GUIDELINE FOR THE LOCATION OF OCCUPIED BUILDINGS IN INDUSTRIAL GAS PLANTS

AIGA 093/16

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As part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has issued this publication 93, *Guidelines for the Location of Occupied Buildings in Industrial Gas Plants*, jointly produced by members of the International Harmonisation Council and originally published by the Compressed Gas Association(CGA) as P-64-2014, *Guidelines for the Location of Occupied Buildings in Industrial Gas Plants.*

This publication is intended as an international harmonized publication for the worldwide use and application by all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), EIGA, and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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1 Introduction

Incidents have shown the need for the chemical industry to consider the location of both permanent and portable occupied buildings on chemical production facility sites. The ignition of flammable vapour released into a congested process area or pressure energy released from process equipment failures can impact personnel located inside these buildings. Industry groups such as the American Petroleum Institute (API), the Center for Chemical Process Safety (CCPS), and the Chemical Industry Association (CIA) have developed guides to assist these industry companies in the safe location and design of occupied buildings to improve the safety of workers. In some regions, assessing the risk to occupants in buildings within air separation unit (ASU) facilities is not specifically required by regulations.

This publication is intended to provide guidance specific to the industrial gas industry for the determination of location and design of both permanent and portable on-site occupied buildings to address the risks in ASU and HYCO plants.

The goal of this publication is to provide guidelines to:

- protect the building occupants so the building does not place the occupants at greater risk than employees located outside; and
- reduce the risk to employees not essential to the operation of the facility by locating such employees in a building that is either:
  - away from the process; or
  - reinforced and/or equipped to achieve comparable risk reduction to that achieved by distance alone.

Risk management and process safety assessment are complex subjects. Technology for determining the location of occupied facility buildings is still evolving. Some aspects of this technology require the application of technical judgement as well as proven scientific methodologies. It is the intention that this publication be used by qualified personnel. Qualified personnel are those who have sufficient training and experience in hazard identification and risk assessment.

While this publication is intended to provide an overview of the processes and evaluations used to determine safe location of occupied buildings, it is not intended to be a strict, prescriptive requirement. As individual company processes, risk targets, facility layouts, and safety procedures vary, each facility should be evaluated individually to ensure safe location of occupied buildings.

2 Scope

This publication addresses the risks to persons in occupied buildings within ASU and HYCO facility boundaries associated with pressure energy. Pressure energy can be generated from ignition of flammable material that has been released into congested or confined area and the sudden failure of pressure vessels. Section 6.4 provides criteria for the exclusion of specific pressure vessel mechanical failures from consideration.

This publication is intended to provide guidance on determining the risk to persons in:

- new permanent or portable occupied buildings on ASU and HYCO facilities;
- existing occupied buildings from a new ASU plant, HYCO plant, or major modification added to an existing facility;
- an occupied building from a relocated ASU plant, HYCO plant; and
- a relocated occupied building.

It is also intended to provide guidance on how to address hazards from neighbouring facilities during the design of new ASU and HYCO plants. The provisions of this publication are effective as soon as hazardous materials are introduced into the ASU or HYCO facility.

The scope of this publication is not intended to cover the following:

- Existing buildings in existing ASU and HYCO plants;
- Occupied buildings beyond the ASU or HYCO facility boundary, as this publication is specific to on-site impacts within ASU and HYCO facilities. CCPS *Guidelines for Facility Siting and Layout*, the Seveso III Directive, and other sources provide general guidance on this topic [1, 2] [1];
- The location and design of occupied buildings as related to exposures from toxic gas releases. API RP 752, *Management of Hazards Associated with Location of Process Plant Buildings*, API RP 753, *Management of Hazards Associated with Location of Process Plant Portable Buildings*, and the CIA document *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites* provide guidance on mitigation of hazards related to a toxic release [3, 4, 5];
- The location of oxygen and inert gas vents relative to the location of buildings. AIGA document 067, *Safe Location of Oxygen and Inert Gas Vents* provides guidance on the safe location of oxygen and inert gas vents [6]; and
- Cryogenic spills from air separation facility equipment. Many CGA and EIGA publications provide guidance on control of cryogenic spill hazards; see Section 10 for additional references.

For industrial gas facilities not included in the scope of this standard, see NFPA 55, *Compressed Gases and Cryogenic Fluids Code* or other equivalent regional standards for siting considerations [7].

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall
Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should
Indicates that a procedure is recommended.

3.1.3 May
Indicates that the procedure is optional.

3.1.4 Can
Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Blast
Transient change in the gas density, pressure, and velocity of the air surrounding an energy release point.

3.2.2 Building
Any permanent or portable structure that is enclosed on all sides with a roof.

3.2.3 Building siting study
Procedures to evaluate the hazards and establish the design criteria for new buildings.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3.2.4 Confinement
Physical surface that inhibits the expansion of a flame front of burning vapour in at least one direction. Examples include solid decks, walls, enclosures, or process areas.

3.2.5 Congestion
Collection of closely spaced objects in the path of the flame front that has the potential to increase flame speed to an extent that it can generate a damaging blast wave.

3.2.6 Consequence
Potential effects due to overpressure resulting from ignition of flammable gas in a congested area, failure of a pressure vessel, or process upsets. Descriptions may be qualitative or quantitative.

3.2.7 Consequence-based methodology
Methodology used for building siting study that is based on consideration of the impact of a blast wave that does not consider the frequency of events.

3.2.8 Energy release
Sudden discharge of chemical or stored energy due to chemical reaction such as combustion of a fuel in air or failure of a pressurized vessel.

3.2.9 Flammable mixture
Mixture of a flammable gas and an oxidant that is within the flammable range.

3.2.10 Impulse
Measure that can be used to define the ability of a blast wave to do damage. It is calculated by the integration of the pressure-time curve.

NOTE—This term is expressed in units of pressure-time.

3.2.11 Individual occupancy
Total number of hours per year spent by an employee in a building.

3.2.12 Light wood trailer
Portable building with a wall design consisting of “2 x 4” studs/wall members (nominal 1.5 in x 3.5 in) with a thin outer skin.

NOTE—This is generally representative of the weakest portable building used by the chemical process industry.

3.2.13 Maximum individual occupancy
Number of hours per year spent by the most present employee in a building.

3.2.14 New facilities
Facilities built, designed, or relocated after publication of this document (January, 2016).

3.2.15 Occupied building
Portable or permanent building where personnel are assigned to perform work on a routine basis or which is used for a recurring group personnel function.

3.2.16 Occupant vulnerability
Proportion of building occupants that could potentially suffer a permanent disability or fatality if an energy release were to occur.

3.2.17 Overpressure
Any pressure above atmospheric caused by a blast.

3.2.18 Portable building
Any building that can be easily moved to another location within the facility, regardless of the length of time it is kept at the site.

3.2.19 Pressure vessel
Vessel that operates at or above 1.03 bar(15 psi)

3.2.20 Pressure volume (PV) energy
Sudden expansion of a compressed gas or flashing liquid generating a blast wave that propagates outward from the source.

3.2.21 Process area
Assembly of equipment consisting of but not limited to pressure vessels, heat exchangers, distillation equipment, compressors, storage containers, vapourisers, manifolds, and piping that terminates at the point where the gas supply first exits the ASU or HYCO unit boundary.

3.2.22 Quantitative risk assessment (QRA)
Numerical estimates of expected frequency and consequence of potential events based on engineering evaluation and mathematical technique. The numerical estimates can vary from simple values of probability/frequency of an event occurring based on relevant historical industry to more complex methods of frequency determination.

3.2.23 Reflected pressure
Impulse or pressure experienced by an object facing a blast.

3.2.24 Side-on pressure
Impulse or pressure experienced by an object as a blast wave passes by it.

3.2.25 Risk-based analysis
Quantitative risk assessment used for building siting study that takes into consideration numerical values for both the consequences and frequencies of vapour cloud explosions, pressure vessel structural failures, or other serious failures resulting in energy releases.

3.2.26 Vapour cloud explosion (VCE)
Energy release (deflagration or detonation) resulting from ignition of a cloud of flammable vapour, gas, or mist in which flame speeds accelerate to sufficiently high velocities to produce overpressures.

4 Building siting study methodologies

4.1 General information

The three methodologies presented in this publication to perform a building siting study are a simplified approach, consequence based, and risk based. The simplified approach is only applicable to locating portable buildings that can be exposed to flammable vapour cloud release risks. Individual companies may use any or a combination of these analysis methods to determine safe locations for occupied buildings at ASU and HYCO plants. Sections 5 and 6 describe information that is necessary for each method.

Where local codes or standards (such as fire codes or building codes) require buildings to be located at greater distances than the distances resulting from the methods described in this guideline, the greater distances should be followed.

In addition to the approaches described in this guideline, there are several other accepted approaches to the calculation of overpressure that can be used in addition to or in place of the methodology presented. CCPS *Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE, and Flash Fire Hazards,* provides extensive guidance on the calculation of overpressure [8]. Examples of commercially available software to calculate overpressure include PHAST™, PHAST Risk™, and SafeSite$_{3G}$® [9, 10, 11].

4.2 Introduction to consequence-based analysis

The consequence-based methodology evaluates the potential impact of sudden energy releases on nearby buildings without considering the probability of the energy release occurring. Some variations of the method may consider impulse as well. A consequence-based methodology determines whether a new building can be located or designed to withstand the overpressure level to which it may be exposed. Guidance regarding which buildings and scenarios should be included or excluded in the analysis is shown in Sections 5 and 6.

4.3 Introduction to risk-based analysis

The risk-based analysis not only considers the information from a consequence-based analysis, but also considers the frequency and probability of hazardous exposures to the building and occupants.

A tolerable risk level shall be defined before performing the analysis.

4.4 Introduction to overpressure concepts

Overpressure radiates from the source of a blast such as a vapour cloud explosion (VCE) or pressure volume (PV) burst but decays rapidly with distance from the source and with time. Figure 1, from Baker Engineering and Risk Consultants, Inc., provides a pressure wave illustration [12].

A secondary effect of the overpressure wave is the drag loading, which is equivalent to a very high velocity wind. It propels the debris generated by the air-blast, creating secondary projectiles. Also, the building is subject to a ground-shock, which produces ground motions similar to a short duration earthquake. The ground shock effect is generally not considered during this building siting analysis.

As the overpressure wave expands and diffracts (wraps or bends) around a building, it exerts an overpressure on the front wall, on the roof, sidewalls, and finally on the rear wall.

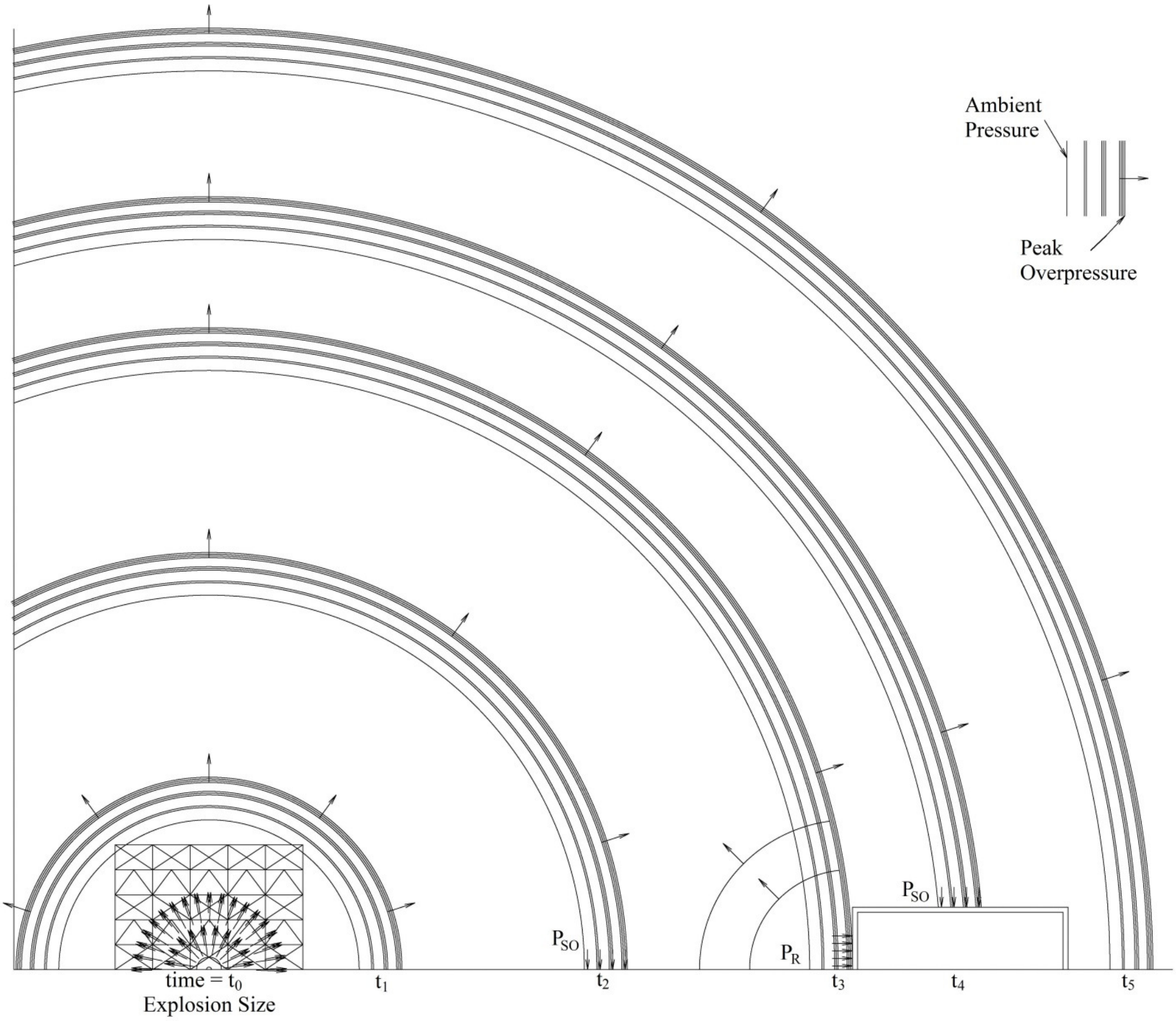

Figure 1—Pressure wave illustration

Building surfaces facing the blast will cause the overpressure wave to reflect off the building surface. As a consequence, the building surfaces facing the blast receive a higher overpressure load than the roof, side, or rear walls. As an example, the reflected pressure (P_R) on the front wall is approximately 2.2 times the peak pressure propagating in the free field. When providing specifications for building design, it is important to be clear whether side-on overpressure or reflected overpressure is being provided to the designer.

