1 INTRODUCTION

This chapter introduces the integration of process safety activities throughout the life cycle of an engineering project. The discipline of process safety has evolved to prevent fires, explosions, and accidental releases of hazardous materials from chemical process facilities. This involves effective management systems comprising practices, procedures, and responsible human performance and behaviors to ensure proper equipment design and installation, and to maintain the integrity of the facility during operations.

Projects are a temporary endeavor undertaken to create a unique product, service, or result. In the case of engineering projects in the process industry, the result is usually a new or modified facility. Engineering projects can vary widely in scope and size, so these guidelines present the broad objectives and considerations for process safety that are appropriate at different stages of the life cycle.

Project Life Cycle

The series of phases that a project passes through from its initiation to its closure.

(from PMBOK Glossary (PMI, 2013)

In oil and gas, and chemical companies in the process industry, the term "stages" is also used in reference to the phases of a project.

Facility

A portion of or a complete plant, unit, site, complex or any combination thereof. A facility may be fixed or mobile.

(from AIChE/CCPS Glossary)

The temporary nature of a project means that its closure corresponds to a point in time when its objectives (i.e. commissioning of a new or modified facility) have been achieved or when the project is terminated because the objectives will not be met. Most projects are undertaken to create a lasting product or result, in this case a facility.

After the project has ended, the facility will continue to operate for a number of years until it is retired, disposed, or dismantled/demolished. During this time the facility will likely be subject to startup/shutdown, periodic inspection, maintenance, and turnarounds. Therefore the facility has its own life cycle, which may partially overlap with the project life cycle. For example, the project may not be closed until the new facility has met production and/or product quality targets, or later the facility may be debottlenecked to increase production or modified, which will involve another project.

The main focus of these guidelines is on *proactively* implementing process safety activities at the optimum timeframe, but also addresses *reactively* conducting "cold eyes" reviews to provide assurance that nothing significant has been missed. This approach ensures that, if the right process safety activities are conducted at the right time, project leadership will have the right (process safety) information in order to be able to make the right risk management decisions regarding safety.

The intent of this book is not to describe in detail ***how*** to perform specific process safety activities, but rather to identify ***what*** needs to be addressed at each stage of a project. Other CCPS publications, together with industry codes, standards and recommended practices, describe methods for specific process safety activities and are referenced throughout the book. For example, the design and management of functional safety is covered in great detail in: *Guidelines for Safe Automation of Chemical Processes,* 2nd edition (CCPS 2017b), and *Functional Safety - Safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and application programming requirements*, IEC 61511-1 (IEC 2016), which are both referenced in multiple chapters of this book.

Process safety in engineering projects involves leadership, managers, engineers, operating and maintenance personnel, contractors, vendors, suppliers and support staff. Therefore, these guidelines were prepared for a wide audience and range of potential users. The chapter concludes by introducing the structure of this document.

1.1 BACKGROUND AND SCOPE

Process safety management systems have been widely credited for reductions in major accident risk within the onshore process industries, such as oil refineries and chemical plants, and some offshore regions like the North Sea. Most companies have had practices for various process safety elements, such as operating procedures and emergency response, for many years, although the scope and quality of these practices was sometimes inconsistent until specific process safety regulations were promulgated.

Some international process safety regulations, such as the Seveso Directive and its various national implementations in Europe (Seveso 1982), and the Offshore Installation (Safety Case) regulations (HM Government 1992), set goal-setting or performance-based requirements for major project facility design and operation. In the United States, the Occupational Safety and Health Administration (OSHA) introduced the Process Safety Management (PSM) standard (OSHA 1992). This was followed by the Environmental Protection Agency (EPA) Risk Management Program (RMP) rule (U.S. EPA 1996). However, the focus of these relatively prescriptive U.S. regulations was primarily on operations rather than engineering projects, although they did address some basic practices for small Management of Change (MOC) projects.

Historically, project managers have been focused on managing the risks and performance indicators related to costs, schedules, and, in some cases, technological risks, i.e. will the facility work and meet production and quality targets. Often safety concerns, from a project manager's perspective, were primarily focused on the construction stage and the *occupational* safety of a contractor's workforce. Increasingly major operating companies have recognized the need to more comprehensively address process safety in their engineering projects as a means of optimizing the residual safety risk that operations teams are required to manage for the life of the facilities. However, despite growing awareness in certain quarters, some project managers have resisted change and remain focused on cost and schedule, almost to the exclusion of process safety.

