# Management of Hazards Associated With Location of Process Plant Buildings

API RECOMMENDED PRACTICE 752
CMA MANAGER'S GUIDE, FIRST EDITION, MAY 1995

Responsible Care®
A Public Commitment

STEP
*Strategies for Today's Environmental Partnership*

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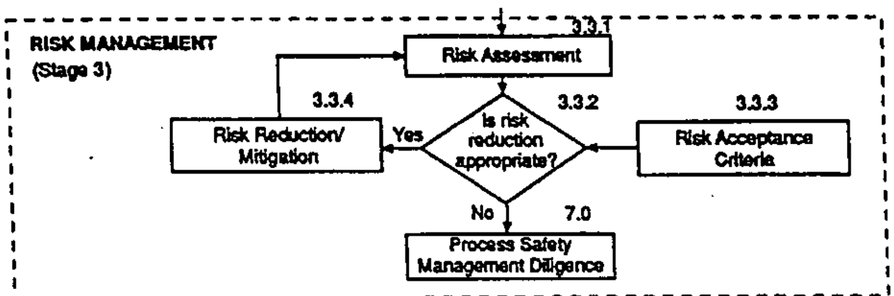
## ERRATA

*On Page 5, in Figure 2, the paragraph references have been added to the Stage 3 box. The Stage 3 box should appear as follows:*




*On Page 21, Item d in C.1.1 should read as follows:*

> d. B4: Steel or concrete framed with unreinforced masonry infill or cladding.

*On Page 21, the first line of Item d in C.1.2 should read as follows:*

> d. *Steel or concrete framed with unreinforced masonry infill or cladding*, B4: ...

# Responsible Care®
## A Public Commitment

In 1988, the Chemical Manufacturers Association (CMA) launched Responsible Care® to respond to public concerns about the manufacture and use of chemicals. Through Responsible Care®, member companies are committed to supporting a continuing effort to improve the industry's responsible management of chemicals.

Responsible Care® has ten key elements:

- The Guiding Principles—the philosophy of Responsible Care®—outline each member company's commitment to environmental, health, and safety responsibility in managing chemicals.
- Six Codes of Management Practices, which are the heart of Responsible Care®, outline practices that cover virtually every aspect of chemical manufacturing, transporting, and handling.
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- Responsible Care® is an Obligation of Membership in CMA.

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One of the most significant long-term trends affecting the future vitality of the petroleum industry is the public's concerns about the environment. Recognizing this trend, API member companies have developed a positive, forward looking strategy called *STEP: Strategies for Today's Environmental Partnership*. This program aims to address public concerns by improving industry's environmental, health, and safety performance; documenting performance improvements; and communicating them to the public. The foundation of STEP is the API Environmental Mission and Guiding Environmental Principles. API standards, by promoting the use of sound engineering and operational practices, are an important means of implementing API's STEP program.

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- To make safety, health, and environmental considerations a priority in our planning and our development of new products and processes.
- To advise promptly the appropriate officials, employees, customers, and the public of information on significant industry-related safety, health, and environmental hazards, and to recommend protective measures.
- To counsel customers, transporters, and others in the safe use, transportation, and disposal of our raw materials, products, and waste materials.
- To economically develop and produce natural resources and to conserve those resources by using energy efficiently.
- To extend knowledge by conducting or supporting research on the safety, health, and environmental effects of our raw materials, products, processes, and waste materials.
- To commit to reduce overall emissions and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations, and standards to safeguard the community, workplace, and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport, or dispose of similar raw materials, petroleum products, and wastes.

# Management of Hazards Associated With Location of Process Plant Buildings

API Health and Environmental Affairs Department
CMA Regulatory Affairs Department

API RECOMMENDED PRACTICE 752
CMA MANAGER'S GUIDE, FIRST EDITION, MAY 1995

CHEMICAL MANUFACTURERS ASSOCIATION

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American Petroleum Institute

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## FOREWORD

This publication is intended to assist management in identifying process plant buildings of concern, understanding the associated hazards, and managing the risk. The hazards that normally can affect the occupants of buildings include fire, explosion, and toxic releases. This publication provides a methodology for assessing and evaluating the hazards associated with location of process plant buildings.

This publication is based on the fact that serious accidental releases of toxic material or an explosion that impacts occupied process plant buildings are not frequent events. Additionally, preventing incidents in process plants is generally a better investment in safety than providing mitigation systems or redesigning process plant buildings. The implementation of process safety management, as described in API Recommended Practice 750 and the Chemical Manufacturers Association's (CMA) Process Safety Code, is intended to improve industry's safety performance. Risk management involves cost-effective applications of risk-reduction alternatives.

Because this publication affects many existing buildings within processing facilities, a substantial effort may be required for full implementation of the recommended practice. This could include identifying buildings of concern, conducting building evaluations, and, if appropriate, performing building upgrades or modifications. It is recognized that a substantial period of time may be required for complete application of the recommended practice, due to the scope and magnitude of the endeavor.

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Suggested revisions are invited and should be submitted to the Director, Health and Environmental Affairs Department, American Petroleum Institute, 1220 L Street, N.W., Washington, DC 20005 or Process Safety Task Group, Chemical Manufacturers Association, 2501 M Street, N.W., Washington, DC 20037.

# CONTENTS

Tables

# Management Of Hazards Associated With Location Of Process Plant Buldings

## SECTION 1—GENERAL

### 1.1 Purpose

This publication (RP 752) provides guidance for identifying hazards that may affect process plant buildings and for managing risks related to those hazards. An analysis process set forth in this Recommended Practice provides a structured approach that can maximize worker safety by the following:

a. Continuing to improve the understanding of identified hazards.
b. Continuing to focus on accident prevention and addressing identified hazards.
c. Managing risk.

The methodology recommended in this document will help provide the user with an understanding of the relative risk of each building studied. This relative.risk should be considered in long-range planning and projects that involve building changes (such as control building consolidation, office building replacements, and so forth).

### 1.2 Scope

#### 1.2.1 APPLICABILITY

This publication was developed for refineries, petrochemical and chemical operations, natural gas liquids extraction plants, and other facilities covered by API RP 750 or the Chemical Manufacturer Association's *Process Safety Code*. This publication does not apply to production facilities surrounded by navigable waters, such as offshore platforms. Such facilities have unique siting issues which are addressed by other recommended practices, such as RP 14J.

Additionally, this publication is not intended for use in designing and locating safe refuge from the effects of fires, explosions, and toxic releases.

#### 1.2.2 RELATIONSHIP OF THIS RECOMMENDED PRACTICE TO OSHA 29 CFR 1910.119

OSHA 29 *Code of Federal Regulations* (CFR) 1910.119, "Process Safety Management of Highly Hazardous Chemicals (PSM)," includes requirements for addressing facility siting as part of a process hazards analysis (PHA).

This publication is intended to assist in identifying the siting issues for process plant buildings, understanding the associated hazards, and managing the risk. Hence, this publication provides a framework that can be used to address facility siting within the PHA requirements of OSHA 29 CFR 1910.119 as applied to buildings.

The PHA as required by OSHA 29 CFR 1910.119 is intended to identify scenarios that could lead to serious release of toxic or flammable materials or an explosion. Those parts of this publication intended to assist in the PHA process are identified on the flowcharts (see Figures 2, 4, and 5) by a dashed-line box labeled "PHA." The remaining parts are intended to serve as management aids in resolving issues that arise when evaluating the location of process plant buildings.

### 1.3 Definitions

For the purpose of this publication, the following defintions apply:

**1.3.1** *Aggregate risk* is a measure of the total risk to all personnel within a building(s) or within a facility, depending upon the risks being evaluated, who are impacted by a common event, taking into account the total time spent in the building(s) or facility.

**1.3.2.** *Assessment* describes a detailed qualitative or quantitative analysis to estimate the potential likelihood and consequences of site-specific events, and to then compare the results with acceptance criteria.

**1.3.3** *Confinement* is a qualitative or quantitative measure of the enclosure or partial enclosure areas where a vapor cloud may be contained.

**1.3.4** *Congestion* is a qualitative or quantitative measure of the physical layout, spacing, and obstructions within a facility that promote development of a vapor cloud explosion.

**1.3.5** An *evaluation-case event* is the scenario with the most severe consequences, considering all incidents and their outcome, that is considered plausible or reasonably believable.

**1.3.6** *Evaluation* describes the application of analytical tools to aid in making decisions about buildings.

**1.3.7** A *hazard* is an inherent physical or chemical characteristic that has the potential for causing harm to people, property, or the environment.

**1.3.8** *Individual risk* is the risk to a single person inside a particular building. Maximum individual risk is the risk to the most-exposed person and assumes that the person is exposed.

**1.3.9** A *process plant building* (also referred to in this recommended practice as a *building*) is any temporary or permanent building within a facility that could be impacted by a serious release from a process covered by OSHA 29 CFR 1910.119.

**1.3.10** *Risk* is a measure of potential economic loss or human injury in terms of both the incident likelihood and the magnitude of the loss or injury.

**1.3.11** *Screening* describes a process of comparing the site-specific materials and process conditions, and building occupancy with pre-established criteria of concern.

## 1.4 Referenced Publications

The following guidelines, standards, codes, and specifications are cited in this publication:

AIChE[1]

*Dow Chemical, Fire and Explosion Index Hazard Classification Guide*, 7th ed.

*Guidelines for Chemical Process Quantitative Risk Analysis*, Center for Chemical Process Safety of AIChE

*Guidelines for Evaluating Process-Plant Buildings for External Explosion and Fire*, Center for Chemical Process Safety of AIChE, Work-in-progress

*Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions*, Flash Fires, and BLEVEs, Center for Chemical Process Safety

*Guidelines for Hazard Evaluation Procedures, 2nd ed.*, Center for Chemical Process Safety of AIChE

*Guidelines for Technical Management of Chemical Process Safety*, Center for Chemical Process Safety of AIChE

*Guidelines for Use of Vapor Cloud Dispersion Models*, Steven R. Hanna and Peter J. Drivas, Center for Chemical Process Safety of AIChE

*Plant Guidelines for the Technical Management of Chemical Process Safety*, Center for Chemical Process Safety of AIChE

API

RP 14J *Recommended Practice for Design and Hazard Analysis for Offshore Production Facilities*

RP 750 *Management of Process Hazards*

CMA[2]

*A Resource Guide for the Process Safety Code Management Practice*

ICI[3]

*The Mond Index*, 2nd ed.

OSHA[4]

29 *Code of Federal Regulations*, Section 1910.119

*The Effects of Nuclear Weapons*, rev. ed., Samuel Glasstone, Editor, Prepared by the U.S. Department of Defense, published by U.S. Atomic Energy Commission

[1]American Institute of Chemical Engineers, 345 East 47th Street, New York, New York 10017.

[2]Chemical Manufacturers Association, 2501 L Street, NW, Washington, DC 20037.

[3]Imperial Chemical Industries PLC, Explosion Hazards Section, Technical Department, Winnington, Northwich, Cheshire CW8 4DJ, U.K.

[4]Occupational Safety and Health Administration, U.S. Department of Labor. The Code Of Federal Regulations is available from the U.S. Government Printing Office, Washington, D.C. 20402.

# SECTION 2—MANAGEMENT OVERVIEW

## 2.1 Hazards to Occupants of Process Plant Buildings

### 2.1.1 FLAMMABLE MATERIALS

Flammable materials, if ignited, can expose buildings to radiant heat from either a flash, jet, pool fire, or fireballs. Additionally, some flammable materials can form vapor cloud mixtures in air, and if delayed ignition occurs and certain site conditions (discussed below) are present, a vapor cloud explosion (VCE) can occur. Depending on the magnitude of the explosion, and the location and specific construction details of the building, the explosion can cause varying degrees of risk to building occupants.

### 2.1.2 TOXIC MATERIALS

Occupants of process plant buildings can be exposed to toxic materials if such material enters the building. The dispersion properties of the toxic material involved, the release conditions, and the toxicity of the substance are some of the factors that should be considered when evaluating the potential for toxic effects on building occupants from intrusion of toxic materials. The building's ability to resist toxic materials ingress should also be considered.

### 2.1.3 OTHER PROCESS MATERIALS

Some process materials pose potential risk from runaway reactions or chemically or thermally induced decomposition. Events involving these materials may produce explosion effects, toxic releases, fire, and projectile hazards to process plant building occupants.