The peak overpressure value measured in the free field is called peak side-on overpressure (P_{SO}). This value is used as the quantifiable value characterizing the overpressure effect at the building location.

Unless otherwise noted, all references in this publication are to peak side-on overpressure.

4.5 Portable versus permanent buildings

Recommended practices in other industries, such as API RP 753, have recognized that personnel in portable buildings can be more vulnerable to injury than personnel in permanent buildings [4]. This increased vulnerability can be attributed to the fact that portable buildings are traditionally of light-weight construction, and often located close to process equipment where work is being done.

Decisions regarding the specified damage-resistance and location of portable buildings in ASU and HYCO plants should take into account the consequences of VCEs and may include consequences of PV events taking place in or near the facility. Where risk-based analysis is being performed, the probability of such events should also be taken into account.

5 Selection of buildings for consideration in the building siting study

5.1 Preliminary considerations

Before siting buildings on the plot plan (facility layout), each building needs to be defined as either occupied or unoccupied. Depending upon the individual company's risk criteria, the peak occupancy may also need to be determined.

Portable buildings may be required for a defined period of time during the construction and the commissioning phase of new facilities and for future maintenance activities on the site. A building siting study should be done for these portable buildings if there is a desire to continue to have these portable buildings occupied during startup or operation of the plant or if neighbouring plants that pose a risk will continue operations while the portable buildings are occupied, see 6.5.

Individual companies may develop their own occupancy criteria to define occupied buildings to be included or excluded from the building siting study as permitted by local regulations. For portable buildings, an occupancy probability of 1.0 shall be used in the study with exception of portable buildings not intended for occupancy as mentioned in API RP 753 [4].

5.2 Buildings that should be included in a building siting study

Buildings or rooms within a building typically found at an ASU or HYCO facility that should be considered occupied during a building siting study include:

- office buildings;
- conference rooms;
- break rooms for drivers;
- buildings specifically designated as evacuation or safe haven locations in the event of an emergency;
- lunch rooms;
- control rooms;
- rooms used for work permit creation and control during maintenance activities;
- change houses or locker rooms;
- training rooms;
- guard houses;
- maintenance shops;
- laboratories;
- scale house;
- rooms intended for occupancy within an enclosed process area (e.g., office, maintenance shop, control rooms); and
- portable buildings used for the functions previously listed.

5.3 Buildings that may be excluded from a building siting study

Buildings typically found at an ASU or HYCO facility that should be considered unoccupied and therefore may be excluded from a building siting study include:

- Enclosed process areas where personnel are assigned to perform activities similar to those performed at an outdoor process area. This exclusion is included for consistency with API RP 752 [3];
- Electrical substations and motor control buildings where routine personnel access is not typically required;
- Remote instrumentation and computer station enclosures where routine personnel access is not typically required;
- Enclosures used to store equipment or raw materials where routine personnel access is not typically required;
- Analyser buildings where essential personnel are only required to perform short duration activities such as calibrations;
- Water or waste water treatment buildings where essential personnel are only required to perform short duration activities such as water treatment analysis; and
- Field sampling/testing station where personnel are only required to perform short duration activities such as sample collection.

Maintenance and calibration activities are not considered routine work for the purpose of this publication with the exception of dedicated maintenance shops and the work permit development and control activity. Additional guidance on classification of buildings as occupied or unoccupied can be found in API RP 752 [3].

This publication does not require evaluation of unoccupied buildings.

6 Selection of scenarios for consideration in the building siting study

6.1 Introduction to scenarios

Scenarios for a siting study can include the following:

- energy releases resulting from ignition of flammable vapour released into congested or confined process areas, see 6.2;
- energy releases resulting from process upsets or deviations, see 6.3; and
- energy releases resulting from structural failure of vessels under pressure, see 6.4.

Some scenarios affecting occupied buildings in ASU or HYCO facilities can result from neighbouring facilities. See 6.5 for additional discussion on how to address neighbour's impact on the siting of ASU or HYCO occupied facility buildings.

Scenarios determined by the company to be noncredible can be excluded from building siting consideration.

6.2 Vapour cloud explosion

6.2.1 Sources

A VCE can occur when flammable gas is released into a confined or congested area, when the gas is between its lower flammable limit (LFL) and upper flammable limit (UFL) and is ignited. The confinement or congestion results in a turbulent mixing of the released flammable gas with air, which increases the possibility of generating overpressures upon ignition.

Causes of flammable gas releases in facilities include but are not limited to:

- misoperation of valves to atmosphere;

- vessel or piping leaks due to corrosion, cracking, or expansion or contraction from large temperature changes;
- significant flange gasket failures;
- flex joint failures in piping;
- leaks from vibration (such as in compressor seals); or
- guillotine breaks of piping.

6.2.2 Excluded vapour cloud explosion sources

The following scenarios are typically excluded in the study because they are considered very low frequency sources of VCE or are addressed by existing industry publications or guidelines:

- All welded piping on pipe racks. Experience indicates that the frequency of failure for welded systems is much lower than flange or other mechanical joints;

  NOTE—If welded piping systems are exposed to other hazards (e.g., vehicle traffic, forklift impact, etc.) they may be included as release sources in the study.

- Coldboxes that are inerted so a release of flammable material into this volume will not create a flammable mixture;
- Permanent flammable gas vents designed to direct the discharge to a safe location away from congested areas of the plant;
- Release of a flammable vapour into an uncongested and unconfined area. Field experiments have shown that the turbulence caused by congestion or confinement is required to initiate a significant overpressure event [7]. One example of this type of release is from an elevated process vent designed to prevent the release of gases from slumping into confined or congested areas;
- Release of flammable material inside small enclosures (not to exceed 1000 ft^3), like analyser buildings, which are equipped with flammable gas monitors, building ventilation, and ventilation monitoring systems;
- Release of flammable material inside enclosures, like analyser buildings, where the only source of flammable material is from compressed gas cylinders stored and used in accordance with NFPA 55 [5]; and
- Refrigeration systems using class 2L refrigerants, such as ammonia, designed in accordance with local regulations or codes, such as ANSI/ASHRAE 15, *Safety Standard for Refrigeration Systems*, CSA B52, *Mechanical Refrigeration Code*, and EN 378-1, *Refrigerating systems and heat pumps. Safety and environmental requirements. Basic requirements, definitions, classification and selection criteria*, are excluded [13, 14, 15].

6.2.3 Included confined and congested spaces for vapour cloud explosions

Any area in which flammable gases or vapours could accumulate within a confined or congested area should be considered as a possible source of overpressure. The distance required for a structure to be considered as separate confined areas is discussed in API RP 753 and the CCPS *Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards* [4, 8]. Examples of typical congested areas in ASU and HYCO plants include but are not limited to:

- equipment skids or process equipment areas;
- pipe racks;
- buildings that house equipment handling flammable gases;
- corridors between two plants or skids where there is interconnected piping;

- parking lots, adjacent wooded areas, or other process areas not handling flammable equipment where dispersion modelling suggests that a released flammable material could reach the confined area while still in the flammable range;
- natural gas metering, clean-up areas, filtering stations;
- reformer ancillary equipment;
- compressors;
- ambient air vapourisers;
- pressure swing adsorbers (PSA) valve skids;
- gaseous carbon monoxide and/or hydrogen trailer loading stanchions;
- flammable liquid or liquefied flammable gas storage areas including vapourisers;
- flammable gas storage; and
- syngas cooling equipment.

6.3 Process deviations

Process equipment failures can occur from deviations in the operating conditions that result in equipment being operated outside design limits. Catastrophic failure of pressure vessels due to process deviations can be minimized by good inspection and management procedures, application of design review techniques such as hazard review and risk quantification, and installation of proper protective devices such as pressure relief and instrumented systems. When these mitigation measures are applied, process deviation failures of pressure vessels in ASU and HYCO plants are so rare that they may be excluded from the analysis for these types of manufacturing facilities. This concept is supported by CIA's *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites* which indicates that the sudden failures of pressure vessels should not be the primary basis for the design of occupied buildings [5].

6.3.1 Included process deviations

Some of the included process equipment failures (unless excluded in the following list of scenarios) that may be considered include but are not limited to:

- vessel overpressure;
- low temperature material embrittlement;
- high temperature material failure (e.g., exceeding maximum design metal temperature or hydrogen embrittlement);
- temperature excursions in the purifier beds and catalyst beds;
- improper cooldown;
- runaway reaction;
- excessive vibration; and
- formation of flammable mixtures inside process equipment.

Each company should carry out its own risk assessments to identify these or other process equipment upset scenarios and include them in their safety analysis and mitigation practices. If the process hazard is reduced to a tolerable level, as defined by company guidelines, the systems previously listed may be excluded from the building siting study.

6.3.2 Excluded process deviations

The following excluded scenarios are considered to be very low frequency process deviations or failure mitigation methods are fully addressed by existing industry publications or guidelines:

- Reboiler explosions or liquid phase adsorber explosions as long as preventive measures as listed in EIGA Doc 142, *Major hazards* are in place [16]. A periodic audit program should be implemented to ensure that the required safeguards are in place and operational; and

- Major failure of flat bottom storage tanks are excluded as a major hazard scenario since the probability of such events is very low as long as preventive measures as listed in CGA P-8.9, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites* are in place [17].

6.4 Pressure vessel mechanical failure

Mechanical failures of pressure vessels while operating within design conditions can result in the creation of an overpressure wave that can impact occupied facility buildings. For the purpose of this publication, mechanical failure of a pressure vessel is the unanticipated failure due to the undetected fatigue or material defects in that vessel. Material defects include manufacturing faults, such as flawed welds and incorrect material selection, or degradation of the vessel due to corrosion mechanisms. Fatigue can be caused by several conditions, including pressure cycling and vibration.

Experience in ASU and HYCO plants is that such failures are extremely rare. As such, pressure vessels or energy sources that may be excluded from the building siting study are:

- Vessels that are operated at less than 103.4 kPa (15 psi);

- Vessels for transport that are covered under local or regional transportation regulations (e.g., 49 CFR) where periodic revalidation is being performed in accordance with those regulations [18];

- Vessels used for permanent storage that are designed in accordance with local or regional transportation regulations and where periodic revalidation of container integrity is being performed at the frequency required for transport [18];

- Liquefied petroleum gas or propane gas cylinders or tanks used specifically for transportation fuel or liquefied petroleum gas tanks containing fuel for building heating purposes, which are located in accordance with NFPA 58, *Liquefied Petroleum Gas Code* or other regional regulations [19];

- , All pressure receptacles and pressure drums such as acetylene and other portable gas welding cylinders when stored, handled, or used in accordance with NFPA 55, ISO 11625, or other regional standards [18, 7, 20];

- Hot water heaters used solely to supply heated water to sinks and washrooms;

- Pressure vessels used solely in building heating, ventilation, and air conditioning (HVAC) systems;

- Cooling water heat exchangers where the pressurized gas is on the tube side of the exchanger, and the shell side is protected from the overpressure that can result from a leak of one of the tubes;

- Piping systems, because there is no recognized method to determine the fraction of the piping volume that would participate in a PV energy release and the location of the energy release point within the length of pipe;

- Vacuum-insulated pressurized cryogenic storage tanks (stationary cryogenic storage vessels) as industry experience with these tanks indicates a very low failure frequency for these types of systems as shown in EIGA Doc 60, *Prevention of major accidents. Guidance on compliance with the Seveso II Directive* [21];

- Pressure vessels in coldboxes based on operating experience, the inherently stable and benign conditions within an operating cryogenic plant and an absence of the traditional failure mechanisms for such equipment; namely corrosion, erosion, fatigue.

- Pressure vessels that comply with the *Pressure Equipment Directive* (97/23/EC) [22];

- Pressure vessels designed for leak-before break (LBB) vessel fracture performance as described in *Fracture and Fatigue Control in Structures, Applications of Fracture Mechanics; Structural Integrity Assurance of High-Strength Steel Gas Cylinders Using Fracture Mechanics*; *Technical Basis for Flawed Cylinder Test Specification to Assure Adequate Fracture Resistance of ISO High-Strength Steel Cylinders* and that meet all of the following criteria [23, 24, 25]:
  - Fracture toughness of the material is high enough to tolerate through thickness crack at design stress corresponding to the maximum allowable working pressure (MAWP)
  - Coded vessel per ASME or equivalent local pressure vessel codes (shall include non-destructive examination of vessel welds equivalent to code requirements) [26]
  - Constructed of materials resistant to corrosion and stress corrosion cracking at the service conditions or periodically inspected for signs of corrosion and stress corrosion cracking.

