

1 INTRODUCTION

1.1 OBJECTIVES

This guideline describes in sequence how the risks associated with hazardous materials and processes are managed when siting a facility, when arranging new or modified process units within a facility, and then when arranging the new or modified equipment within the process unit. It provides a starting point for companies to help make decisions on how to select a facility's location, how to recognize and assess the facility's long-term risks, and how to lay out the processing units and the equipment within the facility. The location of and the arrangement of process units and associated equipment for a petrochemical facility is described to help illustrate how on-site and off-site risks can be reduced when locating the facility, and how on-site risks can be reduced when arranging process units within a facility or equipment within a process unit. This guideline's appendices include additional references, tables listing recommended process unit and equipment separation distances for fire scenarios compiled from industry practices, guidelines, checklists, and standards for selecting the location of facilities (their siting) and for selecting the distances between processes and equipment (their layout within the selected location).

The objectives of this guideline include:

1. Applying a Risk Based Process Safety (RBPS) approach [CCPS 2007a] and providing guidance when selecting the location of a facility handling hazardous materials and energies, when arranging the process units within the facility, and when arranging the equipment within the process units (the "siting" and the "layout" of the facility),
2. Providing guidance for selecting the location selection team, taking into account the type of facility and the local conditions (e.g., geographical, weather, etc.)
3. Applying inherently safer design principles when selecting a facility location, when locating process units within a facility (their "blocks") and when locating the equipment within the process units,

4. Providing guidance on reducing the risks associated with both the potential off-site and on-site consequences, helping reduce a facility's life cycle costs, and
5. Providing guidance when making changes to existing facilities.

The scope of this guideline is for onshore, outside ("open air") refining, petrochemical and chemical operations that handle, process, or store hazardous materials, including:

- Large and small facilities
- New and existing facilities

Although this guideline addresses some of the design issues for structures that enclose process units, it is beyond the scope to address the distances between process equipment within these enclosed structures. In addition, this guideline refers to but does not detail the quantitative methods designed to evaluate the impacts on personnel and structures after an outside loss of containment of hazardous materials. These methods are described in more detail in other references [e.g., API RP 752, API RP 753, API RP 756, CCPS 1999b, CCPS 2009a, and CCPS 2012b].

The information provided in this guideline will help those deciding: 1) on locations for new facilities (a "location selection" team); and, 2) on the layout and separation distances of process units and their associated equipment within the facility ("process unit layout" and "equipment layout" teams). It is important that the decisions made by these teams are consistent with the company's risk tolerance levels, since locating facilities and the processes within a facility may affect potential risks to the facility's infrastructure, to the facility's security, to the surrounding community, and to the environment.

The costs, complexity and safety of process operations and maintenance are highly dependent on the location of the facility and the layout of the process units and their equipment within the facility. Since building inherently safer design into a facility's layout can help reduce both the operational costs and the process complexity, it makes sense to locate a facility and choose the layout for the equipment using inherently safer design principles early when designing the process. Note that changing the process design may not be feasible once the project is approved since such changes may delay the approved project schedule and business objectives to meet the projected market demand. Although it is beyond the scope of this guideline to address cost-benefit

analyses, there may be costly design changes once the facility is constructed if the siting and layout issues are not addressed early. Optimal siting of facilities, and subsequent process unit and equipment layout within them, helps minimize material and construction costs, and more importantly, helps minimize losses throughout the facility's life cycle with potentially less physical/structural damages and decreased business interruption time.

1.2 A SITING AND LAYOUT APPROACH

This guideline describes a preferred approach used to ensure that new or modified facilities consider essential issues early in the process of searching for the location. This can help avoid issues that may become costly short-term project-related design changes, may involve costly changes during construction, or may become costly long term operating and maintenance issues once the facility is built. This siting philosophy begins first with a review of the material and processing hazards, such as toxicity, flammability, explosivity, reactivity, or a combination of these hazards. Other potential hazards should also be considered since they may be unacceptable to the surrounding community, such as odors, loud noises, or the light from flares.

