IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

IChemE Safety Centre Guidance

Applying process safety during concept select phase of a project

2020

IChemE Safety Centre

Contents

1. Preface

The full life cycle of a physical engineering project includes many stages, from the initial concept selection through to eventual decommissioning – as illustrated in the diagram below. Application of inherently safer design principles in the concept select stage applies to all projects regardless of the scale, but the depth explored, and benefit of each section will vary depending on the scope and magnitude of the project.

This document provides guidance on the application of process safety and inherently safer design principles to the concept selection stage of an engineering project. It provides an example checklist tool which can be applied to ensure process safety and Inherently Safer Design (ISD) concepts are considered during the project. Importantly, the application of ISD principles needs to be adhered to for the duration of the project and into the operational life, not just in the concept selection phase.

Concept Select is considered to be the project phase where a series of different ideas are considered with less suitable ideas de-selected, leaving the final concept for further progression through the project life cycle. Traditionally this stage concludes once the concept has been determined, with one of the alternative options being selected. From this the project scope is defined for further detailed design. More deliverables included as we progress from a concept process to an integrated process including Front End Engineering and Design (FEED), Detailed Design (DD) and Engineering Procurement and Construction (EPC) provision. This can be visually represented as shown in Figure 1, with Concept Select highlighted.

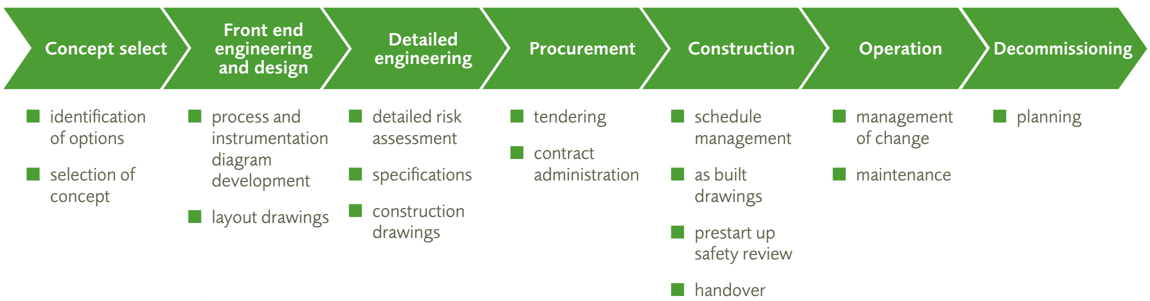

Figure 1. Overall project lifecycle.

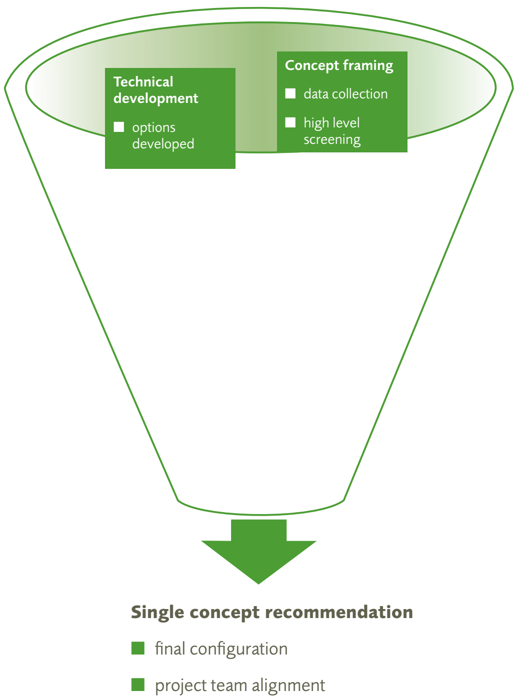

Figure 2. Funnel concept of filtering concepts, adapted from Worley

The concept select stage typically finishes prior to the FEED stage, however there can be some overlapping elements and the output from Concept Select phase informs the FEED process, with a clear scope being developed at the end of concept select. Figure 2 shows how multiple ideas and competing needs combine to deliver a single recommendation.

Incorporating process safety and inherently safer design principles into the initial concept selection stage of a project, enables risk to be better managed throughout the project lifecycle.

Leadership and ownership of process safety in the concept selection phase needs to be well defined and understood. As with all projects and operations, the responsibility for safety does not only rest with the safety personnel. All levels of the organisation need to ensure appropriate representation and inclusion of process safety in all elements of the project.