    NOTE—The inspection method, frequency, and results should be documented.
  - Protected from overpressure due to maximum credible inflow of process fluids by a pressure relieving system (relief valve, rupture disk, depressurization system or a combination of these devices) on the vessel or the upstream source; and
- Pressure vessels not designed for (LBB) vessel fracture performance if the following criteria are met:
  - Defects or deterioration mechanisms (e.g., material flaws due to specification or fabrication errors, erosion, corrosion, stress corrosion cracking, cyclic fatigue, etc.) that can lead to a vessel failure have been identified and
  - Vessels are periodically inspected for the identified defects or deterioration mechanisms and the results are evaluated for continued safe operation.

    NOTE—The inspection method, frequency, and results should be documented.

Other sources of pressure vessel mechanical failure can be minimized through good inspection and management procedures and appropriate materials selection. When these mitigation measures are applied, pressure vessel mechanical failure sources not previously listed are so rare they may be excluded from the analysis for these types of manufacturing facilities. This is also supported by CIA's *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites*, which indicates that the sudden failures of pressure vessels would not be the basis for the design of occupied buildings [5].

6.4.1 Pressure vessels to be considered for HYCO facilities

Unless excluded as allowed in 6.4, pressure vessels that should be considered in the building siting study for a HYCO facility include, but are not limited to:

- vessels in syngas trains including carbon dioxide absorber and stripper columns, drums and separators;
- PSA vessels including PSA tailgas;
- desulfurizers;
- compressor surge drums;
- instrument air receivers;
- pressurized storage vessels;
- feed gas conditioning pressure vessels;
- steam drums, including process gas cooling;
- deaerator;
- reformer process side outlet header;

- shift reactors;
- pressurized front-end gasifiers;
- shell sides of heat exchangers where the shell contains a pressurized or liquefied gas; and
- pressurised vessels associated with process chiller systems.

6.4.2 Pressure vessels to be considered for ASU facilities

Unless excluded as allowed in 6.4, pressure vessels that should be considered in the building siting study for an ASU facility include, but are not limited to:

- molecular sieve vessels (including temperature swing adsorbers, PSA, and filters);
- product purifier vessels;
- direct contact aftercoolers;
- shell sides of heat exchangers where the shell contains a pressurized gas;
- pressurized storage vessels;
- compressor surge tanks;
- instrument air receivers; and
- pressurized vessels associated with process chiller systems.

6.5 Exposure from neighbouring facilities

Neighbouring facilities can cause some scenarios affecting occupied buildings in industrial gas plants. During the design of a new facility or relocation of an existing plant, these scenarios should be investigated through discussions with neighbouring companies and local authorities. Companies may have to ask for information from neighbouring facility owners on the quantifiable effects and frequency of these scenarios in order to identify the potential consequences to employees, process equipment, and buildings. For example, the Seveso III Directive allows access to this kind of information in Europe [2]. As mentioned in EIGA Doc 60, industrial gases establishments that fall under Article 9 of the Directive should establish internal emergency plans that involve sharing this kind of information [21].

7 Determining the consequences of included scenarios

7.1 Decision on the type of analysis

Once the facility occupied buildings (Section 5) and included scenarios (Section 6) have been identified, a decision can be made to perform a simplified approach, a consequence-based, and/or risk-based analysis to determine acceptable locations on the site and design for occupied buildings.

If no permanent or portable occupied buildings have been identified for inclusion in the study, or all scenarios have been excluded from consideration, no further analysis is required.

7.2 Simplified approach for locating portable buildings

A simplified approach for locating portable buildings subject to VCE overpressures is allowed. API RP 753, Figure 1–Portable Buildings Location Guidance can be used to determine safe distances [4].

NOTE—This simplified approach does not address PV energy scenarios.

If the PV overpressure or other events are included for portable buildings, see 7.3 through 7.4 of this publication for information regarding consequence-based and risk-based analyses.

In most ASU and HYCO plants, when the simplified approach is used, plots are not large enough to accommodate the distances in API RP 753, Figure 1 [4]. Therefore, detailed consequence or risk-based approaches are often required to refine the analysis and define practical designs and locations for portable occupied buildings for ASU and HYCO plants.

7.3 Consequence-based methodology

7.3.1 Considerations

In a consequence-based analysis, any lightwood portable building located outside of the 4.1 kPa (0.6 psi) overpressure level can be excluded from further analysis. Any permanent buildings located outside of the **6.2 kPa(0.9 psi) overpressure level can be excluded from further analysis. Exclusion from further analysis i**mplies that the building location is acceptable from a blast overpressure perspective.

If the company has established building vulnerability, damage level, overpressure and impulse, or other targets for occupied buildings, those targets can also be considered throughout the consequence-based analysis. The company should define these targets prior to completing a consequence-based analysis and should use the targets consistently throughout the analysis. See Appendix A to determine vulnerabilities in various building types.

7.3.2 Determination of overpressure

7.3.2.1 Determination of overpressure from vapour cloud explosions

One approach to determine overpressures at building locations consists of the following steps:

a) Identify areas or volumes in the plant for confinement where flammable releases can accumulate;

b) Identify the extent that the volume will fill with flammable gas. The volume determination can exclude the volume already occupied by the vessels and piping. Some models used for the determination of overpressures use the mass of the flammable materials in the confined volume; and

   NOTE—For any equipment installed indoors, see guidance in 7.3.2.5.

c) Use the curves provided in Appendix B or consequence analysis software to determine distances to the 4.1 kPa (0.6 psi) and 6.2 kPa (0.9 psi) overpressures. Distances to other overpressures may also be calculated during this step if desired.

   For ASU and HYCO plants, for VCE scenarios, explosion strength curves of 5 (see Appendix B, Figure B-1) and 7 (see Appendix B, Figure B-2) as defined by the CCPS *Guidelines for Vapour Cloud Explosion, Pressure, Vessel Burst, BLEVE, and Flash Fire Hazards* [8]. Other explosion strength curves can be used by industrial gas companies provided that the choice is justified and well referenced (e.g., depending on gas reactivity, obstruction level, cloud dimensions, ignition source, etc.)

7.3.2.2 Determination of overpressure from PV energy

If a determination has been made that structural failure of pressure vessels should be included in the study, overpressure from PV energy can be determined by the following steps:

a) Identify operating pressures, temperatures, composition, volume of liquid for steam only, and volume of vapour in the vessels included in the analysis; and

b) Determine the gamma value of the gas using the graphs provided in Appendix C. Calculate the Factor = (Pressure • Volume) / (Gamma-1) using the units provided in Appendix D. Use the graphs provided in Appendix C or consequence analysis software to determine distances to the 4.1 kPa and 6.2 kPa (0.6 psi and 0.9 psi) overpressures. Distances to other overpressures may also be calculated during this step if desired.

   NOTE—The gamma values in Appendix C are developed for air, hydrogen, nitrogen, oxygen, and steam. For other gases, the user should identify their own specific values or choose a similar gas from those shown in Appendix C to obtain the values.

7.3.2.3 Determination of overpressure from process deviations

Overpressure from process deviations can be determined by the following steps:

a) Identify vessels where credible deviations outside of the design operating conditions can occur. Based on system design, some process failures may be excluded from the analysis based on low probability of occurrence of the event;

b) Identify deviation pressures, temperatures, composition, volume of liquid for steam only, and volume of vapour in the vessels included in the analysis;

c) Determine the gamma value of the gas using the graphs provided in Appendix C. Calculate the Factor = (Pressure • Volume) / (Gamma-1) using the units provided in Appendix D. Use the graphs provided in Appendix D or consequence analysis software to determine distances to the 4.1 kPa and 6.2 kPa (0.6 psi and 0.9 psi) overpressures. Distances to other overpressures may also be calculated during this step if desired.

   NOTE—The gamma values in Appendix C are developed for air, hydrogen, nitrogen, oxygen, and steam. For other gases, the user should identify their own specific values or choose a similar gas from those shown in Appendix C to obtain the values.

7.3.2.4 Determination of overpressure from neighbouring facilities

Using consequence information provided by neighbouring facilities, or estimates when information is not provided but risks are evident, identify scenarios and include in the consequence analysis.

7.3.2.5 Additional guidance for releases inside of buildings

If fuel is accidentally released inside a building or if combustible gas is drifting into such an area, an energy release can occur. The consequences of such events will depend on several parameters, such as type of fuel, size, and concentration of the gas cloud, ignition, and geometrical layout, i.e., confinement and congestions. In consequence-based analyses all these factors have to be taken into account.

Variations of these parameters can result in large deviations in event peak overpressure. Confinement and congestion are key factors for the development of high overpressures in accidents. In buildings containing process equipment, there will be confinement and congestions. Walls, roofs, floors, and decks will confine the gas cloud. The process equipment and piping engulfed by the cloud will act as congestion during an energy release.

An energy release in a compartment is a very complex process strongly dependent on many parameters. It is not the intent of this publication to describe this process in detail. More information on this can be found in *Gas Explosion Handbook*, 1997 [27].

One method that can be considered to determine the risk of overpressure resulting from releasing flammables into a building would be to include the entire volume of the building as the confined volume with an explosion strength of 5. Mitigating factors, such as building ventilation or building protection by deflagration venting (in accordance with NFPA 68, *Standard on Explosion Protection by Deflagration Venting* or other local codes) can justify the use of smaller congested volumes for releases inside buildings [28]. Congested volumes within the process equipment within the building may be used in such cases. When the equipment inside the building is used for the confined volume, the Figure D-2 curves representing explosion strength of 7 should be used.

A layer of protection analysis (LOPA) or equivalent can be used to evaluate the adequacy of mitigating factors and other safeguards to exclude these areas from confined volume energy release considerations. NFPA 69, *Standard on Explosion Prevention Systems* provides additional guidance on suggested explosion prevention systems [29]. The rationale for such exclusions should be documented.

7.3.3 Determination and review of overpressure levels that can occur at the buildings

If the light wood portable buildings are located outside the greatest distance to 4.1 kPa (0.6 psi), blast-resistant designs are not required for the building. If the other buildings are located outside the greatest distance to

6.2 kPa (0.9 psi), blast-resistant designs are not required for these buildings. Such buildings may be deemed to have tolerable blast vulnerability and excluded from further blast analysis.

If light wood portable buildings are located within the 4.1 kPa (0.6 psi) or greater overpressures, further analysis of the building such as a vulnerability assessment, pressure/impulse assessment, or implementation of mitigation methods should be considered, see 7.3.4.

If the buildings being analyzed for the 6.2 kPa (0.9 psi) are located within the 6.2 kPa (0.9 psi) or greater overpressures, further analysis of the building such as a vulnerability assessment, pressure/impulse assessment, or implementation of mitigation methods should be considered, see 7.3.4.

See 7.4.9 for additional guidance on building design best practices for all buildings regardless of overpressure exposure.

7.3.4 Consideration of mitigation methods

Mitigation methods that may be considered include:

- Relocating the occupied building(s);
- Reconsidering the need for the building in the facility;
- Modifying process or equipment layout;
- Reducing VCE by increasing separation distances; or
- Designing the building to limit damage to a tolerable level:
  a) Determine overpressure that can result at each occupied building of concern from each scenario by evaluating the curves in Appendices B, C, and D for the appropriate scenario. Select the highest overpressure level resulting from the scenarios at each building of concern;
  b) For each building, based on the overpressure that it can be exposed to, estimate the occupant vulnerability using the curves in Appendix A. If the building is designed such that the vulnerability satisfies the company vulnerability target at that pressure, or the degree of damage is acceptable at that pressure, no further analysis for that building is needed; and
  c) If the company vulnerability target cannot be achieved in b), determine whether it is practical to design buildings for these overpressures. If necessary, the impulse of the pressure wave that can result at each occupied building also needs to be determined to develop building designs. CCPS *Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards* provides a method to determine the impulses on each building under the included scenarios [8].

If any of the previous mitigation practices are deemed impractical, the next step in the analysis is to use the risk-based method to further analyze building siting.

7.4 Risk-based methodology

7.4.1 Establishment of risk tolerance level

The company should define the risk tolerance level prior to completing a risk-based analysis. See CCPS 2009, *Guidelines for Developing Quantitative Safety Risk Criteria* and EIGA Doc 75, *Determination of Safety Distances,* for more information [30, 31].

If a company chooses to use individual risk for the risk tolerance measurement, the overall individual risk for the building occupants can be expressed using the following equation:

$$IR_{total} = P_{occupancy} \cdot \sum (F_{event} \cdot P_{scenario\ vulnerability})$$

Where:

- IR_{total} is the total risk to the individual in the occupied building for scenarios that can expose the building
- F_{event} includes the worst case confined volume event and all PV energy sources that can expose the building
- $P_{scenario\ vulnerability}$ is the probability of fatality in the building to an individual based on building type as a function of overpressure that the building can be exposed to by each scenario (see Appendix A to determine this vulnerability)
- $\sum (F_{event} \cdot P_{scenario\ vulnerability})$ is the sum of the frequency of the evaluated scenarios that can expose the occupied building times the probability of fatality of the individual in the building as a function of building type and overpressure experienced at the building for each individual event
- $P_{occupancy}$ is the probability of the individual being in the building during a shift or other specified time period

This equation is used to evaluate the individual risk to occupants in each occupied building.

For hazards where the risk probability is lower than the tolerable risk threshold, no distances need to be established. Even if this individual risk meets risk tolerance levels, care should be taken to locate these vessels to minimize exposure to personnel based on good engineering practices.

An alternative method that can be used separately or in combination with the individual risk is societal risk where the peak occupancy of each building is considered in the risk analysis. This publication does not provide guidance on this alternative method.

7.4.2 Determination of frequency of vapour cloud explosions

7.4.2.1 Generic vapour cloud explosion frequencies

Generic VCE frequencies can be used for the risk-based study.

