Compare and Contrast Non-DoD Explosion Safety Rules to DoD Practices related to Offsite Impacts

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Abstract

Defense related organizations are required to meet published explosives safety standards (DoD and NATO) related to siting of inhabited buildings and impact to off-site community. The government agencies such of Housing and Urban Development and the Environmental Protection Agency have published criteria that address refining and chemical industry impacts to the public. The American Petroleum Institute has facility siting recommended practices. Finally, there are published accounts of explosion accidents that quantify the explosion and document impacts to off-site.

This paper compares and contrasts the above mentioned explosives safety criteria and published incident data related to off-site impacts. Analysis of building damage is performed and discussed to further quantify potential impacts to buildings and occupants.

1. Criteria Document Review

1.1. DDESB 6055.9 and AFMAN91-201

The required separation between Potential Explosion Sites (PESs) and an installation boundary based on blast alone (i.e., not considering fragments, debris, thermal, ground shock, or chemical agents) for Hazard/Division (HD) 1.1 explosives is given as:

- NEW < 250,000 lb IBD = $40W^{1/3}$, corresponding to a Free-field Pressure = 1.2 psi
- NEW >= 250,000 lb IBD = $50W^{1/3}$, corresponding to a Free-field Pressure = 0.9 psi

Where W is the net explosive weight (NEW) in pounds.

This also applies as Inhabited Building Distance (IBD). DoD 6055.09 provides a qualitative description of the expected consequences at IBD for blast as:

- Unstrengthened buildings can be expected to sustain damage that may approximate 5 percent of their replacement cost.

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14. ABSTRACT
Defense related organizations are required to meet published explosives safety standards (DoD and NATO) related to siting of inhabited buildings and impact to off-site community. The government agencies such of Housing and Urban Development and the Environmental Protection Agency have published criteria that address refining and chemical industry impacts to the public. The American Petroleum Institute has facility siting recommended practices. Finally, there are published accounts of explosion accidents that quantify the explosion and document impacts to off-site. This paper compares and contrasts the above mentioned explosives safety criteria and published incident data related to off-site impacts. Analysis of building damage is performed and discussed to further quantify potential impacts to buildings and occupants.

15. SUBJECT TERMS

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- Personnel in buildings are provided a high degree of protection from death or serious injury; however, glass breakage and building debris may still cause some injuries.

AFMAN91-201 also calls for a baseline assessment for all existing occupied buildings of a sensitive nature (e.g. schools, off-base buildings, on-base buildings with significant public access such as a commissary, buildings with large amounts of glass panels, etc.) inside or near IBD arcs.

1.2. NATO AASTP-1

NATO specifies Inhabited Building Distances (IBD) as permissible exposures to conventional buildings at 5 kPA (0.73 psi) and states:

> *"These distances are the minimum permissible distances between PES and inhabited buildings or assembly places. The distances are intended to prevent serious structural damage by blast* <snip> *to ordinary types of inhabited buildings (23 cm <9 inch> brick or equivalent) or caravans and consequent death or serious injuries to their occupants.*

NATO states the expected blast effects to such ordinary buildings (23 cm brick or equivalent) to be:

> *1) Unstrengthened structures are likely to suffer only superficial damage.*
> *2) When large panes of glass are exposed so as to face the PES, 50 % or more breakages may occur.*
> *3) Injuries and fatalities are very unlikely as a direct result of the blast effects. Injuries that do occur will be caused principally by flying glass.*

NATO has exceptions that address at least three types of buildings of vulnerable construction that includes 1) multi-story buildings with curtain walls of glass or lightweight brittle material, 2) multi-story buildings with more that 50% glazed, and 3) buildings with non-load bearing curtain walls such as found in modern construction. For these situations NATO states that that IBD is "*not sufficiently large to prevent breakage of glass and other frangible panels or cladding used in the three types of buildings of vulnerable construction. This broken glass, cladding etc. can cause injury to occupants and those in the immediate vicinity of the buildings.* NATO requires

> *(a) Types 1 and 2: are considered to be of similar vulnerability and such buildings should normally be situated at distances not less than two times Inhabited Building Distances (i.e. > 44.4 Q1/3) (see paragraph 1.3.7.6.). However, such buildings, but probably not schools or hospitals, may be acceptable within the 44.4 Q1/3 distances, particularly if the population outside the building (on whom the displaced glass etc. would fall) is small or virtually nil. When vulnerable buildings have been allowed within the 44.4 Q1/3 distances on these grounds, it will be necessary to check at regular*

intervals that the original conditions (i.e. area around building free of people) have not changed.

