CHAPTER 30

FACILITY PLANNING AND DESIGN

The best time to incorporate safety into a facility is during the planning and design of a new facility or the modernization of an existing facility. Too often, designers consider safety as a design afterthought. Some designers do not find safety important until after construction is underway or after a facility is completed. Incorporating safety during design makes economic sense because it is much cheaper to make changes during design than to negotiate change orders with a contractor or to modify a facility after completion.

30-1 FACILITY DEVELOPMENT PROCESS AND SAFETY

Figure 30-1 represents one way to describe the facility procurement process. Because conditions and requirements change, the process of keeping facilities supportive of an organization and its operations is cyclical and continual. Organizations obtain facilities through new construction, leasing, and modification of existing facilities.

Safety, health, and environmental factors must be considered throughout the process design and development process. Safety cannot be assigned to one step or saved until after a project is completed.

Recognizing the Need

Typically, the process begins with recognition that existing facilities are inadequate. The need for a new or upgraded facility may result from inadequate safety features. The likelihood or consequences of a potential loss or the likelihood of a loss occurring may justify corrective measures in economic or other terms. Changes in regulations and standards may require facility modifications.

Planning and Budgeting

As soon as a facility need has been determined, preliminary planning sufficient to develop and justify a budget request must be carried out. This may involve a needs or feasibility study, which may include analyzing needs and evaluating alternatives for obtaining the needed facility. The planning process also should include a risk analysis. The major systems in a facility must be analyzed because safety affects these systems. For example, there may be a need for special fire protection features (sprinklers, sensors, and alarm devices). Other requirements may include special ventilation, lighting, emergency power, or shielding equipment. There may be a need for barrier walls or physical distance to separate hazards. All of these safety essentials add to the budget for the project.

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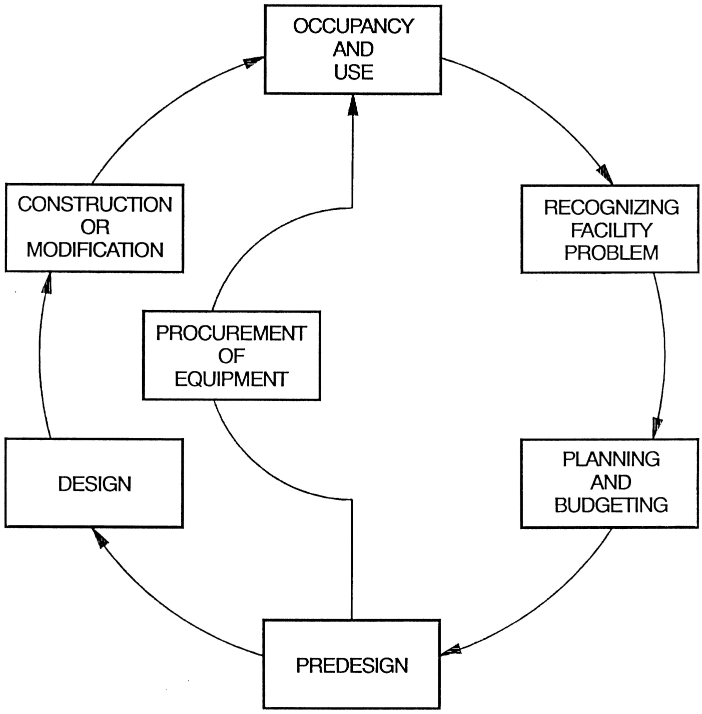

Figure 30-1. The facility procurement process.

Predesign

As soon as a course of action is selected, there are further details to work on, including preparation of detailed requirements and technical information for design. For example, one needs to compute the water supply requirements, to identify which spaces or operations need emergency lighting or power, and to complete a preliminary hazard analysis for each operation or space. From the analysis, there are corrective features to be incorporated into the design of the facility and its systems.

Design

After compiling detailed requirements, project engineers and architects prepare one or more preliminary design concepts. Then, they pursue one approved design concept in detail. Designers try to meet as many requirements as possible. Not all can be met and there are tradeoffs. However, there are some requirements that are not negotiable and must be met. Analyzing and prioritizing safety requirements will help designers deal with important safety features.

The design process must include hazard analysis, and where possible, designers must select corrective measures and integrate them into the design. However, the selected controls for some hazards may not be a part of a facility design. For example, the controls may be procedures or personal protective equipment. The design must deal with these controls through design documentation, warnings, instruction manuals for the facility, and similar means.