Once the types of hazards have been identified, their potential off-site and on-site impacts can be addressed. This step includes determining how the local terrain affects the release scenarios (the ultimate impact on the surrounding community), emergency responder accessibility, and security accessibility (the risks at the facility's boundary). At the same time, the layout of the process units and associated areas within the facility, such as storage tank areas or flares, should be arranged to reduce risks. The layout of the equipment, including both their orientation and the separation distances between them, may affect both off-site and on-site consequences, as well. Since the layout of equipment can affect day-to-day operations, it is important to address the balance between reduced or increased distances and the impact on accessibility when evaluating the on-site consequences. The illustration in Figure 1.1 provides a high level view of this inter-related approach, beginning with understanding the hazards and potential consequences, understanding the effects of the location's terrain, and then understanding both the potential off-site and on-site impacts due to process unit and equipment layout and accessibility.

1.3 HOW TO USE THIS GUIDELINE

This guideline is written to provide a starting point when deciding on locations for new facilities. Once the location has been determined, guidance is provided when evaluating and determining the layout of, and separation distances between, process units and their associated equipment within the new location, as well the locations of buildings intended for personnel occupancy or for housing critical equipment. The preferred sequence for these decision-making steps is shown in the chapter chronology outlined in

Table 1.1, with the objectives of the corresponding appendices (including the checklists) for each of these chapters noted in Table 1.2.

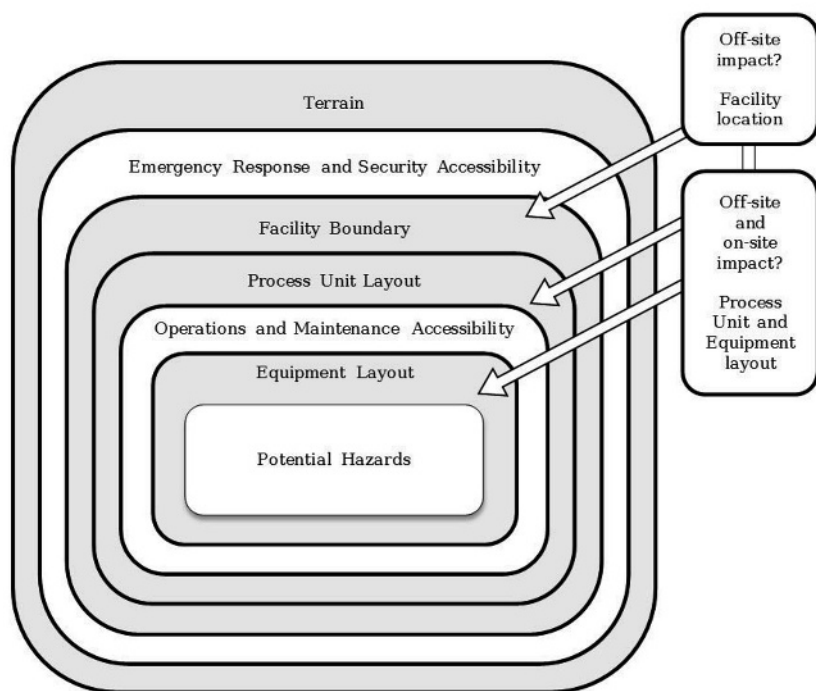


Figure 1.1. A Siting and Layout Approach

Table 1.1. Objectives for the Guideline Chapters

Guideline Chapter		Chapter Objective
1	Introduction	Describes the scope of this Guideline: to provide information on how to select a facility's location, how to identify and assess potential long-term risks, and how to layout the process units and equipment within the new facility location.
2	Benefits Overview	Describes the benefits of combining and applying inherently safer principles and the barrier concepts when addressing the siting and layout of facilities.
3	Identifying the Process Hazards and Risks	Describes what process safety information is needed when performing preliminary hazards analyses of the new process or processes. The hazards and their risks are then used by the location selection team (Chapter 4), the process unit layout team (Chapter 5), and the equipment layout team (Chapter 6).
4	Selecting a Facility Location	Describes who should be included on the location selection team, some potential project-related issues, and how to select a facility location when evaluating and comparing both the pros and cons of the potential location and its surroundings.
5	Selecting Process Unit Layout within a Facility	Describes how the process hazards and risks and the proposed facility's topography, environment and surroundings influence the layout of the process units within the facility.
6	Selecting Equipment Layout within a Process Unit	Describes how the process hazards and risks and the potential operating and maintenance accessibility issues influence the layout of the equipment within the process units.
7	Managing Changes	Describes how to manage process and equipment layout changes.
8	Case Studies	Shares examples of incidents which had severe consequences due, in part, to inadequate consideration and handling of siting and layout issues.

