Management of Hazards Associated with Location of Process Plant Portable Buildings

API RECOMMEDED PRACTICE 753
FIRST EDITION, JUNE 2007

REAFFIRMED, JANUARY 2012

AMERICAN PETROLEUM INSTITUTE

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Downstream Segment

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FOREWORD

The purpose of this recommended practice (RP) is to provide guidance for reducing the risk to personnel located in portable buildings from potential explosion, fire and toxic release hazards. The document is based on the following guiding principles, (1) locate personnel away from covered process areas consistent with safe and effective operations, (2) minimize the use of occupied portable buildings near covered process areas, (3) manage the occupancy of portable buildings, especially during periods of increased risk including unit start-up or planned shut-down operations, (4) design, construct, install, and maintain occupied portable buildings to protect occupants against potential hazards, and (5) manage the use of portable buildings as an integral part of the design, construction, maintenance, and operation of a facility. The recommended practice is organized into five sections with two appendices which provide the user with additional technical background and guidance.

Section 1 defines the purpose and scope of the document. Section 1 also provides the guiding principles for the development of this document and direction regarding implementation and change control.

Section 2 addresses management of personnel in portable buildings. The topics include identification of essential personnel and their use of portable buildings. Further, Section 2 addresses personnel that are not essential and makes recommendations regarding their location relative to covered process areas, including during times of non-routine operations. Section 2 also discusses portable buildings used for various purposes and identifies those that require evaluation for siting relative to covered process areas. This includes criteria such as occupancy and purpose of the portable building.

Sections 3, 4 and 5 address explosion, fire, and toxic release hazards respectively. This document is based on a philosophy that portable buildings are primarily sited (located) in relation to explosion hazards in the area as described in Section 3. Risks associated with fire and toxic release hazards are managed as described in Sections 4 and 5.

The Appendices include two parts. Appendix A describes the technical bases of certain key topics or criteria provided in this document. Appendix B provides guidance on determining congested volumes used in vapor cloud explosion calculations along with examples to demonstrate that guidance.

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1 General

1.1 INTRODUCTION

Occupied permanent buildings (e. g., control rooms, operator shelters) located near covered process areas are typically constructed to be blast and fire resistant. In contrast, conventional portable buildings (i.e., light wood trailers) are typically not constructed to be blast and fire resistant. Past explosion accidents have demonstrated that occupants of conventional portable buildings are susceptible to injuries from structural failures, building collapse, and building debris and projectiles.

1.2 PURPOSE

The purpose of this recommended practice is to provide guidance for reducing the risk to personnel located in portable buildings from potential explosion, fire and toxic release hazards.

1.3 GUIDING PRINCIPLES

This recommended practice is based on the following guiding principles:

- Locate personnel away from covered process areas consistent with safe and effective operations
- Minimize the use of occupied portable buildings in close proximity to covered process areas
- Manage the occupancy of portable buildings, especially during periods of increased risk including unit start-up or planned shut-down operations
- Design, construct, install, and maintain occupied portable buildings to protect occupants against potential hazards
- Manage the use of portable buildings as an integral part of the design, construction, maintenance, and operation of a facility

1.4 SCOPE

This recommended practice was developed for refineries, petrochemical and chemical operations, natural gas liquids extraction plants, and other facilities such as those covered by the OSHA Process Safety Management Standard, 29 *CFR* 1910.119.

1.5 IMPLEMENTATION AND CHANGE CONTROL

This recommended practice provides information that can be used when establishing or updating policies or procedures concerning the placement of portable buildings. Specific portable building siting guidelines and procedures for managing change shall be developed for the use and location of portable buildings. Examples of changes that should be managed include:

- Reassigning personnel
- Changing process conditions
- Adding a building
- Modifying a building
- Reclassifying a building function (e. g., temporary to permanent)
- Relocating a building
- Introducing new hazards affecting a building

Formal written approval by senior management should be required for deviations from established company policies or procedures.

1.6 RELATIONSHIP TO API RP 752

This document supersedes API Recommended Practice 752 with regard to portable buildings.

1.7 DEFINITIONS

For the purpose of this recommended practice, the following definitions apply:

1.7.1 confinement: A physical surface that inhibits the expansion of a flame front of a burning vapor cloud in at least one direction. Examples include solid decks, walls, or enclosures.

1.7.2 congested volume: The volume of congestion that is calculated by considering the size (perimeter boundary and height) of the congestion (usually a process unit but can be other sources of congestion).

1.7.3 congestion: A collection of closely spaced objects that have the potential to increase flame speed to an extent to generate a damaging blast wave. One example is a process area populated with pipes, pumps, valves, vessels, and other process equipment and supporting structures.

1.7.4 consequence-based analysis: An assessment of potential consequences from hazards associated with a process unit without assigning specific frequencies to the events.

1.7.5 covered process area: A process area that contains materials having the potential for an explosion, fire or toxic release.

1.7.6 Emergency Response Planning Guideline, ERPG-3: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

1.7.7 essential personnel: Personnel with specific work activities that require them to be located in portable buildings near a hazardous process area for logistical and response purposes. The identification of essential personnel will vary with the phase of operation and work activities including normal operation, start-up, and planned shut-down. Examples of essential personnel include but are not limited to operators and maintenance personnel. Examples of persons who are not essential personnel include but are not limited to designers, timekeepers, clerical staff, administrative support, and procurement staff.

1.7.8 light wood trailer: A portable building with a wall design consisting of "2 × 4" studs (nominal 1.5 in. by 3.5 in.) with a thin outer skin. This is generally representative of the weakest constructed portable building used in the processing industries.

1.7.9 personnel: Employees, contractors, and visitors.

1.7.10 portable building: Any rigid structure that can be easily moved to another location within the facility, regardless of the length of time it is kept at the site. Examples of portable buildings include wood-framed trailers (single and double-wide), container boxes, semi-trailers, and portable structures designed to be blast resistant. Lightweight fabric enclosures, such as tents, are not covered in this recommended practice.

1.7.11 siting evaluation: The procedures described in Sections 3, 4 and 5 of this document to evaluate the hazards at a specific location and determine the suitability of a particular portable building.

1.7.12 standoff distance: The distance from the edge of the congested volume(s) to the closest edge of the portable building being evaluated.

1.7.13 vapor cloud explosion (VCE): The explosion resulting from the ignition of a cloud of flammable vapor, gas or mist in which the flame speed accelerates to sufficiently high velocities to produce a damaging blast wave.

1.8 REFERENCES

The following guidelines, standards, and codes are cited in this recommended practice:

API

Std 521 *Guide for Pressure-Relieving and Depressuring Systems—Pressure and Natural Gas Industries-Pressure-Relieving and Depressurizing Systems*

RP 752 *Management of Hazards Associated with Location of Process Plant Buildings*

AIChE[1]/CCPS[2]

Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs
Guidelines for Facility Siting and Layout
Guidelines for Chemical Process Quantitative Risk Analysis
Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires

[1]American Institute of Chemical Engineers, 3 Park Avenue, New York, New York 10016, www.aiche.org.
[2]Center for Chemical Process Safety, 3 Park Avenue, 19th Floor, New York, New York 10016, www.ccpsonline.org.

ASCE[3]
Design of Blast Resistant Buildings in Petrochemical Facilities

OHSA[4]
29 *CFR* 1910.119 *Process Safety Management of Highly Hazardous Chemicals*

BakerRisk Paper, *Pressure Levels for Siting Wood Trailers Using the API RP 752*, Report No. 760-110-06, Addendum Simplified Approach, September 8, 2006.

CIA 2003, *Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites*, Revised Second Edition, Identification No. RC 21 ISBN 1 85897 114 4, November 2003.

DOD UFC 2003, *Department of Defense Minimum Antiterrorism Standards for Buildings*, DOD United Facilities Criteria (UFC4 -010-01), 08 October 2003.

2 Management of Personnel in Portable Buildings

The following questions should be addressed when considering placement of a portable building near a covered process area:

- Do personnel need to be located near a covered process area?
- Do personnel need to occupy a portable building?
- Can the portable building be placed further from the covered process area, while allowing the occupants to effectively perform their tasks?

The following sections provide guidance in addressing the above questions.

2.1 ESSENTIAL PERSONNEL AND USE OF PORTABLE BUILDINGS

Owners and/or operators shall determine if essential personnel need to occupy a portable building. Portable buildings that house personnel who are not essential shall be located as far as reasonably practicable from a covered process area consistent with the guiding principles listed in Section 1.3 and the guidance in Sections 3, 4, and 5.

Personnel occupying portable buildings shall be informed of the following:

- The facility's portable building policies or procedures;
- The emergency response plan for the portable building in the event of an explosion, fire, or toxic release incident; and
- Other work activities in the vicinity that could create an explosion, fire or toxic hazard to the portable building occupants.

2.2 PORTABLE BUILDINGS INTENDED FOR OCCUPANCY

Portable buildings that are intended to be occupied shall be evaluated for siting relative to explosion, fire, and toxic release hazards in accordance with Sections 3, 4 and 5.

Occupancy threshold examples in API RP 752 Sections 2.5.2 b, c, and d shall not be used to exclude portable buildings from a siting evaluation.

Portable buildings intended for occupancy include, but are not limited to:

- Offices
- Training rooms
- Orientation rooms
- Lunch rooms
- Conference rooms
- Control rooms
- Laboratories
- Change houses
- Maintenance shops

[3]American Society of Civil Engineers, 101 Constitution Avenue, N.W., Suite 375 East, Washington D.C. 20001, www.asce.org.
[4]Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington D.C. 20210, www.osha.gov.