In accordance with API RP 752 (2003), the frequency of a petrochemical plant major explosion is approximately 4.3×10^{-4} per year [3].

In accordance with CIA guidance for the location and design of occupied buildings on chemical manufacturing sites, the frequency of a major plant fire and explosion is approximately 1×10^{-4} per year [5]. If fires are excluded from the analysis, the remaining frequency of explosions can be even lower.

Both of these numbers are based on large petrochemical and refinery plant operations. These larger facilities have a greater frequency of a significant release of flammable material when compared to a typical ASU or HYCO facility. A lower frequency of occurrence of a release and explosion would be expected at an ASU or HYCO facility. An order of magnitude lower frequency may be used in the analysis for HYCO facilities (on the order of 1×10^{-5} per year per facility). Frequency per scenario may then be distributed among the scenarios as long as the total explosion frequency for the facility matches the estimated value for the overall plant explosion frequency. An even lower value may be justified for ASU facilities, depending on the existence and the proximity of flammable gas sources within or beyond the facility boundary. Flammable materials outside of facility boundaries can impact the probability of a VCE event caused by flammable material drifting onto the site.

7.4.2.2 Detailed vapour cloud explosion frequencies

A more detailed determination of frequency of explosion may be made by dividing the facility into subunits and assigning a release frequency to each and then estimating the probability of ignition for each subunit.

Another method is to determine the failure frequency, release rates for each potential leak point on the site, probability of wind direction, speed, stability to get released flammable into a congested area, and then determine each point's probability of ignition. It is not the intent of this publication to provide detailed information on these approaches, but guidance on failure frequencies can be found in API 581 *Risk-Based*

Inspection Technology, CPR 18E (Purple Book) *Guidelines for Quantitative Risk Assessment*, CCPS *Process Equipment Reliability Database*, OGP *Risk Assessment Data Directory* (Report No. 434-7), and Badri, Nourai, and Rashtchian, *Improving Accuracy of Frequency Estimation of Major Vapour Cloud Explosions for Evaluating Control Room Location through Quantitative Risk Assessment* [32, 33, 34, 35, 36].

7.4.3 Determination of pressure vessel failure frequencies

Experience indicates that generic pressure vessel failure frequencies in normal operating conditions range from 1×10^{-5} to 1×10^{-7} per vessel per year as noted by the CCPS *Layer of Protection Analysis, Simplified Process Risk Assessment* [37]. Vessels in cyclic service are typically in the higher end of this range, while vessels in benign cryogenic service are typically in the lower end of the range. With an effective mechanical integrity program, even the vessels in cyclic service can see failure frequencies in the lower end of the range. For the purposes of this publication, a generic 1×10^{-6} failure frequency per year per vessel is used as a starting point. Adjustments to this generic value may be made based on cyclic service, operations in known corrosive or erosive applications, implementation of mechanical integrity inspection programs, etc.

7.4.4 Determination of pressure vessel failure frequencies from process deviations

A determination of frequency of pressure vessel failure from process deviations may be made unit by unit through a quantitative technique. Each process deviation leading to the potential failure of the pressure vessel and associated mitigation measures should be analyzed and quantified (e.g., cryogenic embrittlement event of a gaseous buffer vessel due to a process deviation). Fault tree and LOPA are two techniques practiced by industry to make these frequency determinations. It is not the intent of this publication to provide detailed information on these approaches but guidance can be found in ANSI/ISA-84.00.01-2004 Part 3, *Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 3: Guidance for the Determination of the Required Safety Integrity Levels – Informative*, CCPS *Guidelines for Chemical Process Quantitative Risk Analysis* [38, 39].

7.4.5 Determination of scenario frequencies from neighbouring facilities

Using event frequency and consequence information provided by neighbouring facilities, or estimates when information is not provided but risks are evident, identify scenarios and include in the risk analysis.

7.4.6 Determination of building occupancy

The maximum individual occupancy load is calculated by determining the maximum number of hours per week spent inside the building by any one person and dividing it by 168. This determination is based on worked examples in CIA's *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites* [5].

When completing this analysis for locating portable buildings, the probability of occupancy to be used in this risk equation should be 1.0 in accordance with API RP 753, with exception of portable buildings not intended for occupancy as mentioned in API RP 753 [4, 3]. This applies if portable buildings will be occupied while the plant is in startup or operating and will contain flammable inventory. If portable buildings are not intended for occupancy, they are not required to be included in the analysis.

For all of the buildings that are excluded from the building siting study that may be at risk, companies should consider managing the occupancy for these excluded buildings during operating conditions such as startup where the risk of a release from flammable gas plants and explosions can be higher.

7.4.7 Determination of occupant vulnerability

Occupant vulnerability is the probability that personnel inside buildings will become permanently disabled or suffer a fatality as a function of overpressure exposure to the building. The curves in Appendix A can be used to approximate the vulnerability as a function of overpressure that the building can be exposed to. In order to identify personnel vulnerability, determine the following:

a) The type of building proposed to be installed (typically API B1, B2, B4 and CIA 3 buildings for industrial gas plant installations);

b) The overpressure to which the building can be exposed for each scenario; and

c) The vulnerability to personnel inside the building for each scenario using the curves in Appendix A.

An alternative to the method above is the evaluation of building damage level. The description of this alternative is beyond the scope of this publication. More information regarding the evaluation of building damage levels can be found in the CCPS *Guidelines for Evaluating Process Plant Buildings for External Explosions, Fires, and Toxic Releases*, the ASCE publication *Design of Blast Resistant Buildings in Petrochemical Facilities*, and the U.S. Army Corps of Engineers Protective Design Center Technical Report (PDC-TR 06-08, 2008) [40, 41, 42].

7.4.8 Determination of risk at each building

7.4.8.1 General

Once all of the information described in 7.4.1 through 7.4.7 has been gathered, the next step is to determine the level of individual risk at each building.

7.4.8.2 Determination of risk at each building

To determine the risk at each permanent and portable building, the frequency of each scenario that can impact the building should be multiplied by the vulnerability that can occur at the building for that scenario. These factors should be added for each scenario that can impact the building and then multiplied by the probability of occupancy for that building to determine the risk. For portable buildings, the occupancy used for the calculations shall be 1.0 with exception of portable buildings not intended for occupancy as mentioned in API RP 753 [4]. This calculation shall be done individually for each occupied building on the site.

See worked examples in Appendices E and F.

7.4.9 Mitigation of building occupant risk

If the risk determined at a building does not meet company risk tolerance levels, the following mitigation methods should be considered:

- location of the building outside of the hazard area;
- design of the building to withstand the calculated blast load (also see the following design considerations);
- reconsideration of the need for installing the building;
- modification of the process or equipment layout to limit exposure to hazardous areas;
- provide or increase separation distances between skids to reduce the confined volume energy;
- increase the frequency and/or improve the method of planned mechanical integrity inspections;
- remove potential leak sources (e.g., use of welded system rather than flanged);
- installing safeguards or inherently safer systems to reduce frequencies of releases;
- limiting hazardous inventory;
- installing passive safety systems (e.g., dikes); and
- removing ignition sources.

If any of these changes are deemed both effective and feasible, the individual risk may be recalculated to determine whether the recommended changes can achieve the company's risk tolerance level for occupied buildings. Optimization of building location and design is often an iterative process in the building siting study.

The following items should also be considered during building design and can reduce the risk to occupants:

- orienting the building to expose the shortest wall to face the explosion risk area;

- avoiding installation of glass windows on the side of the building facing the process area;
- specifying the use of small sized, blast-resistant glass when windows face the process area;
- verifying the adequacy of the window frame;
- installing an exit at the opposite side of the explosion risk area;
- securing all lighting fixtures, ceilings, or wall mounted equipment to minimize projectile hazards inside the building;
- securing large office equipment, stacks of materials, and filing cabinets to minimize projectile hazards inside the building;
- storing heavy materials on the ground floor when practical; and
- avoiding the placement of heavy equipment on the roof of the building, such as HVAC equipment.

8 Documentation and revalidation of building siting study

8.1 Documentation

Documentation should be retained showing the assumptions and parameters used to complete the study. The extent of the documentation should include a description of the methodology so the results can be reproduced or updated at a later time if needed. Documentation should be kept in accordance with the company's record retention policy.

8.2 Revalidation

Periodic reviews should be undertaken to update the building siting study. This should ensure that any impacts from changes to the facility equipment or surroundings are captured and addressed, including:

- changes to applicable local/regional regulations or industry publications;
- changes to the facility such as addition of new equipment, new buildings, or to existing building occupancies; and
- changes to the industries or plants surrounding the facility.

8.3 Management of change

Management of change practices should include overpressure considerations when revisions are made in facility operations or processes that could affect buildings. Structural evaluation of the building should be considered when the recalculated design explosion overpressure exceeds the original design values.

9 References

Unless otherwise specified, the latest edition shall apply.

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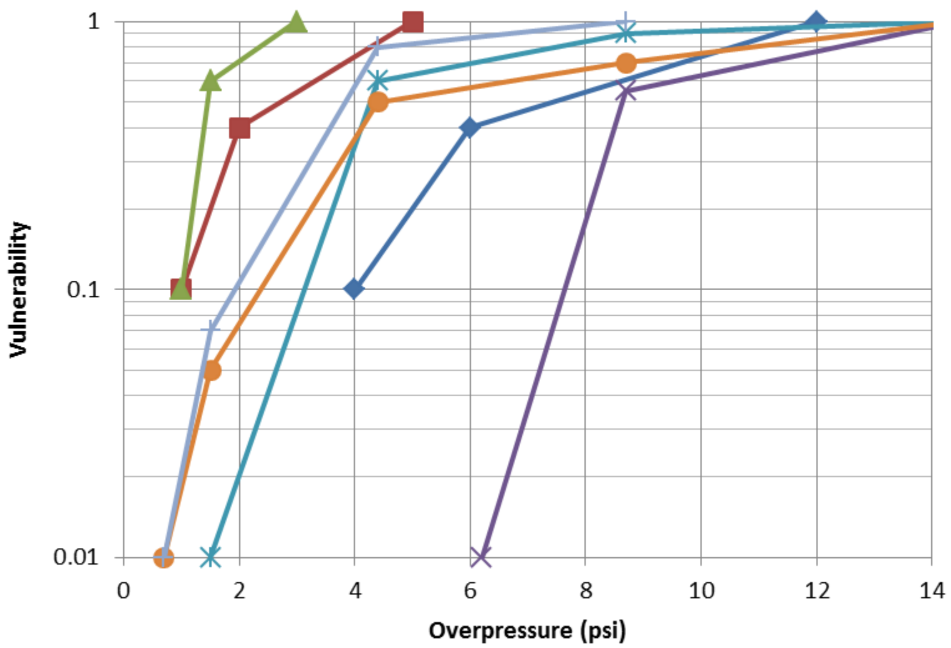
Appendix A - Occupant vulnerability probabilities

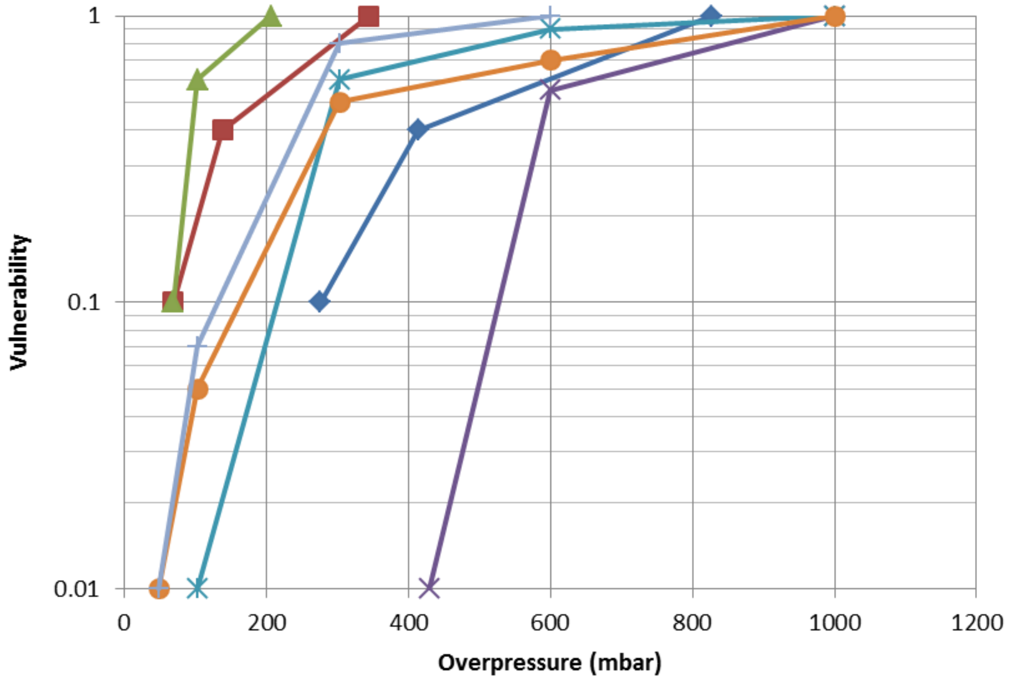
Figures A-1 and A-2 give the vulnerability of individuals in different kinds of buildings submitted to overpressure. It is based on vulnerability data given in API RP 752 (2003); CIA *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites;* and CCPS *Guidelines for Evaluating Process Plant Buildings for External Explosions, Fires, and Toxic Releases* (1996) [3, 5, 40].

NOTE—Occupant vulnerability greater than 0.6 are inferred estimates based on limited data. This range is shown for illustrative purposes and should be used with great caution.



