1 INTRODUCTION

Catastrophic accidents in the chemical process industries, while uncommon, may affect buildings in or near processing facilities. The likelihood of serious events involving hazardous materials can and has been effectively reduced through the application of process safety management. Specifically, the CCPS Guidelines for Technical Management of Chemical Process Safety (CCPS, 1989a) states:

> *As the chemical process industries have developed more sophisticated ways to improve process safety, we have seen the introduction of safety management systems to augment process safety engineering activities.*
>
> *Management systems for chemical process safety are comprehensive sets of policies, procedures, and practices designed to ensure that barriers to major incidents are in place, in use, and effective. The management systems serve to integrate process safety concepts into ongoing activities of everyone involved in operations — from the chemical process operator to the chief executive officer.*

These process safety management systems help ensure that facilities are designed, constructed, operated, and maintained with appropriate controls in place to prevent serious accidents. Despite these precautions, buildings close to process plants have presented serious risks to the people who work in them. This observation is prompted by the fact that some buildings that were not designed and constructed to be blast resistant have suffered heavy damage, and in some instances have collapsed when subjected to blast loads from accidental explosions. Serious injury or fatality to the occupants resulted from the building damage. Experience indicates that personnel located outdoors and away from such buildings, if subjected to the same blast, may have a lower likelihood of serious injury or fatality. Building occupants have also been exposed to toxic vapors that enter through forced or natural convection ventilation, and thermal hazards that result from fires near buildings.

Industry associations and insurers have proposed building design and siting guidelines as a means of improving personnel safety. The resulting standards, however, are not universally applicable to all industry sectors and do not ensure consistent levels of safety. Consequently, the chemical processing industries recognizes the need for guidance on a uniform approach to the design and siting of buildings intended for occupancy. The chemical process industries also recognizes that this guidance needs to be practical and consistently applicable across the spectrum of interested industries, and take into account the specific operations and conditions existing at any particular site.

The purpose of this book, *Guidelines for Evaluating Process Plant Buildings for External Explosions, Fires and Toxic Releases, Second Edition* is to provide guidance to building siting evaluations. The first edition of this book was written in conjunction with the first edition of American Petroleum Institute (API) Recommended Practice (RP) 752, "Management of Hazards Associated with Location of Process Plant Permanent Buildings," issued in 1995. API developed a recommended practice specific to siting of portable buildings in 2007. The new recommended practice was designated API RP-753 and named "Management of Hazards Associated with Location of Process Plant Portable Buildings" (API, 2007). API completed a major revision of API RP-752 in December 2009 (API, 2009). Development of API RP-753 and revision of API RP-752 prompted updating of this book. This book has an expanded role in providing the guidance for all phases of the building siting evaluation process.

API RP-752 was first published in 1995 and provided a three-stage framework for conducting a building siting evaluation. API RP-752 also included examples of numerical occupancy level criteria that could be used to screen buildings from siting evaluation, and some simplified consequence and risk analysis data. The 2009 edition transformed API RP-752 into a management process for siting evaluations, and removed most technical content. Portable buildings were removed from the scope of API RP-752 when API RP-753 was issued, and the scope of API RP-752 was clarified to encompass new and existing rigid structures intended to be permanently placed in fixed locations. Tents, fabric enclosures, and other soft-sided structures are therefore outside the scope of API RP-752.

API RP 752 (API, 2009) and RP 753 (API, 2007) have a set of guiding principles for building siting evaluations. API RP 752 guiding principles are shown below. API RP 753 has a similar set, but modified to be more suitable to portable buildings. The API RP-752 guiding principles are:

- Locate personnel away from process areas consistent with safe and effective operations;
- Minimize the use of buildings intended for occupancy in close proximity to process areas;
- Manage the occupancy of buildings in close proximity to process areas;
- Design, construct, install, modify, and maintain buildings intended for occupancy to protect occupants against explosion, fire and toxic material releases;
- Manage the use of buildings intended for occupancy as an integral part of the design, construction, maintenance, and operation of a facility.

Figure 1.1 depicts the relationship between API RP-752 and API RP-753. Blast resistant modular buildings (BRM) can potentially fall within the scope of either API RP-752 or API RP-753 depending on the intended use of the BRM. BRMs that are intended for permanent installation in a fixed location fall within the scope of API RP-752, whereas all temporary applications fall within the scope of API RP-753. This book addresses both permanent and temporary buildings and provides analysis methods that support both of the API recommended practices.