### 2.1.4 EXTREME PROCESS CONDITIONS

Extreme process conditions, such as high temperature or pressure, can pose hazards even when the process materials, at ambient conditions, might otherwise be innocuous. For example note the following:

a. *Compressed gases*—Failure of vessels containing high pressure gases can result in the explosive expansion of the gases, producing damaging blast waves.

b. *Boiling liquid expanding vapor explosions (BLEVES)*—Liquids stored well above their atmospheric boiling points can evaporate at explosive rates if depressurized by the failure of the containment vessel. As with compressed gases, expansion of the resultant vapor can produce blast waves. Additionally, flammable materials, if ignited, can produce fireballs.

c. *Hot materials*—Rapid combination of a hot material and a cold material can lead to the explosive vaporization of the colder material. Damaging explosions have resulted, for example, from the addition of water to vessels containing hot oil and from the addition of molten metals to water.

#### 2.1.5 FACTORS INFLUENCING EVENTS

Some factors that can determine the type of, or affect an event that may occur include the following:

a. *Inherent properties of the process material*—These include variations in flammability ranges, dispersion properties, flame propagation properties (refer to Appendix B for a discussion of the characteristics of explosions, toxicity, and chemical and thermal stability).

b. *Release conditions*—These include process conditions such as pressures and temperatures, as well as the release rate and location of the release. For example, a pressurized release of a gas or vapor, if ignited immediately, can lead to a jet fire. A release of material at cryogenic conditions might produce a heavier-than-air vapor cloud, even if the substance is lighter than air at ambient conditions.

c. *Other site-specific conditions*—For releases that form vapor clouds with subsequent ignition, a key factor influencing the development of overpressure is the degree of premixing with air and the acceleration of the flame front that results from turbulence generated during combustion. Turbulence can be caused by the release conditions, meteorological conditions, or the physical layout of the release area. A flame front passing through congested areas containing obstacles, such as process plant equipment and structures, can generate turbulence in the unburned portion of the vapor cloud, leading to significant increases in flame speed and resulting overpressure. Confinement is another site-specific condition that affects the development of overpressure. Releases occurring in open areas, with no congestion or obstructions, generally do not develop significant overpressure upon ignition.

d. *Process design and control*—These factors include inventory reduction, process controls, process alarms and interlocks, shutdown systems, redundancies, and mitigation systems.

e. *Emergency response*—The response in an emergency, such as operator intervention, evacuation, emergency team response, and so forth, can impact the event outcomes.

f. *Process safety management system*—Includes policies, programs, procedures, training, audits, and other elements intended to assure that processing plants are designed, constructed, operated, and maintained in a manner that reduces the potential for serious accidents. Examples include equipment and piping inspection programs, personnel training, safe work practices (for example, lockout/tagout and hot work permit), management of change, and operating procedures.

## 2.2 Process-Plant Building Issues of Concern

Process conditions vary from facility to facility. The factors indicated in Section 2.1 may influence the likelihood or severity of an event depending on the facility being evaluated. At the same time, there are wide variations in building design, construction, function, occupancy, and location. Therefore, evaluating the risks to building occupants may require assessing a wide range of situations. Some buildings may be identified as having minimal risk for occupants and will require no further action. However, some evaluations may indicate that risk-reduction measures should be taken. Depending upon the results of the evaluation, a variety of options may be available, including the following:

a. Process changes to reduce inventories or eliminate materials of concern.

b. Preventive measures that reduce the likelihood of possible releases.

c. Installation of mitigation systems.

d. Building structural upgrades to withstand the predicted effects of fire, explosion, or toxic releases.

## 2.3 Overview of Analysis Process

### 2.3.1 EXPLOSIONS

Section 3 of this publication outlines a three-stage analysis process for identifying hazards and managing risk to building occupants from explosions, as shown in Figures 1 and 2.

The staged approach is used to systematically identify and evaluate buildings in which occupants may be at risk. As the user progresses through the stages, the analysis becomes more complex because the site-specific information is developed in more detail. If the user determines during any stage of the analysis that there are no significant risks to the building occupants, then the analysis process can be ended at that point. Also, the user is not constrained to successively follow the stages of the evaluation process, but may proceed directly to Stage 2 or 3—after considering the implications of Stage 1.

Stage 1, "Building and Hazard Identification," (Section 3.1) outlines an initial identification process for select buildings for further investigation due to their proximity, to processes which have the potential for explosions and their

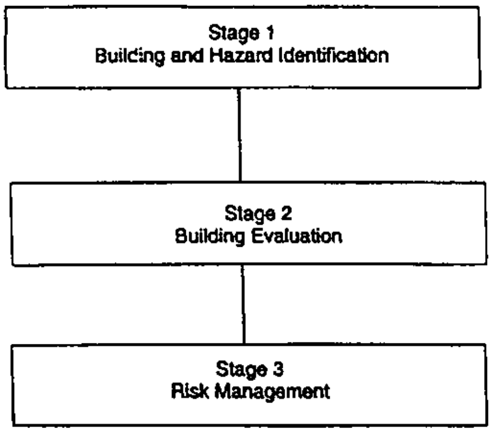



Figure 1—Stages for Explosion Risk Analysis

occupancy level. Stage 2, "Building Evaluation," (Section 3.2) outlines three approaches that can be used to evaluate potential hazards to building occupants. Any or all of the approaches may be used. Stage 3, "Risk Management," (Section 3.3) outlines the use of qualitative and quantitative risk- assessment tools to perform a more complex evaluation for buildings, coupled with proposals for reducing and controlling risk, where warranted.

### 2.3.2 FIRES AND TOXIC RELEASES

Sections 4 and 5 of this publication outline an approach for identifying risks to building occupants from fires and toxic releases. As discussed in Section 2.1, these risks depend upon various factors, including building design and emergency response plans. The analysis process for fire and toxic releases is considerably less complex than that for explosions.

## 2.4 Using This Recommended Practice

### 2.4.1 COMPANY-SPECIFIC ISSUES

This publication has been developed to allow companies flexibility in choosing their preferred analysis techniques. However, to use sections of this publication, a company may need to develop the following:

a. *Occupancy and emergency role of personnel criteria*: These are company-specific criteria that define occupancy levels within a building and the personnel role of building occupants in an emergency.
b. *Evaluation-case events*: These include the fire, explosion, and toxic release events that a company believes are plausible and realistic and may impact process plant buildings.
c. *Consequence modeling/analysis programs*: These are the programs and techniques that a company determines are to be used in evaluating the possible effects of serious releases of highly hazardous materials.
d. *Risk acceptance criteria*: These are the criteria, either qualitative or quantitative, that a company uses in making decisions about acceptable risk.

### 2.4.2 RISK REDUCTION

At any time during the evaluation process, it may become obvious that a potential hazard needs to be mitigated and the effort may proceed to risk reduction.

### 2.4.3 SCREENING, EVALUATION, AND ASSESSMENT

Throughout this publication, the terms *screening*, *evaluation*, and *assessment* are used. For the purpose of this publication, the following definitions apply:

a. *Assessment* describes a detailed qualitative or quantitative analysis to estimate the potential likelihood and consequences of site-specific events and to then compare that estimated result with acceptance criteria.
b. *Evaluation* describes the application of analytical tools to aid in making decisions about building.
c. *Screening* describes a process of comparing the site-specific materials and process conditions and building occupancy with pre-established criteria of concern.

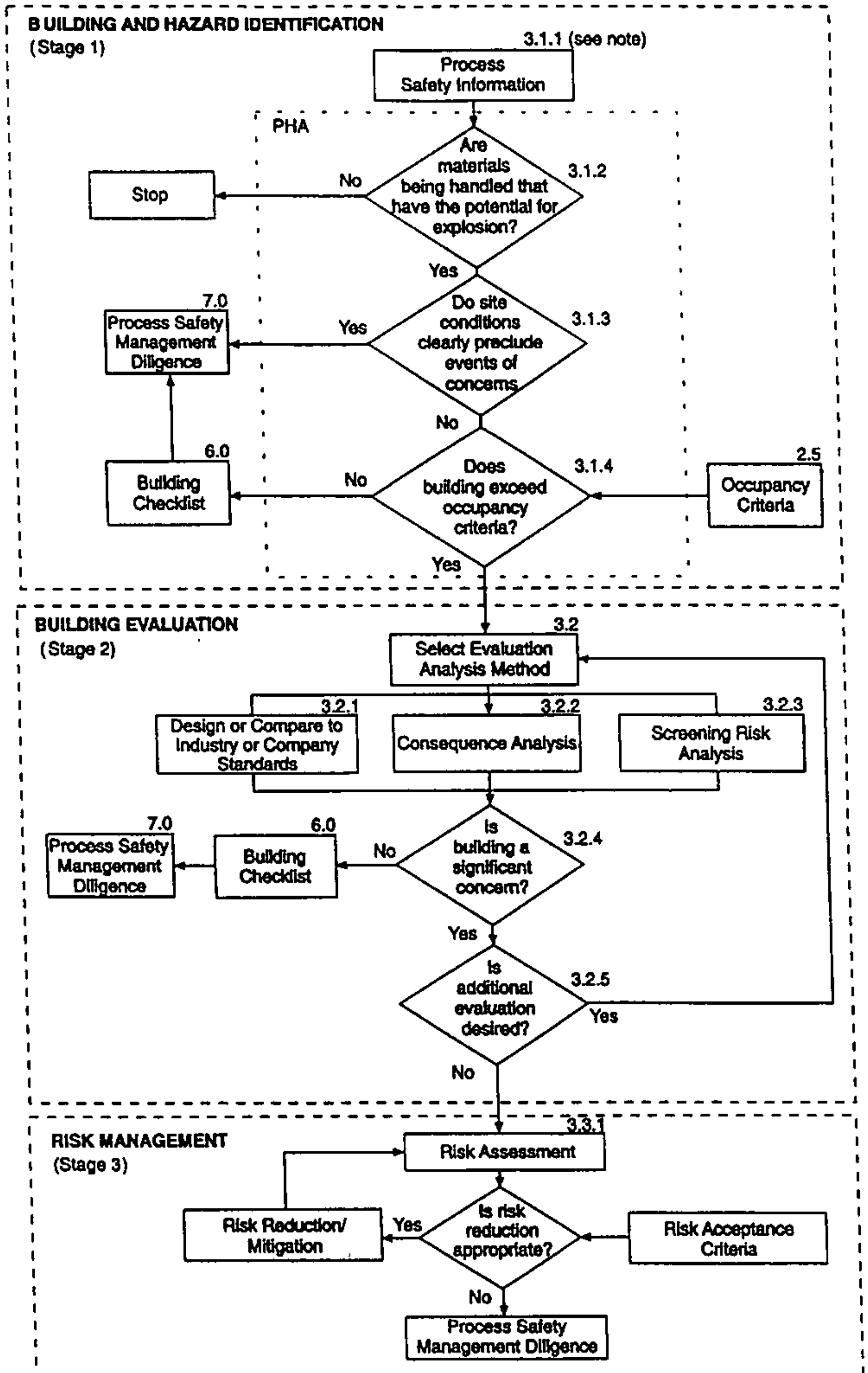
## 2.5 Occupancy and Emergency Role Criteria

This section discusses occupancy and emergency role criteria that should be determined by each company.

### 2.5.1 OCCUPANCY STRATEGY

Each company should define occupancy criteria according to its individual work environment and operating philosophy. When defining these criteria, a company should consider the following:

a. *The number of people housed in buildings located in or adjacent to process units*: Direct support personnel, such as operators, field supervisors, board operators, engineers, and maintenance personal, may have to be located in immediate areas for logistical and response purposes.
b. *Congregations of people in buildings located in close proximity to process areas*: Activities that result in an intermittent congregation of people should be considered. These may include activities involving several people whose duty station is not at the process unit, training activities for personnel who do not need access to process equipment, and activities centered around dining facilities.
c. *Personnel assigned outside the process area*: These personnel (for example, analyzer technicians, process operators, and maintenance personnel) normally have job responsibilities that must be performed primarily on unit equipment




Note: Related paragraph numbers found within text.

Figure 2—An Analysis Process for an Explosion

located outside the process area. These personnel may temporarily enter buildings near process areas (for example, operator shelters) to write reports, use the phone, or seek refuge from inclement weather.

d. *Ability to evacuate*: Buildings may provide adequate means of egress to permit evacuation. The potential events that result in fires, BLEVEs, and in some circumstances VCEs develop over a period of time. In these situations detection, alarm, and evacuation may be available, and consideration should be given to the ability to evacuate. Process materials that have the potential for runaway reactions or chemically or thermally induced decomposition may produce toxic, fire, or explosion effects with little or no warning. These circumstances will normally be discovered during a PHA, and if proper early warning cannot be provided, building evacuation may not be a viable option to mitigate the hazards.