Table 1.2. Objectives for the Guideline's Appendices and Checklists

Appendix		Appendix Objective
A	Additional Siting and Layout References	Provides list of potential resources for additional information on siting and layout of facilities (Chapter 1)
B	CCPS Recommended Distance Tables for Siting and Layout of Facilities	Helps provide distance guidance for fire consequences between equipment and is based on compiled industry data (Chapters 2 through 8)
C	Checklist When Identifying the Process Hazards and Risks	Helps the selection and layout teams identify the types of process hazards and risks associated with the new or expanded facility (Chapters 3, 4, 5, and 6)
D	Checklist When Selecting a Facility Location	Helps the location selection team assess and compare both the pros and cons of the potential location and its surroundings (Chapter 4)
E	Checklist When Selecting the Process Unit Layout within a Facility	Helps the process unit layout team assess potential geographical and environmental issues at the new location (Chapter 5)
F	Checklist When Selecting the Equipment Layout within a Process Unit	Helps the equipment layout team assess potential operating and maintenance accessibility issues within the process unit (Chapter 6)

This guideline is written to help answer these questions:

- What principles are used to decide on the location and layout of a new or expanded facility?
- What critical information is required to select an appropriate location for a facility?
- How is the siting of a facility chosen based on both its location and its surroundings?
- How are security concerns addressed at a new facility?
- How does the facility's topography, environment and its surroundings, combined with the process hazards and risks, affect the layout of the process units within the facility?
- How are the operations and maintenance affected by the layout of the equipment within the process units?
- How can the equipment layout within the process unit be optimized?
- How are new equipment layout issues managed when space is limited at an existing facility?
- What steps ensure that future process and equipment changes do not increase the overall operating risks?

1.4 THE PROTECTION LAYERS

The layout of process units at a facility, the layout of the equipment within a process unit, and the siting of a facility provide different safeguards (barriers) when managing process safety risks. The process unit and equipment layout can be considered a part of the processing design, with the distances between processes and equipment used to separate hazardous material and energy sources from one another. These distances may help reduce the impact of fires and explosions by separating the hazards and helping prevent them from propagating into adjacent areas, subsequently worsening the consequences of the event. The facility's location can also be considered as a barrier when evaluating potential off-site consequences. For example, the location can be selected to help reduce the likelihood of potential receptors in the surrounding communities – people, environment, and property – from being exposed to the hazardous consequences of toxic releases.

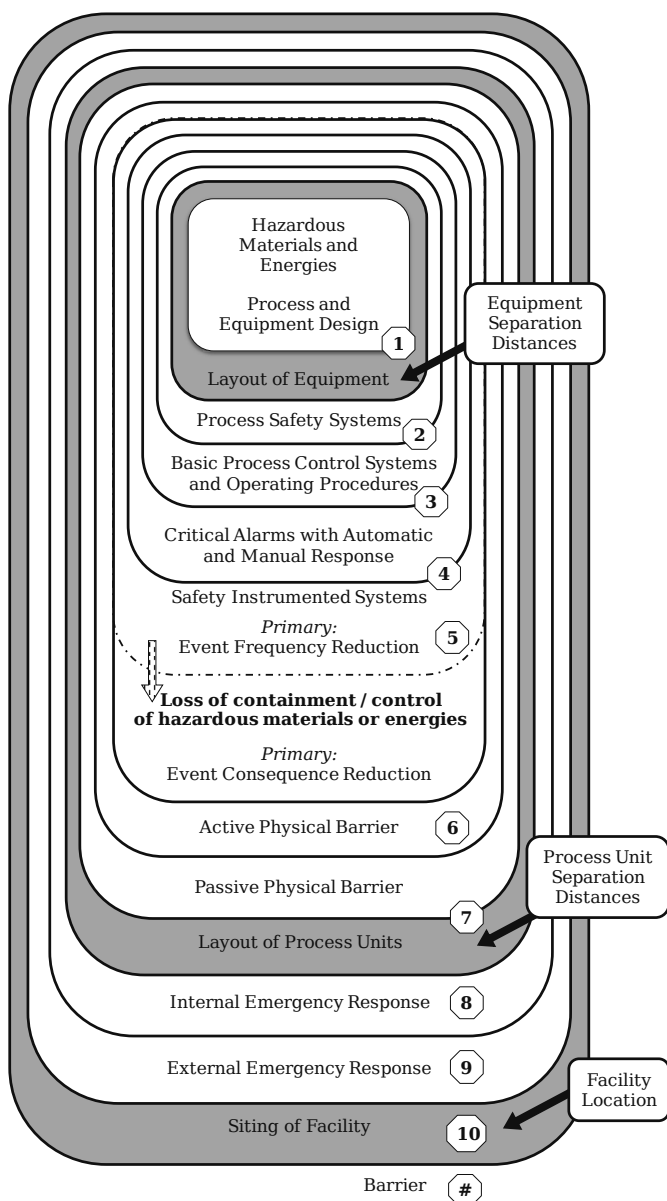
The siting and layout related protection layers for “facility siting,” “process unit layout,” and “equipment layout” are illustrated by the enhanced barrier image shown in Figure 1.2. The sequencing of these protection layers, from inside the facility to the surrounding community (Barriers 1 through 10), begins with applying inherently safer design principles, addresses the equipment and process unit layout, addresses both the preventive and mitigative engineering and administrative controls, and then finishes with the facility’s location.