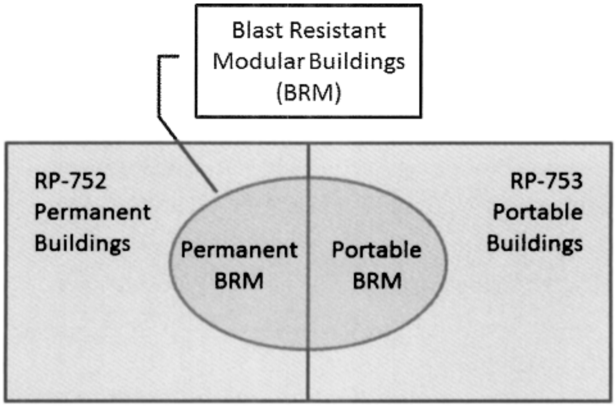

Figure 1.1. Relationship between API RP-752 and API RP-753

API RP-753 includes restrictions on personnel who can be located in portable buildings in certain circumstances. Only essential personnel are allowed in selected portable buildings close to and within process units (API RP-753 Zone 1) when the building has been subjected to a detailed analysis for the hazards at the building location. No such personnel restrictions are included in API RP-752 for permanent buildings; instead, all buildings intended for occupancy undergo a detailed analysis for explosion hazards.

It is not the role of this book to create any additional building siting requirements beyond those defined in API RP-752 and API RP-753. The reader should review both recommended practices before reading this book. Guidance on all aspects of the building siting evaluation process can be found in this book. This book serves as a roadmap to references including CCPS documents.

A wide variety of technical and process safety management issues are referenced throughout this book. Detailed coverage of these issues is outside the scope of this book, however, and readers are referred to other CCPS books for more information. These include, in particular:

- Guidelines for Technical Management of Chemical Process Safety (CCPS, 1989a)
- Guidelines for Hazard Evaluation Procedures, Third Edition, with worked examples (CCPS, 2008b)
- Guidelines for Chemical Process Quantitative Risk Analysis (CCPS, 2000)
- Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards (CCPS, 2010)
- Guidelines for Use of Vapor Cloud Dispersion Models (CCPS, 1987)

- Guidelines for Vapor Release Mitigation (CCPS, 1988)
- Guidelines for Facility Siting and Layout (CCPS 2003a)
- Guidelines for Developing Quantitative Safety Risk Criteria (CCPS 2009b)
- Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities (CCPS, 2003b).
- Guidelines for Risk Based Process Safety (CCPS, 2007)

Additionally, the following references also provide guidance:

- U.S. Army, "Structures to Resist the Effects of Accidental Explosions" (U.S. Army, 1991)
- American Society of Civil Engineers, *Design of Blast Resistant Buildings in Petrochemical Facilities* (ASCE, 2010)
- American Society of Civil Engineers, *Structural Design for Physical Security* (ASCE, 1999)
- "Single Degree of Freedom Structural Response Limits for Antiterrorism Design," (U.S. Army COE, 2006)

1.1 OBJECTIVE

The objective of these guidelines is to provide a practical approach to implementing a building siting evaluation for process plant buildings in accordance with API RP-752 and RP-753. Note that API RP-752 and RP753 provide the process by which building siting evaluations are conducted for permanent and portable buildings, respectively. However, these recommended practices do not provide the technical methods needed to conduct a building siting evaluation.

API RP-752 now requires a building siting evaluation of all permanent buildings intended for occupancy that are located on sites covered by the OSHA PSM regulation (29 CFR 1910.119). The analysis methods described in this book are not limited to U.S. OSHA PSM covered facilities and can be used for any buildings an owner/operator wishes to evaluate; in fact, other countries may have regulatory requirements that differ from the U.S. This book is applicable to on-shore facilities and does not address circumstances that exist in offshore installations. API RP-753 has similar requirements for detailed analysis of portable buildings unless a portable building is sited beyond a distance determined by a conservative simplified analysis method for vapor cloud explosions (VCE). Even the API RP-753 simplified method requires site-specific data in terms of process unit congested volume to calculate the siting distance.

The purpose of this book is to provide the methods to address the explosion, fire and toxic impacts to process plant buildings and occupants occurring as a result of hazards associated with operations external to the building.

Discussion of the following hazards is beyond the scope of this book:

- natural hazards;
- terrorist attack;
- fire and toxic impacts to off-site personnel and on-site personnel in open areas or within non-building structures; and
- secondary or "knock-on" effects that develop relatively slowly, allowing sufficient time for personnel to evacuate buildings.

1.2 BUILDING SITING EVALUATION PROCESS

This book is organized around the overall building siting evaluation process in API RP-752 as depicted in Figure 1.2. Readers are encouraged to read this entire guideline before starting or revising a building siting evaluation. Chapter numbers that provide guidance for each step are shown in parentheses.