Portable buildings or shelters occupied only for short duration (e.g., portable toilet facilities, smoking shelters, weather shelters) should be evaluated on a case-by-case basis.

2.3 PORTABLE BUILDINGS NOT INTENDED FOR OCCUPANCY

Portable buildings not intended for occupancy do not need to be sited for explosion, fire, or toxic release hazards. Controls should be implemented to ensure that the use of these portable buildings does not change to "portable buildings intended for occupancy". Personnel, however, may periodically be present in these portable buildings to perform their duties.

The following examples are portable buildings and structures that are generally not intended for occupancy:

- Tool trailers or storage sheds without attendant stationed inside
- Decontamination facilities
- Control equipment enclosures
- Analyzer sheds
- Portable electrical substations
- Portable electric generators

2.4 OTHER OCCUPIED PORTABLE STRUCTURES

This section addresses a group of portable structures that are used to support temporary work activities within covered process areas and are often mandated by regulatory requirements. Current technology is typically not sufficient to provide the capability to remotely perform these activities. The siting evaluation described in this document does not apply to these structures. Examples include:

- Mobile environmental monitoring stations
- Supplied air trailers
- Inert entry life support trailers
- Vehicles housing equipment stations (e. g., trucks or vans with X-ray equipment)

Special characteristics of these structures include:

- Required to be located inside or near the process unit. (For example, due to physical connections between equipment in the portable building and the unit equipment)
- Support essential activities to ensure personnel safety, necessary maintenance or environmental monitoring and testing
- Present only for the duration of the specific activity and removed immediately thereafter
- Maneuverable for placement in congested areas for access to nested equipment and stacks
- Accommodate low numbers of personnel

Risk mitigation measures for these structures shall include:

- Direct communications of occupants with operations
- Authorized work permit for their temporary presence
- Awareness training of process unit hazards for occupants
- Emergency response and evacuation procedures
- Minimized occupancy, which includes controls to confirm that personnel not directly involved in a critical ongoing activity (e. g., start-up and planned shut-down) are evacuated from these portable structures

This recommended practice does not apply to portable structures that are not buildings. Examples include:

- Welding enclosures
- Asbestos or refractory remediation enclosures
- Cranes or other equipment with operator cabins

3 METHODS FOR LOCATING PORTABLE BUILDINGS FOR EXPLOSION HAZARDS

This section applies to facilities that have the potential for an explosion hazard either from flammable materials within a process area or from a drifting flammable cloud from adjacent process areas. See Section 4 and 5 to address facilities with fire and toxic release hazards. Portable buildings intended for occupancy in accordance with Section 2.2 should be located using either the Simplified Method (Section 3.1) or a Detailed Analysis (Section 3.2).

Figure 1 establishes three zones for siting portable buildings based on external vapor cloud explosions[5]. The technical basis for Figure 1 is shown in Appendix A. The zones are defined by standoff distances as a function of congested volume. The standoff distances are measured from the edge of the congested volume to the portable building. The congested volume is calculated in accordance with Appendix B.

The following requirements apply to siting portable buildings near congested volumes from 7,500 to 1,000,000 cubic ft using Figure 1:

- Zone 1: *Light wood trailers intended for occupancy shall not be located within Zone 1 under any circumstances. All portable buildings intended for occupancy other than light wood trailers require a Detailed Analysis as described in Section 3.2 and may house only essential personnel.*
- Zone 2: *Siting of all portable buildings intended for occupancy including light wood trailers requires a Detailed Analysis as described in Section 3.2.*
- Zone 3: *Any portable building can normally be located in Zone 3.*

These requirements are further summarized in Table 1.

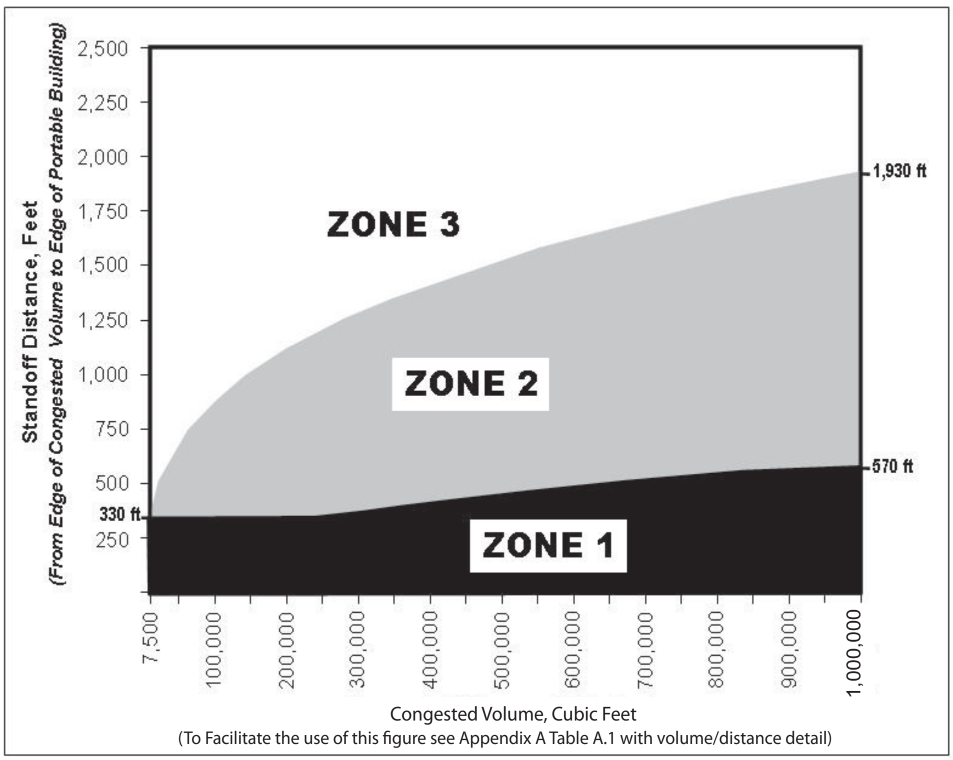

Figure 1—Portable Buildings Location Guidance

[5]The Simplified Method should not be used for internal vapor cloud explosion scenarios such as a release inside a building housing process equipment.

Table 1—Allowable Locations and Personnel for Portable Buildings Intended for Occupancy

	Light Wood Trailers	Portable Buildings other than Light Wood Trailers	Occupancy Restrictions
Zone 1	Not Allowed	Detailed Analysis Required	House Only Essential Personnel
Zone 2	Detailed Analysis Required	Detailed Analysis Required	No Restrictions
Zone 3	No Restrictions	No Restrictions	No Restrictions

For congested volumes less than 7,500 cubic ft, portable buildings intended for occupancy shall be located at a standoff distance greater than 330 ft or at a distance determined by performing a Detailed Analysis.

For congested volumes greater than 1,000,000 cubic ft a Detailed Analysis is required. Further, the Zone 1 guidance in Table 1 applies and the Zone 1 standoff distance for light wood trailers shall not be less than 570 ft.

The use of portable buildings in Zone 1 that have facilities that could be used for meetings shall be controlled such that they are used only by essential personnel.

3.1 SIMPLIFIED METHOD

The Simplified Method recommends placement of portable buildings intended for occupancy only in Zone 3. Standoff distances to Zone 3 in Figure 1 are determined by calculating congested volumes as described in Appendix B. Portable buildings located in Zone 3 are expected to retain structural integrity but may sustain window breakage. Mitigation of potential window hazards should be considered. The additional risk reduction recommendations in Section 3.5 should be considered.

3.2 DETAILED ANALYSIS

A Detailed Analysis is required for siting any portable building in Zone 1 or Zone 2 of Figure 1. Methods include Consequence Analysis and Quantitative Risk Assessment (QRA) both of which are discussed below.

Personnel performing the detailed analysis shall have competence in the analytical procedures and the components of the analysis. Areas of competency shall include as appropriate the application of the methodology being employed, hazard identification, scenario development, flammable dispersion modeling, explosion modeling, blast response of structures, frequency assessment, and mathematical techniques.

3.2.1 Consequence Analysis

A Consequence Analysis is a detailed, technical assessment of potential consequences from explosion hazards, and includes the prediction of blast loads and the estimation of potential damage to defined portable buildings. Consequence Analyses should be based on major release scenarios, considering incidents and their outcomes that have or could have occurred in similar process units within industry (i.e., scenarios with the most severe consequences).

The estimation of Vapor Cloud Explosion blast loading should include but is not limited to:

- Flammable cloud size
- Fuel reactivity
- Process area congestion
- Congested volume
- Confinement
- Explosion severity or flame speed
- Separation distance between adjacent congested volumes
- Distance between the hazardous process area and the portable building

The following additional explosion hazards may require additional or different considerations.