Inherent in Barrier 1 is the final process chemistry which is used to determine the types of equipment needed to convert the materials, handle the energies, and monitor and respond to the processing conditions. The inherently safer design principles, such as using a less hazardous conditions or ensuring proper separation distances between equipment, are a part of Barrier 1 shown in Figure 1.2. The process design influences the equipment designed to manage the hazards with this ultimate goal: to keep the hazardous materials under control and prevent their loss of containment. Note that a passive safeguard against incident escalation (the domino effect) includes selecting less hazardous processes and the layout of and separation distances between hazardous process units (noted as part of Barrier 7).

The “Process Safety Systems,” noted as Barrier 2, are the administrative controls of the management systems in a typical process safety and risk management program that help prevent systemic failures in the safeguards identified to help reduce the process safety risks. These management systems, in part, focus on sustaining the equipment design integrity with protocols that address the basic elements in a Risk Based Process Safety (RBPS) program [CCPS 2007a]. The objectives of these elements include identifying and assessing process hazards, designing and operating safe processes, analyzing and managing process hazards and risks, maintaining reliable equipment and facilities, anticipating and responding to incidents, ensuring organizational capabilities, monitoring process safety system performance, and planning and implementing changes safely [Klein 2017]. Barrier 2 includes the inspection, testing, and maintenance plans and procedures to ensure that the engineered barriers are in place and that they do not degrade over time, and that the equipment integrity is not jeopardized during the facility’s life span. Barrier 2 also includes the training and development of people to ensure their competencies when doing their tasks.

Preventive and mitigative engineered and administrative controls, shown in Barriers 3 through 7, include control systems, procedures, alarms, interlocks, and both active and passive physical protection systems [CCPS 2001, CCPS 2014a, FM Global 7-43, and UK HSE 2015]. Although the most effective process and equipment design should prevent the initiation of a hazardous event, applying inherently safer designs can also reduce the potential for such an event to escalate. Fewer, and most likely simpler, engineering and administrative controls will be needed in Barriers 3 through 7. The separation distances between process units can be considered as a part of Barrier 7, with the distance between the hazardous process units being a passive “physical” barrier. Thus, applied inherently safer design principles can limit the event sequence across the barriers before there are major impacts on people, property, or the environment, both on-site and off-site [CCPS 2008a].

The facility’s internal and external emergency response systems reflect implementation of its emergency response plan (Barriers 8 and 9 in Figure 1.2). The location of the facility (its siting) helps reduce off-site consequences by selecting an inherently safer location (Barrier 10). Hence, the location of the facility is an important barrier, helping to protect the surrounding community from potential impacts of the facility’s hazards. Further discussion on land use guidance for Barrier 10 is provided in Chapter 4, Section 4.7.



[Adapted from Klein 2017]

Figure 1.2. A Facility's Protection Layers

There are many preventive, mitigative, and damage limiting strategies used to reduce process safety risks of fires, explosions, toxic releases, and hazardous reactions. These strategies include, but are not limited to:

- selecting inherently safer designs,
- selecting safe distances to reduce congestion and confinement,
- preventing hazardous conditions,
- mitigating hazardous consequences,
- eliminating ignition sources,
- establishing Hazardous Area / Zone Classification boundaries,
- providing fire protection,
- providing hazardous atmosphere detection systems,
- providing explosion suppression systems,
- providing enclosures for processes and equipment handling highly toxic materials
- providing overpressure relief and venting,
- providing purging systems (i.e., to reduce the oxygen concentration in areas with potentially flammable, combustible dust or explosive atmospheres), and
- providing remotely operated controls for emergency response.