2. Acknowledgements

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- Santos – Kim Pullon
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- Woodside – Dave Harwood
- Worley – Mark Cowan

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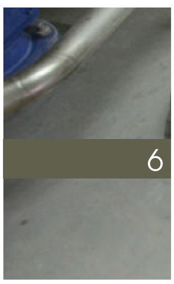
3. Definitions and terminology

There are many different terms used by different companies to describe the different phases of the project life cycle. The Project Management Institute defines the project life cycle as "the series of phases that a project passes through from its initiation to its closure" (PMI, 2013). The CCPS Guidelines for Integrating Process Safety into Engineering projects (CCPS, 2019) looks at the application of process safety across the entire project life cycle. For upstream oil and gas projects there is also an international standard (ISO, 2016). Terms used throughout the project lifecycle are defined in the table below:

Concept select	Project phase where a series of different ideas is considered with non-optimal ideas de-selected, leaving the final concept for further progression through the project life cycle (CCPS, 2019)
Stage gate review	A part of the project lifecycle where the current information is assessed against established criteria and a decision is made whether to progress or abandon the project (CCPS, 2019)
Front-end engineering design or front-end loading	This is the stage of the project following Concept Select. Once this stage is completed the project continues to detailed design (CCPS, 2019)
Inherently safer design	A concept applied to focus on elimination and or minimisation of risks associated with the design and operation of a facility rather than merely controlling the hazards (Mannan, 2012)
Basis of design	The combination of technical documents and drawings that define how the design meets its performance and operational requirements (CCPS, 2019)
Basis of safety	The combination of technical documents and drawings that define how the design meets its safety requirements
ALARP	As low as reasonably practicable. Reasonably practicable involves weighing a risk against the trouble, time and money needed to control it (HSE, 2020)
RAGAGEP	Recognised and generally accepted good engineering practices. Examples may include widely adopted codes, consensus documents, non-consensus documents, or internal standards (OSHA, 2016)
Hierarchy of controls	The ways of controlling risks are ranked from the highest level of protection and reliability to the lowest. This ranking is known as the hierarchy of control measures (Safe Work Australia, 2018)





4. How to use this document

This guidance document is intended for use by project management professionals, design engineers and facility leadership, to improve awareness of ISD principles which should be addressed during the concept selection phase of a project. The guidance is applicable to both operating and contracting companies.

This guidance document is applicable to ISD in the concept selection phase for new installations, upgrades and modifications to existing facilities. By ensuring that process safety is considered at the earliest stage, it allows incorporation of inherently safer design principles when it is feasible and less expensive. Attempting to build in ISD principles at later stages in projects becomes more expensive and difficult to achieve.

This guidance document is not a definitive list but contains some information on process safety which should be considered in the selection process, including an appendix with useful checklists as well as an appendix with a worked example of application.

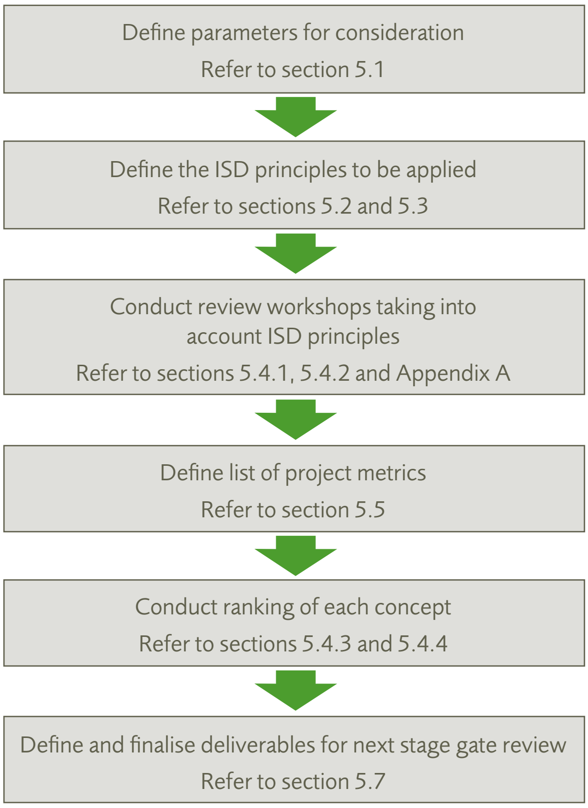


Figure 3. Process flow for applying this guidance document .

Recommended steps on how to implement this guidance:

1. Determine the scope for implementation, including what sections of this guidance document are relevant to your application and experience.
2. Define the parameters for consideration.
3. Define the ISD principles to be used.
4. Conduct the workshop reviews using the checklists in this document, taking into account ISD principles.
5. Define the project metrics to be used.
6. Conduct a form of risk ranking for each concept, taking into account the process safety implications.
7. Finalise the deliverables package for stage gate review.
8. Ensure that the principles of inherently safer design continue to be applied across the life cycle of the project.

5. Process safety within the concept select stage

5.1 Parameters for consideration during evaluation of different options

When commencing the concept selection stage of a project it is necessary to first define the objective and scope of the development. At this stage, decisions such as whether to use conventional or novel technologies need to be taken. A challenge may be that the associated risks for novel technologies may not yet be well understood and documented or available in a literature search, by the very nature of being novel. This does not, however, mean that the novel technology should be avoided; it may in fact be the better choice, which may be demonstrable following detailed risk assessment and further consideration. A challenge when assessing conventional technology may be the misinterpretation or application of equipment failure rates.

This needs to be addressed by ensuring that thorough research is conducted for the assessments. The intent of the list presented in Appendix B is to ensure consideration is given to inherent safer design for input when evaluating the different design options.