- Condensed phase chemical explosion
- Dust explosion
- Boiling Liquid Expanding Vapor Explosions (BLEVEs)
- Vapor cloud explosions at enclosed process units
- Pressure vessel burst
- Runaway chemical reactions

The suitability of a particular type of portable building and the appropriate standoff distance shall be determined based on the blast response of structures. Guidance for evaluating portable buildings is provided in Section 3. Table 4 of API RP 752 should not be used. Additional sources of information are:

- *Explosion Hazards and Evaluation*, Baker, Cox, Westine, Kulesz, and Strehlow, Elsevier, 1983
- *Methods for the Calculation of Physical Effects*, TNO "Yellow Book," CPR 14E, The Hague, Netherlands, 1997.
- *Methods for the Determination of Possible Damage to People and Objects Resulting from Releases of Hazardous Materials*, TNO "Green Book," CPR 16E, The Hague, Netherlands, 1992.
- *Risk-Based Explosives Safety Analysis*, Department of Defense Explosives Safety Board Technical Paper No. 14, Alexandria, Virginia, February 2000.

3.2.2 Quantitative Risk Assessment

A Quantitative Risk Assessment (QRA) can be used by expanding on the information generated in the Detailed Consequence Analysis. Siting of portable buildings may be determined through the use of QRA, provided it is conducted in a manner consistent with recognized government or industry standards, such as the *American Institute of Chemical Engineers*, *Center for Chemical Process Safety*, *Guidelines for Chemical Process Quantitative Risk Analysis*. QRAs should take into account a full range of release scenarios. When performing a QRA for a portable building, the study should assume the portable building to be occupied at least 40 hours a week by an individual. The QRA should assume this occupancy level for the entire year. No credit should be taken for cases where the building will not be used or located at that site for less than a year.

3.3 LIGHT WOOD TRAILER OVERPRESSURE DAMAGE LEVELS

Table 2 includes information on overpressure effects on light wood trailers during a vapor cloud explosion. The overpressure effects listed in Table 2 are for very long duration VCEs (200 milliseconds or greater) and are intended for use in simplified damage assessments. The technical basis for Table 2 is provided in Appendix A.

Table 2—Overpressure Effects on Light Wood Trailers

Building Damage Level (BDL)	BDL Description	Parameters Used for Light Wood Trailers	Upper Bound Pressure
2A	Trailer is damaged in localized areas. Individual components on walls facing the blast sustain up to major damage. Other walls and the roof sustain up to moderate damage. Window breakage and falling overhead items are expected.	Studs on the reflected wall (the wall facing the explosion) are expected to crack but remain in place.	0.6 psi
2B	Trailer damage is widespread, but structural collapse is not expected. Wall components facing the blast sustain major damage and may fail. Wall and roof components not facing the blast sustain up to major damage. Window breakage and falling overhead items are expected	Studs on the walls that do not face the explosion are expected to crack with more significant damage to the reflected wall.	0.9 psi
Data from *Pressure Levels for Siting Wood Trailers Using the API RP 752 Addendum Simplified Approach*, BakerRisk Paper No. 760-110-06, September 8, 2006.			

Metal trailers, wood trailers with wider studs, or other wall construction may be stronger than shown in Table 2.

More sophisticated analysis tools can be applied that may result in different damage predictions than shown in Table 2. For example, analysis for specific loading conditions may be based upon such items as, but not limited to:

- the shape of the blast wave (pressure-time history)
- the blast wave pressure and impulse
- the type of portable building construction
- the failure criteria and structural response of the portable building
- the structural analysis method employed

3.4 PORTABLE BUILDING BLAST RESISTANCE REQUIREMENTS

In accordance with Section 1.3 it is better to locate personnel away from covered process areas and to minimize the use of occupied portable buildings near such areas. However, if placement of a blast resistant portable building is necessary, owners and/or operators shall develop criteria as to when a blast resistant portable building will be allowed in close proximity to a process area.

Portable buildings specifically designed for significant blast loads may be used. This document does not address whether these buildings may offer a similar level of protection to occupants as permanent buildings. The design of portable buildings shall be handled on a case-by-case basis.

A portable building may be located in Zone 1 or Zone 2 only if the conditions described in 3.4.1 and 3.4.2 are satisfied:

3.4.1 Detailed Blast Analysis

Conduct a detailed blast analysis as described in section 3.2 combined with a structural evaluation that demonstrates the building will provide protection to the occupants from the blast hazards. The structural evaluation shall:

- Establish blast design basis loading;
- Design or assess the structure of portable buildings using established blast resistant design procedures. The ASCE 1998 is recommended for blast resistant design or assessment of portable buildings for petrochemical facilities;
- Establish design criteria in terms of the allowable structural response that are appropriate for the intended use of the building;
- Design or assess the support system of portable buildings to limit the acceleration and displacement of the building, including overturning and sliding;
- Address door operability and function after blast;
- Design or assess non-structural features of portable buildings to limit flammable vapor or smoke ingress (post explosion event) and dislodgement of internal features; and
- Address applicable explosion risk reduction measures described in Section 3.5.

3.4.2 Fire and Toxic Release Hazards Analysis

Conduct a fire and toxic release hazards analysis (See sections 4 and 5) combined with an evaluation that demonstrates the portable building will protect its occupants or allow safe escape from the identified scenarios. The fire and toxic release evaluation shall:

- Determine the fire rating of the building shell for thermal radiation and (if applicable) flame impingement;
- Specify flammable and/or toxic release mitigation systems (alarms, HVAC emergency shutdown systems, water sprays, etc.);
- Determine means of escape and emergency evacuation in the event of a toxic/flammable gas release or a fire; and
- Specify personal protective equipment (PPE) requirements for building occupants.

Additional references are:

- *Structure to Resist the Effects of Accidental Explosions*, Department of the Army Technical Manual TM 5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22, Revision 1, November 1990.
- *Introduction to Structural Dynamics*, Biggs, J.D., McGraw-Hill Publishing Company, New York, NY, 1964.
- *The Prediction of Blast and Fragment Loadings on Structures*, Prepared for United States Department of Energy, by Southwest Research Institute under contract with Mason & Hanger, and Battelle Pantex, Report No. DOE/TIC 11268, July 1992.
- *Fundamentals of Protective Structure Design for Conventional Weapons*, Department of the Army TM 5-855-1, Washington, D.C., November 3, 1986.

3.5 ADDITIONAL EXPLOSION RISK REDUCTION PRACTICES

Other risk reduction measures which should be considered for all portable buildings and applied as necessary are:

- Securing internal furniture, office equipment and fixtures to minimize projectile hazards inside the portable building
- Ensuring that portable buildings are assembled and installed in accordance with manufacturers' recommendations and local building codes. Particular attention should be paid to the proper connection of ridge beams and columns in double-wide trailers
- Evaluating and mitigating window hazards from potential explosions for portable buildings regardless of occupancy or location (for example replace glass window with polycarbonate panel, elimination of windows, or application of safety films)
- Considering the orientation of the portable building relative to the potential explosion hazard(s) (e. g., for a rectangular portable building, it is preferred to orient the short face of the building toward the controlling explosion hazard)
- Evaluating and considering the location and the number of emergency doors to provide appropriate emergency egress

- Considering alignment of egress paths relative to potential explosion hazards and overpressure generated escalation events
- Complying with electrical area classifications
- Inspecting portable buildings not intended for occupancy periodically to ensure that the occupancy status has not changed

For additional risk reduction practices, refer to *AIChE/CCPS 2000*.

4 Fire Hazards

In addition to the guidance provided in this document for explosion hazards, owners and/or operators shall consider providing sufficient spacing for fire hazards to allow personnel to escape safely.

A fire analysis or distance criteria shall be performed to determine the safe location of portable buildings based upon the extent of the flammable cloud and radiation levels from specific process hazards. Refer to API Std 521 for guidance on lower flammable limit and maximum radiation level exposures. Owners and/or operators may consider the spacing recommendations published in CCPS 2003 "Guidelines for Facility Siting and Layout" considering both process hazards and accessibility requirements.

Owners and/or operators should also separate portable buildings from flares, vent stacks and atmospheric relief devices based upon guidance in API Std 521 considering thermal radiation, atmospheric dispersion, mist emissions and flare flame-out.

Portable buildings shall not be placed in locations where flammable liquid spill scenarios could affect the building. Portable buildings shall not be placed within the dike, berm or bund areas of storage tanks of flammable or combustible materials.

Additional fire risk reduction measures that should be considered include:

- Position emergency exits away from the nearest potential fire hazard
- Escape routes that lead away from nearest potential fire hazards
- Locate mustering areas away from potential fire hazards
- Develop emergency procedures and related training which will facilitate evacuation given an incident involving a fire
- Use fire rated portable buildings
- Install fire protection measures (e. g., water sprays or deluge systems)

5 Toxic Release Hazards

In addition to the guidance provided in this document for explosion and fire hazards, owners and/or operators shall consider providing sufficient spacing for toxic release hazards. Portable buildings located in areas where a toxic release can reach ERPG-3 levels should meet either of the following:

1. Be designed for shelter-in-place, or
2. Have an emergency response plan that includes the following:
   - Evacuation plan that directs personnel to a designated "shelter-in-place" or specified assembly area;
   - Plan to account for occupants; and
   - Personal protective equipment (PPE) to be used by all occupants during the evacuation if required.