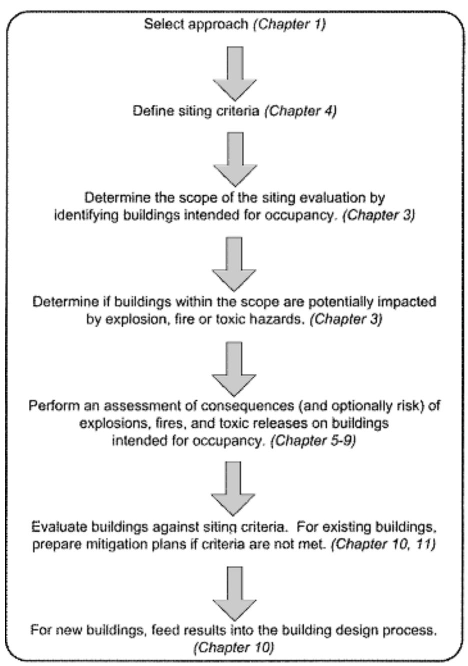

Figure 1.2. Overall Process for a Building Siting Evaluation

1.3 SELECTION OF APPROACH

The building siting process begins with selection of the approach that will be followed. The approach may be consequence-based or risk-based as explained in Chapter 2, Section 2.1.3. A consequence-based methodology does not include consideration of the frequency with which an explosion, fire or toxic scenario may occur; rather, the analysis is limited to computation of the damage or injury that may result from the postulated scenario. Risk-based analysis considers a range of scenarios and incorporates the frequency associated with each scenario. The risk to occupants of buildings is the sum of the risk posed by all of the scenarios impacting the building.

1.4 BACKGROUND

Prior accidents have prompted improvements to the approach to address risks to process plant buildings and their occupants. Table 1.1 provides a selected list of serious incidents involving buildings in process plants. A significant percentage of the fatalities occurred in buildings for the incidents shown in Table 1.1.

Table 1.1. Selected Accidents Involving Buildings in Process Plants

Date	Location	Fatalities	Description
1996	Cactus, Chiapas Mexico	7 (2 in buildings)	Liquefied petroleum gas (LPG) was released during maintenance when a valve was opened before flanges were bolted tight. The flammable cloud filled one liquefaction unit and half of the neighboring unit.
2001	Toulouse, France	29 (28 on-site, one off-site)	Off spec ammonium nitrate in prill form detonated in a large bulk warehouse. Approximately 400 metric tons of product were in the warehouse on the day of the explosion.
1993	Port Neal, Iowa	4 (none in buildings)	An ammonium nitrate (AN) reactor in a temporary shutdown suffered a runaway reaction. The AN plant was destroyed and numerous tanks were compromised by airblast and fragments. Fatalities resulted from ammonia and nitric acid vapor inhalation.
2007	Jacksonville Florida	4 (2 in a building)	A runaway reaction of a batch of methylcyclopentadienyl manganese tricarbonyl caused the reactor to burst, A loss of sufficient cooling lead to uncontrolled pressure and temperature. The contents ignited after the reactor burst.
1992	La Mede, France (Heller, 1993)	6 (most in buildings)	A liquefied petroleum gas (LPG) leak in the gas concentration section of a catalytic cracking unit resulted in an explosion that destroyed the unit and demolished the adjacent control room.

Table 1.1., Continued

Date	Location	Fatalities	Description
1992	Castleford, England (HSE, 1994)	5 (5 in buildings)	Heat-sensitive and unstable nitrotoluene residue was overheated during the preparation for maintenance. A runaway reaction caused a jet flame that destroyed a wooden control room.
1988	Norco, Louisiana (Hagar, 1988)	7 (6 in buildings)	A corrosion-induced propane leak in a fluid catalytic cracking unit resulted in an explosion that destroyed the control room. Six fatalities occurred in or near the control room; the seventh was caused by a falling brick wall.
1978	Texas City, Texas (Davenport, 1986)	7 (unknown number in buildings)	An isobutane storage sphere was overfilled and overpressured during a pipeline transfer operation. The sphere cracked at a defective weld, releasing isobutane. The release subsequently ignited and flashed back to the sphere. The sphere then failed catastrophically, resulting in a large fireball. Multiple BLEVEs of adjacent LPG storage vessels followed. Isolated glass breakage occurred as far as 2 mi (3.2 km) from the facility. A masonry control house less than 260 ft (80 m) away was destroyed by a missile fragment.
1978	Denver, Colorado (Lenoir, 1993; Garrison, 1988)	3 (0 in buildings)	A propane release at a polymerization unit in a process plant resulted in a blast that destroyed the process unit. The blast-resistant control house, located only 98 ft (30 m) from the blast center, sustained little damage.
1975	Beek, The Netherlands (Marshall, 1987)	14 (6 in buildings)	A propylene leak resulted in an explosion that caused severe blast and fire damage to the control house. All controls and plant records were lost.
1970	Linden, New Jersey (Lenoir, 1993; Garrison, 1988)	0	A 2,500 psig (170 bar) reactor of a hydrocracking unit failed explosively due to localized overheating. The blast caused widespread damage over a 900-ft (275-m) radius, including an adjoining unit, where the roof of a nearby building collapsed. Other units were safely shut down from a blast-resistant control building, which sustained minor damage.
1966	Montreal, Quebec (Garrison, 1988)	9 (all in or near buildings)	A release of styrene from a polymerization reactor through a rupture disk and/or a failed sight glass formed a vapor cloud inside and outside the building housing the reactor. The subsequent explosion demolished the three-story reactor building, and a warehouse, guard house, and garage were destroyed by fire. Six other buildings were also damaged.