5.2 Inherently safer design principles

There are certain basic principles that need to be considered in the review process and workshops to ensure inherently safer design options have been considered when reviewing the different concepts. Inherently Safer Design (Mannan, 2012) requires the analysis of the process considering how the following principles have be applied:

- elimination
- substitution
- minimisation/intensification
- moderation/attenuation
- simplification

To assist in applying these principles, the table below, drawn from ISC member experience, highlights further detail. This information feeds into the consideration of items listed in Appendix B:

Principle	Objective	Considerations	Further detail
Elimination and/or substitution	Avoid processing or using toxic, flammable or environmentally hazardous materials	Chemistry	■ feeds ■ intermediates ■ products ■ by products ■ impurities ■ incompatibility ■ toxicity ■ reactivity ■ radioactivity
		Processing aids	■ heat transfer fluids ■ refrigerants ■ absorption/ ■ removal/ ■ conversion ■ recycles ■ absorbents/ ■ adsorbents ■ catalysts
		Where material is	■ stock tanks ■ in process ■ in transport ■ risers ■ flow lines

Principle	Objective	Considerations	Further detail
Minimise/intensification	Reduce inventory of hazardous materials	Unit operations and equipment continuous rather than batch possibility of faster reaction hazard density pressure, volume, temperature interaction	■ Just in time processing ie reduce large storage spread over wide area subdivide inventories
Simplification and/or moderation/attenuation	Reduce the potential for surprise	Keep simple avoid runaways, explosions and detonations Moderate the operating conditions continuous rather than batch Big heat sinks, small amount in process	■ Reduce the overall hazard loadings
		Dynamics	■ High inertia, hazards slow to develop low inertia, deviations quickly corrected ■ Process safety time – ie response time
		Process connections	■ Use of selective couplings on connections to prevent incorrect line up
		New technology instrumentation, eg 5G, drone tech	■ How technological advances may alter design constraints
		Flow, level, pressure, temperature, impurities	■ Minimise the amount of product stored and the conditions it is stored under

5.3 Other items to be considered

In addition:

- passive design and layout
- operability
- previous incident history, local, corporate and international
- resourcing considerations
- reliability, availability and maintainability
- lifecycle and end of life

Principle	Objective	Considerations	Further detail
Passive design, layout	Separate people from the hazards	Integrity of containment	■ Design strength joints ■ Seals ■ Moving parts double wall tanks secondary containment (bunding)
		Minimise corrosion and wear Material of construction selection operability and layout remote control Beware vents and drains Hazards to surrounding community and environment	■ Material of construction selection ■ Occupancy ■ Domino effect ■ Plant layout ■ Hazards to surrounding community and environment
		Walk to work offshore resulting in Reduced helicopter flights	■ Accommodation needs to be sufficiently removed from processing areas, provision of escape pods or self-contained shelters
Operability	Ensure the system is designed for optimum operability	Necessary equipment needs to be accessible for safe operation, normally and in an emergency	■ Access outside confined spaces ■ Remote access ■ Access from platforms
Previous incidents	Apply learning from incidents into design	Designing safeguards into the process	■ Consider available databases to review previous incidents to broaden approach

Principle	Objective	Considerations	Further detail
Resourcing considerations	Manned/unmanned facilities Plan for facilities to recover safely from abnormal events	Control philosophy remote visibility: human machine interface, CCTV, fail safe state	■ Consider requirement for remote operation of critical valves, with local or remote reset ■ Consider requirement to diagnose upsets and plant conditions remotely ■ Consider visibility of the process and plant, and ability to assess conditions eg via CCTV before sending person into an area Eg reducing need for fire pump redundancy in unmanned facility, no need for galley, etc consider what fail safe state for unit operations will likely be, with control to support this? (eg maintain cooling water flow on exothermic reactor jackets)
Reliability, availability, maintainability	Establish reliability requirements	Determine reliability required	■ Minimise entry requirements (via eg material selection, or reduced inspection, or drone technology, including automation or robot applications)
	Establish availability requirements	Determine the availability required for systems	■ Consider how the availability will be maintained during the facility life
	Establish requirements and design for maintainability	How the system is designed to facilitate testing – ensure that equipment can be adequately maintained including isolation philosophy Use of modularisation to minimise maintainability requirements in situ	■ Ensuring that full function testing can be completed on safety systems ■ Isolation philosophy stated, for example, requiring that proven isolation can be achieved on vessels that will require internal inspection
Life cycle and end of life	Plan for safe decommissioning Plan for required service life	Equipment cleaning dismantling disposal Site remediation/ restoration design life Reuse or recycling of equipment	■ Design life clearly stated and challenged for sufficiency against expected service duration

Appendix A contains a checklist of factors to consider during facilitated workshops and Appendices C and D contain worked examples of one option for comparison.