### 2.5.2 OCCUPANCY CRITERIA

There are a number of alternative methods available for defining occupancy criteria. Each company may define its criteria based on a single method or a combination of methods in a tiered approach. Each method has unique merits. The following examples can be used singularly or in combination as a tiered approach.

a. Definition of *occupied* and *unoccupied*: A company may define qualitative criteria for occupied and unoccupied buildings. For example, occupied buildings could be defined as those that personnel occupy while doing the major part of their work, such as control rooms, laboratories, and office buildings. An unoccupied building would then be one that personnel visit infrequently to perform brief tasks or monitor the process.

b. *Occupancy load* may be defined as the total integrated time for the full- or part-time occupants in the building. In this case occupancy load would be obtained by adding the hours that each person spends in that building. The number of personnel present in the building is a function of the normal daily activities and the time of day. The occupancy load is normally expressed as the inhabited time over a specific period, based on an annual average. Some factors to consider in determining the occupancy load are as follows:

1. The routine presence of additional personnel, such as visitors, contractors, and trainees.
2. Activities performed by personnel on a routine basis, such as calibration and maintenance of instruments.

The occupancy load criteria used by some companies ranges from 200 to 400 personnel hours per week.

c. *Individual occupancy* may be defined in terms of the percentage of an individual's total time spent in a building. An occupied building may be defined as one in which one person does a significant portion of his or her work. The individual occupancy criteria used by some companies ranges from 25 percent to 75 percent.

d. *Peak occupancy* may be defined as the number of people potentially exposed for a given period (for example, a safety or toolbox meeting where operators/crafts people meet for a short period). The peak occupancy criteria used by some companies range from 5 to 40 persons.

Buildings with occupancy criteria above the company predefined occupancy criteria should be evaluated further. See Example 3 in Appendix E, which applies these criteria to hypothetical situations.

### 2.5.3 EMERGENCY ROLE

The job duties of occupants during an emergency should be considered. Buildings should be considered for further evaluation if the occupants are required to stay in the building or personnel are required to enter a building during an emergency. Examples of buildings that may be subject to an emergency role are control rooms and emergency response shelters. Buildings that are evacuated in the event of an emergency (for example, satellite control rooms) should be considered for further evaluation to ensure that evacuation can be accomplished safely.

### 2.5.4 CHANGES IN OCCUPANCY

When changes cause the building occupancy to increase or the emergency role of the building changes, the building should be reevaluated using this recommended practice or the company equivalent.

# SECTION 3—EXPLOSION ANALYSIS

A three-stage process for analyzing explosion hazards to occupants of process plant buildings is diagrammed in Figure 2. Each box in the flowchart is numbered with the corresponding section in this publication that discusses the information for that box. The analysis process may be used for both new and existing buildings and is intended to provide the user with multiple options. The user should recognize that as one progresses through the flowchart, the analysis becomes more complex. Some users may elect to perform all three steps. Others may wish to perform Stage 3, Risk Management, after completing Stage 1, Hazard Identification. This flexibility allows the users to select the best option to meet their specific requirements.

## 3.1 Stage 1—Building and Hazard Identification

This section helps teams performing process hazards analyses (PHAs) or site-specific building evaluations to identify buildings that could potentially be impacted by an explosion.

### 3.1.1 PROCESS SAFETY INFORMATION

The starting point for identifying and evaluating risks resulting from the location of process plant buildings is to gather information on site-specific parameters that can influence the likelihood or severity of an explosion. Process safety information as identified by OSHA 29 CFR 1910.119(d) can provide basic information on the process unit, process conditions, and materials handled. The amount of information required increases with each evaluation stage of the process. Table 1 indicates some typical information needs.

### 3.1.2 MATERIALS OF CONCERN

Flammable materials such as light hydrocarbons and chemicals, gases, or heavier hydrocarbons that are processed at elevated temperatures, pressures, or both may have the potential for a vapor cloud explosion (VCE) upon release. Examples of materials that may form vapor clouds upon release include ethane, propane, and butane, and related olefins (ethylene, propylene, and butylene). Under some release conditions, such as elevated temperatures, less volatile materials may also form a vapor cloud. Explosion overpressure may be developed from explosions involving a boiling liquid expanding vapor explosion (BLEVE), vapor cloud explosion, chemical decomposition (such as ethylene oxide), or mechanical failure of a pressure vessel.

See Example 1 in Appendix E, which applies the preceding information to a hypothetical situation.

### 3.1.3 SITE-SPECIFIC CONDITIONS

Although some facilities may handle materials with VCE potential, site-specific conditions may preclude a VCE. Factors that influence the potential for a VCE include the degree of congestion and confinement, plant layout, spacing between areas, sources of ignition, topography, drainage, the amount of material released, and the release rate. In particular, the potential degree of congestion and confinement should be considered, as these are often the key factors contributing to the magnitude of an explosion. In performing the review for site-specific conditions, common equipment arrangement including pipe racks, columns, vessels, and other plant equipment in proximity to one another should be considered. Experience has shown that these conditions can provide sufficient congestion that may lead to a VCE. If flammable materials are processed in an open plant environment and they are released at sufficiently low rates, it is unlikely that a VCE will develop.

Process conditions such as operating temperatures, pressures, and inventory of material in equipment are also site-specific conditions that may affect VCEs.

Emergency response that results in closing of isolation valves, the depressuring of equipment, and the shutdown of the process may be effective in reducing the total quantity of material released. The effectiveness of such actions in preventing or reducing the severity of a VCE will depend upon the magnitude and the initial release rate, the time required to detect the release and complete the emergency response actions, the time required for the release to subside, and the location of potential ignition sources.

Table 1—Examples of Process Safety Information Needs by Stage

| Stage | Examples of Typical Information |
|---|---|
| 1 | Material Safety Data Sheets<br>Occupancy<br>Emergency role of building |
| 2 | Depending on the evaluation used, information needs may include<br>Stage 1 information<br>Inventories of materials<br>Temperatures, pressures, and flow rates<br>Building construction, materials, dimensions<br>Distances between process units and buildings<br>Frequency data for explosions in similar plants |
| 3 | Depending on the analysis process, information needs may include<br>Stages 1 and 2 information<br>Site incident history<br>Complete building design and construction details<br>Operating procedures<br>Description of passive and active mitigation systems<br>Maintenance and inspection standards and records<br>Other pertinent information on the existing process safety management systems |

See Example 2 in Appendix E, which applies the preceding information to a hypothetical situation.

### 3.1.4 OCCUPANCY COMPARISON

Once it has been determined that site-specific conditions may contribute to an explosion impacting the building, the plant buildings should be compared with the company's predefined occupancy criteria. Buildings exceeding the criteria should be further evaluated. Buildings that do not exceed the occupancy criteria may be evaluated using a building checklist as discussed in Section 6.

## 3.2 Stage 2—Building Evaluation

Stage 2, "Building Evaluation," provides a process for evaluating the hazards to buildings. Evaluation options include the following:

a. Design or compare to industry and company standards (Section 3.2.1).
b. Consequence analysis (Section 3.2.2).
c. Screening risk analysis (Section 3.2.3).

Any combination of the evaluation options may be used, with the understanding that the methodologies become increasingly complex.

The user should be aware that all the methodologies listed in this section of the recommended practice have limitations in identifying the actual potential effects of the hazards to buildings and their occupants. These limitations, discussed below, should be understood and matched with the purpose of the evaluation before using or selecting the methodology.

### 3.2.1 DESIGN OR COMPARE TO INDUSTRY AND COMPANY STANDARDS

Industry groups, insurance associations, the government, and many companies have developed standards or guidelines for building design and spacing that are intended to provide protection against the effects of explosions. Many of these standards are based on experience. Because the size and congestion of units have increased, the distances specified in some standards may not apply to newer facilities.

The user should understand the objectives of the spacing standards. Many of the spacing standards are based on broad assumptions of process and plant conditions and not on site-specific conditions such as possible operating conditions, confinement, and process conditions, all of which may have an effect on the potential for a significant overpressure. These variables should be considered when using any standard, including company standards. For example, the user should remember that some standards were developed specifically for chemical processing units and not for petroleum refineries. In general, insurance-industry standards are designed to protect property and minimize business interruption in the event of an incident rather than to protect personnel. A list of some available industry, insurance, and government standards is in Appendix A.

See Example 4 in Appendix E, which applies the preceding information to a hypothetical situation.

### 3.2.2 CONSEQUENCE ANALYSIS

The objective of consequence analysis is to estimate the magnitude of an explosion, evaluate its effects on a building, and relate the damage sustained by the building to the degree of potential injury or damage to the occupants and/or equipment inside. Consequence analysis usually involves the selection of evaluation-case events that include size and duration of expected release. The evaluation-case events of concern may be identified through the PHA process. Both passive and active independent mitigation systems should be considered. Passive mitigation systems include inherent design features such as layout and spacing or design of the equipment that limits the size of an explosion. Examples of active mitigation systems include features such as automatic detection and isolation valves to reduce the quantity of material released, automatic shutdown systems, and automatic water spray systems.

There are several methods available for calculating explosion overpressure, such as the TNT-equivalency, Multi-Energy, and Baker-Strehlow. Additional information on explosion calculation methods is available in Section 4-3 of *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs*, published by the Center for Chemical Process Safety (CCPS).

If the calculated overpressure exceeds the design for the building, further evaluation should be considered necessary. If the building can adequately protect the occupants from the effects of an explosion, the building can be eliminated from further evaluation, and a building checklist may be completed.

Hazard evaluation tools may be used to prioritize buildings for consideration, based on various factors. Hazard evaluation methods may not account for all site-specific conditions that could lead to significant overpressure. Techniques that take into account some site-specific conditions, such as the Dow Fire and Explosion Index and Mond Index, have also been used. The results of these indices should be considered in conjunction with other factors, rather than as stand-alone criteria. These other factors should include an evaluation of the effects of confinement and/or congestion-induced turbulence on the potential for explosion overpressure.

As part of the consequence analysis, the building's response to the overpressure should be considered. The building's response to an explosion will vary, depending on such things as the building's structural design, materials of construction, orientation, and source of the explosion. Table 2 summarizes explosions by source, type, attributes of the impulse, and possible hazards to building occupants.

Table 2—Summary of Possible Explosion Effects on Buildings[a]

| Source of Explosion | Type of Explosion | Nature of Blast Wave | Possible Hazards to Building Occupants |
|---|---|---|---|
| Vapor cloud of flammable material | Deflagration | Moderate to high overpressure of long duration | Building response to the explosion wave, fire, and combustion products |
| Condensed phase chemical reaction | Deflagration or detonation | High overpressure of short duration | Building response to the explosion wave, projectiles, and ground shock |
| Dust cloud | Deflagration | Low to high overpressure of long duration | Building response to the explosion wave, fire, combustion products |
| Release of flammable boiling liquid (BLEVE) | Physical expansion and deflagration | Moderate overpressure of long duration | Fire, combustion products, building response to the explosion wave, and projectiles |
| Rapid loss of confinement of high-pressure gas | Physical expansion | High overpressure of short duration | Building response to the explosion wave, and projectiles |

[a]This list should not be considered an all-inclusive list.

Some buildings in process plants have some inherent capacity to resist explosion loadings if they meet local building codes and company building standards for environmental loads such as wind and snow. However, the buildings' response to explosive load within the process plant will vary depending on construction types, building styles, and siting considerations over the life of the process plant. Additionally, the buildings may have been expanded or modified since their original construction. The variety of construction techniques for buildings makes exact determination of building responses to explosion loads difficult. Buildings should be evaluated based on their specific structural design.

As a means to illustrate potential effects on building components, Table 3 is provided. This table shows approximate values and should not be used for design purposes.

Table 4 indicates effects of overpressure on different types of buildings. Table 5 indicates typical effects of overpressure on people. In a consequence analysis, it may be assumed that building occupants could incur injuries if the integrity of the building is exceeded.

A simple and conservative approach for use in screening evaluations is shown in Table 4. The actual relationship between explosion effects and building damage depends on many parameters including overpressure and impulse of the explosion. Additionally, building parameters such as material of construction, configuration, dimensions of thickness and span, and details of reinforcement and connections play an important part in building evaluations. When additional evaluation is necessary, a detailed analysis of these parameters should be considered in a structural analysis of the building. Table 4 may be used for screening purposes.

### 3.2.3 SCREENING RISK ANALYSIS

A screening risk analysis may be used to determine approximate aggregated and individual risk to occupants of a process plant building. This method provides for coupling estimates of event frequency with explosion consequences to determine risk to a process plant building occupant. This risk may then be compared to company risk acceptance criteria to identify buildings requiring further analysis. The steps for the screening risk analysis may include the following:

a. Identify the process plant buildings and their construction features in proximity to processes where explosions might occur.