Portable buildings used for Shelter-In-Place should have the following features as a minimum:

- Heating, ventilation and air conditioning systems (HVAC) systems capable of rapid shutdown of the system or placement in recirculation mode, whichever is more appropriate. This HVAC shutdown response should be included in the emergency response plan
- Exhaust fans and duct penetrations of exterior surfaces equipped with a positive seal against infiltration of outside air
- Emergency communications equipment (telephones are acceptable)
- PPE to be used by all occupants during the evacuation as necessary
- Seals for windows and doors that are present

APPENDIX A—BASES FOR FIGURE 1 AND TABLE 2

A.1 BASIS FOR FIGURE 1—VCE STANDOFF DISTANCE FOR PORTABLE BUILDINGS INTENDED FOR OCCUPANCY

The calculation of blast pressures and impulses resulting from a vapor cloud explosion is a complex problem that is influenced by many factors. The analysis methods presented in this Appendix are reasonable engineering approaches. The use of different methods or congested volume layout will result in different values.

The calculations for Figure 1 were performed using the TNO method as discussed in this section. There are multiple, similar methods for performing these calculations that may result in higher or lower blast loads for a specific situation. Alternative methods that are widely used within the industry are:

- Baker-Strehlow-Tang
- Congestion Assessment Method

The use of the TNO method is not intended as an endorsement of this method. Each owner operator should use a method that is suitable for their specific operations and unit layout.

The curves separating Zones 1, 2, and 3 in Figure 1 are based on the assumptions and technical analyses described in this Appendix. Use of Figure 1 requires calculation of Congested Volume, which is discussed in Appendix B.

The curve separating Zones 2 and 3 (White/Gray boundary line) in Figure 1 is based on two conservative assumptions, with the intent that locating any portable building in Zone 3 would be appropriate for practically all process plant situations involving VCEs[6]. One conservative assumption is that the VCE event is postulated to have significant severity or violence (i.e., a very high flame speed event). The second conservative assumption is that the portable building used in the analysis was generally representative of the weakest constructed portable building.

The analysis that defined the curve separating Zones 2 and 3 made the following specific assumptions:

- The TNO multi-energy blast chart[7] was utilized with a Blast Strength Number 7[8].
- Distance was calculated based on a free-field overpressure end point of 0.6 psi. This value corresponds to the upper limit for Building Damage Level (BDL) 2A, with the consequences as described in Table 2 for a specific type of light wood trailer as described below.

The curve separating Zone 1 and Zone 2 (Gray/Black boundary line) in Figure 1 captures the greater of two criteria:

1. A threshold distance of 330 ft, which is intended to allow building occupants time to react to flammable gas cloud hazards[9]
2. A VCE generating a free-field overpressure of approximately 0.9 psi.

At lower congested volumes, criterion (1) above controls. At higher Congested Volumes, criterion (2) controls and the distance increases with increasing Congested Volume to a maximum distance of 570 ft at a Congested Volume of 1,000,000 cubic ft. The analysis that defined the curve separating Zone 1 and Zone 2 made the following specific assumptions:

- The analysis utilized the TNO multi-energy blast chart with a Blast Strength Number 5.
- Distance was calculated based on a free-field overpressure end point of 0.9 psi. This value corresponds to the upper limit for Building Damage Level (BDL) 2B, with the consequences as described in Table 2 for a specific type of light wood trailer as described below:

---

[6]Figure1should not be used for internal vapor cloud explosion scenarios such as a release inside a building housing process equipment. those situations should be addressed in a Detailed Analysis.
[7]Figure5.8A of TNO "Yellow Book." *Methods for the Calculation of the Physical Effects due to release of Hazardous Materials* (*Liquids and Gases*), CPR 14E, The Hague, Second Edition, 1997.
[8]Initial Blast Strength Number 7 is in the transition between a strong deflagration (Blast Strength Number 6) and a detonation (Blast Strength Number 10). Use of Blast Strength Number 7 is considered reasonable because in most unconfined vapor cloud cases the mode of flame propagation is a deflagration except under unusual conditions (AIChE/CCPS 1994). It is recognized that it is very unlikely to have a detonation in a fuel-air cloud originating from an accidental release in the open and in typical processing plant environments due to the likelihood of inhomogeneous cloud conditions that would prevent a possible detonation from propagating (TNO Yellow Book). Further, there is no difference in the overpressure predictions between Blast Strength Numbers 6 through 10 in the far field and at overpressures of interest for siting light wood trailers.
[9]Adopted from *Guidance on Practice for Design and Location of Occupied Portable Buildings within Refineries and Chemical Plants*, BP Group Engineering Technical Practices, 2005.

Zone 1 defines the areas that are likely hazardous to light wood trailers for practically all process plant situations involving VCEs. For siting light wood trailers the standoff distance shall be the maximum of the distance to the Zone 1/Zone 2 boundary or the distance to 0.9 psi calculated using Detailed Analysis.

It should be noted that as congested volume increases, the severity of the explosion (expressed as TNO blast strength number) may increase based on scaling effects. For congested volumes at the upper end of the range where the consequence analysis shows that the most severe release scenario can only result in a partial filling of the congested volume (reasons include inventory limitations, cases involving heavier than air hydrocarbons, colder than ambient releases, early contact with ignition sources, and a high release rate needed to form such a large flammable cloud) the distance to 0.9 psi may be similar to the distance to the Zone1/ Zone 2 boundary.

For congested volumes at the lower end of the range considered on the graph with high reactivity materials the distance to 0.9 psi may be greater than the distance to the Zone1/Zone 2 boundary.

The primary purpose of Figure 1 is to illustrate Zones 1, 2, and 3 that are referenced throughout this document; however, it is not well suited for assessing accurate standoff distance values for given congested volumes. Table A.1 was developed, therefore, to facilitate that effort. Table A.1 includes several combinations of Separation Distance and Congested Volume. Values in-between those listed in Table A.1 may be determined by interpolating (prorating) linearly.

Congested Volume (Cubic Feet)	Zone 3 (White) to Zone 2 (Gray) Transition (Feet)	Zone 2 (Gray) to Zone 1 (Black) Transition (Feet)
0	330	330
10,000	369	330
20,000	481	330
30,000	559	330
40,000	621	330
50,000	674	330
60,000	720	330
70,000	761	330
80,000	799	330
90,000	833	330
100,000	865	330
110,000	895	330
120,000	923	330
130,000	949	330
140,000	974	330
150,000	998	330
160,000	1,021	330
170,000	1,043	330
180,000	1,065	330
190,000	1,085	330
200,000	1,105	330
210,000	1,124	330
220,000	1,142	330
230,000	1,160	330
240,000	1,178	331
250,000	1,195	336

Congested Volume (Cubic Feet)	Zone 3 (White) to Zone 2 (Gray) Transition (Feet)	Zone 2 (Gray) to Zone 1 (Black) Transition (Feet)
250,000	1,195	336
260,000	1,212	341
270,000	1,228	347
280,000	1,243	351
290,000	1,258	356
300,000	1,273	361
310,000	1,288	366
320,000	1,303	370
330,000	1,317	375
340,000	1,330	379
350,000	1,344	383
360,000	1,357	387
370,000	1,371	391
380,000	1,383	395
390,000	1,395	399
400,000	1,408	403
410,000	1,420	407
420,000	1,432	411
430,000	1,443	415
440,000	1,455	418
450,000	1,467	422
460,000	1,478	425
470,000	1,490	429
480,000	1,500	432
490,000	1,511	436
500,000	1,521	439

Congested Volume (Cubic Feet)	Zone 3 (White) to Zone 2 (Gray) Transition (Feet)	Zone 2 (Gray) to Zone 1 (Black) Transition (Feet)
500,000	1,521	439
510,000	1,532	443
520,000	1,542	446
530,000	1,553	449
540,000	1,562	453
550,000	1,572	456
560,000	1,581	459
570,000	1,592	462
580,000	1,601	465
590,000	1,611	468
600,000	1,620	471
610,000	1,629	474
620,000	1,638	477
630,000	1,647	479
640,000	1,656	482
650,000	1,665	485
660,000	1,674	488
670,000	1,683	491
680,000	1,692	493
690,000	1,700	496
700,000	1,709	499
710,000	1,717	501
720,000	1,726	504
730,000	1,735	507
740,000	1,742	509
750,000	1,750	512

Congested Volume (Cubic Feet)	Zone 3 (White) to Zone 2 (Gray) Transition (Feet)	Zone 2 (Gray) to Zone 1 (Black) Transition (Feet)
750,000	1,750	512
760,000	1,758	514
770,000	1,766	517
780,000	1,774	519
790,000	1,782	522
800,000	1,790	524
810,000	1,798	527
820,000	1,804	529
830,000	1,812	531
840,000	1,820	534
850,000	1,828	536
860,000	1,834	538
870,000	1,842	541
880,000	1,850	543
890,000	1,856	545
900,000	1,864	548
910,000	1,870	550
920,000	1,878	552
930,000	1,884	554
940,000	1,892	556
950,000	1,898	559
960,000	1,906	561
970,000	1,912	563
980,000	1,918	565
990,000	1,926	567
1,000,000	1,932	569

NOTE: Curves meet at 7,500 cubic feet and 330 feet.

Table A.1—Separation Distances from Figure 1 for Selected Congested Volumes

A.2 BASIS FOR TABLE 2—PRESSURE ASYMPTOTES FOR LIGHT WOOD TRAILERS

The values shown in Table 2 are expressed in terms of free-field pressures and are based on a trailer with a wall design consisting of notched "2 × 4" studs (nominal 1.5 in. by 3.5 in.) with a thin aluminum outer skin. This was selected as the weakest type of wood construction likely to be encountered in processing facilities in the United States. A Two Degree of Freedom numerical analysis was performed on a wall consisting of this typical geometry. Clearing effects were included in the analysis. Wall studs were assumed to be stud grade southern pine, spaced 16 in. apart. A thin (0.030 in.) aluminum skin was assumed to span over the studs. The upper bound for Building Damage Level 2A corresponds to the onset of failure of the studs on the reflected face of the trailer. The upper bound for Building Damage Level 2B corresponds to the onset of failure of the studs on the side-on faces of the trailer. Failure was assumed to take place when the predicted stud ductility ratio exceeds 2.0. The results of this numerical analysis were found to be consistent with observed incident damage.