However, as indicated by the accidents in Denver, Colorado, and Linden, New Jersey, proper design and siting of occupied buildings can substantially reduce the risks of fatality.

For accidents affecting process plant buildings, the potential for serious or fatal injury to building occupants is the foremost concern. Additionally, in cases where buildings house critical controls or equipment, proper design and siting may also help reduce indirect safety impacts (e.g., due to loss of process control or emergency response capability), as well as business interruption costs and property loss from such events.

The following case histories further illustrate the risks to building occupants in structures not designed to be blast resistant and the ramifications of these incidents on changes to regulations and industry standards.

1.4.1 Flixborough, UK: Vapor Cloud Explosion in Chemical Plant

On June 1, 1974, a cyclohexane vapor cloud was released after the rupture of a pipe bypassing a reactor. HSE described the vapor cloud explosion that occurred in the reactor section of the caprolactam plant of the Nypro Limited, Flixborough Works (HSE, 1975). The Flixborough Works is situated on the east bank of the River Trent (Figure 1.3). The nearest villages are Flixborough (800 meters or one-half mile away), Amcotts (800 meters or one-half mile away), and Scunthorpe (4.9 km or approximately three miles away).

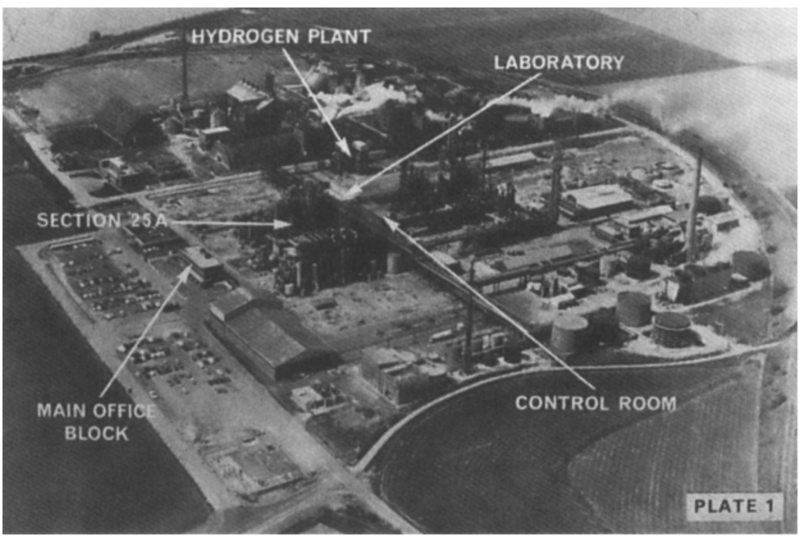

Figure 1.3. Flixborough Works Prior to the Explosion

The cyclohexane oxidation plant contained a series of six reactors. The reactors were fed by a mixture of fresh cyclohexane and recycled material. The reactors were connected by a pipe system, and the liquid reactant mixture flowed from one reactor into the other by gravity. Reactors were designed to operate at a pressure of approximately 9 bar (130 psi) and a temperature of 155°C (311°F). In March 1974, one of the reactors began to leak cyclohexane, and it was, therefore, decided to remove the reactor and install a bypass. A 0.51 m (20 in) diameter bypass pipe was designed and installed by plant personnel to connect the two flanges of the reactors. Bellows originally present between the reactors were left in place. Because reactor flanges were at different heights, the pipe had a dog-leg shape.

On May 29, 1974, the bottom isolating valve on a sight glass on one of the vessels began to leak, and a decision was made to repair it. On June 1, 1974, start-up of the process following repair began. As a result of poor design, the bellows in the bypass failed and a release of an estimated 33,000 kg (73,000 lb) of cyclohexane occurred, most of which formed a flammable cloud of vapor and mist (HSE, 1975).

After a period of 30 to 90 seconds following release, the flammable cloud was ignited. The time was then about 4:53 P.M. The explosion caused extensive damage and started numerous fires. The blast shattered control room windows and caused the collapse of its roof. It demolished the brick-constructed main office block, only 25 m (82 ft) from the explosion center. Fortunately, the office block was unoccupied at the time of the incident. None of the buildings had been constructed to protect the occupants from the effects of an explosion. Twenty-eight people died, and thirty-six were injured. Eighteen of the fatalities were in the control room at the time. If the incident had occurred during a week day rather than on a Saturday afternoon, over 200 people would have been working in the main office block. The plant was totally destroyed (Figure 1.4 and Figure 1.5) in addition to damaging 1,821 houses and 167 shops and factories in the vicinity of the plant.