Table 3—Overpressure Effects on Various Building Components

| Building Component | Reflected Overpressure (psi) | Component Response |
|---|---|---|
| Glass | 0.2 | Breaking |
| Glass | 0.5–1.0 | Shattering with body penetrating velocities |
| Wooden frame | 1.0–2.0 | Structural failure and potential collapse |
| Steel cladding | 1.0–2.0 | Internal damage to walls, ceilings, and furnishings |
| Concrete-asbestos cladding | 1.0–2.0 | Shattering |
| Brick cladding | 2.0–3.0 | Blown-in |
| Unreinforced Masonry | 1.0–3.0 | Wall collapse, possible shattering |

Source: *The Effects of Nuclear Weapons* by Glasstone (1964).

Table 4—Overpressure Effects on Various Building Types

| Building Type | Peak Side-on Overpressure (psi) | Consequences |
|---|---|---|
| Wood-frame trailer or shack | 1.0 | Isolated buildings overturn. Roofs and walls collapse |
| | 2.0 | Complete collapse |
| | 5.0 | Total destruction |
| Steel-frame/metal siding pre-engineered building | 1.5 | Sheeting ripped off and internal walls damaged. Danger from falling objects |
| | 2.5 | Building frame stands, but cladding and internal walls are destroyed as frame distorts |
| | 5.0 | Total destruction |
| Unreinforced masonry bearing wall building | 1.0 | Partial collapse of walls that have no breakable windows |
| | 1.25 | Walls and roof partially collapse |
| | 1.5 | Complete collapse |
| | 3.0 | Total destruction |
| Steel or concrete frame w/unreinforced masonry infill or cladding | 1.5 | Walls blow in |
| | 2.0 | Roof slab collapses |
| | 2.5 | Complete frame collapse |
| | 5.0 | Total destruction |
| Reinforced concrete or masonry shear wall building | 4.0 | Roof and wall deflect under loading. Internal walls damaged |
| | 6.0 | Building has major damage and collapses |
| | 12.0 | Total destruction |

Source: *The Effects of Nuclear Weapons* by Glasstone (1964).

b. Determine the explosion loading (overpressure and duration) for each event for each target building using the TNT-equivalency, Multi-Energy, Baker-Strehlow, or other method.

c. Determine the frequency of explosions, based on historical or industry data for the type of process unit at the facility. Information may be limited, and the user should carefully evaluate the applicability of any such information before using the analysis. See Appendix C for more information on typical data for explosion frequency.

d. Determine the vulnerability of occupants (probability of fatality) in the target building versus overpressure (overpressure as a function of the type of building construction ). See Appendix C for more information on vulnerability of occupants.

e. Calculate the risk to an individual from a single event by multiplying the explosion frequency, the percentage of time that the individual occupies the building, and the vulnerability estimated for building occupants. To obtain the total individual risk to an occupant, add the risks from all potential explosion events. The total risk for the most exposed individual is the maximum individual risk. Other means of expressing individual risk exist, and the user may wish to refer to the CCPS's *Guidelines for Chemical Process Quantitative Risk Analysis.*

f. Calculate the aggregate risk to all building occupants. One simple way of expressing aggregate risk would be to determine the weighted average occupancy of the building by summing, for all individuals, the fraction of time that each individual occupies the building. Next multiply the weighted average occupancy by the explosion frequency and the vulnerability estimated for building occupants. To obtain the total aggregate risk to all occupants, sum the risks from all potential events. There are a variety of means for expressing aggregate risk, and the user may wish to refer to the CCPS's *Guidelines for Chemical Process Quantitative Risk Analsyis.*

g. Compare the calculated risk with the company's risk acceptance criteria to determine whether additional study is required.

The screening risk-analysis method provides an additional level of evaluation because the frequency of the incident has been included in the evaluation. By identifying risk rather than just the consequences, additional buildings not posing significant risk to the occupants may be identified. Screening risk analysis may require more time and effort to complete than those methods previously discussed. Additionally, the use of industry versus site-specific data may not account for factors such as maintenance history, process safety management

Table 5—Typical Overpressure Effects on Unprotected People

| Response | Threshold Overpressure (psi) |
|---|---|
| Eardrum rupture | 5 |
| Fatal head injury | 8[a] |
| Serious lung damage | 10[a] |
| Fatal bodily injury | 11[a] |

Source: *The Effects of Nuclear Weapons* by Glasstone (1964).
[a]Values are for a 165-lb individual and a 0.05-sec positive phase explosion duration.

(PSM) effectiveness, age and condition of the unit, confinement/congestion, and so forth.

See Example 6 in Appendix E, which applies the preceding information to a hypothetical situation.

#### 3.2.4 BUILDINGS REQUIRING FURTHER EVALUATION

The evaluation process in Stage 2 helps identify buildings with sufficient hazard to building occupants to justify either further evaluation or an additional risk assessment. Those buildings that do not need additional evaluation or assessment may benefit by a checklist review, as shown in Example 9 in Appendix E, to verify that routine risk-reduction measures have been taken.

#### 3.2.5 ADDITIONAL EVALUATION

If a building has been determined to require additional evaluation, the user may wish to explore more than one method in Stage 2 before concluding that a risk assessment in Stage 3 is needed.

### 3.3 Stage 3—Risk Management

#### 3.3.1 RISK ASSESSMENT

A risk assessment identifies and analyzes specific events or scenarios either qualitatively or quantitatively. The assessment evaluates the frequency and the consequences of scenarios, and defines an overall potential risk to the building occupants. The techniques for evaluating consequences found in Section 3.2.2 may be useful in the risk evaluation of an explosion.

##### 3.3.1.1 Identifying Events of Concern

A list of potential scenarios may be developed during the PHA or during the evaluation of a building. Most of the scenarios will result from a loss of containment of a flammable liquid or gas, but other scenarios resulting in explosion effects should be considered. A typical list of scenarios may include the following:

a. Pressure failure of a vessel or piping component, resulting in a major leak.
b. Corrosion perforation in piping or a vessel, or a loss of a vessel connection.
c. Inadvertent opening of a valve or connection to the atmosphere.
d. Overfilling a vessel or tank.
e. Mechanical impact or brittle failure of equipment.
f. Failure of pump packing or a mechanical seal.
g. Transfer operations involving loading and unloading.
h. Chemical reactions that may result in runaway reaction.

Several factors should be considered when selecting scenarios. These may include the following:

a. *Previous incident history*: A history of previous incidents at a facility may indicate an increased potential for an explosion that could impact process plant buildings.
b. *Industry experience*: Available industry incident information should be considered when identifying possible scenarios of concern.
c. *Process conditions*: Certain process conditions, such as extremely high or low temperatures and pressures, reactive or corrosive process materials, and exothermic reactions, may increase the possibility of an explosion. Process materials (such as hydrogen and hydrogen sulfide, which may induce degradation of materials of construction), frequent cycling of the process, and mechanical vibration are examples of conditions that could cause an explosion.
d. *Effectiveness of PSM systems*: The effectiveness of a facility's PSM program is fundamental in reducing the frequency of events that lead to serious incidents.
e. *Maintenance and inspection*: A maintenance and inspection program verifies that pressure-retaining equipment, including piping and pressure relief valves, are inspected regularly to reduce the likelihood of an explosion. Functional testing programs verify that mitigation systems, such as protective systems and emergency controls, will operate when needed.
f. *Other safeguards*: Other safeguards that should be considered in developing a list of scenarios may include, but are not limited to the following:

1. Passive mitigation, such as spacing and equipment placement.
2. Minimizing ignition sources through electrical classification.
3. Administrative controls, such as a hot work permit system.
4. Monitoring systems for early detection of loss of containment (such as, hydrocarbon or toxic detectors, fire detectors, and process control system).
5. Mitigation systems (such as, water spray and fire monitors).
6. Emergency depressurization and deinventory systems.
7. Emergency response.

##### 3.3.1.2 Qualitative Risk

Qualitative risk determination is an experience-based evaluation of risk. Additional information on qualitative risk determination can be found in Chapter 7 of the CCPS's *Guidelines for Hazard Evaluation Procedures*. After scenarios of concern are identified, those that have the potential to impact process plant buildings may be ranked by using a risk matrix similar to that shown in Figure 3 and the resulting ranking shown in Table 6. Specific description of likelihood and consequence categories need to be defined if using this risk matrix.

Companies performing qualitative risk assessments may consider developing a risk-ranking matrix based on company-specific risk criteria.

Table 6—Sample Risk-Ranking Categories

| Number | Category | Description |
|---|---|---|
| I | Unacceptable | Should be mitigated with high priority by engineering and/or administrative controls to a risk ranking of III |
| II | Undesirable | Should be mitigated with engineering and/or administrative controls to a risk ranking of III |
| III | Acceptable with controls | Should be verified that procedures or controls are in place |
| IV | Acceptable as is | No mitigation required |

Source: Slightly modified from *Guidelines for Hazard Evaluation Procedures*, 2nd edition. Copyright 1992 by the American Institute of Chemical Engineers; reproduced by permission of the Center for Chemical Process Safety of AIChE.

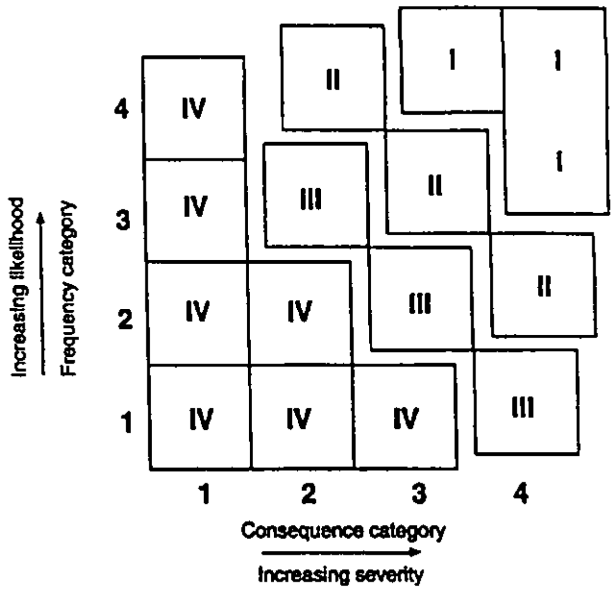



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Figure 3—Sample Risk Matrix

#### 3.3.1.3 Quantitative Risk

A quantitative analysis for risks to building occupants may use a range of techniques, including fault tree analysis and event tree analysis. For specific details on undertaking a quantitative risk analysis, refer to CCPS's *Guidelines for Chemical Process Quantitative Risk Analysis*, Chapters 2 and 3.

### 3.3.2 DECIDING WHETHER RISK REDUCTION IS APPROPRIATE

In any risk assessment, after the risks are determined, a decision needs to be made as to whether risk reduction measures should be taken. This usually is done by comparing the assessed risk with the company's risk acceptance criteria.

When additional risk reduction is suggested, the risk should be reevaluated with the risk reduction measures in place in order to verify that risk has been sufficiently reduced.

### 3.3.3 RISK ACCEPTANCE CRITERIA

The typical risk-ranking matrix, shown in Figure 3, contains qualitative risk acceptance criteria, where certain combinations of event likelihood and severity clearly require action. In contrast, quantitative risk decision criteria assign specific numerical values to tolerable risk.

A company should establish risk acceptance criteria before initiating a risk assessment. Assistance in developing qualitative and quantitative risk acceptance criteria are available from a number of sources[5,6] and can be used to compare work conditions in different industries in order to develop risk acceptance criteria.

[5] *Loss Prevention in the Process Industries*, Volume I, Frank P. Lees, 1980.
[6] CCPS, *Guidelines for Chemical Process Quantitative Risk Analysis*, 1989, and *Guidelines for Evaluating Process-Plant Buildings for External Explosion and Fire* (work in progress).

### 3.3.4 RISK REDUCTION

Reducing risk to building occupants from the effects of explosions generally falls into two broad categories:

a. *Prevention*: Activities that eliminate or reduce process incidents.
b. *Mitigation*: Activities that reduce the consequences associated with the occurrence.

Generally, prevention activities such as modifications in operating and maintenance practices, equipment, maintenance, inspection, personnel training, and audits may reduce the process incident occurrence rate. Mitigation measures may include installation of detection and isolation systems, fire suppression systems, structural enhancements, and emergency response planning.

#### 3.3.4.1 Prevention Measures

Preventing the incident from occurring should be the first priority in reducing the risk. Some examples of preventive risk-reduction measures may include but are not limited to the following:

a. Reducing the inventory of hazardous material.
b. Engineering controls such as process controls, emergency shutdowns, and redundant instrumentation.
c. Altering process conditions or materials to reduce the potential for runaway reactions or corrosion.

d. Increasing inspection frequencies for piping and equipment in corrosive service.
e. Upgrading metallurgy of equipment.
f. Enhancing work practices such as crane lifting or excavation to reduce the likelihood of incidents.
g. Administrative controls such as permits for hot work, lockout/tagout, line breaking, and so on.

