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INTRODUCTION

The Center for Chemical Process Safety (CCPS) has published a number of guidelines that focus on the evaluation and mitigation of risks associated with catastrophic events in process facilities. Originally published in 1993, the purpose of *Guidelines for Engineering Design for Process Safety* was to shift the emphasis on process safety to the earliest stage of the design where process safety issues could be addressed at the lowest cost and with the greatest effect. Almost 20 years later, this 2nd edition of *Guidelines for Engineering Design for Process Safety* continues to stress the importance of emphasizing process safety during Front-End Engineering and Design (FEED) to achieve the greatest risk reduction at the lowest cost – *and also emphasizes the benefits of diligence to process safety design issues through the life of the facility*. This updated book also incorporates material from *Guidelines for Design Solutions for Process Equipment Failures*, which was originally published by CCPS in 1998 (Ref. 1-1).

This book focuses on process safety issues in the design of chemical, petrochemical, and hydrocarbon processing facilities. Enough information is provided on each topic to ensure that the reader understands:

- The concept and issues
- The design approach for process safety
- Areas of concern
- Where to go for detailed information

The scope of this book includes avoidance and mitigation of catastrophic events that could impact people and facilities in the plant or surrounding area. The scope is limited to selecting appropriate designs to prevent or mitigate the release of flammable or toxic materials that could lead to a fire, explosion, and impact to personnel and the community. Process safety issues affecting operations and maintenance are limited to cases where design choices impact system reliability. These *Guidelines* are intended to be applicable to the design of a new facility, as well as modification of an existing facility.

The scope excludes:

- Transportation safety
- Routine environmental control
- Personnel safety and industrial hygiene practices
- Emergency response
- Detailed design
- Operations and maintenance
- Security issues unrelated to process safety

These *Guidelines* highlight safety issues in design choices. For example, Section 7.1.1, Electrical Area Classification, covers the safe application of electrical apparatus in the process environment required for plant safety but does not address detailed design of the electrical supply or distribution system required to operate the plant.

It is clear that choices made early in design can reduce both the potential for large releases of hazardous materials and the severity of such releases, if they should occur.

1.1 ENGINEERING DESIGN FOR PROCESS SAFETY THROUGH THE LIFE CYCLE OF THE FACILITY

Engineering design for process safety must be an integral part of the life cycle of a facility. Process safety has been defined in previous publications as:

> *A discipline that focuses on the prevention and mitigation of fires, explosions, and accidental chemical releases at process facilities. Excludes classic worker health and safety issues involving working surfaces, ladders, protective equipment, etc.* (Ref. 1-2).

Hazard evaluations are one method used to identify, evaluate, and control hazards involved in chemical processes. Hazards can be defined as characteristics of systems, processes, or plants that must be controlled to prevent occurrence of specific undesired events. Hazard evaluation is a technique that is applied repeatedly throughout the design, construction, and operation phases of a facility (Figure 1.1). Engineering design for process safety should be considered within the framework of a comprehensive process safety management program as described in *Plant Guidelines for Technical Management of Chemical Process Safety* (Ref. 1-3).

Hazard evaluation is synonymous with process hazard analysis and process safety review. From conceptual design to decommissioning, no single method of hazard evaluation applies to all of the stages of a project. Different methods are required for different stages of a project, such as research and development, conceptual design, startup and operation. Table 1.1 presents some of the stages of facility life cycle and typical corresponding process hazard evaluation objectives. An objective shown for one stage may be applicable to another.

As illustrated in Table 1.1, different types of hazards can be identified during the stages of a facility's life cycle. Findings from the Baker Panel report (Ref. 1-4) associated with the 2005 Texas City Refinery Explosion illustrate the importance of engineering design for process safety:

> *Not all refining hazards are caused by the same factors or involve the same degree of potential damage. Personal or occupational safety hazards give rise to incidents—such as slips, falls, and vehicle accidents—that primarily affect one individual worker for each occurrence. Process safety hazards can give rise to major accidents involving the release of potentially dangerous materials, the release of energy (such as fires and explosions), or both. Process safety incidents can have catastrophic effects and can result in multiple injuries and fatalities, as well as substantial economic, property, and environmental damage. Process safety refinery incidents can affect workers inside the refinery and members of the public who reside nearby. Process safety in a refinery involves the prevention of leaks, spills,*

equipment malfunctions, over-pressures, excessive temperatures, corrosion, metal fatigue, and other similar conditions. Process safety programs focus on the design and engineering of facilities, hazard assessments, management of change, inspection, testing, and maintenance of equipment, effective alarms, effective process control, procedures, training of personnel, and human factors. The Texas City tragedy in March 2005 was a process safety accident. (Ref. 1-4).