These guidelines were written primarily for engineering projects within the process industries, and outline effective approaches for integrating process safety into both large and small projects, including small management of change (MOC) works. Some content may be applicable to other industries. Many engineering and operating companies have their own practices, with differing terminologies, for managing capital projects. The guidance in this book follows the general approach for project management advocated by the Construction Industry Institute (CII) (CII 2012), although some of the terminology varies by industry sector. Although written in the United States, a conscious effort has been made to offer guidance applicable to projects worldwide.

1.2 WHY INTEGRATING PROCESS SAFETY IS IMPORTANT

As Trevor Kletz was fond of saying "… if you think safety is expensive, try an accident. Accidents cost a lot of money. And, not only in damage to plant and in claims for injury, but also in the loss of the company's reputation."

Certainly, process safety activities can incur significant resource requirements. However, several major incidents that involved newly commissioned projects with a range of inherent weaknesses bear testimony to the need for building process safety systematically into future engineering projects.

Case Study: T2 Laboratories

T2 Laboratories was a small facility in Jacksonville, Florida that produced specialty chemicals. On December 19, 2007, a chemical reactor ruptured, causing an explosion that killed four employees, injured another 32, including 28 members of the public, and hurled debris up to a mile from the plant. The batch reactor was producing methylcyclopentadienyl manganese tricarbonyl (MCMT), a gasoline additive, at the time of the rupture.

In their report (CSB 2009), the U.S. Chemical Safety and Hazard Investigation Board (CSB) determined that the immediate cause was due to failure of the reactor cooling water system, which led to a runaway exothermic reaction. CSB further determined the root cause was that T2 Laboratories did not fully understand the reactivity hazards, especially those associated with MCMT runaway reactions. No evidence was found that indicated a Hazard and Operability (HAZOP) study had ever been conducted, which would likely have identified the need for more thermodynamic data.

CSB also identified two contributory factors: inadequate overpressure protection, and lack of redundancy in the cooling water system. No data on the sizing and relief pressure of the reactor rupture disk could be found, although it is believed to have been sized based on normal operations, without considering potential emergency conditions. The cooling water system was susceptible to single-point failures, such as an inadvertently closed valve, blockage and faulty thermocouple, and lacked design redundancy. Operating procedures did not address loss of reactor cooling.

The plant was destroyed and T2 Laboratories has ceased all operations. An understanding and implementation of fundamental process safety principles and practices (e.g. layers of protection and HAZOP) during design would have prevented this tragic incident.

1.2.1 Risk Management

No matter how good the process safety input is into any engineering project, the newly installed and commissioned facility has a residual safety risk that the operations team must manage through an effective process safety management system for the life of the facility. This is true for all projects. Therefore, one of the main benefits of successfully integrating process safety into a project is to reduce this residual safety risk. Inevitably, project managers have several competing priorities to consider, such as financial, political, and practical factors, in addition to safety, so that the final solution may be a compromise. Nevertheless, project management should seek to optimize residual risk to as low as reasonably practicable through careful selection of the final development concept and good engineering design. This goal infers an inherently safer design (ISD) approach that should place fewer demands on operations personnel, while also limiting potential for major incidents.

The adoption of an ISD approach requires project management to introduce the appropriate ISD policies and practices as early as possible in the project life cycle, although opportunities for risk reduction continue, albeit diminish, throughout the project life cycle. Therefore, ISD policies and practices should ideally be integrated into a company's capital project management system. The successful implementation of ISD practices throughout a company's portfolio of engineering projects can reduce major incidents, and contribute to long-term business success. Companies that experience major incidents also experience significant business interruption and reputation damage, and often struggle to survive in a competitive industry. Indeed, this is consistent with the CCPS Business Case for Process Safety (CCPS 2006), which identifies four benefits involving demonstration of corporate responsibility, greater business flexibility, improved risk reduction, and creation of sustained value.

