due to the cold weather on the morning of the launch but the safety of the design of the joints that required these seals and the impact of weather on the o-ring performance had been the subject of discussion within the project team for some time.

The contract engineering firm responsible for the design of the solid rocket boosters, including the o-rings, was Morton Thiokol (MT). Performance issues with the o-rings had been known by NASA since 1977 with the joints flexing in unexpected ways. Some NASA engineers had expressed the view at that time that the design itself was unsafe and the joints requiring o-rings should be eliminated or redesigned. Despite this, the design was accepted for flight in 1980.

The operating history of the space shuttle program also indicated that o-rings were not reliable and were sometimes being eroded. Of particular concern to some MT engineers was the apparent correlation between low temperature and o-ring erosion. In the lead up to the fatal accident, weather forecasts suggested that the launch temperature on 28 January would be well below the experience base of the operating data. MT engineers made the argument to MT and NASA middle management that launch under these conditions was unsafe as the performance of the o-rings could not be guaranteed. Their advice was not accepted and ultimately a management decision was made to proceed with the launch, with catastrophic consequences.

Again, this accident shows the adverse consequences that can occur when engineers' concerns are not acted on. NASA and MT management should have paid more attention but there are ways in which pipeline engineers can make it more likely their warnings are heeded. These include articulating concerns early and often, documenting them for the attention of management, and requesting a written response, making a clear link to the specific undesirable outcome that they wish to avoid, drawing on evidence of past similar cases to support their argument and proposing potential solutions.

3.1.4 Think beyond compliance

The fourth individual practice principle is to think beyond compliance.

The Australian Standards approach recognises a requirement to conform to Standards and comply with legislation and regulation. Written rules such as engineering standards, codes of practice, plans and procedures of various kinds represent a form of collective professional knowledge. Knowing which rules apply in each situation is a key professional competence, but expertise is much more than simple rule following.

Senior engineers in particular have an obligation to understand *why* something is required and so make professional judgments in accordance with the intent of requirements, not just the letter. Sometimes compliance alone is not enough to keep the public safe.

Examples for discussion

Example 1

Situation

Yousef is a mechanical engineer working on a new pipeline design. The project is using some innovative materials. It meets all the code requirements, but the new material has a failure mode that was not anticipated by the code drafters. His boss says if the design complies, then that is all that is required. What should he do?

Discussion

Codes are ultimately about ensuring the design is fit for purpose. If an innovative design solution meets the letter of the code but not the intent, it is not code compliant (NB AS 2885 Part 0 makes this point). Yousef might enlist his discipline lead or engineering manager in the discussion to support this position that more investigation is needed. It is important for Yousef to explain how it is that he knows about the failure mode and give examples of where it has already occurred. They might draw on the implications of getting this wrong (i.e., leaks, explosions, fatalities or whatever is realistic) in describing the reason for their position. Plain language discussion about consequences can sometimes cut through bureaucratic language about deadlines, etc.

If power relationships are such that Yousef feels he has no choice but to move on without further investigation, he should ensure that his objections are recorded in writing and seek a response from management in writing.

Example 2

Situation

Lisa is a project manager working on a major modification project that requires some customers including a major hospital to be without gas for 12 hours. She knows that the backup system at the hospital only has six hours' capacity. Completing the work in under six hours will have much higher labour costs but the legal penalties for interruption of supply to the hospital are not time dependent. What should she do?

Discussion

Decision-making needs to focus on risk, rather than contractual penalties. Rather than limit this to a decision about the relative costs of a six or 12-hour job, good engineering practice would be to fully investigate opportunities for extending or augmenting the back-up system at the hospital, or changing the schedule for the work to a time when demand for gas at the hospital is known to be lower.

Example 3

Situation

Jacinta is a pipeline engineering consultant with many years' experience in pipeline integrity management for major pipeline networks. She has designed a pipeline integrity management plan (PIMP) for her new client, a small operator with a single pipeline in a very low-risk location. Her client tells her that many of the requirements of the system she has written are far too onerous and must be deleted. What should she do?

Discussion

Pipeline integrity management plans must be risk-based and fit for purpose. Jacinta should clearly link her proposed integrity management requirements to the potential integrity threats to check that the proposed mitigations are relevant to the risk. Linking risks to requirements may also facilitate an

easier conversation with her client to demonstrate the safety implications of pipeline failures that must be appropriately managed. Thinking beyond compliance and understanding the underlying reasoning of how and why we apply engineering methods, can also reduce unnecessary cost by focussing efforts on where risk reduction is meaningful.

Disaster case study 1

The Enbridge dilbit pipeline failure from 2010 described earlier has another key lesson for us.