Figure 1.4. Aerial View of Damage to the Flixborough Works

Figure 1.5. Damage to the Office Block and Process Areas at the Flixborough Works

Sadée et al. (1976–1977) gives a detailed description of structural damage due to the explosion and derived blast pressures from the damage outside the cloud. Several authors estimated the TNT mass equivalence based upon the damage incurred. Estimates vary from 15,000 to 45,000 kg (33,000 to 99,000 lb) of TNT. These estimates were performed at a time when TNT equivalence was the predominant prediction method, which is not recommended today.

The Flixborough incident brought initial focus to the potential hazards of vapor cloud explosions and the brittle response of unreinforced masonry (block) construction buildings. Subsequently, research was undertaken in a number of countries to improved understanding of vapor cloud explosions, develop blast prediction methods, and improve design of buildings to withstand blast loads.

1.5 PHILLIPS, PASADENA, TEXAS USA: PROPYLENE HDPE UNIT VCE AND BLEVES

On October 23, 1989, an explosion and a fire occurred at the Phillips 66 Company's Houston Chemical Complex located near Pasadena, Texas. This incident was caused by an accidental release of 40,000 kg (85,000 lbs) of a mixture containing ethylene, isobutane, hexene and hydrogen in a low density polyethylene unit (Figure 1.6). In this incident, 23 persons were killed and 314 people were injured.

Figure 1.6. Phillips Pasadena Plant Prior to the Incident

An OSHA report (OSHA, 1990) described the accident. On Sunday, October 22, 1989, a contractor crew started the maintenance procedure on the valves of a high density polyethylene reactor. Polyethylene was produced in loop reactors, which were supported by tall steel frame structures (Figure 1.6). The maintenance procedure consisted of disassembling and clearing a leg that had become clogged with polyethylene particles. On Monday afternoon (October 23) at about 1:00 P.M., a release occurred when the valve upstream of the discharge leg was accidentally opened. Almost all the contents of the reactor, approximately 40,000 kg (85,000 lbs) of high reactivity materials, were dumped. A large vapor cloud formed in a few seconds and moved downwind through the plant. Within two minutes, this cloud was in contact with an ignition source and exploded with the force of 2,400 kg (5,300 lbs) of TNT.

Following this VCE, two other major explosions occurred. The second explosion occurring 10 to 15 minutes after the initial explosion and involved BLEVEs of two 75 m^3 (20,000 U.S. gal) isobutene storage tanks (Figure 1.7). The third explosion occurred 25 to 45 minutes later, which was the catastrophic failure of the ethylene plant reactor. Damage to the process unit and nearby buildings is shown in Figure 1.8.

Figure 1.7. BLEVE at the Phillips Pasadena Site

Figure 1.8. Phillips Pasadena Area Damage (Courtesy of FM Global)

The initial blast destroyed the control room and caused the rupture of the adjacent vessels containing flammable materials and the water lines. The proximity between the process equipment and the buildings contributed to the intensity of the blast. Twenty-two of the victims were found within 76 m (250 ft) of the release point, 15 of which were within 45 m (150 ft). Most of the fatalities were within buildings, but the actual number was not reported.

The Phillips Pasadena 1989 incident, along with the 1984 Bhopal, India, 1988 Shell Norco, 1987 Arco Channelview, and 1989 Exxon Baton Rouge incidents, triggered the U.S. Congress to enact the Clean Air Act of 1990 with a requirement for both OSHA and EPA to develop process safety regulations. OSHA promulgated their standard first in 1992 as Process Safety Management (PSM) for Highly Hazardous Chemicals (29 CFR 1910.119) followed in 1996 by the EPA producing Section 112(r) of the Clean Air Act (CAA), which requires documentation of a site Risk Management Plan (RMP).

1.5.1 BP, Texas City, Texas USA: Discharge from Atmospheric Vent Resulting in a VCE

On March 23, 2005 at 1:20 P.M., an explosion and fire occurred at the BP Texas City Refinery Isomerization (ISOM) plant. In this incident, 15 people were killed and 180 were injured. During the incident, a shelter-in-place order was issued that required 43,000 people in the surrounding community to remain indoors.