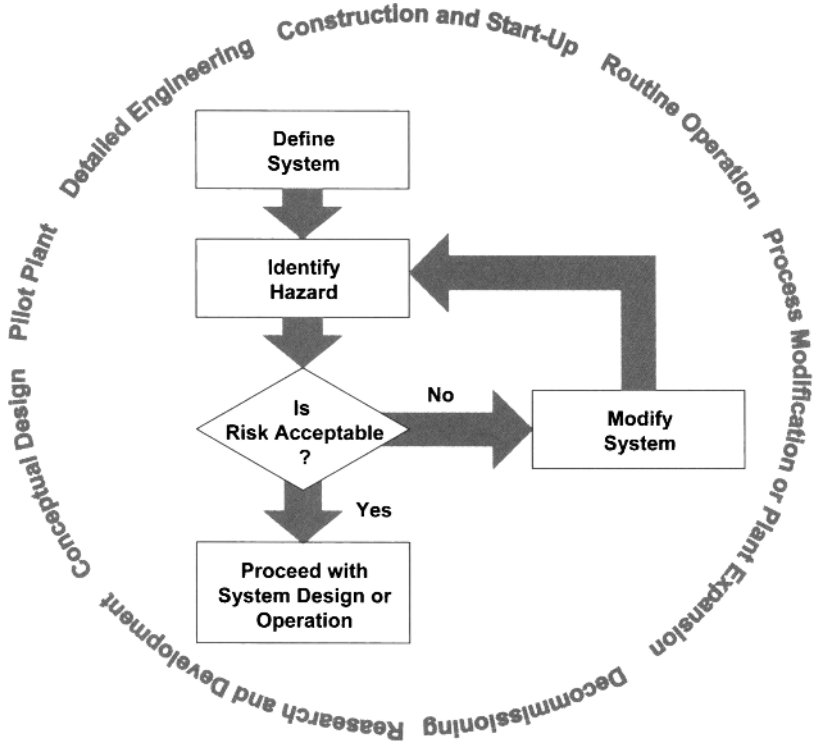

Figure 1.1 Identifying Hazards Through the Facility Life Cycle

Table 1.1 Typical Hazard Evaluation Objectives at Different Stages of a Facility Life Cycle

Stage of Facility Life Cycle	Example Hazard Evaluation Objectives
Research and Development	• Identify chemical interactions that could cause runaway reactions, fires, explosions, or toxic gas releases • Identify process safety data needs
Conceptual Design	• Identify opportunities for inherent safety • Compare the hazards of potential sites
Pilot Plant	• Identify ways for toxic gas to be released to the environment • Identify ways to deactivate the catalyst • Identify potentially hazardous operator interfaces • Identify ways to minimize hazardous wastes
Engineering	• Identify ways to prevent flammable mixtures inside process equipment • Identify how a loss of containment might occur • Identify which process control malfunctions will cause runaway reactions • Identify ways to reduce hazardous material inventories • Identify safety-critical equipment that must be regularly tested, inspected, or maintained • Identify operating conditions that effect selection of materials of construction (e.g., corrosivity) • Identify incompatibility / reactivity issues • Identify relief system and discharging location impact
Construction and Startup	• Identify error-likely situations in startup and operating procedures • Verify that all issues from previous hazard evaluations were resolved satisfactorily and that no new issues were introduced • Identify hazards that adjacent units may create for construction and maintenance workers • Identify hazards associated with the vessel-cleaning procedure • Identify any discrepancies between the as-built equipment and the design drawings
Routine Operation	• Identify employee hazards associated with the operating procedures • Identify ways an overpressure transient might occur • Identify hazards associated with out-of-service equipment
Process Modification or Plant Expansion	• Identify whether changing the feedstock composition will create any new hazards or make any existing hazards more severe • Identify hazards associated with new equipment
Decommissioning	• Identify how demolition work might affect adjacent units • Identify any fire, explosion, or toxic hazards associated with the residues left in the unit after shutdown

1.2 REGULATORY REVIEW / IMPACT ON PROCESS SAFETY

The ideas presented here are not intended to replace regulations, codes, or technical and trade society standards and recommended practices. Specifically, implementation of these guidelines requires the application of sound engineering judgment because the concepts may not be applicable in all cases.