#### 3.3.4.2 Typical Mitigation Measures for Buildings

Typical mitigation for process plant buildings may include, but are not limited to the following:

a. Relocating personnel or rearranging the room functions within the building.
b. Eliminating windows.
c. Modifying windows to reduce risk to occupants. Two generic approaches are as follows:
  1. Strengthening the glazing and its framing system to resist the design explosion overpressure.
  2. Or designing a glazing/framing system that will fail in a manner that minimizes laceration risks to occupants (for example, polycarbonate, tempered glass, or laminated glass with internal catch bars).
d. Strengthening doorways and reducing or eliminating glazing in doors.
e. Providing structural reinforcement or performing modifications to the building to improve flexibility and strengthen the connections.
f. Installing external walls for explosion and projectile protection.
g. Constructing a new building using explosion-resistant design or siting sufficiently remote for the hazard.
h. Designing floor and hub drains to prevent the backflow of explosive vapors.

#### 3.3.4.3 Considerations for Existing Explosion-Resistant Buildings

Structural evaluation of the building should be considered when the recalculated design explosion overpressure exceeds original design values. This evaluation should review, among other things, the loading assumptions used in the building's structural design in view of current techniques to evaluate explosion effects, the explosion-resistant-design philosophy at the time of construction, and the as-built details relevant to explosion loadings.

#### 3.3.4.4 Occupancy Reduction Considerations

A study of the building's occupancy patterns may yield opportunities to reduce the number of people at risk. The reduction of personnel in a building may be considered, based on the expected building damage and occupant vulnerability.

## SECTION 4—FIRES

Uncontrolled fires in process plants are typically pool, fireballs, jet, flash fires, or fireballs. These fires may result from or cause explosions within process plants. Pool fires are usually the result of a spilled flammable or combustible liquid, for example, a fire in the dike area of a storage tank. Jet fires occur at the source of release of a pressurized flammable material, for example, a ruptured natural gas pipeline. A jet fire impinging on a vessel may be a source of heat input that results in failure of a vessel containing a pressurized flammable liquid, causing a BLEVE. Flash fires usually involve flammable materials, combustible dusts, or vapors, that are mixed sufficiently with air to burn after being exposed to an ignition source. A fireball usually involves a large flammable release that burns quickly, with radiant heat being the primary concern.

The combustion products from a fire may enter the building and, depending on the burning material, may create respiratory problems, physiological hazards, fire within the building, or hazards from the lack of visibility, which could hinder egress from the building. Figure 4 provides an example of a tool that may be used to evaluate fire hazards to building occupants.

### 4.1 Materials of Concern

Buildings that are located in the proximity of equipment that processes flammable material may be exposed to a fire. This recommended practice applies to flammable materials covered under OSHA 29 CFR 1910.119.

### 4.2 Building Occupancy

Once it has been determined that site conditions may contribute to a fire, the plant buildings should be compared with the company's predefined occupancy criteria for fire hazards. See Section 2.5 for additional information on occupancy criteria.

### 4.3 Spacing

Unless a building is directly involved in a fire, the fire hazard to the structure is low for most types of construction. Radiant heat effects are significantly reduced by distance. Buildings made of noncombustible construction materials and even some combustible materials are generally of minimal concern unless the building has direct flame impingement. Appendix A lists, as a general reference, several industry and insurance standards for separation distance and spacing for fire hazards and not personnel protection. The user should be aware that standards are developed for various purposes. In general, insurance industry standards are designed to protect property and minimize business interruption in the event of an incident. The user should determine the appropriateness of the standard to the application. See Example 7 in Appendix E, which applies the preceding information to a hypothetical situation.

## 4.4 Mitigation and Emergency Response

The hazards for occupants in a building exposed to an external fire depend on the building's materials of construction, distance from the fire, and systems to prevent flammable vapor ignition. The design of most buildings may provide enough time for the occupants to leave the building, for the fire suppression measures to be activated, and for emergency response plans to be implemented.

Generally, the emergency response plans for the building should include appropriate measures for the occupants to take, such as sheltering-in-place, using personnel protective equipment (PPE) for escape, or—depending on wind conditions—evacuating in a safe, upwind or crosswind direction. Also, procedures for ensuring a safe process shutdown should be considered if the process is solely controlled from the building that is being evacuated.

## 4.5 Risk Reduction for Fire

### 4.5.1 PREVENTION MEASURES

Generally, preventing the incident from occurring should be the first priority in reducing the risk. Some examples of preventive risk-reduction measures may include, but are not limited to the following:

a. Reducing the inventory of hazardous material.
b. Altering process conditions or materials to reduce the potential for runaway reactions or corrosion.
c. Implementing inspection programs for piping and equipment.
d. Upgrading materials of construction.
e. Enhancing work practices such as crane lifting and excavation to reduce the likelihood of incidents.
f. Providing administrative control such as permits for hot work, lockout/tagout, line breaking, and so forth.
g. Installing properly classified electrical equipment to prevent ignition of flammable materials.

### 4.5.2 MITIGATION MEASURES

Typical mitigation measures for reducing hazards to building occupants from an external fire may include, but are not limited to these:

a. Providing physical separation from the fire event by distance or barriers.
b. Providing appropriate fire-resistant exterior construction.

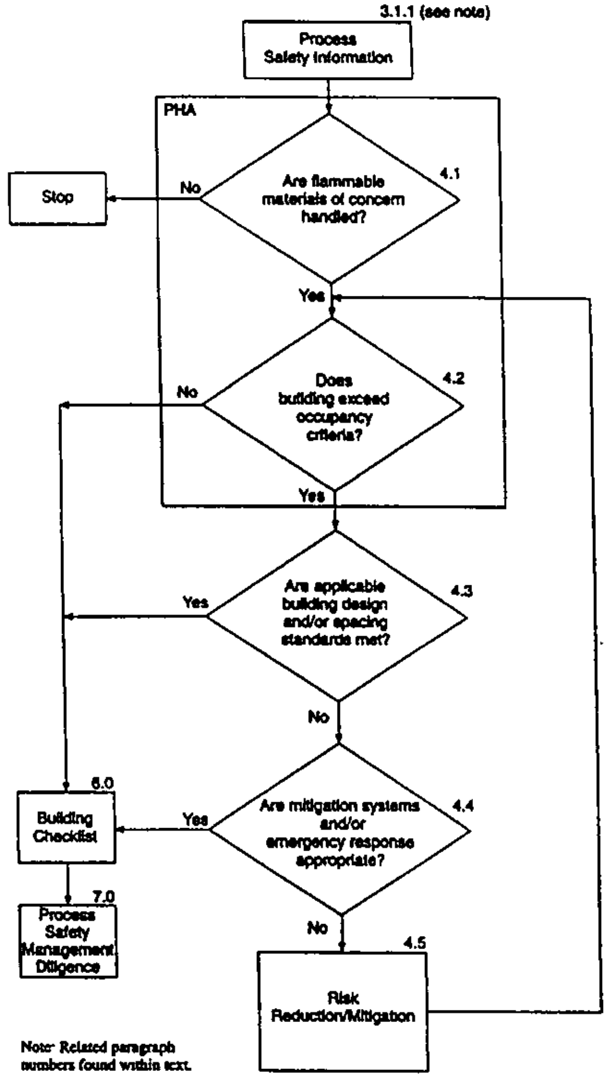



Figure 4—An Analysis Process for a Fire

c. Providing properly designed fire and smoke suppression equipment inside and outside the building, which may include the following:
1. Fire-fighting/suppression systems for the building and outside monitors or water spray in appropriate locations to address a possible fire.
2. Building ventilation controls, which detect combustion products, stop fresh air intake, and stop air circulation within the building.
3. Providing area drainage to direct spill from the building.

d. Providing escape routes in the emergency response plan for each building.
e. Installing isolation valves.
f. Installing spill containment.

# SECTION 5—TOXIC MATERIALS

Toxic materials released to the atmosphere in process plants can affect building occupants. Figure 5 may be used to evaluate toxic material effects on building occupants.

Toxic vapors may enter a building and cause impairment and/or physiological harm to the occupants, depending on the material released, its concentration, and the exposure duration. The combustion products from a fire may enter the building and may create respiratory problems, physiological hazards, or hazards due to the lack of visibility to building occupants.

## 5.1 Toxic Material of Concern

Buildings that are located in the proximity of equipment that process volatile, acutely toxic materials specified in 29 CFR 1910.119, Appendix A should be evaluated.

## 5.2 Building Occupancy

Once it has been determined that site conditions may contribute to a toxic release, the plant buildings should be compared with the company's predefined occupancy criteria for toxic releases. See Section 2.5 for additional information on occupancy criteria.

## 5.3 Site Conditions

The meteorological dispersion of a toxic material depends on many site-specific factors, including the physical properties and release conditions of the material, the quantity released, the weather conditions, obstacles, and the direction and source of the release. The dispersion of these gases may be modeled using a variety of techniques.

The amount and speed of entry of the toxic material into a building depend on the location and size of the entry point, exterior concentration of the gas, and relative pressure between the interior and exterior of the building. Entry points can be open or unsealed windows or doors, vent stacks, fresh air makeup openings, instrument cabling or conduit, or sewer connections that are unsealed. An explosion may also cause structural damage, which may allow toxic material to enter the building.

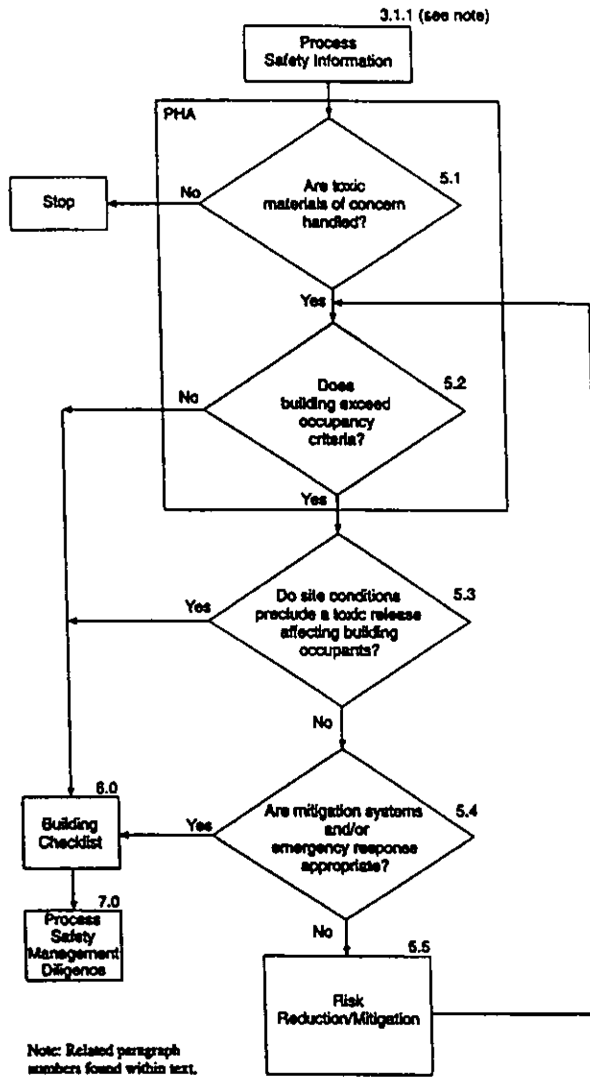



Figure 5—An Analysis Process for a Toxic Release

## 5.4 Mitigation and Emergency Response

The dispersion dynamics of a gas cloud may allow sufficient time for the occupants to appropriately respond to the release. A ventilation system that (a) controls fresh air makeup, (b) is equipped with a toxic gas detection alarm, and (c) provides automatic or manual air intake shutdown capability may be an effective means to control the ingress of toxic materials.

Generally, the emergency response plan should include appropriate measures for building occupants to take, such as shelter in place, use personnel protective equipment (PPE) for escape, or—depending on wind conditions—evacuate in a safe, upwind or crosswind direction. Also, a method for ensuring a safe process shutdown should be considered and factored into the emergency response plan when the process is controlled solely from the building that is being evacuated.

See Example 8 in Appendix E, which applies the above information to a hypothetical situation.

## 5.5 Risk Reduction for Toxic Release

### 5.5.1 PREVENTION MEASURES

Generally, preventing the incident from occurring should be the first priority in reducing the risk. Some examples of preventive risk-reduction measures may include, but are not limited to the following:

a. Reducing the inventory of hazardous material.
b. Altering process conditions or materials to reduce the potential for runaway reactions or corrosion.
c. Providing inspection programs for piping and equipment.
d. Upgrading metallurgy of equipment.
e. Enhancing work practices for activities such as crane lifting and excavation to reduce the likelihood of incidents.