APPENDIX B—GUIDANCE FOR LOCATING PORTABLE BUILDINGS

B.1 Guidance For Congested Volume Assessment

B.1.1 BACKGROUND

An important part of this document is Figure 1, which applies to Vapor Cloud Explosion (VCE) scenarios and relates "Standoff Distance" to "Congested Volume." Congested Volume was used as the basis for Figure 1 rather than other indicators such as the total quantity of flammable material released for a given scenario. This is because the size (energy) of a conventional VCE is directly related to the volume of congestion that is blanketed by the portion of the cloud that is within flammable limits. Flammable mixtures in congested environments are conducive to accelerating flames to levels that can generate damaging blast waves. By contrast, flammable mixtures in the open (areas without congestion) tend to burn relatively slowly, generating a fire hazard but not damaging blast waves[10].

Guidance for calculation of Congested Volume for use of Figure 1 for both the Simplified Method (see Section 3.1) and a Detailed Analysis (see Section 3.2) is provided below, followed by examples.

B.1.2 SIMPLIFIED METHOD

The use of Figure 1 and the Simplified Method requires calculation of Congested Volume, which is defined as "*the volume of congestion that is calculated by considering the size (perimeter boundary and height) of the congestion (usually a process unit but can be other sources of congestion)*." There are two parts to this definition. The first is to assess separation distance between volumes of congestion, which determines if the volumes can be treated as discrete congested volumes or should be considered together as one larger congested volume. The second is calculating the volume of each congested area present. These two parts are addressed below.

- **Separation distance**—A Congested Volume can be considered as separate from other Congested Volumes if bounded on all sides by open areas. Those open areas should be of adequate width and relatively free of overhead piping and equipment. An example of adequate separation is a wide roadway or a wide, clear access way between congested areas. Hence, a typical process plant with open areas separating units may consist of many separate Congested Volumes. Example situations that would not provide adequate separation are a narrow pipe-rack or pump alley through a unit where there are significant overhead appurtenances connecting the two sides. Figure 1 is used for each individual Congested Volume separately to determine the required Standoff Distances for each of those Congested Volumes.
- **Congested Volume**—Congestion is defined as "a collection of closely spaced objects that have the potential to increase flame speed to an extent to generate a damaging blast wave. One example is a process area populated with pipes, pumps, valves, vessels, and other process equipment and supporting structures." The Simplified Method uses a conservative definition of Congested Volume, which is based on all the congestion present. The Congested Volume equals the average "footprint" of the congestion region (its horizontal area, excluding any individual projections such as connecting pipes, isolated drums, or valve actuators) times the average height of congestion (not including columns, furnace stacks, and other tall items.) A common point of reference for process areas may be the top of pipe racks, but average congested area heights range anywhere from 10 to 30 ft tall, but can be taller or shorter. See Example 1 for calculation of congested volume.

B.1.3 DETAILED METHOD

One may choose to consider the impact of site specific factors when evaluating Congested Volume by performing a Detailed Analysis. Site specific factors may include the geometry of the unit, release conditions, properties of the flammable material, quantity of flammable material present, and the configuration of the associated equipment and piping. One approach is for Detailed Analysis to utilize dispersion modeling[11] to evaluate release scenarios. For example, releases of certain heavy flammable substances may not fill the entire height of the congestion present. Another example is that the release may be of an insufficient quantity to cover the entire unit with a flammable cloud[12]. In these cases, the portion of congestion that contributes to the explo-

---

[10]Other mechanisms can be conducive to VCEs, such as high velocity, intensely turbulent jet releases or mechanically induced turbulent environments. See *AIChE/CCPS* 1994 for additional information.

[11]*AIChE/CCPS* 1996, *Guidelines for Use of Vapor Cloud Dispersion Models*, Center for Chemical Process Safety of the American Institute of Chemical Engineers, New York, Copyright 1996 and *AIChE/CCPS* 1999, *Guidelines for Consequence Analysis of Chemical Releases*, Center for Chemical Process Safety of the American Institute of Chemical Engineers, New York, Copyright 1999.

[12]The Detailed Analysis should also consider cloud expansion that occurs during the explosion, as the gas cloud burns the gas will expand and push the unburned gas into surrounding areas.

sion energy could be less than that defined above for the Simplified Method when calculating Congested Volume. Another approach is for Detailed Analysis to account for lateral venting associated with long, narrow congested volumes (e. g., a unit whose length is much greater than its width or height) that tends to limit flame acceleration.

The Detailed Analysis should also consider discussions on separation distance that are provided in the literature[13]. A company performing a Detailed Analysis may be able to sub-divide the congestion present in the plant into Congested Volumes differently than following the guidance above for the Simplified Method. For example, a Detailed Analysis may be able to justify sub-dividing a single unit into multiple congested volumes if adequate separation is present. This would allow use of Figure 1, or other detailed methods, for determining the appropriate Standoff Distance.

B.1.4 NON-OPERATING UNITS AND OTHER CONGESTED VOLUMES

It is noted that Congested Volumes may support a Vapor Cloud Explosion (VCE) if flammable releases can reach them. Congested Volumes, regardless of materials handled, should therefore be considered as potential explosion sites due to material drifting from adjacent facilities. The operating status of a process unit does not exempt it from assessment under this recommended practice. Examples include a unit processing non hazardous material, process units under a turnaround or maintenance, a shutdown process unit, or an abandoned process unit. This includes situations where the process unit is de-inventoried. Congested Volumes can also be present in areas that are not process units. Both the Simplified Method and the Detailed Method should take this into consideration.

B.2 Example Problems

B.2.1 EXAMPLE NO. 1: LOCATION OF PORTABLE BUILDINGS AWAY FROM AN AREA OF CONGESTION

Question: How far away from the edge of the hypothetical process unit shown in Figure B.1 can an occupied "2 × 4" light wood trailer be located?

Answer: To find the light wood trailer location distance relative to this particular process unit, the following steps will need to be taken:

1. Determine the congested volume of the process unit
2. Use Figure 1 to determine the appropriate location distance away from the edge of the process unit. Table A.1 may also be used to obtain more accurate distances.

Step 1—Estimate congested volume:

A process unit congested volume may be calculated by taking into account the average perimeter boundary (L × W) and height (H) (see Figure B.1). The perimeter boundary can be calculated by an average line through the edge of equipment associated with the congested area, provided that there is a clear separation distance between adjacent process units (e.g., a roadway or a wide access way). The average height should be the height of a horizontal plane representative of the unit congestion. Tall columns and chimneys protruding above the average height can be neglected as they will play a negligible role in blast generation. See the rectangular volume marked in the above typical process unit model.

Note that the rectangular volume contains some areas that are not congested (e.g., lower right-hand corner) and it excludes some other areas (e.g., above the rectangle and at the sides) that are congested or contain equipment. The intent is to estimate a rectangular volume that will simulate the average congestion of the entire unit. The rectangular volume may be thought of as the box that will be needed to fit inside it all the equipment of the congested area (excluding any protruding tall columns, chimneys, etc.). One can imagine disassembling the equipment that extend outside the box and fitting them all neatly inside the box where there is empty space, like the lower right-hand corner of Figure B.1.

[13]TNO Research Report RR 369, *Research to Improve Guidance on Separation Distance for the Multi-Energy Method* (*RIGOS*), 2005 and Harris and Wickens, *Understanding Vapor Cloud Explosions—An Experimental Study*, British Gas PLC, Communication 1408, 1989.