Another benefit of conducting the right process safety activities at the right time is the avoidance of costly change orders during project execution, or even more costly modifications to the facility after startup. It is much more efficient and inexpensive to iteratively develop and change the design on paper during the early stages of the project.

To successfully integrate process safety into projects and achieve the full benefits described above strong and consistent leadership from company executives and project management is required. This implies that these same individuals need to understand basic process safety principles and practices. It is important that project managers know when and which process safety activities to request in order to reduce risks and add value, or, at the very least, know they can trust and rely on an experienced process safety engineer to advise and make the correct calls. Project managers should also know which challenging process safety questions to ask across the multiple interfaces that they have to manage. This level of informed leadership, knowing that the right activities are occurring in the correct order, will have the ability and confidence to assure executives and other stakeholders that a fully functional process safety management system will be delivered to Operations when the facility is ready to startup.

1.3 WHAT TYPE OF PROJECTS ARE INCLUDED?

Engineering projects for the process industries come in all shapes and sizes – from management of change (MOC) works to large capital projects for new facilities. These projects cover a wide range of facilities including, but not limited to, research and development, exploration, production, transportation and storage of oil and gas, chemicals, and pharmaceuticals, as illustrated in Table 1.1.

The objectives of the relevant process safety activities at each stage of the project are broadly consistent irrespective of the nature of the project, although the scope and level of detail may vary. For example, hazard evaluation for a relatively simple modification covered by MOC may use checklists or a What If approach, whereas a complex capital project may warrant HAZID, HAZOP, LOPA and QRA. Nevertheless, both examples share a common objective of identifying hazards and evaluating whether safeguards are adequate to manage the hazards and their risk.

Table 1.1. Types of Projects Covered by these Guidelines

Types of Projects
Greenfield and Brownfield
Onshore and Offshore
Continuous and Batch Operations
Indoors and Outdoors
Modifications (covered by MOC)
Modular and Stick-built
Pilot Plants and Full-scale Process Units
Chemical Complexes and Refineries
Fixed and Semi-Submersible Production Platforms
Drilling Rigs and MODUs
Debottlenecking
Control Systems (DCS, SCADA, SIS, HIPS, etc.)
Tankage and Storage
Utility Systems (Electrical Power, Fuel Gas, Cooling Water, Nitrogen, Compressed Air, etc.)
Buildings (Control Rooms, Offices, Workshops, Warehouses, etc.)
Loading and Offloading Systems (Road, Rail, Marine)
Pipelines (Cross-Country, Intra-Plant, Subsea)
Other Infrastructure

1.4 PROJECT LIFE CYCLE

Previous publications have described the life cycle of projects within the chemical industry, and the requirement to integrate EHS activities, including process safety (CCPS 1996a, CCPS 2001b). However these publications focus more on the integration of the individual EHS disciplines rather than their integration into the project. Furthermore, much of the focus on early conceptual design was related to laboratory experimentation and pilot plant scale operation.

The CII places much emphasis on Front End Planning, which is a process that involves developing sufficient information early in the project's life cycle to allow companies (i.e. owners) to address risk and make decisions to commit resources in order to maximize the potential for a successful project (CII 2012). The front end of a project is a phase when the ability to influence changes in design is relatively high and the cost to make those changes is relatively low.

Front End Planning is divided into three main phases:

- Feasibility
- Concept
- Detailed Scope

This is illustrated in CII's Front End Planning Process Map (see Figure 1.1).

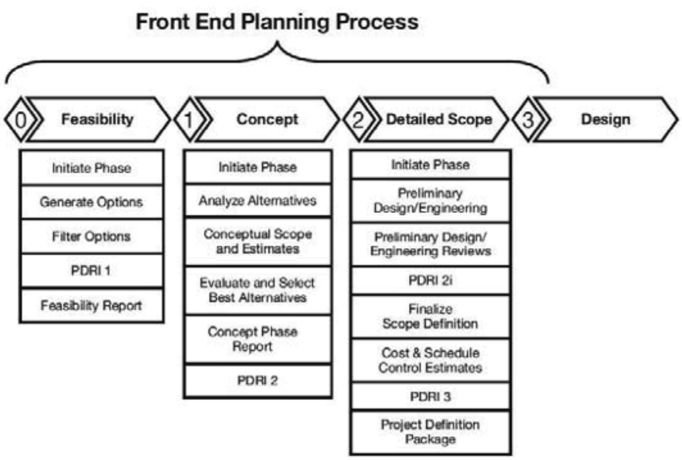

Figure 1.1 Front End Planning Process Map[1] (CII 2012).