Selection and Procurement of Equipment

Closely associated with the facility design is selection and procurement of equipment that will be used in the facility. For process facilities, the planning, budgeting, requirements analysis, and design of equipment are an integral part of the facility design. Designers identify hazards associated with the equipment and specify what controls to procure with purchased or fabricated equipment for the facility project. Decisions about hazards and controls cannot be left to purchasing agents. Safety requirements and responsibility for determining compliance with safety requirements in facilities belongs to designers.

For facilities that have uses other than manufacturing and production, analysis of activities that will occur in a facility and equipment that users may bring in should be part of the design process. What hazards equipment users may bring into a facility and what to incorporate in the facility design also should be considered. It may be important to identify what hazards do not have controls in the facility and what controls user equipment must have.

Construction or Modification

After design and funding, the facility project moves to construction. The project may be new construction or modification of an existing facility. Contractors also install new or modified equipment. Part of the construction or modification is quality assurance. Designers should implement steps to ensure that a design is built correctly. This may require testing, evaluation, and formal acceptance procedures. The designer must be sure that contractors do not make changes that introduce dangers and that safeguards are correctly constructed and installed.

Occupancy and Use

After completing a facility project, occupants move in and the facility is put to use. It now should meet its functions safely, although after moving in, there will be some fine adjustment, which may include safety features. Users may change operations and activities, thereby reducing the effectiveness of some safety features or requiring new ones. Continual monitoring of hazards and controls after moving in will prevent introduction of hazards from changes in operations and activities or minimizing them.

30-2 TOOLS TO HELP SAFETY IN DESIGN

There are a variety of tools and procedures that help designers reach solutions that satisfy as many requirements as possible. Some tools, such as the energy theory (see Chapter 3) and the four Ms and goal accomplishments models (see Chapter 9), aid in hazard recognition.

Later chapters (Chapters 35–38) describe procedures and methods for identifying hazards and selecting and ranking controls. These apply knowledge about hazards and controls covered in other portions of the book.

There are many references that deal with the control of hazards in facilities, and this book covers many in other chapters. There are laws, regulations, and consensus standards for many kinds of hazards. There are references containing design guidance and criteria that capture the experience of others. Many of these references deal with particular kinds of facilities. Table 30-1 is a checklist derived from a survey of process company experi-

TABLE 30-1 Checklist of Hazard Factors for Facility Design and Operation[a]

Plant site problems
- Unusual exposure to natural emergencies
- Inadequate water supply and other utilities
- Exposure to hazards from nearby plants
- Unreliability of public fire and emergency protection
- Traffic difficulties limit emergency equipment access
- Air and water pollution problems
- Inadequate waste disposal facilities
- Climate problems requiring moving hazardous processes indoors
- Poor drainage

Inadequate plant layout and spacing
- Congested process and storage areas
- Lack of isolation for very hazardous operations
- Exposure of high value and difficult-to-replace equipment
- Lack of adequate emergency exit facilities
- Insufficient space for maintenance or emergency operations
- Source of ignition too close to hazardous materials
- Critical plant areas exposed to hazards
- Inadequate hazard classification of plant areas
- Lack of isolation of critical plant areas from community

Structure not in conformity with use requirements
- Disregard for code requirements
- Lack of fire-resistive structural support
- Failure to provide blast walls or cubicals to isolate extra hazard operations
- Inadequate explosion venting and ventilation of buildings
- Insufficient exit facilities
- Electrical equipment does not meet code
- Unprotected critical wiring
- Inadequate hazard anticipation (i.e., explosion)

Inadequate material evaluation
- Fire, health, and stability of materials not evaluated
- Inadequate controls for quantities of materials
- Inadequate evaluation of processing environment for hazards of materials
- Lack of information on dust explosion properties of materials
- Inadequate evaluation of health hazards of materials
- Incomplete inventory of hazardous materials in the plant
- Lack of long-term exposure information
- Improper packaging and labeling of chemicals

Chemical process problems
- Lack of information on process temperature and pressure variations
- Hazardous by-products or side reactions
- Inadequate evaluation of process reactions
- Lack of identification of processes subject to explosive reactions
- Inadequate evaluation of environments
- Overlooking conditions for extreme process conditions
- Lack of evaluation of vapor cloud hazard

Material movement problems
- Inadequate control of chemicals during night operations
- Inadequate control for hazardous dusts
- Piping problems
- Improper identification of hazardous material during transportation
- Loading and unloading problems inadequate control of heat transfer
- Flammable gases and vapor problems in pneumatic conveyors
- Waste disposal and air pollution problems
- Vapor cloud problems