5.4 Methods of analysis

5.4.1 Facilitated workshops

Facilitated ISD workshops can be used to identify process safety hazards associated with a particular concept and assess options to eliminate or reduce the severity or likelihood of an incident. The workshop applies the ISD checklist (ref Appendix A) to ensure ISD opportunities are addressed. The facilitated workshops should be cross functional to ensure that all relevant perspectives are considered. The minimum involvement should consist of the following roles:

1. Facilitator – experienced and trained to lead the group in the workshop process. This role is vital to ensure all perspectives are presented and that the workshop remains on track. They may also have some technical contribution, but their main role is to facilitate.
2. Engineering representative – design engineers who are developing the concept. They should be knowledgeable in the technologies being considered.
3. Operations representative – personnel who have operational experience. This contribution is necessary to ensure the options developed take into account operability.
4. Reliability representative – personnel who have reliability and maintenance experience. This contribution is necessary to ensure the options developed take into account maintainability and the necessary availability.
5. Technical safety representative – personnel who have technical safety experience, such as functional safety, pressure relief, cyber security, etc.
6. Health, safety and environment representative – personnel who have experience in managing HSE aspects of the business.
7. Human Factors specialist, including ergonomics and operability.

All facilitated workshops must include both the owner's team and the design and engineering consultant where they have been contracted to deliver the project.

5.4.2 Checklist

A checklist can be a useful way to trigger discussion in the concept select stage to ensure that relevant options are considered. The checklists take into account the items listed in Section 5.2 and 5.3. An example checklist is contained in Appendix A. There are many useful checklists available to prompt and guide hazard identification. For example, ISO 17776 Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations contains Annex F HAZID guidewords. This can be read in conjunction with the checklist in Appendix A.

5.4.2.1 Worked examples

Two worked examples have been provided in Appendices C and D. These are not exhaustive examples and only show one option for review and comparison in each appendix to show how the checklist can be used.

a. Example 1 (Appendix C)

   Project: Gas gathering, dehydration and compression.

   Node to be reviewed: offshore manned dehydration and compression platform facility.

   This example looks at one option for the gathering, dehydration and compression of the gas. Other options for nodes to be considered could be an unmanned platform or an onshore processing facility. Once all possible nodes are reviewed at this stage they can be compared for selection. This could then use a form of ranking such as those listed in section 5.4.3.

b Example 2 (Appendix D)

Project: Polyvinyl Chloride (PVC) manufacturing facility.

Node to be reviewed: vinyl chloride monomer (VCM) storage and charge facility, where storage is filled by road tanker.

This example looks at one option for receipt of VCM into the storage and then charging to the process. Other options for nodes to be considered could be **receipt of VCM via rail or pipeline**. Once all possible nodes are reviewed at this stage they can be compared for selection. This could then use a form of ranking such as those listed in section 5.4.3. **This example does not distinguish between the different processes for polymerising VCM into PVC, for example emulsion verse suspension technology. This would have been another node to examine when looking at the reactor design.**

5.4.3 Ranking methodologies

Once options have been determined it is necessary to rank them to facilitate selection. There are a number of different ranking methodologies available. This document does not go into detail about these, but rather lists the different types. Selecting which methodology to use is up to the reader. It is important to ensure process safety is adequately weighted into the process.

1. Internal company risk matrix and/or assessment methodologies based on comparison of key scenarios.
2. Pugh's concept selection (Pugh, 1981)
   – The Pugh concept selection is typically used to evaluate options against a baseline, with options given a positive, negative or neutral ranking against the baseline for an established set of criteria.
3. Weighted rating method (Ulrich, 2000)
   – This method applies a weighting to each established criterion, which the option is then rated against.
4. Saaty's analytical hierarchy process (Saaty, 1980)
   – The different options are placed at the bottom of a hierarchy, with the overall goal at the top and the criteria for ranking between them. The options are then evaluated against the criteria with priorities applied, similar to probabilities.
5. Roy's electre III (Roy, 1991)
   – This applies a systematic analysis of the relationship between different options and applies a score against established criteria.

5.4.4 Quantification

Often quantification is required to evaluate one option against another. There are a number of methods that can be used to do this. This document does not go into detail about these, but rather lists the different types. Selecting which methodology to use is up to the reader.

1. Hazard studies
2. Mond index
3. Inherent safety index
4. Decision matrices

5.5 Process safety project metrics

Each project will require different metrics to measure its success, though some metrics may be consistently needed across many projects. For example, when considering the assessment of capacity and patterns of demand, or availability and occupancy, there may be metrics that are used across every project, while metrics concerning a land-based activity would be different from an ocean-based activity. Therefore, customised metrics need to be established and tracked from the beginning of each project to ensure the outcomes are delivered. In defining metrics and targets, an initial decision will need to be made on whether the project is aiming for risks as low as reasonably practicable (ALARP) or risks managed to recognised and generally accepted good engineering practices (RAGAGEP). This decision will depend on the local regulatory regime requirements.

In any case, a metric required for all projects is the closure of action items identified in the reviews conducted. Undertaking the reviews themselves do not deliver inherently safer design, only the addressing of gaps via actions can work toward this. Some metrics to consider are how the actions are distributed against the hierarchy of controls, as this points to the application of ISD.

The hierarchy of controls is shown in figure 4, showing level of protection as well as reliability of control.