[1] PDRI: Project Definition Rating Index is a comprehensive checklist of scope definition elements to enable evaluation of the status of an industrial project (CII 1996). A.k.a. FEL Index.

Front End Planning is also known as pre-project planning, front-end engineering design (FEED), feasibility analysis, and conceptual planning. However the most popular terminology in many oil and gas, and chemical companies in the process industry is Front End Loading (FEL). For the purposes of these guidelines, the terminology of FEL will be used.

Under FEL, the three phases or stages are commonly referred to as:

- FEL 1 Appraise, Appraisal or Visualization
- FEL 2 Select, Selection, or Conceptualization
- FEL 3 Define or Definition

After FEL and the completion of all planning activities, projects usually move into execution, where the plan(s) developed in FEL are put into action. In the process industry, this typically involves at least three phases or stages:

- Detailed Design or Detailed Engineering
- Construction
- Commissioning and Startup

Pre-commissioning activities are normally included in the construction phase, but some companies may address them as a separate phase or include them in the commissioning phase.

After project execution, the project life cycle moves into the Operation phase, which generally lasts until stable production is achieved at which point the project is closed. The facility life cycle continues for a number of years. Some facilities commissioned in the mid-twentieth century remain in operation today. However, eventually the facility will enter the final phase of the facility life cycle, End of Life, when its useful life is at an end.

Therefore the typical stages in the life cycle of a capital project and its resulting facility in the process industry are illustrated in Figure 1.2. The project typically closes during the early phase of the facility operation. Thereafter, small projects and management of change modifications may occur during facility operation. Finally the facility reaches its end of life and a new project is initiated for decommissioning the facility.

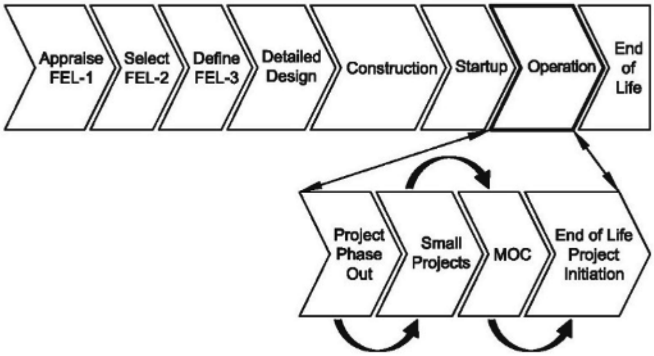

Figure 1.2 Capital Project Stages

The objectives of each stage from a business and project management perspective are as follows:

Appraise (FEL-1)

A broad range of development options is identified, and the commercial viability of the project is evaluated. A technical and commercially viable case plus alternatives should be identified for the project to proceed.

Select (FEL-2)

The alternative concept options are evaluated seeking to identify the optimum project by maximizing opportunities, while reducing threats and uncertainties to an acceptable level. Upon completion of technical and commercial studies, a single concept is selected.

Define (FEL-3)

The technical definition and execution plan for the project are improved to confirm the conceptual design, cost and schedule. A basic design is developed with plot plan, preliminary process flow diagrams, material and energy balances, and equipment data sheets. Timing varies between companies/projects, but sanction for financial investment usually occurs at the end of this stage, if sufficient confidence in the project is achieved.

Detailed Design

Detailed engineering of the defined scope from the front end loading (FEL) process is completed, scope changes managed, and materials and equipment procured.

Construction

Fabrication, construction, installation, quality management, and pre-commissioning activities are completed. Operational readiness activities are performed in preparation for commissioning, startup and operation.

Commissioning

The project is commissioned, and the facility and documentation handed over to the operations team for normal operation.

Operation

Test runs may be required to confirm that performance specifications are met before the project is closed. The project team may conduct a lessons learned review to aid future projects. At this point the facility is handed over completely to the client Operations team, the project team phases out, and the project is closed.