According to the report by BP Products North America (Mogford, 2005) and the U.S. Chemical Safety and Hazard Investigation Board (CSB, 2007), on the morning of the accident, the raffinate splitter tower in the ISOM unit was restarted after a maintenance outage. During the procedure, the night shift charged the raffinate splitter to 100% of normal operating range (equivalent to 3.1 m [10 ft 3 inches]) height above the bottom tangent line in the 50 m (164-ft) tall tower and stopped flow. The day shift resumed pumping raffinate into the tower for over three hours without any liquid being removed, introducing an additional 397 m^3 (105,000 U.S. gal). As a consequence, the tower was overfilled, and the liquid overflowed into the overhead pipe at the top of the tower. The pressure relief valves opened at about 1:14 P.M. for 6 minutes and discharged an estimated 175 m^3 (46,000 U.S. gal) of flammable liquid to a blowdown drum with a vent stack open to the atmosphere. This blowdown drum overfilled after about 4½ minutes, which resulted in a geyser-like release that reached 6 m (20 ft) above the top of the stack at about 1:18 P.M. An estimated 8 m^3 (2,000 U.S. gal) of the hydrocarbon liquid overflowed from the blowdown drum stack. The flammable cloud was predominately on the west side of the unit to the south of the release point; the flammable cloud did not reach the eastern leg of the ISOM unit.

The vapor cloud was ignited at about 1:20 P.M. by an undetermined ignition source. A diesel pickup truck by the road on the north side of ISOM was observed to have its engine racing, and was a high potential ignition source.

In the explosion, 15 workers in or near trailers sited to the west of the ISOM unit were killed. Three occupants in a single-wide trailer perished, and 12 of 20 workers inside a double-wide trailer were killed; the others were seriously injured. Trailer locations are shown in Figure 1.9. Debris from the destroyed double-wide trailer is shown in Figure 1.10. The temporary office trailers were light wood construction. The cause of death for all 15 was blunt force trauma, probably resulting from being struck by structural components of the trailers. A total of 180 workers at the refinery reported injuries.

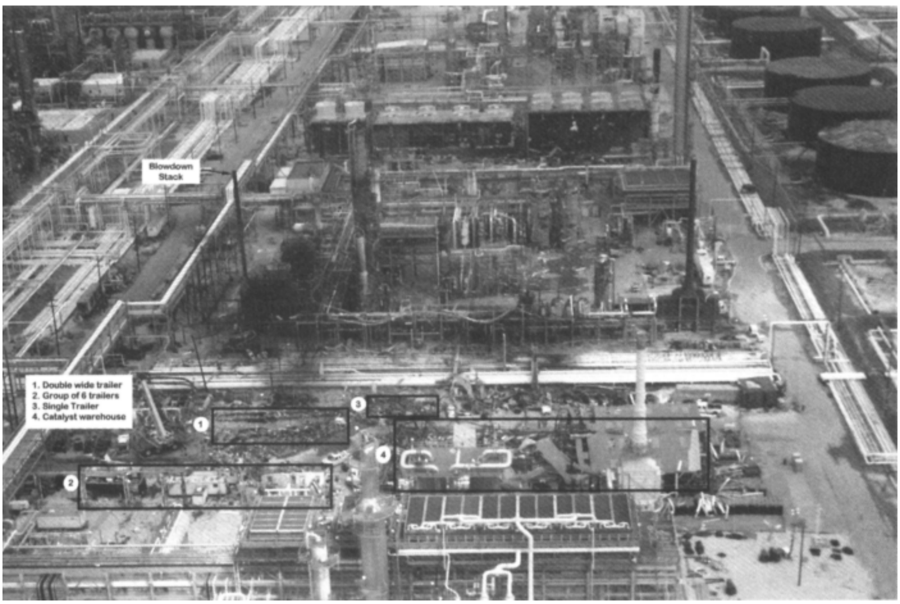

Figure 1.9. Aerial View of the ISOM unit after the Explosion (CSB, 2007)

The trailers were placed about 46 m (150 ft) west of the blowdown stack in the open area next to a pipe rack that was about 1 m (3 ft) above grade. The pipe rack provided congestion between the western edge of the ISOM unit and the trailers. The flammable cloud extended west past the pipe rack and trailers, resulting in the trailers adjoining a congested area that was involved in the VCE.

Figure 1.10. Destroyed Trailers West of the Blowdown Drum (arrow in upper left of the figure)

The BP Texas City incident showed the conventional office trailers were not as strong as previously believed and should not be sited near process units with potential explosion hazards. Portable buildings are often sited for convenience for temporary operations, such as turnarounds, and for permanent staff who need expedient work locations. Siting of portable buildings needs to consider all surrounding hazards, not just the hazards of the operations with which the portable buildings are associated. Industry response to CSB's urgent recommendation was the development of API RP-753, the first guideline that explicitly addressed siting of portable buildings.