Graph Key:	
	CIA 1: Hardened structure building: special construction, no windows
	CIA 2: Typical office block: four story, concrete frame and roof, brick block wall panels
	CIA 3: Typical domestic buildings: two story, brick walls, timber floors
	CIA 4: Portacabin: timber construction, single story
	API B5: Reinforced concrete or reinforced masonry shear wall building
	API B3: Unreinforced masonry bearing wall building
	API B1, B2, B4: Wood frame trailer or shack, steel-frame/metal siding or pre-engineered building, steel or concrete reinforced masonry infill or cladding
NOTE—Building key items 1 - 4 are defined by CIA; items B1 - B5 are defined by API RP 752 (2003) [5, 3].	

Figure A-1—Probability of occupant vulnerability in psi

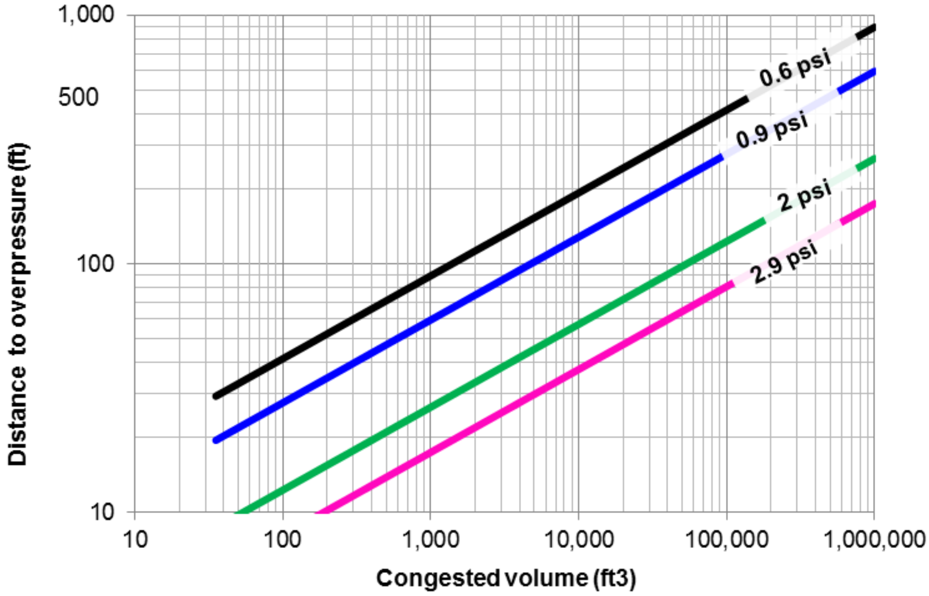


Graph Key:	
	CIA 1: Hardened structure building: special construction, no windows
	CIA 2: Typical office block: four story, concrete frame and roof, brick block wall panels
	CIA 3: Typical domestic buildings: two story, brick walls, timber floors
	CIA 4: Portacabin: timber construction, single story
	API B5: Reinforced concrete or reinforced masonry shear wall building
	API B3: Unreinforced masonry bearing wall building
	API B1, B2, B4: Wood frame trailer or shack, steel-frame/metal siding or pre-engineered building, steel or concrete reinforced masonry infill or cladding
NOTE—Building key items 1 - 4 are defined by CIA; items B1 - B5 are defined by API RP 752 (2003) [5, 3].	

Figure A-2—Probability of occupant vulnerability in mbar

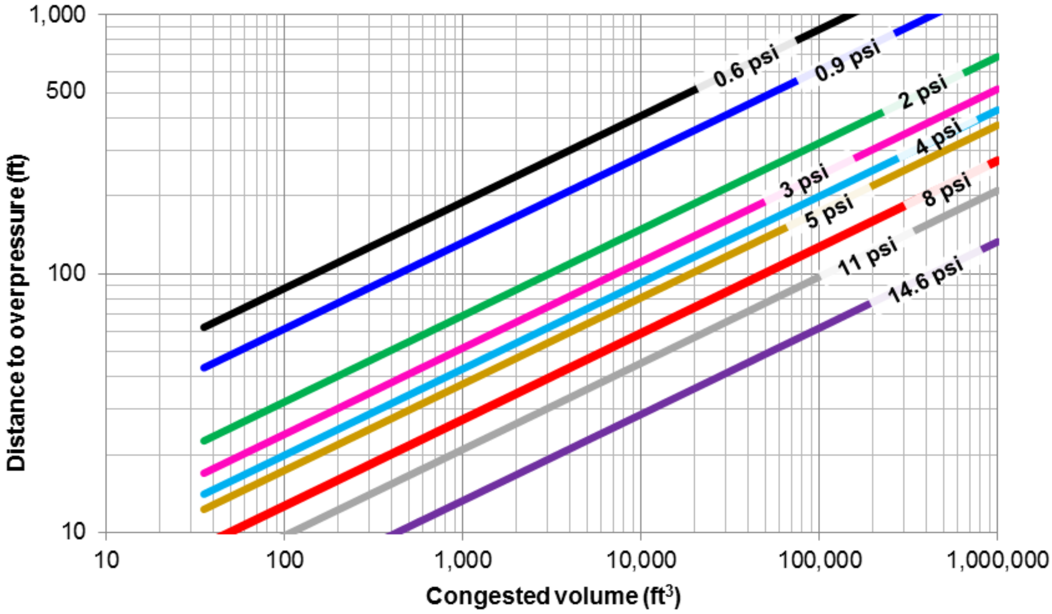
Appendix B—Overpressure versus distance curves for vapour cloud explosions

The data for Figures B-1 and B-2 were generated using PHAST™ software's implementation of the multi-energy correlation [9]. The multi-energy correlations were developed by others by curve-fitting equations to a large set of experimental blast data.



NOTE—Explosion strength 5 develops a maximum overpressure of approximately 2.9 psi.

Figure B-1—Side-on overpressure versus distance for hydrogen using multi-energy correlation at explosion strength = 5



NOTE—Explosion strength 7 develops a maximum overpressure of approximately 14.6 psi.

Figure B-2—Side-on overpressure versus distance for hydrogen using multi-energy correlation at explosion strength = 7

Appendix C - Gamma factors for various materials in ASU and HYCO plants

The gamma factors presented below are used to simplify the method to determine overpressures from failure of pressure vessels. Gamma is the ratio of specific heats C_p/C_v.

The National Institute of Standards and Technology (NIST) database was used to determine the values for the materials shown below, and can be accessed online at http://webbook.nist.gov/chemistry/fluid/.

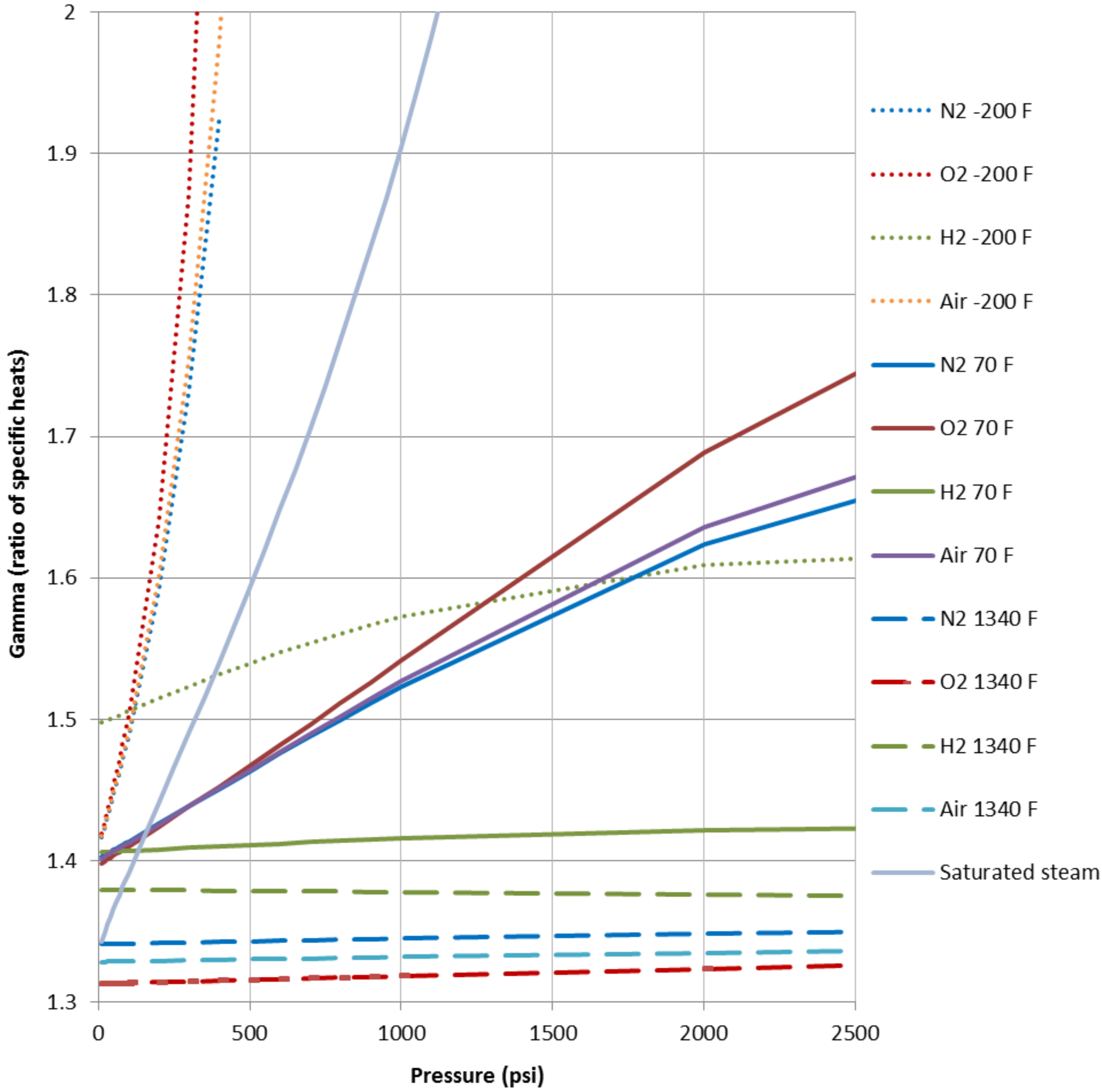


Figure C-1—Gamma factors for typical industrial gas materials at +70° F, +1500° F, and –200° F

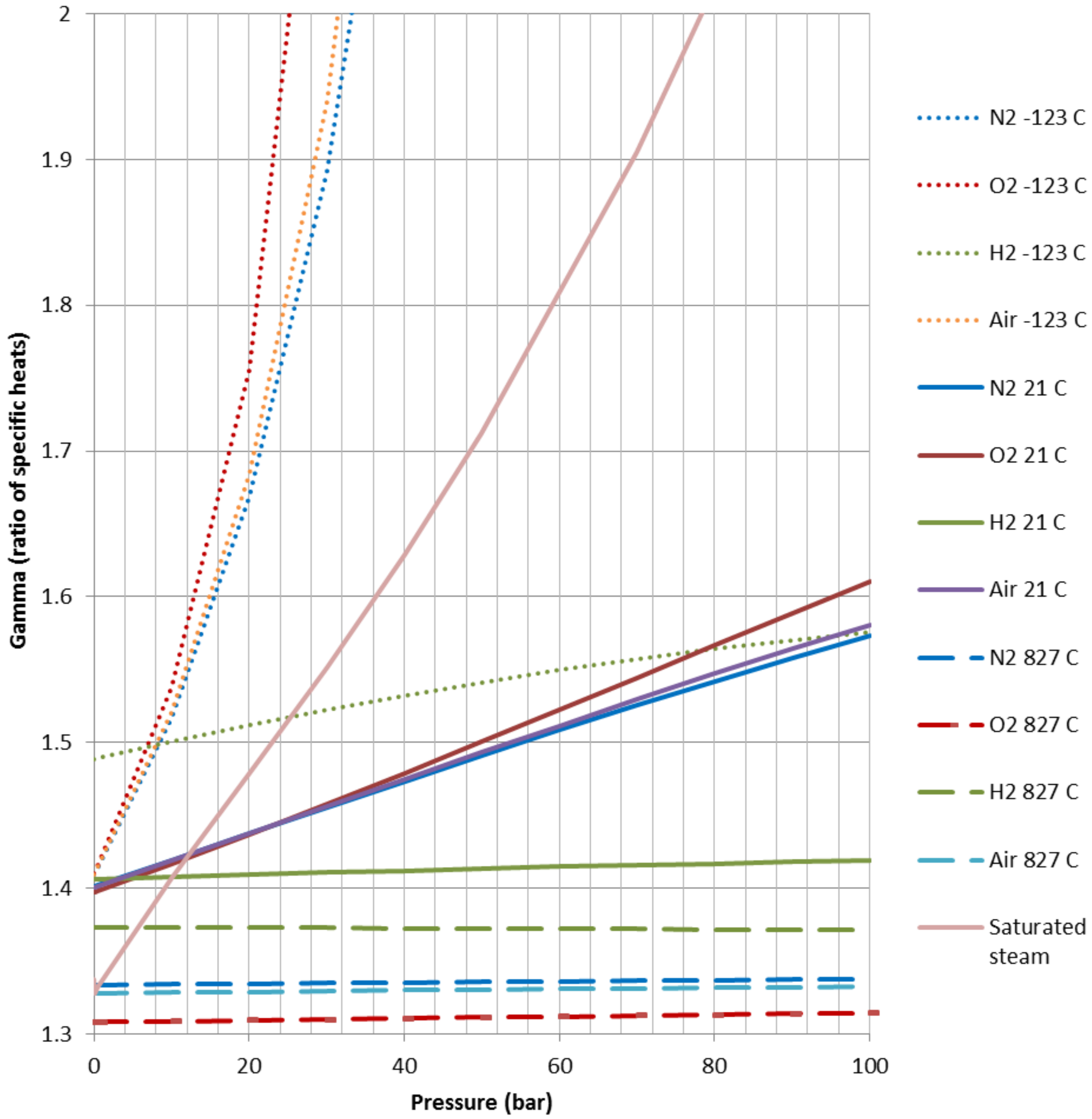


Figure C-2—Gamma factors for typical industrial gas materials at – 123° C, +21° C, and +827° C

Appendix D - Pressure volume energy

The curves below are built considering that the whole PV energy will participate to the blast waves. In reality, a fraction of the energy can participate to the emission of fragments (CCPS *Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards*) [8]. These curves give a conservative way to assess the overpressure. Companies can adjust these curves based on the participation of energy provided that it is justified and well referenced (e.g., ductile rupture analysis, projectiles).