End of Life

When a business decision is taken to cease operations, the facility is de-commissioned. Depending upon local circumstances and regulations, the facility may be dismantled, diposed and/or demolished, or modified for future use. End of facility life typically involves a new project.

Although small modification type projects covered by MOC may not follow these stages in a formal manner, each MOC should address similar objectives. Small capital projects or identical repeat projects may elect to combine two or more stages to streamline efficiencies, while meeting the overall objectives.

Each stage of a project has specific process safety activities in support of the overall project management objectives. These process safety activities are described below.

1.5 RELATIONSHIP TO OTHER PROGRAMS

Successful engineering projects usually have a Safety Plan, often comprising Health and Environment into an EHS Plan, which lays out a strategy and schedule of process safety and occupational safety activities over the project life cycle. Starting from early feasibility (FEL 1), these plans tend to be *living* documents that evolve over time as more detail is added as the project definition is established. Effective integration of process safety into a project makes use of process safety elements routinely employed in day-to-day process plant operations.

Although *Guidelines for Risk Based Process Safety* (RBPS) (CCPS 2007b) was developed primarily for operations, its elements are appropriate at various stages of a project. For example, all four pillars of RBPS are involved, as follows:

- Commit to Process Safety

  Project EHS Plans and engineering standards demonstrate commitment.

- Understanding Hazards and Risks

  Design of new facilities requires process knowledge, hazard identification and risk analysis.

- Manage Risks

  New facilities require integrity, operability and maintainability by competent personnel.

- Learn from Experience

  Lessons learned from similar facilities should be built into new facilities.

Significant relationships with process safety elements are shown in Table 1.2. As can be seen from this table, nearly all elements of a risk-based process safety management system have some bearing on project development. However, reliance on integrating RBPS alone may not be sufficient for many projects. Other process safety practices are likely to be relevant, such as inherently safer design (ISD), and other engineering design practices.

Table 1.2. Relationships between Projects and Risk-Based Process Safety Elements

RBPS Pillar	RBPS Element	Project Activities Related to RBPS Element
Commit to Process Safety	Process Safety Culture	Present in all project activities
	Compliance with Standards	Use standards and RAGAGEP
	Process Safety Competency	Involve competent employees and contractors
	Workforce Involvement	Safety responsibilities in design, construction, and operations for employees and contractors
	Stakeholder Outreach	Consult and inform on potential risks during project planning and execution
Understand Hazards & Risk	Process Knowledge Management	Incorporate knowledge on materials, technology and equipment
	Hazard Identification and Risk Analysis	Identify hazards and assess associated risks Identify measures for risk reduction

RBPS Pillar	RBPS Element	Project Activities Related to RBPS Element
Manage Risk	Operating Procedures	Develop procedures for commissioning and operations
	Safe Work Practices	Develop procedures for construction activities Plan and perform installation and pre-commissioning
	Asset Integrity & Reliability	Ensure maintainability and reliability, especially SCE Ensure quality of design, procurement and construction
	Contractor Management	Pre-qualify candidate contract firms Ensure contracted services meet safety goals
	Training and Performance Assurance	Train employees and contractors Certifications for engineers, inspectors and technicians
	Management of Change	Evaluate post-HAZOP design changes Evaluate field changes
	Operational Readiness	Confirm assets as installed meet design specifications Confirm no outstanding actions and/or documentation
	Conduct of Operations	All project activities Promptly address unsafe activities / conditions
	Emergency Management	Develop ERP Plans for construction and operations
Learn from Experience	Incident Investigation	Incorporate lessons learned from similar facilities Investigate incidents promptly
	Measurement & Metrics	Collect, analyze and archive data
	Auditing	Conduct independent technical / stage gate reviews
	Management Review and Continuous Improvement	Evaluate if all RBPS elements performing as intended and producing desired results

A well-designed facility should start by addressing ISD principles from an early stage (FEL-1). CCPS provides guidance through their publication, *Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd edition* (CCPS 2009d). As the project definition progresses, guidance from the CCPS publication *Guidelines for*

Engineering Design for Process Safety, 2nd edition (CCPS 2012a) is available for further reference.