What is of particular interest here is why the line failed. The problem was external corrosion. A series of inline pipeline inspections over several years had identified many cracks including (in 2005) a crack over four feet long that ultimately led to the rupture. Despite evidence that this flaw was present, Enbridge had chosen not to excavate this line to further investigate the physical state of the pipeline and conduct appropriate repairs. Instead, the engineering analysis focused on demonstration that the pipeline did not meet the regulatory trigger for excavation and repair.

In this case, a focus on compliance meant that an opportunity to repair the line before it failed was missed. Compliance was not enough to prevent a major oil leak.

Disaster case study 2

On 23 March 2005, plant operators at the Texas City Refinery were restarting a distillation column after a routine maintenance shutdown. A series of operating errors meant that the column was overfilled with hydrocarbon liquids. The pressure relief system activated, and the excess fluids were released into the blowdown system. The blowdown system was also overwhelmed by the material being released from the distillation column. A massive vapour cloud originating from the blowdown stack was ignited by a nearby vehicle. The resultant vapour cloud explosion was heard several miles away. The blast wave damaged surrounding buildings causing 15 deaths and 180 injuries.

There are many contributing factors to this accident, but one key issue was the design of the blowdown system. The blowdown drum and stack were designed in the 1950s and complied with engineering standards of the time. Subsequently, it was appreciated in the industry that such systems are potentially hazardous and refinery pressure relief standards were changed to require closed relief to flare, that is, waste gases need to be burned, rather than vented.

The fact that the blowdown system for this part of the refinery did not meet current standards was well known, but company standards required old systems to be upgraded only when major modifications were carried out. A major refinery flare and venting study in the early 1990s included consideration of this blowdown system. The refinery owner at the time (Amoco) decided not to go ahead with any changes as it concluded (correctly) that neither state nor federal regulations were likely to mandate closed relief systems in the foreseeable future. The drum and stack were modified on several occasions in the 15 years before the accident including a full replacement in 1997 with identical equipment, even though engineering standards by that time required a flare for this type of service. Decisions were made over and over again to ‘grandfather’ the old system, that is, to declare that the old design was acceptable given that it met the required standard at the time the facility was originally designed.

Modern process safety design requires the preparation of a relief contingency table showing all possible overpressure cases (of which overfilling the column is one) with the relief system designed for the worst possible case and relief flowing to a closed flare system. Such scenario-based analysis was never completed for this unit. Instead, those in charge relied on compliance-based arguments to avoid spending money on upgrading the system which remained undersized and venting to atmosphere.

3.1.5 Work only within your area of competence

The fifth individual practice principle is working only within your area of competence.

Much of this practice guide is about how pipeline engineers should best exercise their professional judgment. The difficult skill of professional judgement is critical to ensure the best outcomes, but we must never forget that excellent engineering also involves hard technical skills.

Part of working within your area of competence is keeping up to date with developments in your discipline. Another key aspect is having a keen sense of what you know and what you don't know – and sticking to what you know.

Examples for discussion

In some cases, an engineer may be tempted to take on engineering work for which he or she is not fully competent.

Example 1

Situation

David is working on the detailed design of a lateral pipeline. It becomes clear part way through the project that a new independent cathodic protection system will be required. David's company does not employ specialists with knowledge of cathodic protection system design, but he has been in the industry for years and feels that he can appropriately select the anode and use a design from another project, even though the location is different. Is this okay?

Discussion

This is not okay. However seemingly simple the cathodic protection design work is, it needs to be done by someone with competency in this area, who considers all the required project specific information and completes the design based on an informed technical understanding of the method, including awareness of subtleties that may not be apparent to those with only superficial knowledge.

Example 2

Situation

For the past decade, Jerry has worked as a project manager. As a result of a company restructure, he is moving into the engineering design area, with sole technical responsibility for mechanical design. He is developing a fracture control plan and has worked in this area before, but his knowledge is now a decade old. What should he do?

Discussion

Requirements established in standards will change over time, as knowledge is further developed through industry experience and incidents, knowledge development and research. Jerry must ensure that he is up to date with current standards and practices, and that his current level of competence is appropriate for the role he is in. As part of the restructure, he could request time and funding for self-learning to regain his past competence level.

Example 3

Situation

Sarah is a senior process engineer, leading the design of a new transmission pipeline. She is asked by a junior mechanical engineer from her team to check and sign the stress analysis report as he hasn't done this task before. She doesn't have knowledge of stress analysis and isn't sure what details to check as this is outside her discipline, but she signs the report so she can issue the document to the construction team and give them the approval to start. Is this okay?