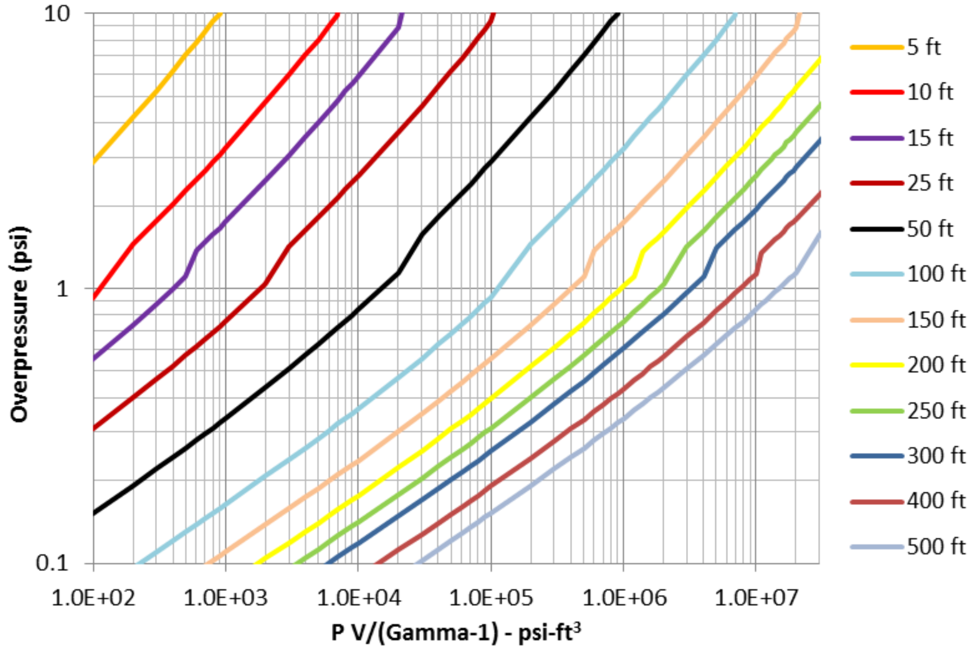


Figure D-1—Overpressure versus P • V / (Gamma-1) factor for gases in psi and ft^3

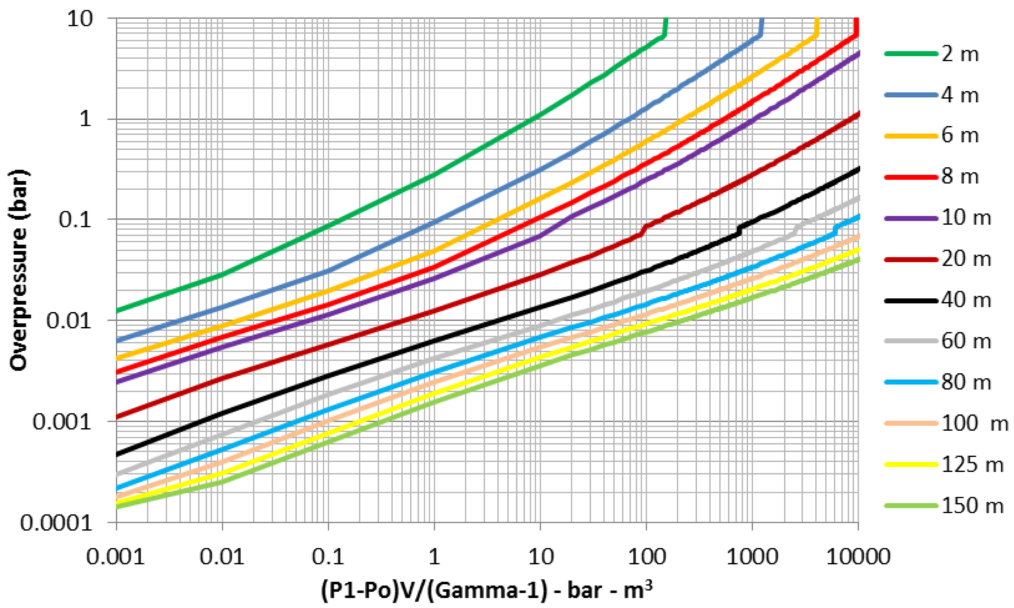


Figure D-2—Overpressure versus P • V / (Gamma-1) factor for gases in bar and m^3

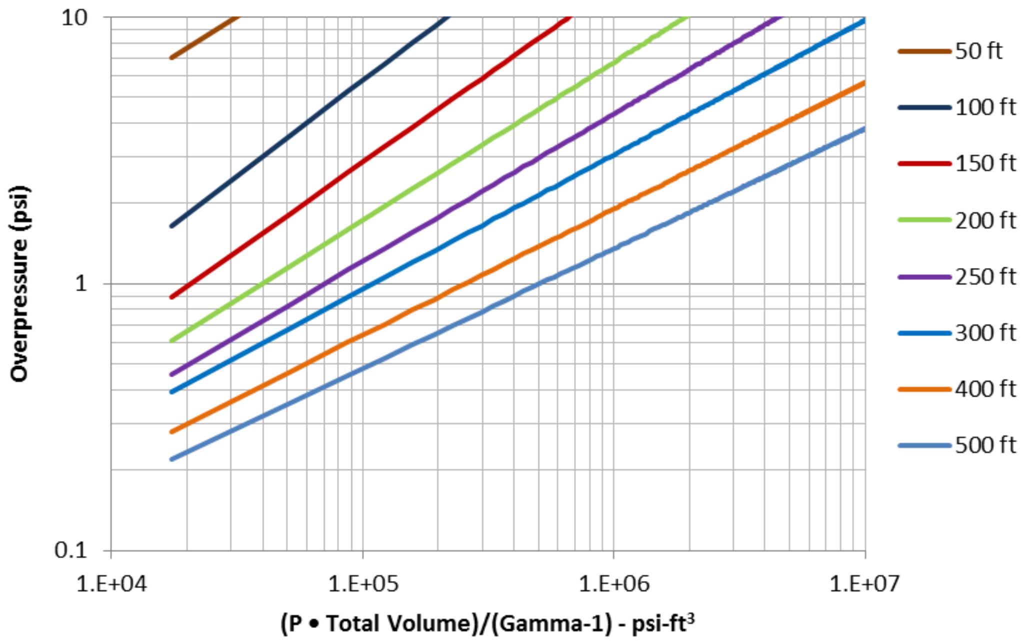


Figure D-3—Overpressure versus P • V / (Gamma-1) factor for 50% liquid full steam vessel in psi and ft^3

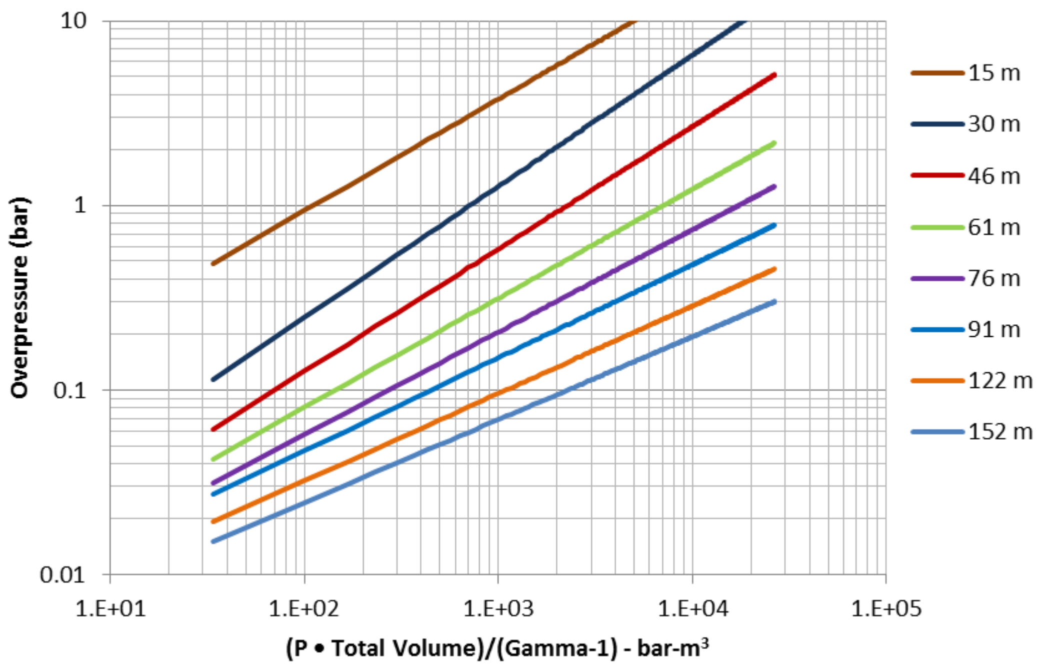


Figure D-4—Overpressure versus P • V / (Gamma-1) factor for 50% liquid full steam vessel in bar and m^3

Appendix E - Worked example for a HYCO plant

E.1 Consequence-based analysis

To perform a consequence-based analysis, the occupied buildings on the facility should be identified. For this worked example, the following occupied buildings are shown on the plot in Figure E-1:

- control room and office building;
- maintenance building; and
- chemical dosing building.

For this worked example, only the exposures to the control room and office building are considered. A complete consequence-based analysis would also include the maintenance and chemical dosing buildings.

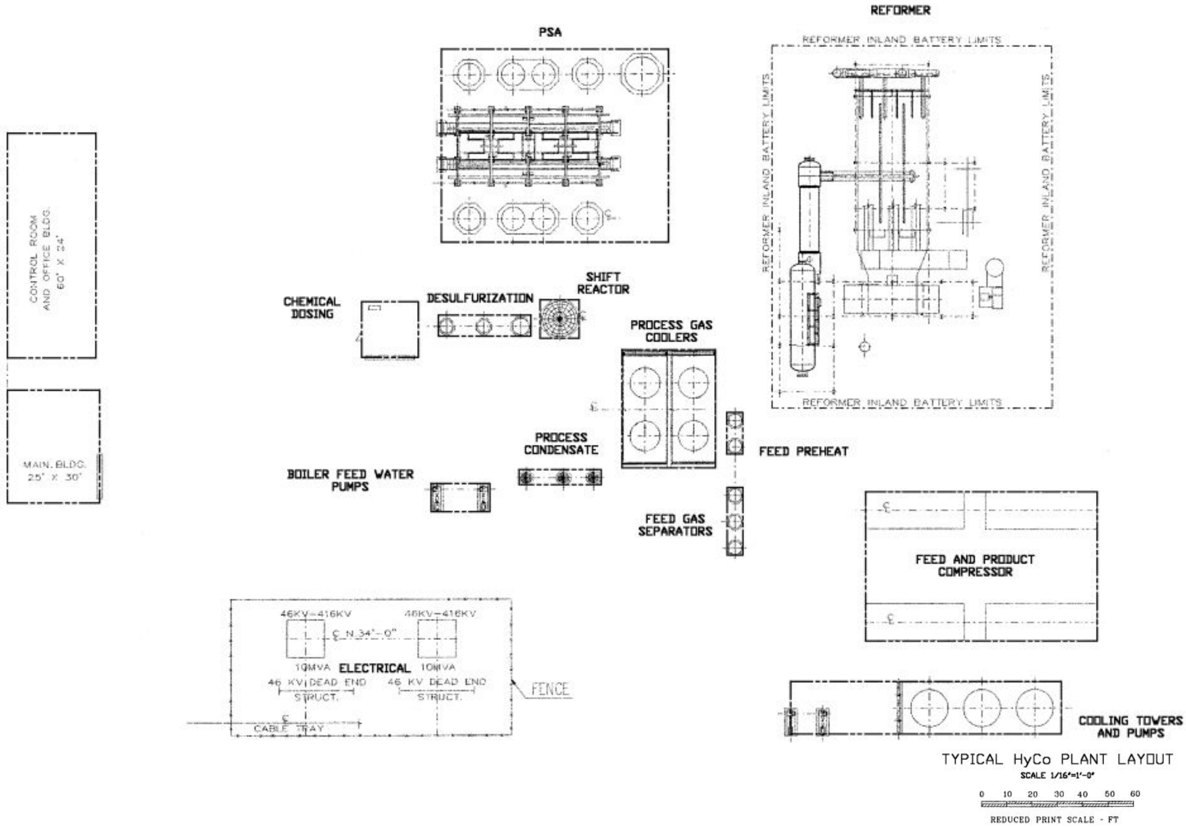


Figure E-1—HYCO plot example

The first step is to identify the confined volumes on the site that can contain flammable materials. The dimensions and void fraction of those confined volumes are recorded to determine the net flammable gas volume that could accumulate.