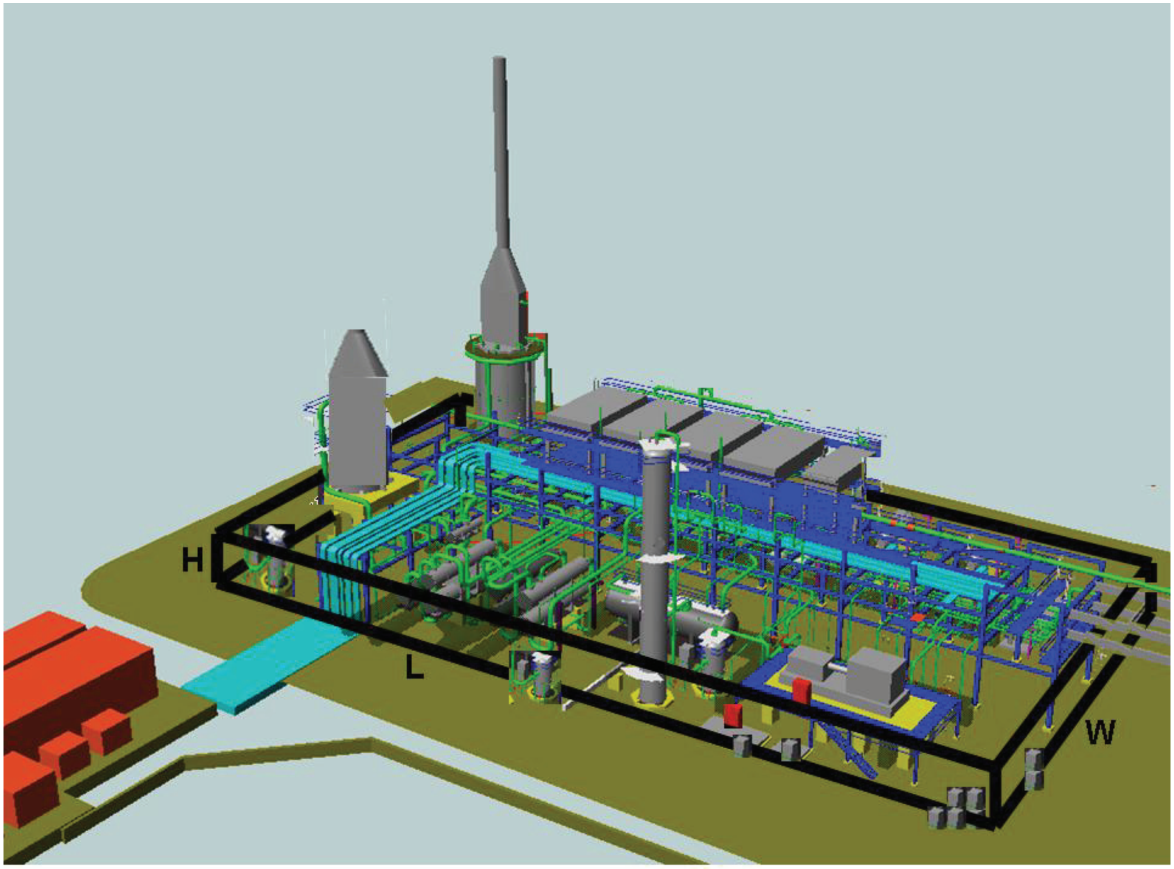

Figure B.1—Example No. 1 Hypothetical Process Unit

Sample calculation follows:

Average Length (L) = 200 ft;

Average Width (W) = 100 ft;

Average Height (H) = 15 ft.

Congested volume is: 200 × 100 × 15 = 300,000 ft^3

Step 2—Determine light wood trailer location distance away from edge of process unit using Figure 1 and Table A.1:

With the Simplified Method, i.e. without further Detailed Analysis, the trailer may only be located in Zone 3 at the following minimum distance per Figure 1 (use Table A.1 to obtain more accurate distance values using linear proration, if necessary):

At 300,000 ft the location distance is at least 1,273 ft away from edge of process unit.

B.2.2 EXAMPLE NO. 2: LOCATION OF PORTABLE BUILDINGS AWAY FROM MULTIPLE AREAS OF CONGESTION

Question: How are the Zones 1, 2, and 3 of Figure 1 identified for a plant with several operating units?

This example uses the fictitious site in Figure B.2 that includes three process units. A close up of each process unit is shown in Figure B.3. The three process units represent three Congested Volumes (CV-1, CV-2, and CV-3). Note that CV-2 and CV-3 contain flammable inventories but CV-1 does not. However, CV-1 will still be treated as a potential explosion site because there are units in the vicinity that have sufficient quantity to generate a flammable vapor cloud that can cover CV-1.

Answer: To identify Zones 1, 2, and 3, the following steps are taken, each of which is discussed in more detail below:

1. Identify areas of congestion
2. Determine congested volume of each area of congestion
3. Determine transition distances from Zone 3 to Zone 2 and from Zone 2 to Zone 1
4. Plot Zone transition distances from Step 3 on site plan
5. Identify the three Zones of Figure 1 for Locating Portable Buildings.

Step 1—Identify areas of congestion:

The site is evaluated to identify areas of congestion. These are identified in Figure B.2 as CV-1, CV-2, and CV-3 for this example. Each of these congested areas is surrounded by wide roadways where no congestion exists and can, therefore, be treated as separate congested areas.

Step 2—Determine the congested volume of each area of congestion:

Estimate the average congested volume of each area identified in Step 1 as described in Example No. 1 (Section B.2.1). For this example, the three congested areas have the dimensions shown in Figure B.3 and the congested volumes are summarized below:

- CV-1: 200,000 cubic ft
- CV-2: 300,000 cubic ft
- CV-3: 585,000 cubic ft

Step 3—Determine the transition distances from Zone 3 to Zone 2 and from Zone 2 to Zone 1:

Zone transition distances for each congested volume are determined using Table A.1 and are summarized in Table B.1. Note that CV-3 falls between two values in Table A.1 and can either be interpolated or the next highest distance value may be used (as done in this case.)

Table B.1—Zone Transition Distances

	Congested Volume	**Zone 3 to Zone 2 Transition**	**Zone 2 to Zone 1 Transition**
	cubic feet	feet	feet
CV-1	200,000	1,105	330
CV-2	300,000	1,273	361
CV-3	585,000	1,611	468

Step 4— Plot Zone transition distances from Step 3 on site plan:

The Zone 3 to Zone 2 transition distances from Step 3 are plotted on the site plan remembering that those distances are measured from the perimeters edges of the congested volumes. The corners of the rectangular congested volumes are rounded while maintaining the required standoff distances. Figure B.4 shows the distances plotted around each congested volume.

Figure B.5 shows the Zone 2 to Zone 1 transition distances from Step 3 plotted around each congested volume, as measured from the perimeters (edges) of each volume.

Step 5—Identify the three Zones of Figure 1 for locating portable buildings:

To identify the three zones for locating portable buildings connect the outermost zone transition distances in Figure B.4 and in Figure B.5. This is accomplished in Figure B.6 which shows the final zone boundaries. Figure B.6 illustrates that the left half of the plant is governed by CV-3 while the right half is governed by CV-2. CV-1, being a small explosion domain, plays a minimal role in defining the zone boundaries (and only for the Zone 2 to Zone 1 transition, see solid line), since the other two congested volumes are larger and impact wider areas. Hence, it is important to consider all congested volumes when determining the location of portable buildings, not just the closest congested volume.

Having determined the three zones of Figure 1 by following the five steps described above, portable buildings can now be located in accordance with Figure 1, with Table 1 and with the other more detailed guidelines provided in this recommended practice, and as summarized in Figure B.7.