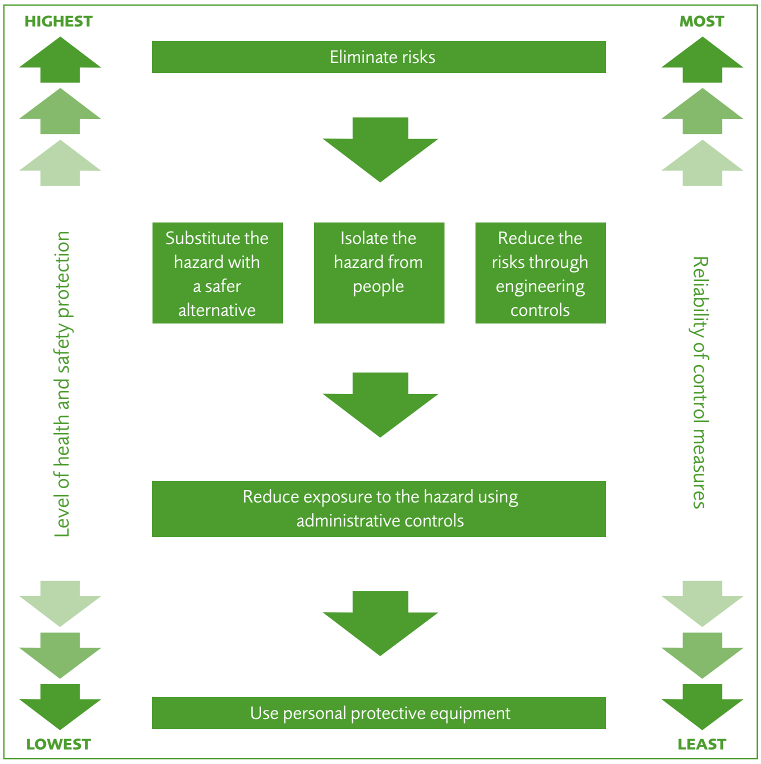


Figure 4. Hierarchy of controls adapted from Safe Work Australia.

Example metrics could include the following:

- closure of actions raised during review workshops, verified to meet initial intent
- number of overdue actions from review workshops
- review of current risk versus defined risk tolerance as project progresses
- changes to inventory of hazardous chemicals from initial concept as review continues
- changes to defined philosophies as review continues
- changes to resourcing requirements (both in project and resourcing of operations) as review continues
- changes that trigger a different regulatory approach

5.6 Concept design process safety deliverables

Once the scope of the development has been defined, there are certain documents that could be prepared for further review as the project works through the technical development stage. Typical documents required may include:

- objective and scope and design philosophy. This feeds directly into the next stage of the project, including any stage gate reviews
- block flow diagram or process flow sheet showing the overall concept including main hazard centres
- preliminary layout/plot plan which highlights potential hazard sources and sensitive receptors (workforce, public and environment)
- potential capacity, inventories and feedstocks defining the magnitude of the project
- regulatory requirements (including future directions in regulations) and community expectations. Future changes to regulations could include things like being prepared for different operator resourcing or designing back up battery systems to cope with variable renewable energy being used as the main load
- further required reviews and people required to ensure that the appropriate phases are costed and therefore completed
- defining process safety critical roles across the project should be completed to facilitate a seamless move from concept selection into FEED
- a conceptualisation of HAZID and preliminary quantitative risk analysis may be developed at this stage, aiming identification of major hazard events. This may lead to some elimination or minimisation of hazards at this stage
- initial scope for safety case development, defining the basis of safety or safety philosophy

5.7 Package for stage gate review

Once all the necessary reviews have been completed and a single concept has been chosen to progress, all necessary deliverables (refer Section 5.6) should be packaged for the next stage gate review.

6. Project lifecycle

It is important to remember that the concepts of ISD do not only apply in the initial selection and design process but also throughout the project life cycle. This includes aspects such as operation and ongoing maintenance as well as decommissioning.

Organisations need to ensure that ISD is applied during each of these stages of the project as a means to prevent process safety incidents.

Appendix A – Checklist

Project:

Node/section of facility under review:

Team members:

Date of review:

	Factors to consider	Applicable yes/no	Consideration of principle (Sections 5.2 and 5.3)	Decision/ action
Chemical hazards	Explosivity and flammability			
	Combustible dusts			
	Reactivity/stability			
	Incompatibility			
	Immediate health hazards			
	Long term or delayed health hazards			
	Nuisance impacts			
	Radiation			
	Environmental hazards			
	Hazardous breakdown products			
	Toxicity			
	Toxic combustion products			
	Physical agents affecting chemicals (eg noise, vibration)			
Means of handling	Storage			
	Transport			
	Problems in handling			
	Process conditions			
	Materials of construction, corrosion/ erosion			
	Decontamination			
	Gaseous emissions			
	Aqueous emissions			
	Effluent/solid waste disposal			
	Flare/thermal oxidiser			
	Quality control			
	Emergency procedures			
	Plant layout, spacing, access			
	Area classification			
	Provision of services			
	Codes of practice			

	PPE			
Other considerations	Subsidence			
	Landslide			
	Dam burst			
	Earthquake			
	Storm and high winds			
	Aircraft crash			
	Storm surge			
	Rising water courses			
	Flood			
	Storm water run off			
	Breach of security			
	Lightning			
	Tsunami			
	Forest fire			
	Vermin/insect infestation			
	Water depth offshore			
	Local community			
	Local regulations – future directions			
	Ship collision			
	Vehicle collision			
	Underground services impacted			

Appendix B – Design considerations during facilitated workshops

Substances involved

1 Process inventories? Material properties? Eg flammability/explosion and toxicity risks, composition and properties of key components. Process chemistry both intended and unintended but possible, eg exotherms or mixing of chemicals.