1.5.2 Hickson & Welch Ltd, Castleford, UK; Jet Fire

On September 21, 1992 at 1:20 PM, a jet fire occurred at the Hickson & Welch Ltd. Chemical plant in Castleford, UK. The jet severely damaged a control room and impacted a more distant main office block. Five people died, all of whom were located in buildings.

The incident occurred during clean out of a batch still to remove residues. The batch still was part of the nitrotoluenes area of the plant. This vessel, shown in Figure 1.11, had never been cleaned since it was installed in 1961. The sludge was estimated to have a depth of 34 cm (14 in). The sludge was tar-like with the consistency of soft butter and had entrained liquid. The sludge was not analyzed nor was the atmosphere checked for flammable vapors. It was mistakenly thought that the material was a thermally stable tar. The investigation later revealed that the sludge contained flammable dinitrotoluene and nitrocresols, and covered one of the vessel's steam heating elements.

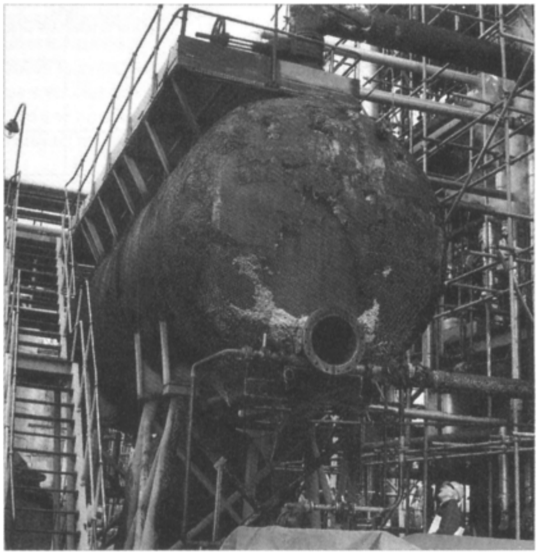

Figure 1.11. Vessel Involved in the Hickson & Welch Incident

Steam was applied to the bottom heating element to soften the sludge, with the temperature not to exceed 90°C. The clean out operation was started using a metal rake through an open manhole at one end of the vessel (see Figure 1.11). After about one hour, a longer rake was used to reach further into the vessel. Once the vessel's temperature gauge in the control room was reported to be reading 48 °C, instructions were given to isolate the steam.

At approximately 1:20 PM, a number of employees involved in the raking left the base of the vessel. One person left on the scaffold had stopped raking. He noticed a blue light, which turned instantly to an orange flame. As he leapt from the scaffold, an incandescent conical jet erupted from the manhole. This jet projected horizontally over 50 m, breaching and passing through the plant control building into the main office block. A second, vertical jet of burning vapors shot out of the top rear vent to the height of the distillation column nearby.

Investigations suggested that the sludge decomposed in an exothermic reaction that produced enough heat to ignite the vapors in the tank. The jet fire lasted for approximately one minute before subsiding. The force of the jet destroyed the scaffold, threw the manhole cover into the control building, and severely damaged this building and then impacted the main office block causing a number of fires to start inside the building. Damage to the control room and office block are shown in Figure 1.12 and Figure 1.13.

All of the casualties were located in the control building and main office block. Two of the five people in the control building died at the scene. Two others in the control room were badly burned and died later in hospital. The fifth victim, located in the main office, died of smoke inhalation.

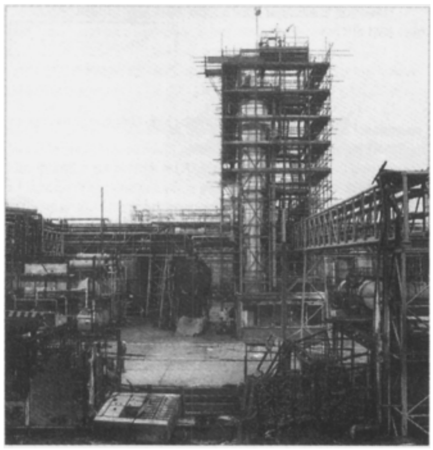

Figure 1.12. Damage to the Control Building from the Jet Flame at Hickson & Welch

Figure 1.13. Damage to the Control Room and Impact on the Office Block from the Jet Flame at Hickson & Welch

1.6 EVOLUTION OF DESIGN AND SITING PRACTICES FOR BUILDINGS IN PROCESS PLANTS

Chemical process design and controls have often dictated the design and siting of buildings. This section contains a brief review of industry practices on the design and siting of process plant buildings.

1.6.1 Brief History of Building Designs

As process plant designs and management practices have evolved, building functions and locations have changed to reflect the new operating requirements, often leading to an increase in the number of buildings and personnel that were in or near the process units. For example, control facilities have typically been located within or adjacent to the process plants to provide effective control. Other buildings, such as maintenance facilities, are also sometimes located adjacent to process plants to allow prompt support of operations.