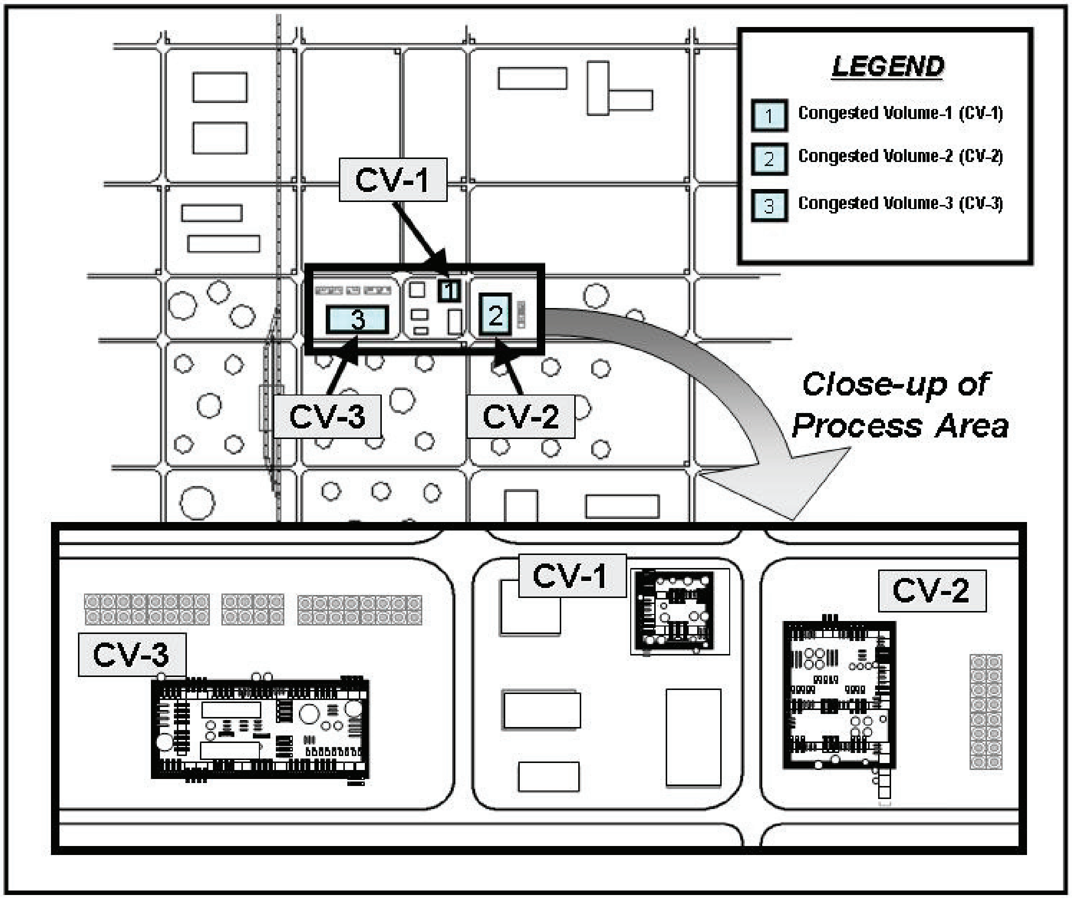

Figure B.2—Example No. 2 Site Layout

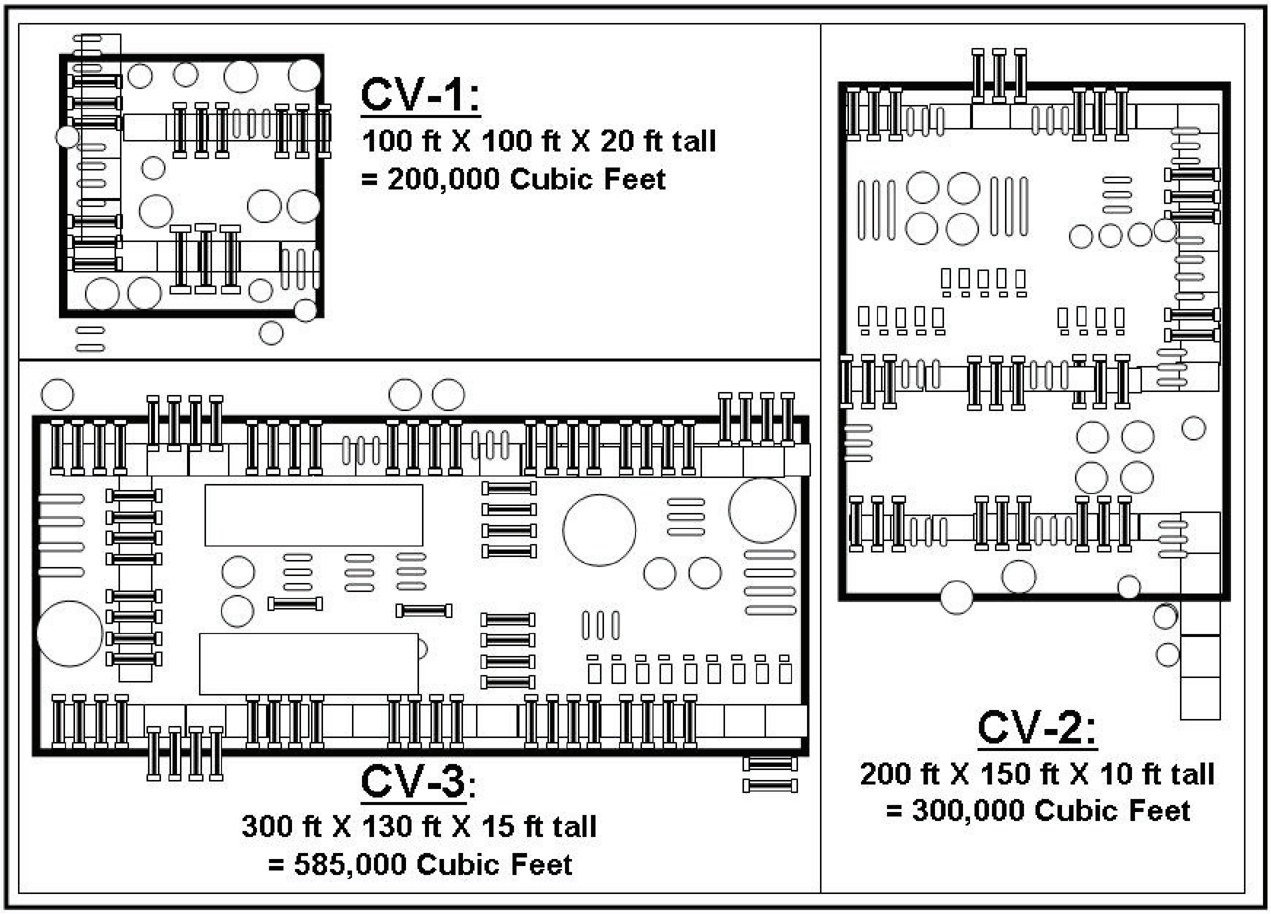

Figure B.3—Close up of Process Areas that Represent Congested Volumes

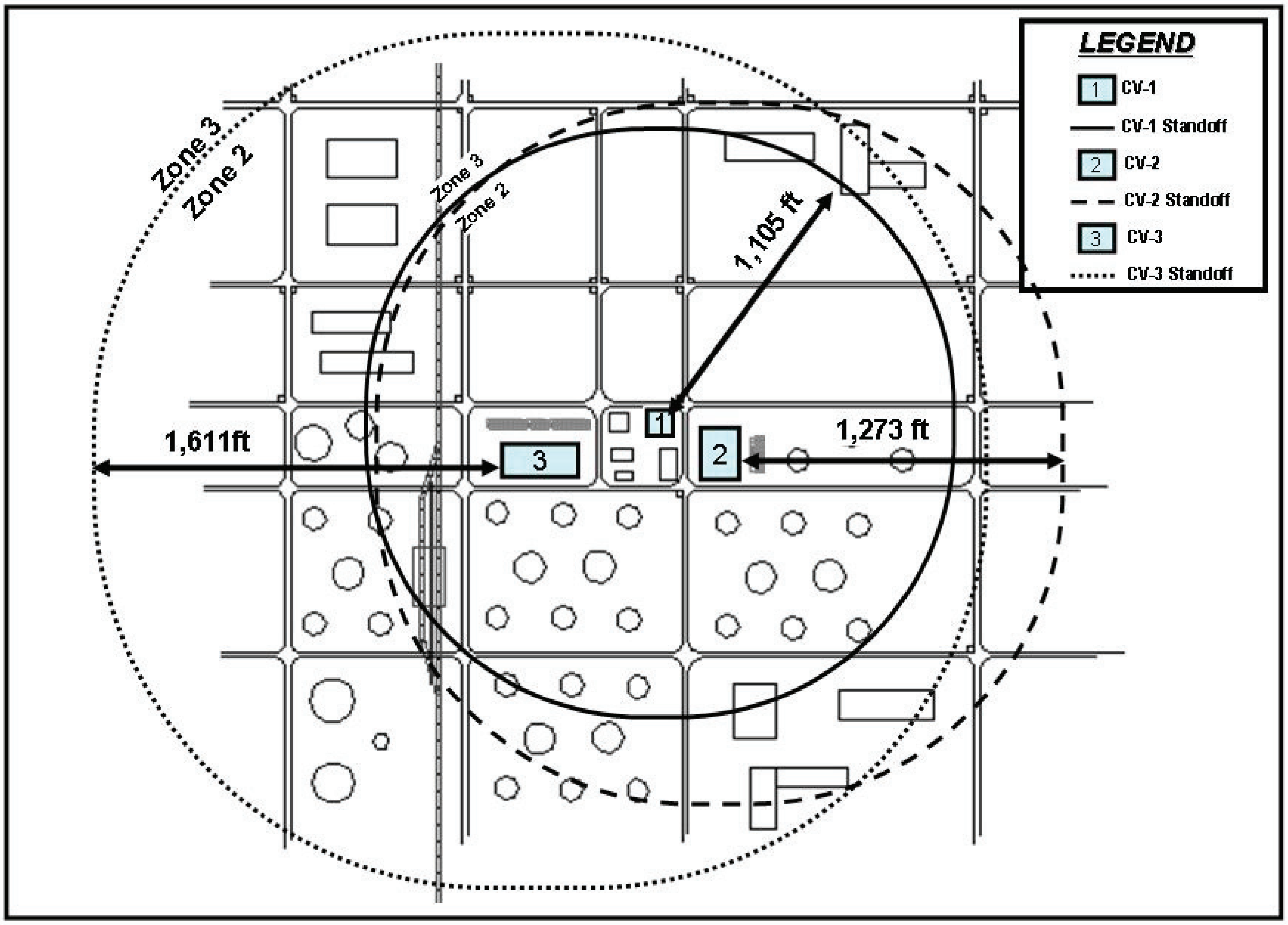

Figure B.4—Zone 3 to Zone 2 Transition Distances for Each Congested Volume

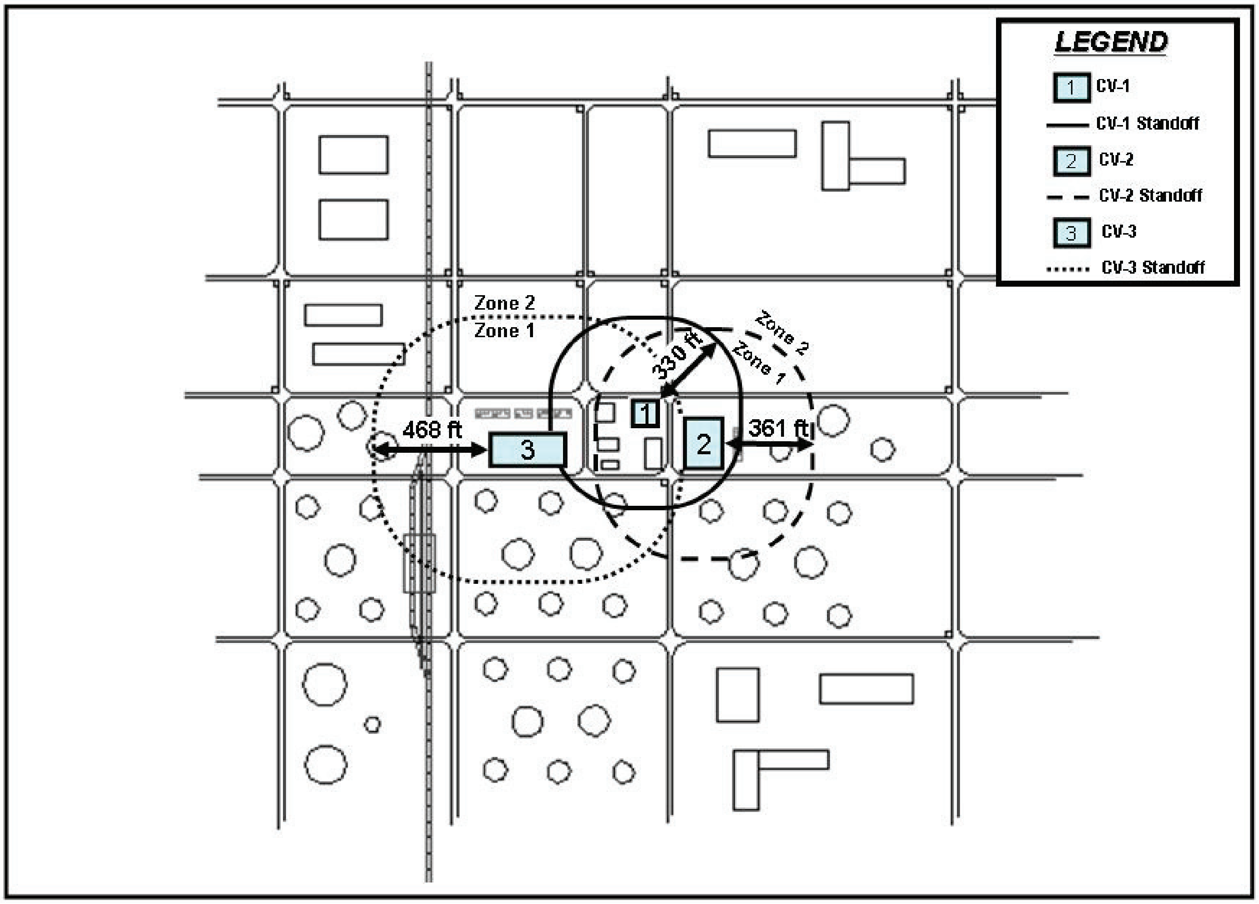