Discussion

The engineering checking function is important, particularly when leading junior colleagues. However, this needs to be done by someone specifically qualified in the right discipline, who has knowledge in the specific analysis method being applied, otherwise errors generated by an inexperienced engineer may go undetected. An engineering process that involves assessing the safe application of loads to a pipeline is critical to the safety of the asset. An error made in design that continues through to construction may result in a much more costly event, if detected after construction or if it results in an incident during operation.

In some cases, an engineer may be pressured by others to undertake work for which he or she is not fully competent.

Example 4

Situation

Cheng is working on the design basis for a new pipeline passing through some unusual soil conditions. He flags to his client that this issue needs specialist review. The client is reluctant to pay for extra advice and pressures Cheng to use his professional judgment and experience to include his best estimate of requirements in the design basis. What should he do?

Discussion

Cheng should stand firm and not pass a view on issues that are outside his area of competence. Getting this wrong in the design basis could have major implications for him and for the client.

Example 5

Situation

Harry is an electrical engineer responsible for developing the design basis for a new compressor station project. He completes the document to the best of his knowledge but hasn't asked for input from the other discipline engineers in the multidiscipline design team. He knows that he has limited knowledge in the process sizing conditions and the materials proposed for the project. However, he is under pressure from his manager to issue the document for use before the team review, as the client has asked for it urgently. What should he do?

Discussion

Without knowledge across engineering disciplines outside of your field of expertise you may omit critical information. Time pressure will often create an environment that encourages short cutting of the engineering process. The desire to satisfy the urgent needs of others can impact the quality of the deliverable if the proper process isn't followed. Harry should advise his manager of the limits of his knowledge and explain the requirements of the cross-discipline review of the document to ensure the basis is correct. A conversation with the client may help to explain the process and importance of the review to support the technical outcome of the project.

Disaster case study 1

An explosion at the Flixborough chemical plant in the UK in 1974 killed 28 people. The plant produced an intermediary chemical used to make nylon. The process involved large volumes of cyclohexane circulating through a series of reactor vessels. Two months before the accident, one of the reactors was found to be cracked. The reactor was taken out of service, and it was decided that a temporary bypass should be installed so that the plant could continue to run while a repair was made.

The role of Works Engineer (to be filled by a chartered mechanical engineer) had been vacant for several months so at the time of the accident there were no qualified engineers working in the plant engineering department. Mechanical engineering advice was available from another site owned by the same company, but it was not called upon because the people involved didn't know what they didn't know, i.e. they did not understand the limits of their professional competence. The bypass was fabricated out of materials available in the plant workshop at the time and was designed in a full-size chalk sketch on the workshop floor.

None of the senior engineering staff on the site had mechanical engineering qualifications (they were all chemical engineers). They had no understanding of the forces that the temporary line needed to withstand and, as the subsequent inquiry found, the line was under designed for this service. After two months, a minor operating upset caused the temporary line to fail, well within the normal operating envelope of the plant. This accident dramatically illustrates the need for strict control of engineering modifications and gave rise to development of the HAZOP technique of multidisciplinary design review.

This accident is a vivid reminder of the potential consequences of individuals working outside their area of competence.

4 Further reading

4.1 Organising for safety

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Hollnagel, E. (2014). *Safety I and Safety II: The Past and Future of Safety Management*. Farnham, Surrey: Ashgate.

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Reason, J. (1997). *Managing the Risks of Organizational Accidents*. Aldershot: Ashgate.

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4.2 Engineering practice

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Trevelyan, J. (2014). *The Making of an Expert Engineer*. Leiden: CRC Press.

The APGA Pipeline Engineer Competency System creates a framework for understanding competency and a means of assessing and documenting competency for pipeline engineers. More information can be found here: https://www.apga.org.au/about-pipeline-engineering-competency-system

4.3 Disaster case studies

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4.4 Energy Pipelines CRC research reports

The following reports produced by the Energy Pipelines CRC from 2012 to 2019 are relevant.

Maslen, S., & Hayes, J. (2019). *Final Report RP4-23 Building Professional Practice through Case Based Learning*. Energy Pipelines Cooperative Research Centre Research Program 4 Public Safety and Security of Supply.

Hayes, J., Wong, J., & Merad, M. (2018). *Final Report RP4-23 Investigating how standards are formed – case study of AS2885 and AS4822*. Energy Pipelines Cooperative Research Centre Research Program 4 Public Safety and Security of Supply.

Hayes, J., Maslen, S., Scott-Young, C., & Wong, J. (2016). *Final Report RP4-23 The Rise of Defensive Engineering – Personal Liability Concerns and the Impact on Public Safety*. Energy Pipelines Cooperative Research Centre Research Program 4 Public Safety and Security of Supply.

Balu, S., & Hayes, J. (2015). *RP4-03 Organisation Design*. Energy Pipelines Cooperative Research Centre Research Program 4 Public Safety and Security of Supply.

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