Operational failures
- Lack of detailed descriptions and procedures for operating all sections of the plant
- Poor training program
- Lack of training on health hazards
- Lack of supervision
- Inadequate start-up and shutdown procedures
- Poor inspection and housekeeping
- Inadequate permit system
- Lack of emergency control plans
- Inadequate drills
- Lack of medical and biological surveillance

Equipment failures
- Hazards built into equipment
- Corrosion or erosion failures
- Metal fatigue
- Defective fabrication
- Inadequate controls
- Process exceeded design limitation
- Poor maintenance program
- Inadequate repair and replacement program
- Lack of "fail-safe" instrumentation
- Poor check on construction criteria or material specification

TABLE 30-1 continued

Equipment not capable of toxic or hazardous materials	Poor check on boiler and machinery risks
Ineffective loss prevention program	Lack of preemployment physical examinations and periodic checkups
Inadequate support of top management	Lack of training on health hazards and use of personal protective equipment
Lack of assigned responsibility	Lack of conformance with government regulations
Poor accident and hazard prevention program	Insufficient in-plant monitoring of physical and chemical hazards
Insufficient fire protection manpower, equipment, and organization	Individual hazard approach instead of "total loss control" concept
Ineffective explosion prevention and control program	
Lack of emergency planning	

[a] Derived from *Hazard Survey of the Chemical and Allied Industries*, American Insurance Association, New York, 1979. The items resulted from a questionnaire survey of failures of many plants and operations.

ences. The survey compiled data on things that went wrong with process facilities. Organizations, like Underwriters Laboratory[1] and Factory Mutual System,[2] offer both publications and experience that can help identify safety problems with facility designs.

Another important tool for incorporating safety in facility design involves the makeup of the design team. Safety and health specialists should be a part of the design team.

Ideally, there should be a safety specialist on the design team who should be knowledgeable in safety, health, the environment, and fire protection. The practice of having safety specialists involved in design is growing. For example, many petroleum and chemical companies have safety engineering specialists involved in the planning and design of processing plants and facilities. The Department of Defense requires that system safety be applied to major facility projects. The Army Corps of Engineers created a computer data bank of lessons learned about facility safety that allows people working with them to search in various ways for facility safety problems that others have experienced.

If safety specialists are not part of a design team, at least there should be a thorough safety review of a design by a specialist. The review should cover safety features built into the facility and safety during use of the facility. The review should consider operation, maintenance, repair, and servicing of the facility, its subsystems, and equipment. The design must cover routine use of a facility and activities of those who are its caretakers. It must cover special activities important for emergencies and rescue.

A design can be broken into several components, and one way to organize the components is by scale. One can evaluate the *site* and *siting*; one can evaluate the *building* or *facility*; one can check the facility *interior* and *occupancy*. Sometimes evaluation of *work stations* is important. One must look at particular *equipment*. One must consider the *operations*, *processes*, or *activities* for each of these components. Table 30-2 provides a checklist covering some considerations when planning a site and a building.

A review of some facility factors about safety is given in the following section. This review gives an example of an approach by facility scale. Particular operations, processes, and activities will include additional considerations. The review reflects some information presented in other chapters.

TABLE 30-2 Incomplete List of Safety Considerations in Facility Planning

Site	
Drainage	Prevention of spills, leaks, or activities that may contaminate storm water or to control runoff
	Flood control and protection
Utilities	Prevention of damage to utilities (power lines, pipelines, communication lines)
	Remote shutoff of utilities
	Barricades to protect people from utilities
	Water supply for operations and fire protection
	Storage of fuels on site
Traffic	Traffic load on or adjacent to site (pedestrian, vehicular, railroad, public, employees, delivery, etc.)
	Need to separate kinds of traffic
	Types and quantities of materials entering or stored on site
	Access for emergency vehicles and equipment
Hostile conditions	Wind loads and conditions
	Snow loads
	Earthquake zones
	Lightning protection
	Protection from sun, water, weather, or other hazards
	Physical security
Site storage	Storage of fuels, water, hazardous materials on site (type and quantity)
	Separation requirements
Adjacent properties and community	Barricades and fences to keep unauthorized people from dangerous areas or materials
	Protection from hazards of adjacent or nearby properties or transportation routes
	Dangers to adjacent properties from site or operations
	Emergency response plan
	Community right-to-know requirements
	Emissions and controls
Fire and emergency	Access for emergency vehicles and equipment
	Fire load
	Fire response management
	Fire suppression and extinguishment
Buildings	
Walkways, stairs, and access	Adequate lighting at entries, transition points, stairs, landings, etc.
	Guard rails for elevated surfaces
	Handrails for stairs and certain types of pedestrians
	Handrail dimensions for firm grip
	Floor finishes to minimize slipperiness, prevent corrosion, etc.
	Drainage or raised flooring for wet or oily areas or where foreign material is slippery
	Spill isolation to prevent distribution of contaminants
	Minimize changes in surfaces (elevations, irregularities, slipperiness)
	Aisle and area markings for pedestrian areas, vehicles, materials, handling, or hazardous operations
	Door sizes for vehicles and materials
	Safe access for building and equipment maintenance
Hazard zones	Enclosure, isolation, separation, or other controls for hazardous sources (noise, gaseous or particulate contaminants, etc.)
	Exhaust ventilation, hoods, or cabinets for hazardous contaminants
	Barricades for hazardous operations
	Sensors and monitoring equipment for hazardous materials