The facility should provide a description of each pressure vessel on site not excluded in 6.4, the operating pressure for each pressure vessel, and the void volume of each vessel. Once the net flammable volumes are determined, the figures in Appendices B, C, and D are used to determine the distance to a 6.2 kPa (0.9 PSI) overpressure. The 6.2 kPa (0.9 PSI) overpressure represents the threshold risk level to typical building installations on HYCO plants.

Table E-1 provides an example of a consequence-based calculation for a HYCO plant.

NOTE—Process related risks were not included in this example; as they are considered to be rare events in accordance with 6.3. These risks should be considered during a consequence-based analysis if identified during the scenario evaluation process.

The results in Table E-1 indicate that a typical building design (unreinforced) would need to be installed on the site with the following separation distances.

Confined volume explosion (CVE) considerations:

- 210 ft from the PSAs;
- 105 ft from the reformer;
- 110 ft from the desulfurization unit and shift reactor;
- 140 ft from the process gas coolers; and
- 220 ft from the feed and product compressor skid.
- PV energy considerations:
- 100 ft from the PSAs;
- 90 ft from the desulfurization units;
- 160 ft from the shift reactor;
- 700 ft from the steam drum;

  NOTE—This distance can be conservatively high due to the ground burst assumption for this elevated vessel.

- 80 ft from the feed gas separators; and
- 140 ft from the compressor pulsation dampers (snubber bottles).

These separation distances are not always available within HYCO plots. The following considerations individually or in combination may allow for the use of shorter separation distances:

- use of blast-resistant building design for occupied buildings;
- adjustment of preventative maintenance and inspection programs on vessels, which require large safety distances to reduce the probability of incident occurrence to justify the removal of the vessel from siting considerations;
- adjustment of operating conditions (e.g., lower operating pressures, lower operating volumes);
- the use of alternative, more rigorous analysis tools for overpressure determination; or
- use of a risk-based analysis to include frequency of occurrence and occupant vulnerability considerations into the evaluation, see 7.4.

Table E-1—HYCO consequence-based analysis worked example

Confined volume					
Vessel description	**Dimensions (ft)** [1]	**Confined volumes (ft^3)** [1), 2)]	**Void fraction** [3]	**Net flammable gas volume (ft^3)** [4]	**Distance to 0.9 psi (ft)** [5]
PSA	50 x 30 x 5	7 500	50%	3 750	210
Reformer	50 x 19 x 5	4 750	10%	475	105
Desulfurization unit and shift reactor	25 x 5 x 10	1 250	50%	625	110
Process gas coolers	25 x 25 x 3	1 875	50%	940	140
Feed and product compressor skid	44 x 60 x 10	26 400	20%	5 280	220

1) Equipment measurements provided by facility; height is based on an estimate of the area that could become congested.

2) Calculated by multiplying dimensions.

3) Estimate of the fraction not occupied by piping or equipment.

4) Calculated by multiplying confined volume by void fraction.

5) See figures in Appendix B for side-on overpressure curves for multi-energy release; explosion strength 7 is used for this example.

PV energy							
Vessel description	**Operating pressure (psi)** [1]	**Operating temperature**	**Gamma** [2]	**Inclusion in building siting study** [3]	**Vessel volume (ft^3)** [1]	**Factor = (P•V) / (Gamma-1)**	**Distance to 0.9 psi (ft)** [4), 5)]
PSA vessels (8 vessels)	400	90 °F	1.41	Included	100(each)	9.8×10^4	100
Tail gas vessels (2 vessels)	5	80 °F		Exempt; less than 15 psi operating pressure			
Desulfurization unit (3 vessels)	500	730 °F	1.4	Included	50(each)	6.25×10^4	90
Shift reactor	425	750 °F	1.41	Included	450	4.7×10^5	160
Steam drum	675	500 °F	1.61	Included	850	9.4×10^5	700 [6]
Feed gas separators (3 vessels)	500	100 °F	1.41	Included	40(each)	4.9×10^4	80
Compressor pulsation damper (snubber bottle) (6 vessels)	2000	150 °F	1.42	Included	40(each)	1.9×10^5	140

1) Values provided by facility

2) Except for the steam drum, all gamma values are based on hydrogen.

3) See 5.3 for buildings that may be excluded.

4) See figures in Appendices B, C, and D for overpressure curves.

5) Assumes ground burst for all vessels. If vessels are elevated, calculated distances would be smaller.

6) Assumes 50% liquid fraction.

E.2 Risk-based analysis

To perform a risk-based analysis, the occupied buildings on the facility should be identified. For this worked example, the following occupied buildings are shown on the plot in Figure E-1:

- control room and office building;
- maintenance building; and
- chemical dosing building.

For this worked example, only the exposures to the control room and office building are considered. A complete risk-based analysis would also include the maintenance and chemical dosing buildings.

The first step is to identify the confined volumes on the site that can contain flammable materials. The dimensions and void fraction of those confined volumes are recorded to determine the net flammable gas volume that could accumulate.

The facility should provide a description of each pressure vessel on site not excluded in 6.5, the operating pressure for each pressure vessel, and the void volume of each vessel. Once the net flammable volumes are determined, the figures in Appendices B, C, and D are used to determine the overpressures that the buildings can experience from each process vessel or confined volume location.

Table E-2 provides an example of a risk-based calculation for a HYCO plant.

NOTE—Process related risks were not included in this example; as they are considered to be rare events in accordance with 6.4. These risks should be considered if identified during the scenario evaluation process.

The 1.4 x 10^{-6} per year represents the total individual risk for occupants in the control room and office building. This risk level should be compared to the company's risk tolerance to determine if any modifications should be made to the building design or location. The same type of calculation would need to be performed for the occupants of the maintenance and chemical dosing buildings.

The results presented in this risk-based example use the probability of serious injury for the occupants in the calculation. These probabilities are based on the specific layout reviewed for this example. A generic approach that ignores plant layout and distances can be used if all the occupant vulnerability probabilities are defaulted to 1.0 (100% chance of overpressure resulting in serious injury or fatality to building occupants). The individual risk for the building occupants on the plant shown in this example would then be represented by the following equation:

$IR_{total} = IR_{PV} + IR_{CVE}$

Where:

- IR_{PV} = Number of pressure vessels included in analysis x Estimated frequency of catastrophic pressure vessel rupture per vessel per year x 1.0 Occupant vulnerability x Occupancy probability
- IR_{CVE} = Number of confined/congested volumes included in analysis x Estimated frequency of filling and igniting the volumes per volume per year x 1.0 Occupant vulnerability x Occupancy probability

For the worked example used in this Appendix, the calculation of this equation would be as follows:

- IR_{PV} = Number of pressure vessels included in analysis (19) x Estimated frequency of catastrophic pressure vessel rupture per vessel per year (1 x 10^{-6}) x Occupant vulnerability (1.0) x Occupancy probability (0.24)
- Individual risk for pressure vessel explosion = 4.6 x 10^{-5} per year
- IR_{CVE} = Number of confined/congested volumes included in analysis (5) x Estimated frequency of filling and igniting the volumes per volume per year (1 x 10^{-5}) x Occupant vulnerability (1.0) x Occupancy probability (0.24)

- Individual risk for confined volume explosions = 1.2×10^{-5} per year
- $IR_{total} = 5.8 \times 10^{-5}$

If this individual risk meets company risk tolerance levels, the occupied buildings can be located anywhere on the site and the individual risk will be maintained. It should be noted that this risk level is based on the following items:

- Number of pressure vessels identified in the analysis; and
- The 1×10^{-6} estimated frequency of catastrophic pressure vessel rupture per vessel, per year.
- A conservative approach for PSA vessels has been used in this example. PSA vessels do not always operate at high pressures 100% of the time. Factors may be taken in a more detailed analysis to address the variation in operating pressures of these vessels.

Even if this individual risk meets risk tolerance levels, care should be taken to locate these vessels to minimize exposure to personnel based on good engineering practices.

Table E-2—HYCO risk-based analysis worked example

Confined volumes										
Vessel Description	Dimensions (ft) 1)	Confined volumes (ft^3) 1), 2)	Void fraction 3)	Net flammable gas volume (ft^3) 4)	Distance to building (ft)	Frequency of incident occurrence	Overpressure from VCE (psi)	Occupant vulnerability 5)	Occupancy probability 6)	Individual risk level 7)
PSA	50 x 30 x 5	7 500	50%	3 750	115	1 x 10^{-5}	2.0	0.4	0.24	9.6 x 10^{-7}
Reformer	50 x 19 x 5	4 750	10%	475	210	1 x 10^{-5}	<0.6	0	0.24	0
Desulfurization unit and shift reactor	25 x 5 x 10	1 250	50%	625	105	1 x 10^{-5}	1.0	0.1	0.24	2.4 x 10^{-7}
Process gas coolers	25 x 25 x 3	1 875	50%	940	150	1 x 10^{-5}	0.8	0	0.24	0
Feed and product compressor skid	44 x 60 x 10	26 400	20%	5 280	240	1 x 10^{-5}	0.8	0	0.24	0
Total confined volume explosion individual risk for building occupants (per year)										1.2 x 10^{-6}

1) Equipment measurements provided by facility; height is based on an estimate of the area that could become congested.

2) Calculated by multiplying dimensions.

3) The fraction not occupied by piping or equipment.

4) Calculated by multiplying confined volume by void fraction.

5) See figures in Appendix A to determine occupant vulnerability (using API B1, API B2, API B4 building curve).

6) Calculated by dividing number of hours in a normal 5-day work week (example: 40) by total number of hours in a week (168).

7) Calculated by multiplying frequency of incident occurrence, occupant vulnerability, and occupancy probability.

PV energy												
Vessel Description	Operat-ing pressure (psi) 1)	Operating temper-ature	Gamma	Inclusion in building siting study 2)	Vessel volume (ft^3) 1), 3)	Factor = (P • V) / (Gamma-1)	Distance to building (ft)	Frequency of incident occurrence 4)	Over-pressure from vessel (psi)	Occupant vulnerability 5)	Occupancy probability 6)	Individual risk level 7)
PSA vessels (8 vessels)	400	90 °F	1.41	Included	100(each)	9.8 x 10^{4}	115	8 x 10^{-6}	0.8	0	0.24	0
Tail gas vessels (2 vessels)	5	80 °F		Exempt; less than 15 psi operating pressure								
Desulfurization unit (3 vessels)	500	730 °F	1.4 8)	Included	50(each)	6.25 x 10^{4}	110	3 x 10^{-6}	0.75	0	0.24	0
Shift reactor	425	750 °F	1.41	Included	450	4.7 x 10^{5}	150	1 x 10^{-6}	1.0	0.1	0.24	2.4 x 10^{-8}

Vessel Description	Operat-ing pressure (psi) [1]	Operating temper-ature	Gamma	Inclusion in building siting study [2]	Vessel volume (ft^3) [1], [3]	Factor = (P • V) / (Gamma-1)	Distance to building (ft)	Frequency of incident occurrence [4]	Over-pressure from vessel (psi)	Occupant vulnerability [5]	Occupancy probability [6]	Individual risk level [7]
PV energy												
Steam drum	675	501 °F	1.61	Included	850	9.4×10^{5}	240	1×10^{-6}	4.1	0.8	0.24	1.9×10^{-7}
Feed gas separators (3 vessels)	500	100 °F	1.41	Included	40 (each)	4.9×10^{4}	115	3×10^{-6}	0.8	0	0.24	0
Compressor pulsation damper (snubber bottle) (6 vessels)	2000	150 °F	1.42	Included	40 (each)	1.9×10^{5}	210	6×10^{-6}	0.5	0	0.24	0
Total PV energy individual risk for building occupants (per year)											2.14×10^{-7}	
Total individual risk for building occupants (per year)											1.4×10^{-6}	

1) Values provided by facility.

2) See 5.3 for buildings that may be excluded.

3) Vessel volume only includes the void fraction (subtract catalyst, absorbent, or equipment volume). For steam drums, no volume reduction was made to allow for water flashing.

4) Multiplier is determined by the number of vessels.

5) See figures in Appendix A to determine occupant vulnerability.

6) Calculated by dividing number of hours in a normal 5-day work week (example: 40) by total number of hours in a week (168).

7) Calculated by multiplying frequency of incident occurrence, occupant vulnerability, and occupancy probability.

8) Hydrogen gamma value used for the purposes of this example.

Appendix F – Worked example for an ASU plant

This Appendix provides a worked example for an ASU that goes directly to a risk-based analysis as permitted by section 7.1.

For this worked example, the following occupied buildings are shown on the plot in Figure F-1:

- control/plant maintenance office building;
- guard house; and
- scale house.

For this worked example, only the exposures to the control/plant maintenance office building are considered. A complete risk-based analysis would also include the guard house and scale house shown in Figure F-1.