It is worth noting at this point, that many companies have developed upon and applied the concept that efforts to reduce risk should be continued until the incremental sacrifice (cost, time, effort, or other expenditure of resources) is grossly disproportionate to the incremental risk reduction achieved. The terms As Low As Reasonably Practicable (ALARP) and As Low As Reasonably Achievable (ALARA), have been used to describe this concept. Since the development, adoption and application of ALARP by a company is beyond the scope of this guideline; the reader should reference the literature for more guidance [e.g., UK HSE 2001, Ellis 2003, Baybutt 2014, UK HSE 2016a, and UK HSE 2016b].

1.5 TERMINOLOGY

The terminology used in this guideline is defined as follows:

A “**complex**” is a collection of facilities that may or may not be owned by the same company, but are located within the contiguous boundaries of a specific geographic location, such as an industrial or chemical park. A facility within a complex may feed or take raw materials from another facility in the complex or may be totally independent of its industrial neighbors.

A “**facility**” contains one or more process units and other manufacturing areas within a single geographical location – within the company’s boundary limit or property line. In context of this guideline, a “facility” may also be referred to as an “establishment” in some jurisdictions. It is the physical location where the manufacturing process is performed, such as a chemical or refining facility, or where materials are handled, transferred or stored, such as terminals, wharves, or distribution centers. Areas within the facility may have their own support groups or they may share support groups with other areas. Support groups may include administrative or engineering offices, maintenance, warehousing, shipping, fire station, medical, and security. Areas for employee and contractor parking should be addressed at the facility, as well, with larger facilities using dedicated buses to transport them within the facility (i.e., during outages and turnarounds with extensive process unit work). Different processing areas within a facility may have different hazards and risks, such as a chemical processing area which is connected directly to a refining area.

A “**process unit**” is a part of a “process area” dedicated to a common purpose. The process area contains equipment (e.g., pipes, pumps, valves, vessels, reactors, and supporting structures) intended to transfer, process or store materials [CCPS Glossary]. Hazardous process units have the potential for runaway reactions, toxic releases, fires, and explosions. For example: a fuels process unit that produces materials for blending gasoline; a lubricating oil blending process unit; a tank farm area supporting a refinery, chemical operation or both; a pier, dock, jetty, or wharf receiving raw materials and loading products; a processing and pellet silo storage area; or a pipeline pumping station. An illustration of process units in different process areas is shown in Figure 1.3.

A “**train**” or “**process section**” is an area within a process unit containing combination of processing equipment that is focused on a single operation (see Figure 1.3.) For example, a refrigeration system that supplies a frozen food operation; a crude distillation tower; a water treatment system that chlorinates waste-water effluent from a waste disposal facility; a polyethylene unit; or a batch reactor train.

A “**utility**” is an energy or services supplier, including electricity, instrument air, lubricating systems, steam or heating medium, fuels (oil, gas, etc.), refrigeration, cooling water or cooling medium, and inert gases. Some facilities may also include waste treatment facilities in this category, as they may supply energy and are connected to portions of the facility (i.e., incinerators).

The term “**greenfield**” describes undeveloped property being considered as a location for a new facility that has not been used before for either commercial or industrial purposes.

The term “**brownfield**” describes an industrial or commercial property being considered as a location for a new facility or for redevelopment. This is land that has been previously used, abandoned, and now awaits a new use. If the brownfield property has older structures or existing contamination issues, they will need to be addressed before renovation or new construction occurs. If the brownfield land is adjacent to an operating process unit, simultaneous operations (SimOps) issues will need to be addressed, as well. Additional SimOps discussion is provided in Chapter 5, Section 5.6.2, Planning for phased construction.

The term “**grassroots**” describes a totally new facility that may be built on a greenfield or a brownfield.

The term “**property line or boundary**” is the dividing line between the site property and the adjacent property not owned by the company. The adjacent property may be public or industrial.

The term “**on-site**” represents the processes and support operations within the company’s boundary or property limits (this may be the “fence line” if the adjacent land is not owned by the company).