In *continuous-process* industries such as petroleum refining, petrochemicals, industrial chemicals, and fertilizers, the siting and size of buildings have been influenced by factors such as the following (Marshall, 1987):

- Increased unit capacities resulted in larger equipment. These units could no longer be enclosed in buildings.
- Outside location of process units or equipment required separate control buildings. Initially, their function was limited to displaying process variables. World-scale, single-train units, coupled with advances in automation, led to the use of servomechanisms for valve plug positioning.
- Signal transmission limitations of pneumatic control systems made it necessary to limit the distance between the control house and the transmitter or control valve. As a result, early control houses were located within or at the periphery of the process unit.
- The development of electronic and/or computer controls made it possible to control several process units from a centralized control center, leading to continued concentration of equipment and personnel in control rooms.
- Support services such as administration, engineering, and laboratory functions were moved closer to process units to facilitate operations. These functions were often located in the control center or in separate buildings adjacent to process areas.

Also, many batch processes, such as those in the specialty chemical industry (e.g., pharmaceuticals, paints, and plastic end-products), have typically located the control and support functions adjacent to the process. In a typical arrangement, the process plant building contains all or most of the process, with the control function frequently housed in a centrally located room within the plant building or an adjacent building.

1.6.2 Standards for Building and Equipment Siting and Separation

Many companies, as well as industry insurers, trade associations, and standards organizations, have developed specific criteria for spacing between plants, buildings, equipment, and property lines. These criteria were meant to reduce the impact of explosions or fires on major equipment and facilities, including adjacent units and buildings.

The wide ranges in spacing criteria are available from various organizations including CCPS, NFPA, API, IRI, and FM Global. For example, the spacing between control houses and process units ranges from 50 to 1200 ft (15 to 365 m), reflecting the diversity of potential hazards as well as the different objectives of the various organizations that developed the criteria. In general, insurance industry standards are designed to protect property and minimize business interruption in the event of an incident. NFPA standards are designed to prevent the occurrence of a fire and reduce the spread of fire to adjacent structures. Individual company or trade association standards may attempt to address both of these objectives as well as personnel safety. Due to the large variations in the types of processing facilities, materials handled, and objectives (i.e., equipment protection versus personnel protection), no single spacing standard is appropriate for all applications.

1.6.3 Standards and Criteria for Building Design, and the Need for Site-Specific Evaluation

Design guidelines for buildings in process plants have also evolved over the years in response to major incidents. These guidelines typically specify the desired building response to design criteria blasts, such as those resulting from a TNT detonation or a vapor cloud explosion of an assumed size and distance from an occupied building. A specific standard, for example, might specify that a building be designed to withstand a blast equivalent of 1 ton (900 kg) of TNT at 200 ft (61 m) from the blast source. Another standard might require that a building be designed for a 3 psi (0.21 bar) positive blast overpressure, 1 psi negative pressure, and 100 ms duration for a vapor cloud explosion hazard.

Many of these building design and siting criteria are based upon broad plant design guidelines and not upon an evaluation of specific materials, release conditions, or plant geography. While effective in many applications, this approach can lead to designs that are overly conservative in some instances or that fail to provide the desired degree of protection in other instances. The approach proposed by this book allows the use of appropriate building design and siting standards that have evolved over the years and takes into account site-specific conditions. These include an evaluation of the materials being handled, process conditions, building location and occupancy, building design and materials of construction, and effectiveness of process safety management systems.

The proposed approach in these guidelines allows process plant owners and operators to assess their sites and plant buildings based on these site-specific conditions. This allows building design and siting issues to be managed at the local level without imposing prescriptive standards that may not be appropriate to a specific facility. This approach has the overall result of providing informed, cost-effective management of the risks associated with buildings in process plants.

1.7 ORGANIZATION OF THE BOOK

The book is organized around the building siting process depicted in Figure 1.2. An overview of the entire process is provided for management in Chapter 2, with emphasis on the role of management in the process. Chapter 3 addresses inclusion or exclusion of buildings; both permanent and portable, in a building siting evaluation. Managers involved in company risk management and subject matter experts are the intended audiences for Chapter 3. Chapter 4 presents building siting criteria, which is technical material for subject matter experts.

Chapters 5, 6 and 7 present hazard assessment methodologies for explosions, fires and toxic material releases, respectively. Consequence analysis subject matter experts are the audience for these chapters.

Risk analysis is presented in Chapters 8 (Frequency Assessment) and 9 (Risk Assessment). Subject matter experts in risk analysis are the audience for these chapters.

Chapter 10 addresses mitigation plans and risk reduction strategies, as well as the need for an ongoing process to manage occupancy and building in addition to any changes that may trigger management of change (MOC). Subject matter experts and managers are the audiences for Chapter 10.

Chapter 11 addresses documentation of a building siting evaluation.