Depending upon the scope and magnitude of the engineering project, a vast array of process safety studies and activities may be appropriate at various stages of the project life cycle. Table 1.2 represents a matrix of some of the key process safety activities at each stage of a typical project. Some of these activities may be conducted by experienced process safety engineers, while other multi-discipline engineering studies would benefit from input by process safety expertise.

Appendix A presents an overview of typical process safety studies at each stage of a project life cycle.

1.6 STRUCTURE OF THIS DOCUMENT

These guidelines begin with a chapter that sets the groundwork for engineering projects. Chapter 2 discusses the management and organization of capital projects, and introduces the project structure and terminology promoted by the Project Management Institute (PMI) and the Construction Industry Institute (CII). The characteristics of various types of projects and strategies for their implementation are discussed. Finally, the management and objectives of process safety risk are introduced.

Once this basic understanding of projects is established, the life cycle of an engineering project is addressed in terms of the process safety objectives, scope and activities of each stage. These include:

- Front End Loading 1 (FEL-1)
- Front End Loading 2 (FEL-2)
- Front End Loading 3 (FEL-3)
- Detailed Design
- Construction
- Commissioning/Startup
- Operation
- End of Useful Life

Each of these stages is addressed in turn in Chapters 3 through 7, and 9, 10, and 11, as illustrated in Table 1.3.

Chapter 3 covers the feasibility of proceeding with a new project to produce a specific product(s) in a certain location, employing various process technologies. This initial phase of Front End Loading (FEL-1) involves preliminary Hazard Identification and Risk Analysis (HIRA) of multiple development options, from which a range of viable options are identified.

Chapter 4 deals with the next phase of FEL (FEL-2) where the various development options are reduced through a concept selection process involving more detailed HIRA, including offsite major accident risk. The site, process technology, facilities, and infrastructure requirements are determined considering an ISD approach, and a preliminary EHS and Process Safety plans developed.

Chapter 5 addresses the final phase of FEL (FEL-3) during which the technical scope of a single development option is defined. Increasingly more detailed HIRA studies are used to determine the site layout, spacing, grading and other siting concerns as a result of potential fires, explosions and toxic releases. The front-end engineering and design (FEED), including assumptions, philosophies, and engineering codes and standards, is completed, as well as the detailed EHS and Process Safety plans.

Table 1.3. Chapters Addressing Project Life Cycle Stages

Project Stages	New Equipment	Procurement	Quality Management	Documentation
FEL-1 Appraisal	Chapter 3	-	-	Chapter 12
FEL-2 Selection	Chapter 4	-	-	Chapter 12
FEL-3 Definition	Chapter 5	-	-	Chapter 12
Detail Design Detail Engineering	Chapter 6	Chapter 6	Chapter 8	Chapter 12
Construction PreCommissioning	Chapter 7	Chapter 7	Chapter 8	Chapter 12
Commissioning Startup	Chapter 9	-	-	Chapter 12
Operation ITPM	Chapter 10	-	-	-
End of Useful Life Decommissioning	Chapter 11	-	-	-

Chapter 6 covers the first stage of project execution, detailed design, involving layout and detailed engineering of individual items of equipment. Change management is introduced following the final HIRA study, and process safety information documented and compiled. The procurement of long-lead items of equipment are also covered.

Chapter 7 addresses the construction phase of the project, involving construction plans and management, procurement of equipment and materials, fabrication, installation, and management of engineering and integrity baseline documentation.

Chapter 8 covers quality management activities to ensure that the new facilities are designed, procured, fabricated and installed according to the technical specifications.

Chapter 9 deals with commissioning and startup activities, commencing with pre-commissioning, shakedown, check-out and resolution of problems, and hand-over to Operations before proceeding with startup. Operations readiness activities such as training and pre-startup safety reviews are performed in preparation to operate and startup.

Chapter 10 addresses post-project operation, when the facility is running with acceptable product quality. The project has been closed out and the facility, data, and documents have been handed over to Operations. Technical safety projects are performed periodically throughout the operational phase to ensure performance specifications are met, maximize return to shareholders, and protect license to operate.

Chapter 11 covers decommissioning, abandonment, demolition/dismantling and other end-of-useful-life issues from a process safety perspective.

Chapter 12 reviews the essential design files and process safety information that must be compiled by the project team for hand-over to Operations.