Identifying and addressing relevant process safety standards, codes, regulations, and laws over the life of a process is one of the five elements in the Risk Based Process Safety pillar of committing to process safety (Ref. 1-5). Companies should establish a process for maintaining adherence to applicable standards, codes, regulations, and laws. *Guidelines for Risk Based Process Safety* (Ref. 1-5) recommends establishing a *standards* system to achieve this objective, including:

- Establishing a system to identify, develop, acquire, evaluate, disseminate, and provide access to applicable standards, codes, regulations, and laws that affect process safety
- Promoting consistent interpretation, implementation, and efficiency in the initial identification of and ongoing monitoring of changes in standards

Safe operation and maintenance of facilities that manufacture, store, or otherwise use hazardous chemicals require robust process safety management systems. The primary objective of establishing a *standards* system is to ensure that a facility remains in conformance with applicable standards, codes, regulations, and laws, including voluntary ones adopted by the company over the life of the facility. Long-term conformance to such standards of care helps ensure that the facility is operated in a safe and legal fashion. Key principles and essential features of maintaining a dependable *standards* system include:

- Ensuring consistent implementation of the standards system
- Identifying when standards compliance is needed
- Involving competent personnel
- Ensuring that standards compliance practices remain effective

The Baker Panel also emphasizes the importance of implementation of external good engineering practices and a corporate safety management system that supports and improves process safety importance (Ref. 1-4).

For detailed information on establishing a system to comply with standards, readers are referred to Chapter 4, Compliance with Standards, of *Guidelines for Risk Based Process Safety* (Ref. 1-5).

Table 1.2 provides some examples of the types of process safety standards, codes, and regulations that many facilities comply with.

Table 1.2 Examples and Sources of Process Safety Related Standards, Codes, Regulations, and Laws

Voluntary Industry Standards
• American Chemistry Council Responsible Care ® Management System (Ref. 1-6) • European Chemical Industry Council (Cefic) Responsible Care (Ref. 1-7) • American Petroleum Institute Recommended Practices (Ref. 1-8)
Consensus Codes
• American National Standards Institute (Ref. 1-9) • American Petroleum Institute (Ref. 1-8) • American Society of Mechanical Engineers (Ref. 1-10) • The Instrumentation, Systems and Automation Society / International Electrotechnical Commission (Ref. 1-11) • National Fire Protection Association (Ref. 1-12)
U.S. Federal, State, and Local Laws and Regulations

• U.S. OSHA
    • Process Safety Management Standard (29 CFR 1910.119) (Ref. 1-13)
    • Flammable and Combustible Liquids Standard (29 CFR 1910.106) (Ref. 1-14)
    • PSM Covered Chemical Facilities National Emphasis Program (09-06 CPL 02) (Ref. 1-15)
    • Petroleum Refinery Process Safety Management National Emphasis Program (Ref. 1-16)
• U.S. EPA Risk Management Program Regulation (40 CFR 68) (Ref. 1-17)
• California Accidental Release Prevention Program (Ref. 1-18)
• Contra Costa County Industrial Safety Ordinance (Ref. 1-19)
• Delaware Extremely Hazardous Substances Risk Management Act (Ref. 1-20)
• Nevada Chemical Accident Prevention Program (Ref. 1-21)
• New Jersey Toxic Catastrophe Prevention Act (Ref. 1-22)

International Laws and Regulations
• Australian National Standard for Control of Major Hazard Facilities (Ref. 1-23) • Canadian Environmental Protection Agency, Environmental Emergency Planning (Section 200) (Ref. 1-24) • European Commission Seveso II Directive (Ref. 1-25) • Korean OSHA PSM Standard (Ref. 1-26) • Malaysia, Department of Occupation Safety and Health Ministry of Human Resources Malaysia, Section 16 of Act 514 (Ref. 1-27) • United Kingdom, Health and Safety Executive COMAH Regulations (Ref. 1-28)

It is important to note that regional or local laws and regulations often mandate more stringent requirements than similar federal regulations. For example, the State of California's Accidental Release Prevention Program requires compliance by facilities with over a threshold quantity of 100 lb of chlorine, while the U.S. EPA Risk Management Program's threshold quantity for compliance is 2,500 lb of chlorine.

Different global, federal, and regional requirements pose challenges to facilities that operate in different geographic locations.