### 5.5.2 MITIGATION MEASURES

The hazards to building occupants from a release of toxic materials depend on the (a) factors affecting the dispersion of the toxic material, (b) location of the building, (c) control of the ventilation system in the building, (d) infiltration rate into the building, and (e) effectiveness of the building's emergency response plans. Time is usually a very important factor in reducing occupant vulnerability.

Typical mitigation measure for reducing the hazards to building occupants from a toxic material release may include, but are not limited to the following:

a. Ventilation system controls with appropriate detection, which stop the flow of a contaminated air supply to the building.
b. Use of elevated intake stack for potential releases of heavier-than-air materials.
c. An emergency response plan, which may include safe shelters in the building and clearly identified evacuation routes.
d. A detection and alarm system for early notification of a release.
e. Appropriate PPE for the building occupants.
f. Reductions in the number of people in the building.
g. Pressurized ventilation systems.
h. Review of locations of gas infiltration into the building for possible sealing.

# SECTION 6—BUILDING CHECKLIST

Even those process plant buildings identified during the various analyses as not presenting a significant hazard to occupants may still benefit from a checklist review to verify that routine risk-reduction measures have been taken. Appendix D shows an example of typical questions included on a building checklist.

# SECTION 7—PROCESS SAFETY MANAGEMENT DILIGENCE

The credibility of the techniques discussed in this publication are founded on the continuing and improving practice of process safety management (PSM) within a process facility. Practicing PSM will help to reduce the likelihood of serious events. Additionally, it can assist in identifying measures to mitigate the consequences to the occupants from the hazards. Applicable references concerning the specific PSM activities include the CCPS, *Guidelines for Technical Management of Chemical Process Safety* and *Plant Guidelines for Technical Management of Chemical Process Safety*.

To maintain the currency of the techniques and validity of the assumptions discussed in this publication, it is important for a facility to assess its PSM activities by systematic auditing.

# APPENDIX A—BIBLIOGRAPHY OF ADDITIONAL READING

This appendix provides a list of guidelines, standards, codes, specifications, and publications that may be useful in evaluating hazards to building occupants. The user should evaluate each document for its suitability and application as described in Section 3.2.1, and use the most recent edition.

## A.1 Explosion


Baker, W. E., P. A. Cox, P. S. Westine, J. J. Kulesz and R. A. Strahlow, *Explosive Hazards and Evaluation*, Elsevier Scientific Publishing Company, 1983.

CIA[7]

*Process Plant Hazard and Control Building Design—An Approach to the Categorization.*

Department of Defense

TM5-1300, *Structures to Resist the Effects of Accidental Explosions*, U.S. Army.

AMCR 385-100, *U.S. Army Safety Manual.*

MIL-STD-882C, *Military Standard System Safety Program Requirements.*

FM[8]

FM 7-45S, *Process Control Houses and Other Structures Subject to External Explosion Damage.*

FM 7-44, *Spacing of Facilities in Outdoor Chemical Plants.*

IRI[9]

IRInformation IM.8.0.1.1, *Oil and Chemical Properties Loss Potential Estimation Guide.*

IM.2.5.2, *Plant Layout and Spacing for Oil and Chemical Plants.*

*Minimizing Damage to Refineries from Nuclear Attack, Natural and Other Disasters*, Maynard M. Stephans.

Nolan, P.F. and C.W.J. Bradley, *A Simple Technique for the Optimization of Lay-Out and Location for Chemical Plant Safety*, Department of Chemical Engineering, Polytechnic of the South Bank, Borough Road, London, England SE1 0AA.

Page, Robert. "Technical Aspects of Unconfined Vapor Cloud Explosions and the TNT Model," *Industrial Fire Safety*, May/June 1993.


## A.2 Fire


AIChE

Center for Chemical Process Safety of AIChE, *Guidelines for Engineering Design for Process Safety.*

Dow Chemical, *Fire and Explosion Index Hazard Classification Guide.*

Stull, Daniel R., *Fundamentals of Fire and Explosion*, AIChE Monograph Series, No. 10, Volume 73.

API

Recommended Practice 2510, *Design and Construction of Liquified Petroleum Gas (LPG) Installations.*

Recommended Practice 2508, *Design and Construction of Ethane and Ethylene Installations at Marine and Pipeline Terminals, Natural Gas Processing Plants, Refineries, Petrochemical Plants, and Tank Farms.*

FM[8]

FM 7-44, *Spacing of Facilities in Outdoor Chemical Plants.*

IRI[9]

IM.2.5.2, *Plant Layout and Spacing for Oil and Chemical Plants.*

Imperial Chemical Industries

*The Mond Index*, 2nd ed.

NFPA[10]

*The Fire Protection Handbook*, 17th ed. Edited by Arthur E. Cote, Editor-in-Chief, and Jim L. Linville, Managing Editor.

*The Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering*, 1st ed., Phil J. DiNenno (ed.).

NFPA 30, *Flammable and Combustible Liquids Code.*

NFPA 58, *Standard for the Storage and Handling of Liquid Petroleum Gases.*

NFPA 59A, *Standard for the Production, Storage and Handling of Liquified Natural Gases.*

NFPA 80A, *Recommend Practice for the Protection of Buildings from Exterior Fire Exposures.*

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Locations.*


## A.3 Toxic Material


AIChE

Dow Chemical, Chemical Exposure Index

API

Recommended Practice 2031, *Combustible-Gas Detection Systems and Environmental Operational Factors Influencing Their Performance.*

NFPA[10]

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Locations.*


[7]Chemical Industries Association, The Chemical Industry Safety, Health, and Environmental Council (CISHEC), U.K.

[8]Factory Mutual Engineering Corporation, 1151 Boston Providence Turnpike, Norwalk, Massachusetts 02062.

[9]Industrial Risk Insurers, Eastern Region, 85 Woodland Street, Hartford, Connecticut 06102.

[10]National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269-9101.

# APPENDIX B—EXPLOSION, FIRE, AND TOXIC RELEASE PHENOMENA, AND HAZARDS TO THE OCCUPANTS OF PROCESS PLANT BUILDINGS

The information contained in this appendix is derived in part from *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVES* (1994), American Institute of Chemical Engineers, with permission of its Center for Chemical Process Safety. For more detailed information, consult the above reference.

The primary events of concern for occupants of process plant buildings are explosion, fire, and release of toxic materials.

## B.1 Structural Design and Analysis for Explosion Resistance

The structural design and analysis should be performed by a structural engineer familiar with explosion design. In order to perform this task, it is necessary to establish the pressure-versus-time relationship of the load as it applies to the different parts of the building. This determination should be performed with input from experts on the process and be based on a thorough knowledge of the postulated explosion scenarios. However, it is important to realize that these explosion design criteria are only an approximation.

## B.2 Explosion Phenomena

Explosions in process plants occur because of the loss of containment of a pressurized gas or pressurized boiling liquid, the rapid combustion of a flammable or finely divided solid material, or the uncontrolled reaction of chemical materials.

### B.2.1 EXPLOSION

**B.2.1.1** Explosions may occur through a variety of mechanisms and may take one or more of the following forms:

**B.2.1.1.1** *Vapor cloud explosion (VCE)*: A VCE is the result of a flame front propagating through a mixture of air and flammable gas or vapor. The flame front must propagate with sufficient velocity to create a pressure wave. For a VCE to occur, several conditions must be met. These include (a) a release of flammable material, (b) sufficient mixing with air that results in a flammable mixture, (c) ignition, (d) confinement, and (e) congestion within the flame path, which tends to accelerate the flame front. The explosion intensity of a VCE can vary greatly and is determined by the flame speed. The flame speed in turn is affected by the turbulence created within the vapor cloud. One of the key factors creating turbulence in a vapor cloud is the degree of congestion within the release area. Experience has shown that normal process plant design and equipment spacing may create enough congestion to cause turbulence and rapid flame propagation. A high-pressure jet release may also produce sufficient turbulence to increase the rate of flame propagation. The rate of release and the elapsed time before ignition will determine the amount of material involved in a VCE, and thus affect the overpressure and duration of the explosion wave.

**B.2.1.1.2** *Boiling liquid expanding vapor explosion (BLEVE)*: A BLEVE results from the rapid release of a pressurized liquid above its atmospheric boiling point, usually caused by the rapid failure of its containment vessel. The failure often is caused by flame impingement on the vessel's vapor space, which weakens the metal to the point of rupture. A BLEVE may produce an explosion wave, fragmentation, and, if flammable material is involved, a fireball.

**B.2.1.1.3** *Physical explosion*: A pressurized system may produce an explosion upon catastrophic rupture or failure of the equipment. Depending upon the failure mechanism that leads to the release, fragmentation of the container may also result. Released gas or fluid may ignite, resulting in a VCE or fire.

**B.2.1.1.4** *Chemical explosion*: An uncontrolled chemical reaction with sufficient energy may cause a failure of the vessel, resulting in overpressure and missile effects.

**B.2.1.2** The damage to buildings and subsequent injury to the occupants from an explosion may be caused by the explosion wave, missile fragments, or fire.

### B.2.2 EXPLOSION LOAD

The typical blast load is characterized by a rapid rise in pressure to a peak value, a period of decay to ambient pressure (positive phase), and a period in which the pressure drops below ambient (negative phase).

The explosion load differs with the various parts of the building. The front wall receives a larger pressure (reflected pressure) than do the back wall, side walls, and roof. The passage of the explosion wave across the building is a diffraction process as the wave bends and interacts with the geometry of the structure. Consequently, each area of the building—depending on its location and orientation—is subject to an explosion pressure that is different from the pressure on other areas of the building.

The shape of the loading curve, as well as the duration of the load, depends on many parameters, such as the characteristics of the explosion (detonation, deflagration, pressure vessel rupture), material and quantity released, ignition source (location of the explosion), degree of confinement, distance from the explosion, possible obstructions in the path of the pressure wave, and the orientation of the loaded surface relative to the direction of the explosion wave.

The material involved in the explosion is converted into a high-pressure gas at high temperatures and a rapidly expanding shock front. The pressure behind the explosion wave is the incident pressure. When the incident-pressure shock front strikes the front wall of the building, the pressure rises from ambient to the reflected pressure, which is a function of the incident pressure.

For each pressure range, there is a particle or wind velocity that causes a dynamic pressure on objects in the path of the wave. The magnitude of the drag force that results from this effect is a function of the particle velocity, particle density, and object geometry. The explosion loading on an object comprises two components: the loading due to the overpressure (incident and reflected) and the loading due to drag forces induced by the particle motion. For buildings, only overpressure is important—drag forces are significant, compared to overpressure loads, only for slender objects such as lamp posts.

The explosion wave's potential to cause building damage is time dependent and directly related to the shape and size of the explosion wave's pressure-time curve. The impulse value is used in conjunction with the dimensions of the building, orientation of the building, and speed of the explosion wave to determine the net and instantaneous loading on a building from an explosion wave.

### B.2.3 HAZARDS TO BUILDING OCCUPANTS FROM EXPLOSIONS

The response of the building to the explosion wave is related to the distance of the building from the explosion event, the type of building construction, and materials of construction. Ground shock may also occur from an explosion; however, its effects on buildings and occupants are considered insignificant compared to airborne effects.

A collapse or partial collapse of the building normally poses the greatest hazard to building occupants in an explosion scenario. Building components such as lighting fixtures, suspended ceilings, and furnishings, which may dislodge or topple and possibly injure the occupants, should be evaluated. Breakable objects, primarily glass, may be a hazard to occupants. Normally open penetrations, or the nearly instantaneous loss of window, wall, or door integrity, create openings in the building and decrease the reflected overpressure. The explosion conditions are transferred to the interior of the building, creating possible hazards for the occupants, including the possibility of an individual being thrown against stationary objects and/or being injured by flying debris. These hazards are of concern around large openings such as windows, doors and associated entry areas, and hallways where the explosion effects may be channeled. The external attachments and interior furnishings are potential hazards to occupants if these items are displaced and impact with building components or occupants.

There is a low likelihood of injury to occupants from an external projectile impacting the building, because external projectiles produce extremely localized effects on buildings in comparison to explosion loadings, which involve the entire building.

## B.3 Fire

Generally, process fires will be in the form of one or a combination of the following:

a. *Jet fire*: A liquid or gas release under pressure that burns from its release point. The stability, magnitude, and distance of the flame are a function of the release pressure, wind direction, hole size, flame direction, and other site-specific variables.

b. *Pool fire*: A release of flammable liquid, including liquid from releases of a two-phase material that forms a fire in which the flammable material burns above the liquid surface.

c. *Flash fire*: The combustion of a flammable gas or vapor and air mixture, in which the flame propagates through the mixture such that negligible or no damaging overpressure is generated.

d. *Fireball*: A burning fuel-air cloud whose energy is emitted primarily in the form of radiant heat. The inner core of the cloud consists almost completely of fuel; whereas, the outer layer (where ignition first occurs) consists of a flammable fuel-air mixture. As the buoyancy forces of bot gases increase, the burning cloud tends to rise, expand, and assume a spherical shape.