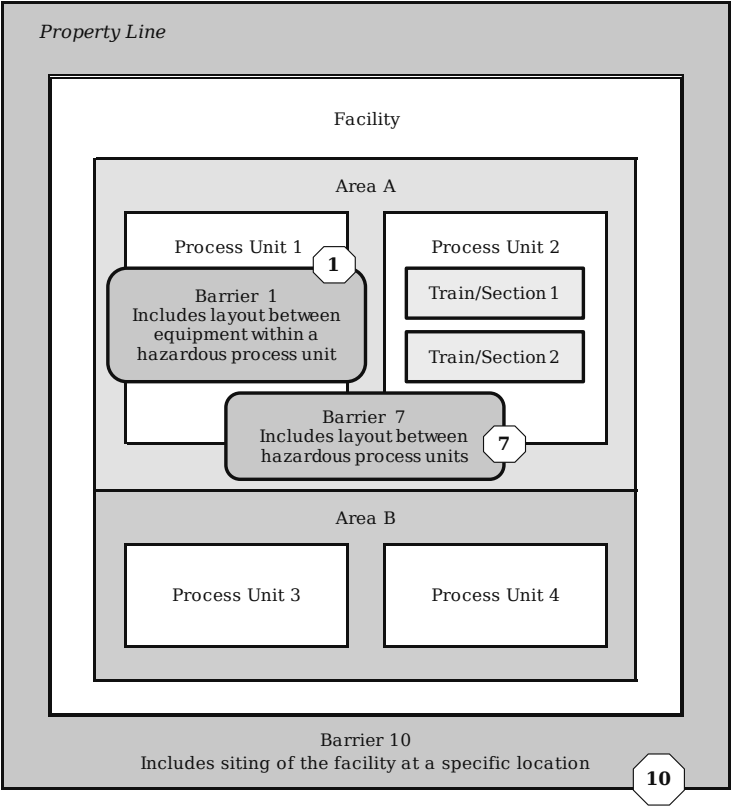


Figure 1.3. Guideline Terminology

Barrier Notes for Figure 1.3	
1	Distances separating equipment within a hazardous process unit based on the hazards associated with the equipment in the hazardous process
7	Distances separating hazardous process units based on the hazards associated with the hazardous processes
10	Distances separating the hazardous processes in a facility from its neighbors based on the risks associated with the facility's siting (its geographic location)

The term ***“off-site”*** represents the adjacent area external to the company’s boundary limits, with the “off-site consequences” representing the impact, if any, on industrial neighbors and the surrounding community and environment.

Thus, for the protection layers illustrated in Figure 1.2 and Figure 1.3, the terminology is defined as follows: the distances between equipment and the orientation of equipment within the process unit are part of Barrier 1; the distances between the process units are part of Barrier 7; and the distance between the location (siting) of the facility and potential off-site industrial neighbors, the surrounding community, or environmental receptors is represented as part of Barrier 10.

1.6 GUIDELINE REFERENCES

Where appropriate, this guideline references regulations and industry codes, guidelines and standards. A list of the referenced industry practices at the time of publication, including applicable regulations and CCPS guidelines, is included in Appendix A.

1.7 SEPARATION DISTANCES BASED PRIMARILY ON FIRE CONSEQUENCES

Early equipment spacing or layout tables were based on engineering judgement and experience and were developed in the 1960s by different refining and petrochemical companies (and thus, are no longer easily assessable). These tables described the recommended equipment separation distances to help reduce the consequences during fires in outdoor processes. In the 1970s/1980s, these tables were updated based on incident learnings, additional engineering experience (including the potential for flash fires and jet fires), industry consensus guidelines and standards, regulatory requirements, insurance loss reviews, and insurance guidelines. Since then, facility scale-up and increased automated process complexity have changed the potential likelihood and severity of incidents.

The separation distances provided in the tables in Appendix B have been compiled from historical guidance and industry data and include updates from the tables provided in the 2003 edition of this book. These separation distances apply primarily to potential fire consequence scenarios between the process blocks,

process units, process unit equipment, and facility's industrial neighbors. Although these tables may not provide an exact, analytical answer, they can be used to help with preliminary process unit lay out design and then with preliminary equipment lay out designs, taking advantage of industrial experience. When applicable and available, the facility-specific thermal radiation, toxic dispersion and blast overpressure analyses should be used to establish the optimum separation distances. These modeling distances may differ than those listed in Appendix B. In addition, industry guidance for highly reactive chemicals, such as alkyls and peroxides, may require additional protection layers and specify different separation distances than those provided in Appendix B. Note that distances required by applicable codes, standards, or local regulations will take precedence and may differ than those listed in Appendix B.