TABLE 30-2 continued

	Warning signs that meet various standards and markings to identify hazardous areas
	Communication systems
Fire protection	Fire loads
	Smoke and heat detectors
	Alarm systems and evacuation management systems
	Sprinklers and other fire suppression equipment
	Fire ratings for materials, finishes, and partitions (walls, ceilings, floors, doors)
	Exit signage
	Roof vents and curtain boards
	Explosion venting
	Fire control equipment and systems for flammable operations
	Utility shut off systems for emergencies
Sanitation and first aid	Sufficient washrooms
	Clean areas for food and eating, including isolation from sources of contamination
	Lockers, change rooms, and showers for control of contaminants
	Emergency showers
	Emergency eyewash fountains
General	Enclosure of dangerous equipment and building systems
	Maintainability to minimize repair, cleaning, and servicing hazards
	Storage areas for hazardous materials
	Proper separation of noncompatible materials
	System, equipment, and operations shutoffs in nonhazardous areas

30-3 SITE CONSIDERATIONS

Location

There are many location factors that impact plant design and potential hazards.

Climate and Natural Conditions In planning a facility, there is a need to know about wind, particularly if there are any potential releases from the facility. Drainage is important and there should not be an accumulation of water from processes, leaks, or storms. Hazardous materials should not contaminate runoff water, and stored materials should not create pollution. It is important to know if there is a flood potential or dangers from flight paths and other forms of transportation. Soil characteristics, water table, and ground water are important factors in case of spills.

Neighborhood and Population The population living or working in the vicinity should be known. It is necessary to know if there are periods when there are high densities of people from traffic or special activities, if there are playgrounds or schools nearby, and if there are hazards from nearby plants and operations.

Size of Site

If there are hazards such as noise, explosions, or heat, the distance to the periphery of the site and between parts of the plant or facility must be great enough for protection.

Access and Circulation

The site should have adequate access for facility occupants, emergency, equipment and delivery vehicles. If possible, circulation routes for pedestrian traffic should not have to cross vehicular traffic routes. Routes for emergency access should not be blocked by normal or peak traffic. Materials handling, delivery, and rail traffic should be isolated from employee and visitor parking and walkways.

Layout

The site arrangement should isolate hazardous materials and operations from nonhazardous activities. The operations should have smooth flow. As few people as possible should have exposure to any hazard. Quantities of materials, particularly those with high energy content, should be separate from activities that could trigger fire.

Utilities

Utilities should be located to avoid creating hazards. For example, gas lines should not be near rail lines or public or employee areas. Shutoff locations should be separated from areas where the utilities may be hazardous, and shutoff controls should be accessible to emergency crews even during incidents. Lines should be protected from vehicle damage. Utilities, such as water, should be sufficient for emergency needs from supply mains to use points in the facility. Consideration should be given to the effects of power outages or shutdown of ventilation systems, lighting, process equipment, and computers. There may be a need for uninterrupted power supply, alternate power, or generator sets and battery systems, such as those for emergency lighting.

Storage

Sufficient storage capacity for quantities of materials should be available. Hazardous materials should be isolated from other materials and areas of the site. Storage equipment and layouts should minimize traffic problems for materials handling equipment.

Security

The need for security of the plant site and elements on it should be considered. For example, the facility may have control points for anyone entering the site, for access to plant areas but not administrative areas, or for areas where there are special hazards. Hazardous areas may require fencing and other physical security equipment to monitor unauthorized access.

Many of the aforementioned factors apply to the design of a building on a site. Additional considerations are listed in the following text. They are certainly not all the safety factors that are important in designing a building.