Fires expose process plant buildings to radiant heat and products of combustion that may enter the building. Generally, fires do not impact process plant buildings as severely as do explosions. Their effects occur over a period of time, and emergency response and mitigation can reduce the impact.

## B.4 Toxic Materials

Certain materials, when released, may present a toxic exposure to personnel. In some cases, the material released may contain both toxic and flammable substances and may present potential for fire, explosion, and/or toxic exposure.

Generally, the releases of toxic materials, unless corrosive, will not affect buildings. However, ingress into the building can occur with exposure to personnel. Ingress usually occurs in a time frame that allows for emergency response and mitigation.

# APPENDIX C—DAMAGE CATEGORIZATION FOR BUILDINGS AND VULNERABILITY OF OCCUPANTS TO EXPLOSION OVERPRESSURE

As part of the risk screening for explosion in Section 3.2.3, information is required on the vulnerability of occupants to injury and on generic frequency of occurrence for process units. The information presented in this appendix is one company's approach for these items and is an example only. Each company should develop its own approach.

## C.1 Vulnerability of Occupants

To assess the vulnerability of occupants within a given building from explosion overpressure, the following information is required:

a. Type of building.
b. Overpressure relationship for each type of building.
c. Damage-vulnerability relationship.

### C.1.1 BUILDING TYPES

Buildings within facilities have a wide range of design and construction features; however, the most important is building structure. The following types of major structures can be found:

a. B1: Wood-frame trailer or shack.
b. B2: Steel-frame/metal siding or pre-engineered building.
c. B3: Unreinforced masonry bearing wall building.
d. B4: Steel or concrete framed with reinforced masonry infill or cladding.
e. B5: Reinforced concrete or reinforced masonry shear wall building.

### C.1.2 OVERPRESSURE DAMAGE FOR BUILDING TYPES

Damage estimates have been obtained from past incidents, effects on buildings from testing nuclear weapons, and other sources. The overpressure shown are appropriate for the different building types.

a. *Wood-frame trailer or shack*, B1: From observation of destruction by severe storms, it is inferred (for permanent buildings) that an explosion loading of approximately the design wind pressure or about 0.2 psi would mark the onset of serious damage to these buildings. Pressures of about 1 psi could overturn an isolated building and partially destroy temporary building complexes.
b. *Steel-frame/metal siding or pre-engineered building*, B2: The frame in this type of building provides support to the roof, which is independent of the walls. Information is available in the literature on explosion performance from war records. These records indicate that sheeting is ripped off and internal walls are damaged at overpressures >1.5 psi; the building frame stands but cladding and walls are damaged at > 2.5 psi, and complete building collapse occurs at > 5 psi.
c. *Unreinforced masonry bearing wall building*, B3: This type of building is similar to domestic/small commercial buildings. The walls collapse about 1.0 psi and total building collapse occurs about 1.5 psi.
d. *Steel or concrete framed w/reinforced masonry infill or cladding*, B4: This type of building regularly suffers damage in storm conditions; however, this type of building provides robust performance under explosion loading. Wall damage may occur at 1.0 psi. The roof slab may collapse at 2.0 psi and total building collapse at 2.5 psi.
e. *Reinforced concrete or masonry shear wall building*, B5: The building is generally designed for 2.0 psi, so very minor damage will occur. The roof and walls will deflect under loading and internal wall damage at about 4.0 psi. The building has major damage and possible collapse at 6.0 psi.

### C.1.3 OVERPRESSURE DAMAGE AND VULNERABILITY RELATIONSHIP[11]

Assumptions on the relationship between damage and vulnerability of occupants (probability of fatality) were derived from several sources. The following general data was identified:

a. *Building destruction*: A vulnerability of 1.0 was chosen for buildings subject to a blast significantly greater than that leading to building collapse, based on extrapolation (shown on dotted lines in Figure C-1).
b. *Building collapse*: A vulnerability level of 0.6 was chosen based on building collapse data from earthquakes, war, and past incidents.
c. *Minor damage*: On the basis of studies reported by Lees[12], it was assumed that the vulnerability of occupants would be 0.01 from minor damage, such as broken windows.

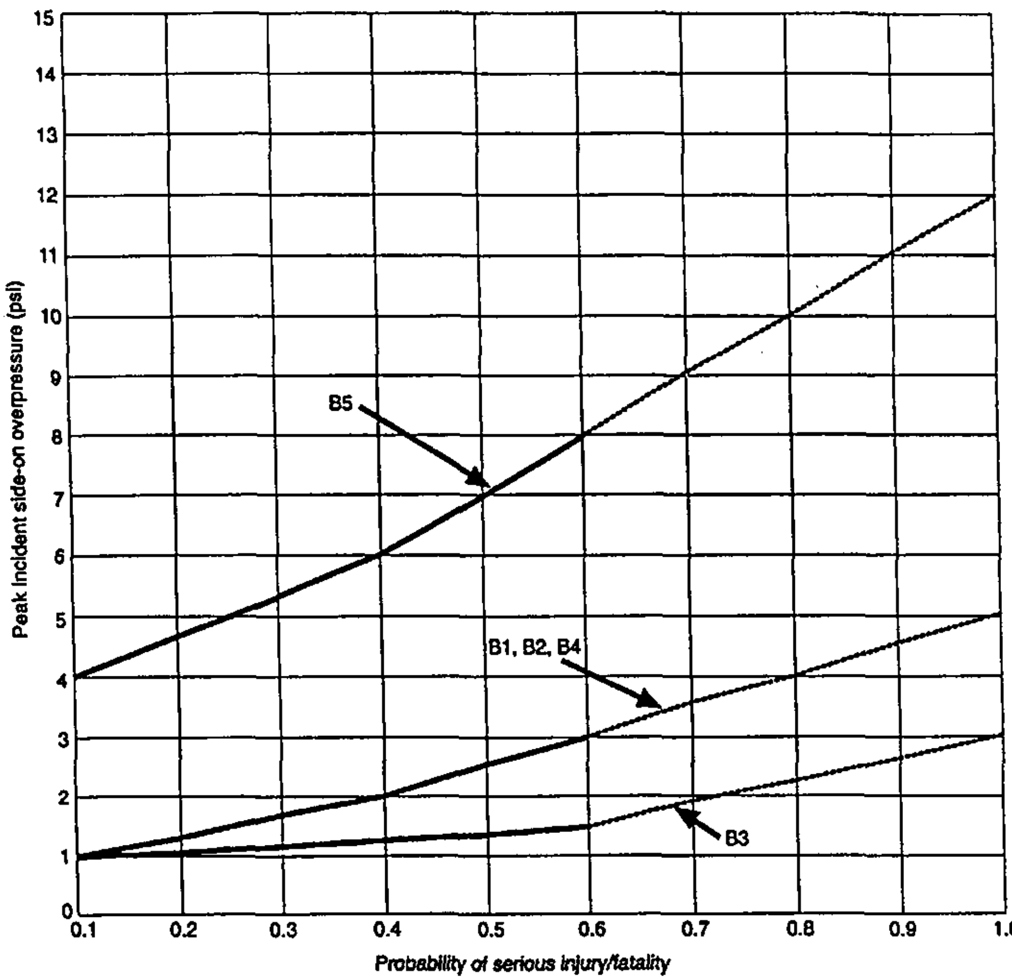
### C.1.4 OVERPRESSURE VERSUS VULNERABILITY NOMOGRAM

An overall summary of the relationship between levels of overpressure and vulnerabilities to occupants for building types is shown in Figure C-1, "Overpressure Versus Vulnerability."

## C.2 Generic Frequencies of Explosions

The process plant under consideration should be divided into process units of isolatable inventories, with release

[11]For additional information, see CCPS, *Guidelines for Evaluating Process-Plant Buildings for External Explosion and Fire* (work in progress).
[12]*Loss Prevention in the Process Industries*, Volume I, Frank P. Lees, 1980.




Note: Figure taken from CCPS, *Guidelines for Evaluating Process-Plant Buildings for External Explosions and Fires* (work in progress).

Figure C-1—Sample Overpressure Versus Vulnerability

frequencies estimated for failures of pipes, valves, flanges, pumps, compressors, and other equipment. This would be supplemented with failures from other events such as earthquakes, floods, tornadoes, and effects from adjacent units in order to build a comprehensive listing of release scenarios. Knowledge of the likelihood, release size, and duration of individual scenarios would then be combined with vapor cloud dispersion distances and direction to site-specific ignition sources in order to calculate the overall frequency of occurrence for major explosions impacting plant buildings.

A simple approach for risk screening was taken by one member company. The company developed a historical record of all major explosions and an estimate of the number of plant years of operating experience to arrive at estimated frequencies of explosions for generic process units. This information is shown in Table C-1 for specific refinery units. Companies may wish to develop similar data for their operations. If not, the generic data shown could be used when a company is performing a screening risk-analysis.

Table C-1—Generic Frequencies of Major Explosions (see note)

| Process Unit | Frequency of Explosions/Year of Operation |
|---|---|
| Alkylation | $5.1 \times 10^{-4}$ [a] |
| Cat cracking | $6.5 \times 10^{-4}$ |
| Cat reforming | $2.6 \times 10^{-4}$ |
| Crude | $4.9 \times 10^{-4}$ |
| Hydrotreating | $2.0 \times 10^{-4}$ |
| Hydrocracking | $5.6 \times 10^{-4}$ |
| All units | $4.3 \times 10^{-4}$ |

Note: Information in this table is derived from the following sources: OSH ROM Occupational Safety and Health on CD-ROM, Major Incident Database (MHIDAS), UK Atomic Energy Authority, July 1993; Engineering Services Loss Database, Sedgwick Engineering Limited, Sedgwick House, The Sedgwick Centre, London E1 8DX; and Worldwide Refining Report, *Oil and Gas Journal*, Penwell Publishing Company, December 23, 1991.
[a]A frequency of $5.1 \times 10^{-4}$ explosions/year of operation is the same as one explosion in 1961 years of operation.

## APPENDIX D—PROCESS PLANT BUILDING CHECKLIST*

The following is an example of a building checklist. Some of the questions in the checklist may not apply to all work sites; likewise, additional questions may be necessary.

**PROCESS PLANT BUILDING CHECKLIST**

Building: Date: Name:

| E,F,T* | Questions | Yes | No | NA* | Remarks |
|---|---|---|---|---|---|
| FT | 1. Is the building located up wind of the hazard? | | | | |
| EFT | 2. Is the building included in an emergency response plan for fire and toxic release? Are the occupants trained on emergency response procedures? Are evacuation instructions posted? | | | | |
| E | 3. Are large pieces of office equipment or stacks of materials within the building adequately secured? | | | | |
| E | 4. Are the lighting fixtures, ceilings, or wall-mounted equipment well supported? Are process controls mounted on interior walls? | | | | |
| E | 5. Is there heavy material stored on the ground floor only? | | | | |
| E | 6. Have all the exterior windows been assessed for potential injury to occupants? | | | | |
| EFT | 7. Are there doors on the sides of the building opposite from an expected explosion or fire source? | | | | |
| FT | 8. Are there exterior and interior fire suppression equipment available to the building? | | | | |
| FT | 9. Is there a detection system within the building or in the fresh air intake to detect hydrocarbons, smoke, or toxic materials? | | | | |
| FT | 10. Is the air intake properly located? | | | | |
| FT | 11. Can the ventilation system prevent air ingress or air movement within the building? Are there hydrocarbon or toxic detectors that shut down the air intake? Does the building have a pressurization system? | | | | |
| FT | 12. Are there wind socks visible from all sides of the building? | | | | |
| EFT | 13. Is there a building or facility alarm or communication system to warn building occupants (of an emergency)? | | | | |
| T | 14. Is there sufficient bottled air or fresh supplied air for the occupancy load? | | | | |
| EFT | 15. Are all sewers connected to the building properly sealed to prevent ingress of vapors? | | | | |

*E =Explosion; F=Fire; T =Toxic; NA = Not Applicable. This checklist may or may not be appropriate for every particular circumstance.

# APPENDIX E—EXAMPLES

The examples in this appendix are intended to guide the user in applying the concepts presented in this publication. Each example is designed to illustrate a specific aspect of the application of this publication, and does not attempt to convey the complexity or to make trivial the issues associated with location of buildings in process plants. The numerical criteria used as standards for occupancy or risk acceptance in the examples are not intended to serve as numerical guides. The numbers used in these examples are solely for illustration purposes and do not reflect recommended numerical criteria. Each company should select criteria reflecting its needs.