Process technology options

2 Are there technology options for processing? Conventional versus new technologies eg topsides compression versus subsea compression. Process parameters understood (eg high pressure/temperature versus low pressure/temperature, cryogenic storage verses pressurised).

Tie into existing facilities

3 Does the project impact on existing facilities and or services? Can future needs be handled later? Consider for example, processing capability, available relief capacities, blowdown, utilities, storage, fire-fighting capability.

Capacity and patterns of demand and supply

4 The capacity of the facility is needed to determine the size and scope of the option selected. It is also important to understand the pattern of demand as this may alter how the facility is scoped, eg is the output seasonal and therefore needs to be mothballed during the off seasons? Or, is the raw material supply seasonal, and therefore additional storage capacity is required on site?

Availability/occupancy

5 The availability of the facility to operate needs to be understood to ensure adequate planning. The occupancy will impact the risk reduction strategies, for example how often personnel will be present. It is important to recognise however that when a process is upset, there are likely to be more personnel present, so claiming risk reduction based on lack of personnel exposure may not be valid.

Process operating philosophy

6 How is the facility to be operated? Continuous operation, batch operation or semi batch operation for example. Are toxic substances to be used, and if so, can less toxic substances be substituted? How would this impact the process conditions?

Maintenance philosophy

7 How is the facility to be maintained? Run to failure or have preventative maintenance regimes implemented for example. Are maintenance crews available or is it an unmanned facility?

Control philosophy

8 How will the facility be controlled? Will it be manual, autonomous or a mixture of both? Will it have a distributed control system or programmable logic control? How can the system be overridden if necessary? How will it be protected from cyber-attack? Will the control be remote? How will remote control, where geographically significant, be assured?

9 Is there a preference for overpressure protection type? For example, full pressure relief, high integrity pressure protection (HIPPs) or a combination?

Containment philosophy

10 In the event of a leak, how is management of the substance to be achieved? How will drainage be used to contain and redirect spills? How are potential spill inventories separated from populations?

11 What are the main hazardous inventories? Rule sets for basis of design to minimise volume contained. In process verses in storage, lower volume, etc.

12 In the event of fire, what is the expected philosophy? Containment, foam application, cooling or burndown?

Toxic and fire philosophy

13 What is the response with respect to evacuating plant and allowing it to burn and only protect the critical buildings? Use of toxic shelters or use of personnel gas masks and evacuation?

Buildings

14 What type of buildings are necessary (eg assembly points or refuges), where will they be located? How will they be accessed (escape routes)? How often will people be present in them? How would buildings be best located to minimise process safety risk. In an incident will responders go to the area as part of the response and therefore be present when not anticipated? Occupancy?

Physical environment/location/access considerations

15 Where is the facility to be built? How accessible is it for services such as power, water and sewerage? How can emergency services reach it? Is it located in deep water offshore? Is it located in a highly populated area or near sensitive receptors such as hospitals or schools? Are there sensitive environments nearby, such as water courses?

16 Community and regulator engagement. How is engagement with the local community to be achieved? Are potential regulatory changes anticipated and have these been accounted for?

17 Will there be transport of dangerous goods to/from the facility? Will this be by pipeline, rail or road?

Demolition/decommissioning

18 At the end of life how can the facility be safety demolished? Is it designed to remain in situ, and how has ongoing safety been taken into account for this?

Defining risk reduction strategies

19 What specific risk reduction strategies can be employed? For example, is fire water actually required at the site and if so, how can this be achieved, or could it be substituted for passive fire protection?

20 Are there any risk reduction strategies that are 'expected' (by local standards, codes, insurance companies, corporate, etc.) to be included? For example, deluge on flammable liquid storage bullets, fire protection on cooling towers, fire protection within switch rooms.

Human factors in design

21 Ergonomics of facility or machinery design.

22 Location of buildings – is one needed at all, if so, is it permanent and temporary, etc during shutdowns, building for minimal intervention so what happens when it goes wrong?

23 Providing access to maintenance versus what should not be accessible for safety reasons?

24 How does the design support correct operation rather than errors? In the event of a human error, how has resilience been achieved to ensure this does not escalate to an incident?

25 Control system design and operating philosophy. Remote monitoring and diagnostic capability? Automation versus manual input/handling?

26 Cyber security design and operating philosophy. Ensure cyber policy, process, technology and people are factored into concepts.

Appendix C – Worked example – offshore

Note this is an illustrative example only and is not exhaustive. It shows only one option considered. For example, an unmanned process, as well as onshore options would also be assessed for comparison. Refer section 5.4.3 And 5.4.4 for comparison techniques.

Project: Gas gathering system; dehydration and compression facility.

Node/section of facility under review: Offshore manned dehydration and compression platform facility.