1.3 WHO WILL BENEFIT FROM THESE GUIDELINES?

Process safety is an important part of risk management and loss prevention. Although these *Guidelines* do not provide all the "answers," they do highlight the process safety issues that must be addressed in all stages of design. These *Guidelines* will benefit many different people within an organization:

- *Corporate Leadership* - Senior executives define the basis for the development of design philosophies. Their commitment and recognition of the value of integrating process safety at all levels of the design process is essential.
- *Project Managers* - Project Managers are responsible for executing projects, usually from design through startup and commissioning. A Project Manager is responsible for determining the basic protection design concepts to apply in the execution of a project. The Project Manager is responsible for implementing the decisions and abiding by the process safety systems associated with the design.
- *Engineers* - Engineers are responsible for specifying and designing process units and protection systems that meet their company's requirements. This still leaves room for making decisions when designing process units and protection systems.
- *HSE Professionals* - Health, Safety, and Environmental (HSE) Professionals provide technical guidance to engineers and typically are in an assurance role for process safety systems.

1.4 ORGANIZATION OF THIS BOOK

Figure 1.2 provides an overview of the contents of these *Guidelines* and also provides examples of how each chapter can assist in integrating process safety throughout the life of the process. Each chapter has been updated to include state-of-the-art information, industry experience, and references to other CCPS publications.

Specific references and applicable industry standards are listed at the end of each chapter. It is not the intent of this book to make specific design recommendations, but to provide a good source of references where the interested reader can obtain more detailed information.

Guideline Chapter	Questions This Chapter Will Answer
Chapter 1 **Introduction**	*What is process safety?* *How can this book help me?* *When is process safety incorporated into engineering design?*
Chapter 2 **Foundational Concepts**	*Why is incorporating process safety into a facility's lifecycle important?* *What is engineering design that incorporates process safety?* *How are unsteady state conditions included in the design?*
Chapter 3 **Basic Physical Properties / Thermal Stability Data**	*What basic physical properties do I need to know before beginning design?* *What flammability data is important?* *What chemical reactivity data is needed?* *What is the impact of hazards on people?*
Chapter 4 **Analysis Techniques**	*Why conduct hazard assessments during engineering design?* *What techniques do I use for hazard identification?* *How does risk assessment influence engineering design?*
Chapter 5 **General Design**	*What are safeguarding strategies?* *How does process safety influence unit or plant design?* *What materials of construction and insulation are needed to prevent corrosion?*
Chapter 6 **Equipment Design**	*How does process safety influence equipment design?* *What are typical failure scenarios for different types of equipment?* *What are common equipment design errors?*
Chapter 7 **Protection Layers**	*How do I recognize the difference between prevention and protection?* *What are prevention design features?* *What are protection design features?*
Chapter 8 **Documentation to Support Process Safety**	*What do I need to document?* *How can this documentation help my facility?*

Figure 1.2 Overview of Guideline Contents

1.5 OTHER CCPS RESOURCES

Other CCPS Guidelines provide additional resources for topics discussed in these *Guidelines*. Some of these include:

- Continuous Monitoring for Hazardous Material Releases
- Deflagration and Detonation Flame Arresters
- Guideline for Mechanical Integrity Systems
- Guidelines for Analyzing and Managing the Security Vulnerabilities of Fixed Chemical Sites
- Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition
- Guidelines for Chemical Reactivity Evaluation and Application to Process Design
- Guidelines for Developing Quantitative Safety Risk Criteria
- Guidelines for Facility Siting and Layout
- Guidelines for Fire Protection in the Chemical, Petrochemical and Hydrocarbon Processing Industries
- Guidelines for Hazard Evaluation Procedures, Third Edition
- Guidelines for Integrating Process Safety Management, Environment, Safety, Health and Quality
- Guidelines for Pressure Relief and Effluent Handling Systems
- Guidelines for Preventing Human Error in Process Safety
- Guidelines for Process Safety Documentation
- Guidelines for Process Safety in Batch Reaction Systems
- Guidelines for Risk Based Process Safety
- Guidelines for Safe and Reliable Instrumented Protective Systems
- Guidelines for Safe Handling of Powders and Bulk Solids
- Guidelines for Safe Storage and Handling of Reactive Materials
- Inherently Safer Chemical Processes a Life Cycle Approach, Second Edition
- Plant Guidelines for Technical Management of Chemical Process Safety
- Safe Operation of Process Vents and Emission Control Systems

Additional information on these publications can be found at www.aiche.org/ccps/.

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