Example 1—Materials of Concern (Section 3.1.2)

Problem 1: A sweet crude oil treating and storage facility has an office 35 feet from the process equipment. Because the unit contains more than 10,000 pounds of flammable liquid, the facility is covered by OSHA process safety management regulations.

Solution: Due to the conditions in which the crude oil is processed at this facility, it was concluded that the risk of vapor cloud explosions (VCEs) is low, and that the primary concern is fire. Figure 4 should be used to evaluate the hazard to building occupants.

Example 2—Site-specific Conditions (Section 3.1.3)

Problem 1: An occupied shipping office for a large automated chemical warehouse handling solid products extends out from the warehouse on the north side. The manufacturing process for this product contains flammable gases and dust. The product is manufactured, compounded, and packaged in a separate building 200 feet to the south of the warehouse, and explosion venting for the building has been designed to release to the south.

Solution: The shipping office is eliminated from further study because the site-specific condition of the process plant building directs the effects of a potential explosion away from the occupied building. A building checklist may be completed.

Example 3—Occupancy Criteria (Section 2.5.2)

Problem 1: A company's internal criterion for occupancy load is 400 hours per week. A cafeteria is located within a refinery complex with process units located on three sides. The closest unit containing hydrocarbon is 250 feet away. The cafeteria is open from 6:00–8:00 A.M., 11:00 A.M.–1:00 P.M., and 6:00–7:00 P.M. on a daily basis. Approximately 200, 600, and 150 people, respectively, use the facility for each meal on weekdays. About 100 people per meal use the facility on weekends (each individual averages 0.5 hour in the building).

Solution: The occupancy load is calculated as:

Breakfast (0.5 hour × 200 people × 5 days) + (0.5 × 100 × 2) = 600
Lunch (0.5 hour × 600 people × 5 days) + (0.5 × 100 × 2) = 1,600
Evening (0.5 hour × 150 people × 5 days) + (0.5 × 100 × 2) = 475

The occupancy load is 2,675 hours per week. Therefore, evaluation of the building using Section 3.2 should be considered necessary.

Problem 2: The same company has two permanent trailers. Another trailer is to be added. A process unit is 200 feet from the trailers. A question of siting of the trailers was raised. The existing trailers house eight individuals. The assigned personnel spend, on average, six hours per day in the trailers. In addition, two meetings are held that average six people for six hours per day, four days a week.

Solution: The occupancy load is calculated as:

6 hours × 8 people × 5 days = 240
6 hours × 6 people × 4 days × 2 meetings = 288

The total occupancy load is 528 hours per week. This exceeds the internal criterion of 400 hours per week. The company decided that the best option for reducing risk was to not install the new trailer at this location, and to move one of the existing trailers to a different location. The Building Checklist may be completed.

Problem 3: A company has tiered occupancy criteria of (1) occupancy load of 300 hours per week, (2) occupied more than 50 percent of the time, or (3) more than 40 people in the building for one hour. A metal-clad building is used to house maintenance offices and serve as a warehouse. The building is approximately 350 feet from the closest process unit and 750 feet from the flammable storage area. The building is occupied by two warehouse personnel and one supervisor 40 hours per week. Additionally, the maintenance department has 65 personnel who average 2 hours per day, five days a week, including 1 hour per week for a safety meeting in the building.

Solution: Since the first and third tier of the occupancy criteria were exceeded, further evaluation using Stage 2 or 3 (Section 3.2 or 3.3) should be considered necessary. The company decided to proceed with further evaluation using Stage 2.

Problem 4: A company has established an occupancy load criteria for individuals assigned to the building more than 40 percent of the time. A shelter is provided for operators' use in the process unit. The shelter is occupied by four people less than 30 percent of the time. Employees are required to leave the building in the event of an emergency.

Solution: No further evaluation is required because the building does not meet the occupancy criteria. A building checklist may be completed.

Problem 5: A small field laboratory in a chemical plant has been designated as an emergency shelter during gas releases. The building is designed to prevent ingress of gases.

Solution: Since the building is an emergency shelter, and is designed to prevent ingress of toxic releases, no further evaluation is required. A building checklist may be completed. However, if there is a potential for an explosion, further evaluation should be considered necessary using Stage 2 or 3 (Section 3.2 or 3.3).

### Example 4—Design and Spacing Standards (Section 3.2.1)

Problem 1: An engineering building at a refinery is about 500 feet from the closest process equipment. The building's occupancy load is over 400 personnel hours and the building is of masonry/steel-frame construction.

Solution: The company's standard states that for processing units, the distance for this building type should be more than 400 feet from the hazard. A building checklist may be completed.

Problem 2: An existing control building is designed for 10 psi overpressure and is 150 feet from the process unit.

Solution: The applicable internal company standard on building design indicates that this building meets the current standard. Since the spacing is greater than the required minimum spacing, no further explosion evaluation is required. A building checklist may be completed.

### Example 5—Consequence Analysis (Section 3.2.2)

Problem 1: A control building designed for a 3 psi overpressure is about 100 feet from a Depropanizer. The Overhead Accumulator holds 4000 gallons of propane at 110°F and 210 psig. A process hazards analysis (PHA) concluded that a release could involve a severed 2-inch pipe, and would occur in a congested area.

Solution: The overpressure was calculated to be 3 psi at 150 feet, using the multi-energy method. This exceeds the design of the building. Based on these results, additional evaluation should be considered necessary.

Example 6—Screening Risk Analysis (Section 3.2.3)

Problem 1: A refinery has a Light Ends Unit containing propane/butane. A building of masonry construction with windows is 50 feet from the process with a fractionator 60 feet away. The original building housed only the control room with two operators. The building has been expanded to accommodate a change room and several offices. The control room is occupied by two personnel all the time on eight-hour, five-days-a-week shifts. The change room has an occupancy of ten for one hour per day, seven days a week. The offices have five people for nine hours per day, five days a week.

Solution: This solution is based on the steps outlined in Section 3.2.3 of this recommended practice as follows:

Step 1 The building meets the definition of B3, unreinforced masonry with supporting walls, as indicated in Section C.1.2.

Step 2 In calculating the overpressure, the choice of methods is up to the user. A release scenario from the fractionator, using the multi-energy method, yielded an overpressure of 5.2 psi at the control building, based on a release scenario developed during the PHA.

Step 3 The frequency of explosions should be based on a company's specific experience. If data or company-specific experience is not available, then the generic information in Appendix C could be used. From Section C.2, a frequency of 4.3 × 10-4 is used for all refinery units, since a Light Ends Unit is not listed in Appendix C.

Step 4 The vulnerability of occupants is calculated using Section C.1.3. Given the building type (B3) and overpressure (5.2 psi) from Figure C-1 in Appendix C, the vulnerability of occupants is 1.0.

Step 5 The maximum individual risk is calculated by multiplying the explosion frequency, individual occupancy fraction, and vulnerability of occupants. The maximum individual occupancy load is calculated by determining the maximum number of hours per week spent inside the building by anyone (9 hours/day × 5 days/week = 45 hours/week) and dividing by 168 hours/week. The individual risk is as follows:

4.3 × 10-4 (explosion frequency) × 0.26 (maximum individual occupancy) × 1.0 (vulnerability of occupants) = 1.1 × 10-4

The maximum individual risk from the Light Ends Unit is 1.1 × 10-4 . The maximum individual risk from two adjacent units is 6.3 × 10-4 and 3.7 × 10-3. Thus, the total maximum individual risk for the maximum exposed individual in the building is the following:

1.1 × 10-4 + 6.3 × 10-4 + 3.7 × 10-3 = 4.4 × 10-3

Step 6 The total risk of 4.4 × 10-3 calculated in Step 5 is compared to the internal company risk decision criteria. The following criteria will be used for this example:

| | |
|---|---|
| >1.0 × 10-3 | Risk mitigation or further risk assessment is required. |
| 1.0 × 10-3 to 1.0 × 10-5 | Risk reduction should be considered. |
| < 1.0 × 10-5 | Further risk or assessment reduction need not be considered. |

The value of total risk is greater than 1.0 × 10-3. Based on these criteria, risk mitigation or further risk assessment should be considered necessary using Stage 3, Risk Management.

Step 7 The risk assessment screening indicated that either risk mitigation or further risk assessment is required. The cost of mitigation measures relative to the costs of a risk analysis should be considered. If the mitigation costs are relatively high, then a risk analysis may be conducted to improve the confidence level of these screening results. Possible risk-reduction measures to be considered include the following:

a. Modify process or install emergency shutdown system.
b. Move some of the population to reduce the occupancy load.
c. Modify the building by providing separate supports for the roof.
d. Move the control building.

An evaluation of the most cost-effective approach for each of these options should be considered necessary.

Example 7—Fire (Section 4.0)

Problem 1: A noncombustible control room/office building is 100 feet from a pumping row in a refinery unit handling flammable materials. The pumping row is diked, and an automatic water/foam spray system is provided. For the purposes of this example, the materials and site conditions preclude the potential for explosion or jet fire.

Solution: Figure 4 was used to evaluate the hazard to building occupants. The quantity of material handled exceeds 10,000 pounds. The building does not meet the company's internal standard for locations 150 feet from flammable pumping stations. There is a building emergency response plan to vacate the building in the event of a nearby fire, and the fire brigade will respond to control the fire. Also, the water/foam spray system on the pumps can be activated from the building to minimize the effects.

Based on the mitigation and emergency response capability, no additional fire evaluation should be considered. A building checklist may be completed.

Example 8—Toxic Release (Section 5.0)

Problem 1: A chemical plant uses ammonia in a process. The ammonia is stored in a 15,000-gallon tank and is pumped to the processing unit. The storage tank is 250 feet from the engineering building.

Solution: Figure 5 was used for the evaluation. Ammonia is listed in OSHA 29 CFR 1910.119, and the stored amount exceeds the specified threshold quantity. All occupied buildings on-site that could be impacted by an ammonia release are provided with pressurization and fresh air supply shutdown systems to preclude entry of ammonia. Additionally, ammonia detectors are located around the storage tank and pump as well as in each building air intake.

Based on the pressurization system, which prevents ingress of ammonia, no further toxic evaluation should be considered necessary. A building checklist may be completed and the emergency response actions for occupants defined.

Example 9—Building Checklist (Section 6.0)

Problem 1: In Example 4, Problem 1, an engineering building was evaluated and it was determined that no further evaluation was required. It may be considered for a final review using a building checklist.

Solution: See the completed Building Checklist that follows.

The following is an example of a building checklist. Some of the questions in the checklist may not apply to all work sites; likewise, additional questions may be necessary.

## PROCESS PLANT BUILDING CHECKLIST

Building: Engineering Date: February 29, 1994 Name: J. Alderman

| E,F,T* | Questions | Y | N | NA* | Remarks |
|---|---|---|---|---|---|
| FT | 1. Is the building located up wind of the hazard ? | ✓ | | | |
| EFT | 2. Is the building included in an emergency response plan for fire and toxic release? Are the occupants trained on emergency response procedures? Are evacuation instructions posted? | ✓ | | | |
| E | 3. Are large office equipment or stacks of materials within the building adequately secured? | ✓ | | | Library and file room equipment need proper anchoring. |
| E | 4. Are the lighting fixtures, ceilings, or wall-mounted equipment well supported? Are process controls mounted on interior walls? | | ✓ | | Ceiling tile and lights need better anchoring. |
| E | 5. Is there heavy material stored on the ground floor only? | | | ✓ | |
| E | 6. Have all the exterior windows been assessed for potential injury to occupants? | | ✓ | | Evaluate the need for windows on south side of building. |
| EFT | 7. Are there doors on the sides of the building opposite from an expected explosion or fire source? | ✓ | | | |
| FT | 8. Are there exterior and interior fire suppression equipment available to the building? | ✓ | | | Fire monitors in range of building. |
| FT | 9. Is there a detection system within the building or in the fresh air intake to detect hydrocarbons, smoke, or toxic materials? | | ✓ | | Smoke and toxic gas in air intake. |
| FT | 10. Is the air intake properly located? | | ✓ | | Intake on process side of building. |
| FT | 11. Can the ventilation system prevent air ingress or air movement within the building? Are there hydrocarbon or toxic detectors that shutdown the air intake? Does the building have a pressurization system? | | ✓ | | System is not capable of pressurizing the building. No automatic shutoff of air intake. |
| FT | 12. Are there wind socks visible from all sides of the building? | | | | |
| EFT | 13. Is there a building or facility alarm or communication system to warn building occupants (of an emergency)? | ✓ | | | |
| T | 14. Is there sufficient bottled air or fresh supplied air for the occupancy load? | ✓ | | | |
| EFT | 15. Are all sewers connected to the building properly sealed to prevent ingress of vapors? | ✓ | | | |

*E=Explosion; F=Fire; and T=Toxic. This checklist may or may not be appropriate for every particular circumstance.

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