Team members:

Date of review:

	Factors to consider	Applicable yes/no	Consideration of principle (Sections 5.2 and 5.3)	Decision/ action
Chemical hazards	Explosivity and flammability	Yes	Elimination	Design compression facility subsea to eliminate hydrocarbon inventories on topsides eliminating exposure to personnel
			Minimisation	Minimise flanges and threaded joints in preference to welded joints to reduce leak points
	Combustible dusts	No		
	Reactivity/stability	Yes	Substitution	Use of ME.G. rather than MeOH for hydrate inhibition
	Incompatibility	No		
	Immediate health hazards	Yes	Minimisation	Design to minimise quantity of ME.G. and hydrocarbon on facility as far as is reasonably practicable

	Long term or delayed health hazards	Yes	Simplification	Design mercury impacted equipment to minimise inspection and maintenance frequencies to reduce break-in work and exposure to mercury
	Nuisance impacts	No		
	Radiation	Yes	Minimise/ intensification	Design for identification and separation of Normally Occurring Radioactive Material (NORM)
	Environmental hazards	Yes	Passive design and layout	Design for known environmental hazards in the area
	Hazardous breakdown products	No		
	Toxicity	Yes	Substitution	Use of hypochlorite for wastewater treatment instead of chlorine
	Toxic combustion products	Yes	Minimise/ intensification	Design so that any combustion products from diesel or fuel gas are reduced and segregated from people
	Physical agents affecting chemicals (eg noise, vibration)	Yes	Reliability	Install flexible gas export riser instead of steel riser to allow for vibrations

Means of handling	Storage	Yes	Minimisation	Reduce the storage of materials as far as reasonably practicable, while still facilitating operations
	Transport	Yes	Passive design and layout	Locate diesel loading/ bunkering connections away from critical infrastructure to minimise risk of impacting during fuel transfer
	Problems in handling	Yes	Maintainability	Provision of cranes and monorails for maintenance of equipment
	Process conditions	Yes	Simplification	Replace design for 3 production headers (LP, HP, test) with 2 production headers (HP, test) to reduce complexity and potential for errors; reduce leak points and congestion
	Materials of construction, corrosion/ erosion	Yes	Minimisation	Use corrosion resistant materials rather than corrosion inhibition-based systems
	Decontamination	Yes	Minimisation	Design system for adequate purging techniques to manage contaminates such as Mercury, NORM, BTEX or H2S for example

	Gaseous emissions	Yes	Minimisation	Design system to reduce to acceptable levels
	Aqueous emissions	Yes	Minimisation	Design system to reduce to acceptable levels
	Effluent/solid waste disposal	Yes	Minimisation	Design system to reduce to acceptable levels
	Flare/thermal oxidiser	Yes	Passive design and layout	Designed as per standards for location and thermal radiation
	Quality control	Yes	Simplification	Establish moisture targets to reduce chance of hydrates forming in pipeline
	Emergency procedures	Yes	Passive design and layout	Install passive fire protection to minimise escalation and ERT intervention
	Plant layout, spacing, access	Yes	Passive design and layout	Orientate and locate turbines (whose failure could result blade shedding) to minimise the potential for missile damage to personnel, buildings and safety critical equipment
	Area classification	Yes	Passive design and layout Minimisation	Apply engineering standards for classification Reduce likely leak sources in hazardous areas (such as joints, flanges, etc)

	Provision of services	Yes	Resourcing considerations	Can the facility be remotely operated to reduce human exposure
	Codes of practice	No		
	PPE	No		
Other considerations	Subsidence	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc
	Landslide	No		
	Dam burst	No		
	Earthquake	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc
	Storm and high winds	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc
	Aircraft crash	Yes	Passive design and layout	Provide 'self-extinguishing' helideck design to direct spilled hydrocarbons away from the helideck without transferring to the flame
	Storm surge	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc

	Rising water courses	No		
	Flood	No		
	Storm water run off	No		
	Breach of security	No		
	Lightning	No		
	Tsunami	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc
	Forest fire	No		
	Vermin/insect infestation	Yes	Operability	Consider measure to minimise sea bird nesting to reduce guano build up
	Water depth offshore	Yes	Passive design and layout	Design for local geotechnical considerations – eg floating verses fixed platform, semi-submersible, etc
	Local community	Yes	Elimination	Consider measure to eliminate the access for fishers to use light sources such as the flare for attracting fish
	Local regulations – future directions	Yes	Minimisation	Consider options for flare gas recovery system to reduce gas to flare

	Ship collision	Yes	Passive design and layout	Locate utility lines as far as practicable from buildings and SCE; and locate away from vulnerable areas that could be damaged by ship impact or damaged by impact from dropped objects
	Vehicle collision	No		
	Underground services impacted	Yes	Passive design and layout	Pipeline routing to avoid pipeline and utility crossings and shipping anchor locations

Appendix D – Worked example – chemical plant

Note this is an illustrative example only and is not exhaustive. It shows only one option considered. For example, a pipeline feeding the storage tanks rather than trucking, or technology selection between suspension and emulsion polymerisation also be assessed for comparison. Refer section 5.4.3 And 5.4.4 for comparison techniques.

Project: Polyvinyl Chloride (PVC) Manufacturing Facility.