30-4 BUILDINGS AND FACILITIES

Layout

Designers should separate processes that have noise, heat, or cold, require ventilation, or have other environmental hazards from areas that do not have these hazards. Partitions most be provide to isolate fire hazards.

Access and Circulation

Review whether emergency equipment and personnel have easy access to all locations. Arrange circulation to prevent traffic congestion and conflicts between vehicular and pedestrian traffic. There should be sufficient exit routes and exit units. Doors should also have enough width and height for vehicles and materials handling. Circulation areas should be marked or delineated clearly.

Materials of Construction

Select materials to meet fire protection requirements or withstand corrosive or reactive materials that may be used and minimize dangers from operations.

Flooring

Flooring should be selected for many factors, especially safety. Ensure that floors will carry the anticipated loads and analyze the structure before authorizing new uses for a facility designed for other uses. Surfaces should be slip resistant and there should be no sudden changes in slipperiness coefficients. Small changes in elevation (one or two steps) should be avoided, but if necessary, clearly visible. Open stairs and other openings should be protected. Avoid patterned finishes on stairs and sudden changes in view on stairs that create visual distractions.

Ventilation

Check operations for generation of heat, gases, vapors, or airborne contaminants and place them in locations to minimize the portions of the building affected. Capture contaminants at the source to minimize the volume of air that must be treated. Consider the effects of spills and leaks and how they will be managed.

Lighting

Besides adequate lighting for routine activities, watch for transition zones near entries. Make sure these zones allow for eyes to adjust, particularly if there are stairs or other walking hazards. Determine if interior spaces have adequate emergency lighting to allow for safe exiting.

Storage

Analyze the types and quantities of materials that may be present. Plan storage locations for each type of item. Separate incompatible materials, such as oxidizers and fuels. Provide adequate storage equipment and racks to keep materials organized. Storage areas should be clearly marked.

Communication

Consider routine and emergency communications. If there are potential emergencies, provide communication systems that can reach occupants to inform them of dangers and corrective actions to take. Voice systems may need equipment dedicated for emergencies to ensure that emergency communication does not compete with regular equipment use.

Video systems may be needed for security and computer systems for monitoring equipment for safe operations.

Fire Protection

Analyze the fire loads and fire controls. Determine if compartmentation is adequate. Analyze water supplies for adequacy at all locations where extinguishing water is needed. Consider the value of sprinkler systems and the type best suited to each location.

30-5 WORK STATION CONSIDERATIONS

Work station design must address details of particular tasks. There should be room to sit and stand. Seating should be comfortable and adjustable. Handling of materials should be minimized. Furniture and layouts should avoid the need to twist, turn, bend, or stoop. Ergonomic considerations (Chapter 33) are important in work station designs. Facility designers should specify safety features for furnishing. Requirements should not be left to procurement people.

30-6 EQUIPMENT AND PROCESS CONSIDERATIONS

There are many safety considerations for equipment. Proper controls, guarding, noise characteristics, electrical grounding, and other factors are important. One must apply techniques to identify hazards and risk and options for eliminating or reducing risks. Chapters 35 and 36 review some of these approaches.

For process equipment, designers need to specify what safety features are needed and what tests will determine if requirements are met. For process equipment, there should be fail-safe features. Fire protection, overpressure, excess heat, runaway reactions, dust control, exhaust ventilation, dangers of flammable liquids, leaks, sensing devices to report status, and many other safety features are important. Designers need to consider access for setup, maintenance, and cleaning. Access by stairs, fixed ladders, or platforms should be part of equipment where applicable. Chapter 36 covers some of the approaches for complying with the OSHA Process Safety Standard. References from the Center for Chemical Process Safety provide considerable details for identifying and controlling hazards process plants.

EXERCISES

1. Obtain the drawings and specifications for a public assembly, commercial, or retail building. If documents are not available, visit an existing building. Evaluate the design for safety of employees and public users and their activities. Prepare a report of findings indicating to the designer what is wrong or can be improved for safety and what corrections you recommend.
2. Meet with designers from an architect-engineering firm. Ask them how they incorporate safety into their facility planning and design process.
3. Review a process safety audit report. Summarize the procedures used and the resulting recommendations. Find out how the results were actually implemented.

REVIEW QUESTIONS

1. When is the best time to put safety features into a facility?
2. Describe major steps in the facility development process and safety considerations for each.
3. What are some resources for information about safety in facility design?
4. Identify three safety considerations for each of the following:
   (a) site
   (b) building
   (c) work station
   (d) equipment

NOTES

1 Northbrook, IL.

2 Norwood, MA.

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