(b) Type 3: presents a difficult problem and it is intended to cover the multiplicity of new construction types which have been introduced since the curtain wall concept was first thought of. Each such building has to be treated on its merits, the hazard assessed and an appropriate quantity-distance selected. It is likely, however, that this will be in the 44.4 Q1/3 region.

The free-field overpressure at 44.4 Q1/3 is 2.0 kPA or about 0.3 psi.

NATO goes on to state that because "*even superficial damage may in some instances be unacceptable, National Authorities may require siting at <44.4 Q1/3> for facilities of especially vulnerable construction or public importance."* Examples are given as follows:

1) Large facilities of special construction of importance including:
- Large factories of vulnerable construction.
- Multi-storey office or apartment buildings of vulnerable construction.
- Public buildings and edifices of major value.
- Large educational facilities of vulnerable construction.
- Large hospitals.
- Major traffic terminals (e.g. large railway stations, airports etc.)
- Major public utilities (e.g. gas, water, electricity works).

2) Facilities of vulnerable construction used for mass meetings:
- Assembly halls and fairs.
- Exhibition areas.
- Sports stadiums.
3) Built-up areas which are both large and densely developed.

1.3. Housing and Urban Development (HUD)

HUD published "Siting of HUD-assisted Projects near Hazardous Facilities (HUD-1060-CP (Sept. 1996) which handle petroleum products or chemicals of an explosive or flammable nature. That document includes acceptable separation distances from explosive and flammable hazards. HUD selected a blast criterion of 0.5 psi free-field overpressure, indicates it is bases on a "wooden framed structure and level topography", and states:

"Research conducted by military services indicated that 0.5 psi is an acceptable level of blast overpressure for both people and buildings. At this level, people will probably not be injured (especially if located inside a building) and no major structural damage will result to buildings, with the exception of broken windows."

1.4. Environmental Protection Agency (EPA) Risk Management Plan (RMP) Rule

The EPA-RMP applies to facilities that manufacture, use, or store toxic and flammable substances that have the potential to cause serious harm to the public and the environment. Included are facilities such as refineries or chemical plants that can experience explosions. In Chapter 4 of the EPA-RMP, it is stated that a 1 psi free-field overpressure can be used as the endpoint for vapor cloud explosion analysis. It is stated that:

> *"The endpoint of 1 psi is intended to be conservative and protective; it does not define a level at which severe injuries or death would be commonly expected. "*
>
> *"An overpressure of 1 psi is unlikely to have serious direct effects on people; this overpressure may cause property damage such as partial demolition of houses, which can result in injuries to people, and shattering of glass windows, which may cause skin laceration from flying glass."*

1.5. API 753

API 753 was developed by the American Petroleum Institute (API) and provides recommended practices for siting of portable buildings at refinery, chemical plants, and similar facilities.

API 753 provides information for "Light Wood Trailers" defined as "*a portable building with a wall design consisting of "2X4" studs (nominal 1.5 inch by 3.5 inch) with a thin outer skin. This is generally representative of the weakest constructed portable building used in the processing industries."*

API 753 provides the following related to Free-field pressure

- 0.6 psi or less:
    - Trailer is damaged in localized areas.
    - 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 to 0.9 psi:
    - Trailer damage is widespread, but structural collapse is not expected.
    - Wall components facing the blast sustain major damage and may fail
    - Window breakage and falling overhead items are expected.