Node/section of facility under review: Vinyl Chloride Monomer (VCM) storage and charge facility. Storage filled from road tanker.

Team members:

Date of review:

	Factors to consider	**Applicable yes/no**	**Consideration of principle (Sections 5.2 and 5.3)**	**Decision/ action**
Chemical hazards	Explosivity and flammability	Yes	Minimisation	Replace flanged or threaded connections with fully welded joints where design permits to minimise potential leak sources
	Combustible dusts	No		
	Reactivity/stability	Yes	Moderation	VCM in storage tanks to be inhibited
	Incompatibility	Yes	Simplification	Use of selective couplings on tanker unloading to prevent incompatible material being put into tanks
	Immediate health hazards	Yes	Operability	Use of equipment to reduce potential exposure to VCM

	Long term or delayed health hazards	Yes	Operability	Use of equipment to reduce potential exposure to VCM
	Nuisance impacts	No		
	Radiation	No		
	Environmental hazards	No		
	Hazardous breakdown products	No		
	Toxicity	Yes	Operability	Use of equipment to reduce potential exposure to VCM
	Toxic combustion products	Yes	Elimination	Use thermal oxidiser to dispose of VCM gas
	Physical agents affecting chemicals (eg noise, vibration)	No		
Means of handling	Storage	Yes	Minimisation	Reduce the amount of VCM that is needed to be stored on site while still facilitating operations
	Transport	Yes	Moderation	Transport of chemicals in least hazardous form
	Problems in handling	Yes	Maintainability	Provision of access points for tank cleaning
	Process conditions	Yes	Moderation	Review whether storage is better under refrigeration or under pressure to keep in liquid phase

	Materials of construction, corrosion/ erosion	Yes	Elimination	Design tank in suitable material to address cold temperature embrittlement
	Decontamination	Yes	Simplification	Establish nitrogen purge system to decontaminate tanks for inspection
	Gaseous emissions	Yes	Elimination	Recovery system to pipe VCM to thermal oxidiser
	Aqueous emissions	No		
	Effluent/solid waste disposal	No		
	Flare/thermal oxidiser	Yes	Minimisation	Install thermal oxidiser for destruction of VCM gas as necessary
	Quality control	Yes	Elimination	Ensure VCM in storage tanks and during transport is inhibited to prevent unexpected polymerisation
	Emergency procedures	Yes	Simplification	Incorporate remote emergency response activation of water fog to knock down vapour cloud
	Plant layout, spacing, access	Yes	Passive design and layout	Ensure storage tanks are located away from reactors to prevent domino impact

	Area classification	Yes	Passive design and layout Minimisation	Apply engineering standards for classification Reduce likely leak sources in hazardous areas (such as joints, flanges, etc)
	Provision of services	Yes	Resourcing considerations	Can the facility be remotely operated to reduce human exposure
	Codes of practice	No		
	PPE	Yes	Minimisation	Reduce possible exposure paths to workers to allow for reduction in some PPE
Other considerations	Subsidence	Yes	Passive design and layout	Design for local geotechnical considerations – eg pile construction versus pad, etc
	Landslide	Yes	Passive design and layout	Design for local geotechnical considerations – eg pile construction versus pad, etc
	Dam burst	Yes	Passive design and layout	Locate equipment upstream of any dams
	Earthquake	Yes	Passive design and layout	Design for local geotechnical considerations – eg pile construction versus pad, etc
	Storm and high winds	Yes	Passive design and layout	Design for local geotechnical considerations – eg pile construction versus pad, etc

	Aircraft crash	Yes	Passive design and layout	Locate major equipment away from flights paths
	Storm surge	Yes	Passive design and layout	Design for local geotechnical considerations – eg elevate facility to account for foreseeable surge or locate away from coastline
	Rising water courses	Yes	Passive design and layout	Design for local geotechnical considerations – eg elevate facility to account for foreseeable rising water courses or locate away from rivers, etc
	Flood	Yes	Passive design and layout	Design for local geotechnical considerations – eg elevate facility to account for foreseeable flood waters
	Storm water run off	Yes	Passive design and layout	Design for local geotechnical considerations – eg elevate facility to account for foreseeable flood waters and provide storm water system of sufficient capacity

	Breach of security	Yes	Minimisation	Ensure access is controlled sufficiently to prevent unauthorised use of VCM, while allowing for production activities
	Lightning	No		
	Tsunami	Yes	Passive design and layout	Design for local geotechnical considerations – eg locate away from coastline or install suitable wave wall
	Forest fire	Yes	Passive design and layout	Design for local geotechnical considerations – eg provide sufficient fire break
	Vermin/insect infestation	Yes	Elimination	Use of hardstand to prevent burrowing animals, use of equipment to prevent nesting birds
	Water depth offshore	No		
	Local community	Yes	Passive design and layout	Locate storage away from local residents, design facility to contain liquid and vapour release on site
	Local regulations – future directions	No		
	Ship collision	No		

	Vehicle collision	Yes	Passive design and layout	Locate roads away from safety critical and high inventory equipment; or install vehicle impact protection
	Underground services impacted	Yes	Passive design and layout	Install underground services based on provisions for facility expansion to minimise impacts in future

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