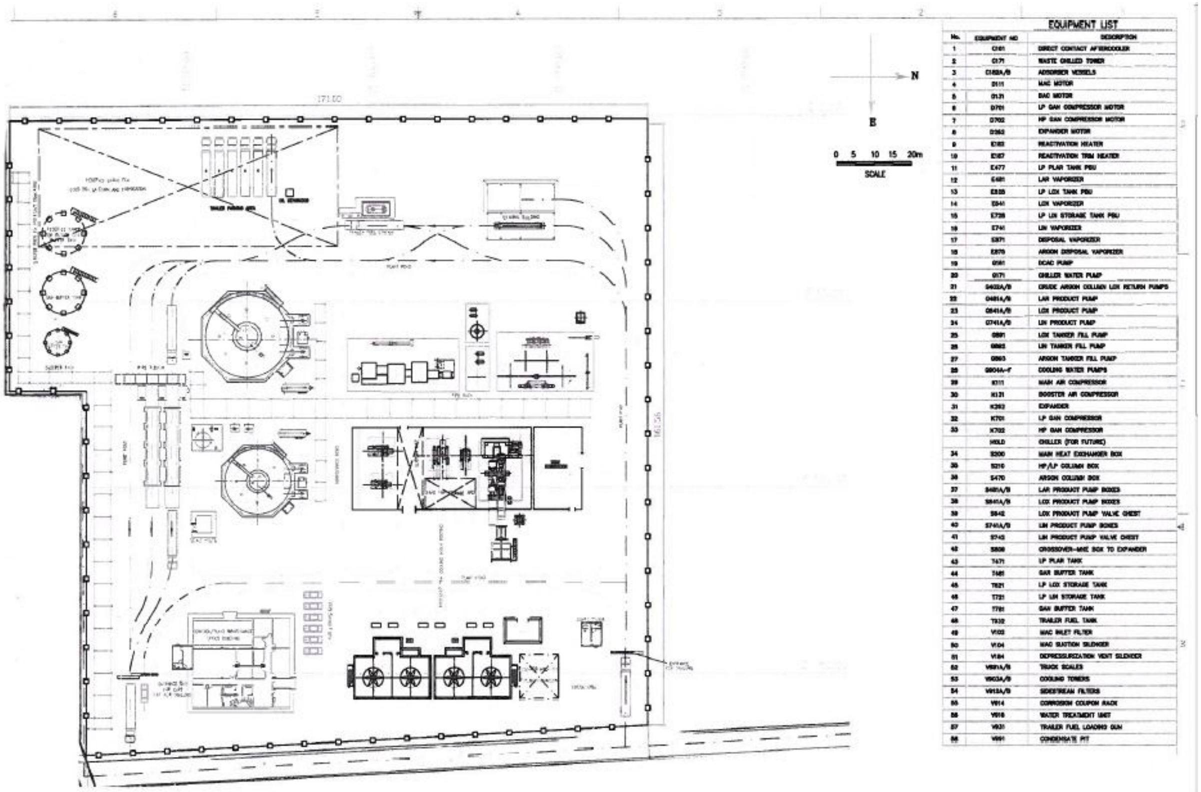


Figure F-1—ASU plot example

Table F-1 provides an example of a risk-based calculation for an air separation unit.

NOTE— Process related risks were not included in this example; as they are considered to be rare events in accordance with section 6.4. These risks should be considered if identified during the scenario evaluation process.

The 3.1 x 10^{-7} per year represents the total individual risk for occupants in the control/plant maintenance office building. This risk level should be compared to the pre-defined risk tolerance to determine if any modifications should be made to the building design or location. The same type of calculation would need to be performed for the occupants of the guard shack and scale house.

The results presented in this risk-based example use the probability of serious injury for the occupants in the calculation. These probabilities are based on the specific layout reviewed for this example. A generic approach that ignores plant layout and distances can be used if all the occupant vulnerability probabilities are defaulted to 1.0 (100% chance of overpressure resulting in serious injury or fatality to building occupants). The individual risk for the building occupants on the plant shown in this example would then be represented by the following equation:

– Individual risk = Number of pressure vessels included in analysis x Estimated frequency of catastrophic pressure vessel rupture per vessel per year x 1.0 Occupant vulnerability x Occupancy probability

For the worked example used in this Appendix, the calculation of this equation would be as follows:

– Individual risk = Number of pressure vessels included in analysis (19) x Estimated frequency of catastrophic pressure vessel rupture per vessel per year (1×10^{-6}) x Occupant vulnerability (1.0) x Occupancy probability (0.24)

– Individual risk = 4.6×10^{-6} per year

If this individual risk meets company risk tolerance levels (see 7.4.1.), the occupied buildings can be located anywhere on the site and the individual risk will be maintained.

It should be noted that this risk level is based on the following items:

– number of pressure vessels identified in the analysis;

– the site does not contain any flammable refrigerants that would require a VCE analysis; and

– the 1×10^{-6} estimated frequency of catastrophic pressure vessel rupture per vessel, per year.

Even if this individual risk meets risk tolerance levels, care should be taken to locate these vessels to minimize exposure to personnel based on good engineering practices.

Table F-1—ASU risk-based analysis worked example

Vessel description	Operating pressure (psi) 1)	Operating temperature	Gamma	Inclusion in building siting study 2)	Vessel volume (ft³) 1), 3)	Factor = (P•V) / (Gamma-1)	Distance to control/ plant maintenance building (ft)	Frequency of incident occurrence 4)	Overpressure from vessel (psi)	Occupant vulnerability 5)	Occupancy probability 6)	Individual risk level 7)
DCAC	73	50 °F	1.4	Included	6700	1.2×10^{6}	265	1×10^{-6}	0.75	0	0.24	0
TSA (4 vessels)	73	50 °F	1.4	Included	2820	5.1×10^{5}	280	4×10^{-6}	0.5	0	0.24	0
High Pressure (HP) column	58			Exempt; pressure vessel inside coldbox.								
Low Pressure (LP) column	6			Exempt; less than 15 psi operating pressure and pressure vessel inside coldbox.								
LP column reboiler	6			Exempt; less than 15 psi operating pressure and pressure vessel inside coldbox.								
Main heat exchanger (air) 8)	1100			Exempt; pressure vessel inside coldbox.								
Crude argon column	4			Exempt; less than 15 psi operating pressure								
Argon column reboiler	4			Exempt; less than 15 psi operating pressure								
Pure argon column	3			Exempt; less than 15 psi operating pressure								
Pure argon column condenser	15			Exempt; pressure vessel inside coldbox.								
Argon storage tank	15	–300 °F	1.4	Included	7060	2.6×10^{5}	190	1×10^{-6}	0.6	0	0.24	0
GAR buffer tank	390	70 °F	1.45	Included	7060	6.1×10^{6}	265	1×10^{-6}	1.9	0.35	0.24	8.4×10^{-8}

Vessel description	Operat-ing pressure (psi) 1)	Operat-ing tempera-ture	Gamma	Inclusion in building siting study 2)	Vessel volume (ft3) 1), 3)	Factor = (P•V) / (Gamma-1)	Distance to control/ plant maintenance building (ft)	Frequency of incident occurrence 4)	Overpressure from vessel (psi)	Occupant vulnerabil-ity 5)	Occupancy probability 6)	Individual risk level 7)
GOX buffer tank	247	70 °F	1.43	Included	28 230	1.6×10^{7}	350	1×10^{-6}	2.0	0.4	0.24	9.6×10^{-8}
GAN buffer tank	116	70 °F	1.42	Included	17 650	4.9×10^{6}	300	1×10^{-6}	1.5	0.2	0.24	4.8×10^{-8}
Main air compressor (MAC) 1st stage intercooler (shell side)	15	200 °F	1.4	Included	880	3.3×10^{4}	220	1×10^{-6}	0.25	0	0.24	0
MAC 2nd stage intercooler (shell side)	29	200 °F	1.4	Included	850	6.2×10^{4}	220	1×10^{-6}	0.3	0	0.24	0
Booster air compressor – 1st stage intercooler (shell side)	131	200 °F	1.41	Included	880	2.8×10^{5}	185	1×10^{-6}	0.7	0	0.24	0
Booster air compressor – 2nd stage intercooler (shell side)	232	200 °F	1.42	Included	850	4.7×10^{5}	185	1×10^{-6}	0.8	0	0.24	0
Booster air compressor – 3rd stage intercooler (shell side)	392	200 °F	1.44	Included	810	7.2×10^{5}	185	1×10^{-6}	1.0	0.1	0.24	2.4×10^{-8}
Booster air compressor – 4th stage intercooler (shell side)	710	200 °F	1.5	Included	775	1.1×10^{6}	185	1×10^{-6}	1.2	0.12	0.24	2.9×10^{-8}
Booster air compressor aftercooler (shell side)	812	200 °F	1.52	Included	705	1.1×10^{6}	185	1×10^{-6}	1.2	0.12	0.24	2.9×10^{-8}
GAN compressor – 1st stage intercooler (shell side)	29	200 °F	1.4	Included	105	7.6×10^{3}	165	1×10^{-6}	0.18	0	0.24	0
GAN compressor – 2nd stage intercooler (shell side)	58	200 °F	1.4	Included	105	1.5×10^{4}	165	1×10^{-6}	0.23	0	0.24	0
GAN compressor– aftercooler (shell side)	130	200 °F	1.41	Included	105	3.3×10^{4}	165	1×10^{-6}	0.3	0	0.24	0
LOX storage tank	3			Exempt; less than 15 psi operating pres-sure								
LIN storage tank	3			Exempt; less than 15 psi operating pres-sure								
Cryogenic vapourizer	N/A			Exempt; Ambi-ent air vapourizers are								

Vessel description	Operat-ing pressure (psi) 1)	Operat-ing tempera-ture	Gamma	Inclusion in building siting study 2)	Vessel volume (ft³) 1), 3)	Factor = (P•V) / (Gamma-1)	Distance to control/ plant maintenance building (ft)	Frequency of incident occurrence 4)	Overpressure from vessel (psi)	Occupant vulnerabil-ity 5)	Occupancy probability 6)	Individual risk level 7)
				considered piping								
Total individual risk for building occupants (per year)												**3.1 x 10^{-7}**

1) Values provided by facility.

2) See 5.3 for buildings that may be excluded.

3) Vessel volume only includes the void fraction (subtract catalyst, absorbent, or equipment volume).

4) Multiplier is determined by the number of vessels.

5) See figures in Appendix A to determine occupant vulnerability (using API B1, API B2, API B4 building curve)

6) Calculated by dividing number of hours in a normal 5-day work week (example: 40) by total number of hours in a week (168).

7) Calculated by multiplying frequency of incident occurrence, occupant vulnerability, and occupancy probability.

8) Main exchangers have several passes through them of different materials at different volumes and operating pressures. The pass selected for this example was the pass that resulted in the worst case overpressure distance to 0.9 psi.

Appendix G—Building analysis flowchart

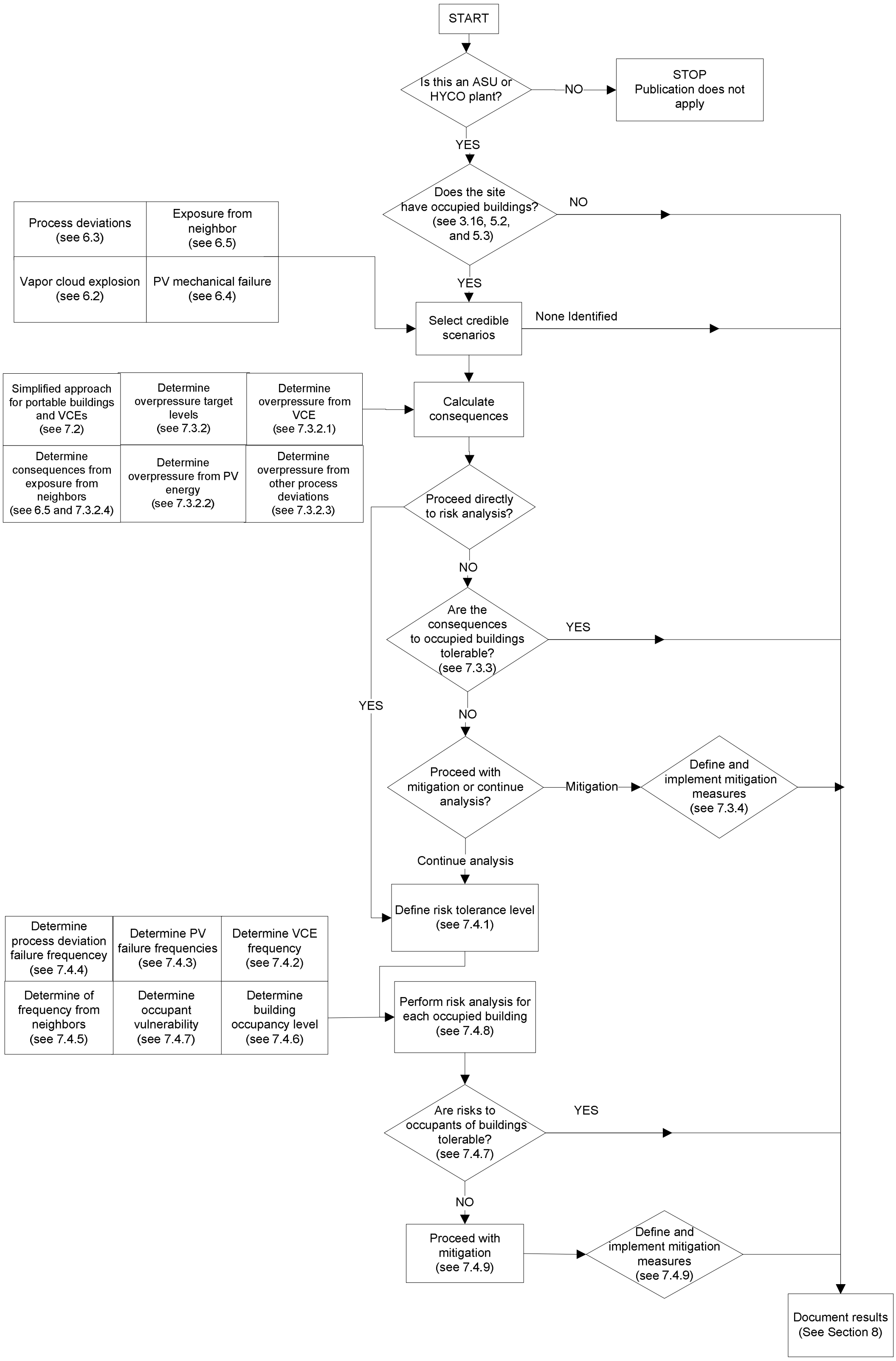


Figure G-1—Risk assessment methodology flowchart