Figure B.5—Zone 2 to Zone 1 Transition Distances for Each Congested Volume

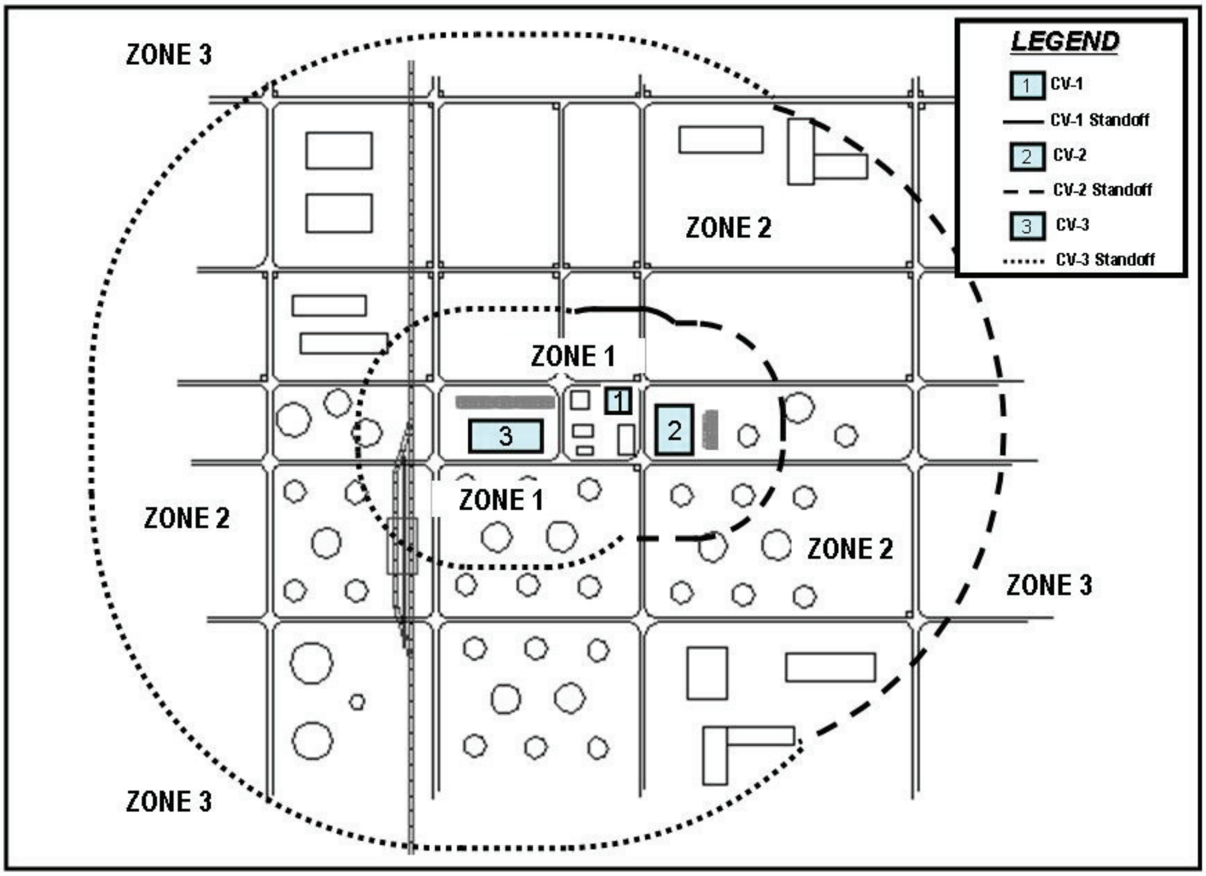

Figure B.6—Zones Created by Connecting the Outermost Transition Distances from Figures B.4 and B.5

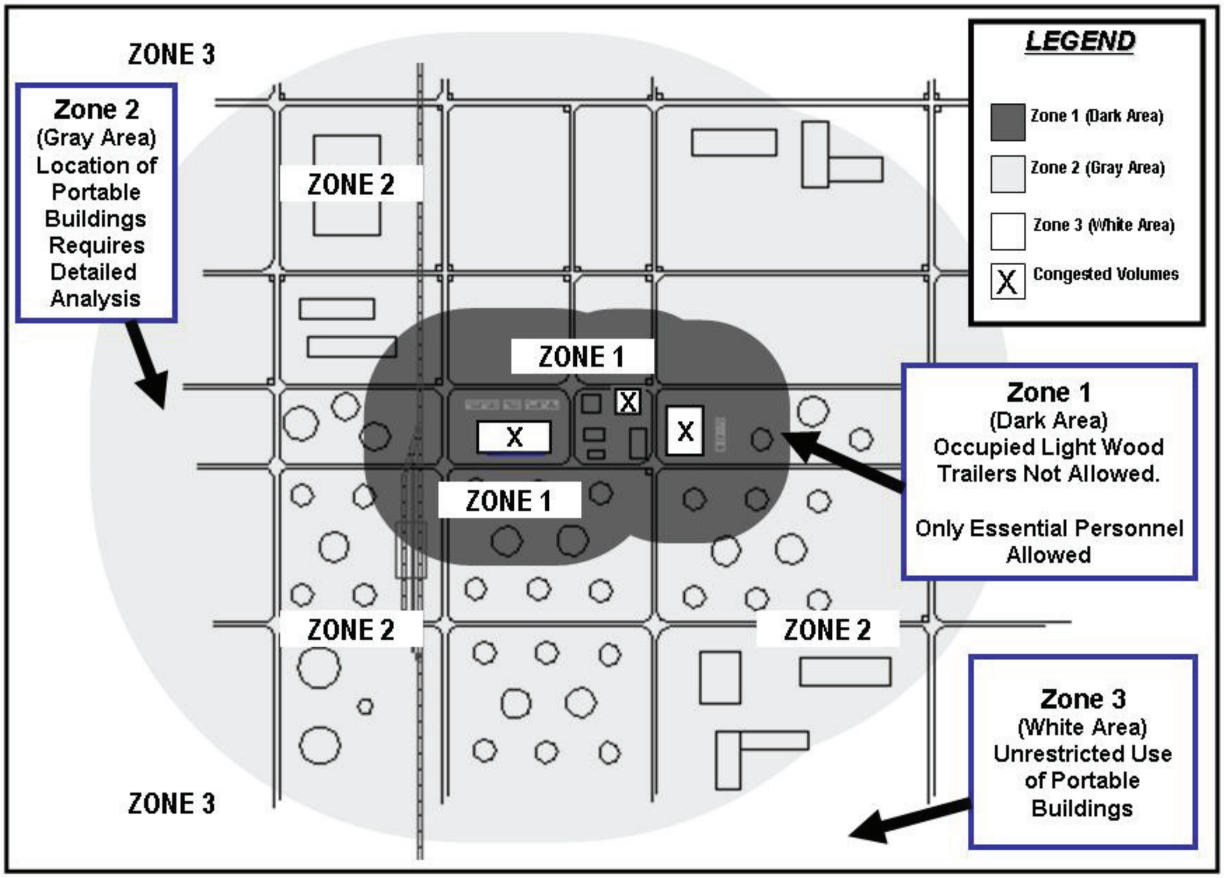

Figure B.7—Zones for Locating Occupied Portable Buildings

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