API 753 also provides portable building siting requirements and restrictions in the form of three zones shown in Figure 1. The zone boundaries are related to "congested volume" which is directly related to explosion energy term for vapor cloud explosions

(see API 753 Appendix for information regarding the influence of congestion on vapor cloud explosions). Restrictions related to the three zones are provided in Table 1. In addition, the following are some of the risk reduction measures are recommended:

- *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);*

In general, API 753 establishes there zones. The closest to explosion sources (Zone 1) excludes non-essential personnel and/or the use of portable buildings of vulnerable construction (i.e., light wood trailers). Zone 3, the farthest from explosion sources, has no restrictions on personnel or types of buildings; however, should address the risk reduction measures above that includes addressing window hazards. Zone 2 is between these two extremes. Light wood trailers can be sited there but requires a detailed analysis to justify such placement

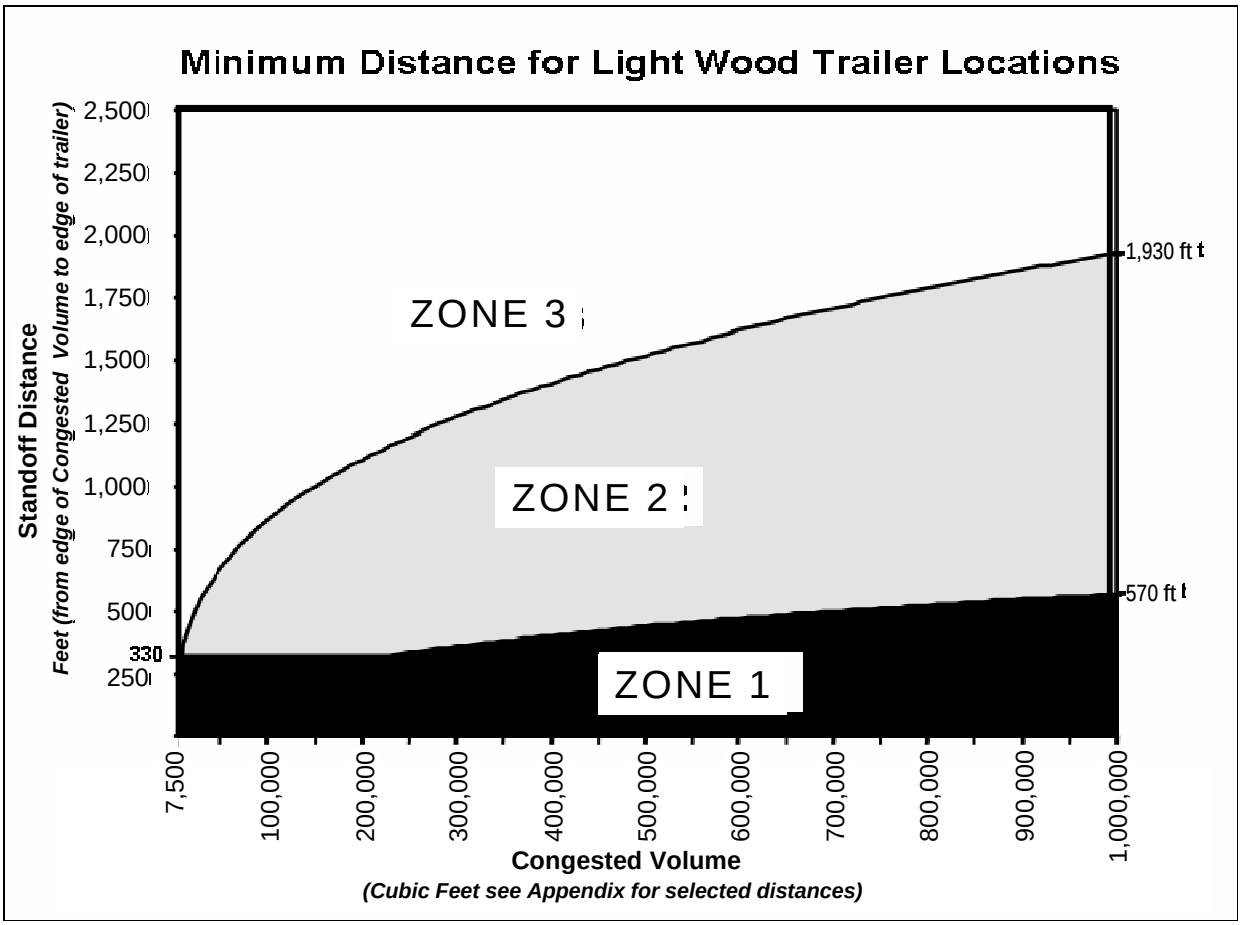


Figure 1. API 753 Zoning Map

Table 1. API 753 Zone Restrictions

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

1.6. Discussion

Table 2 provides a summary of criteria quoted in the sections above. Note that DoD criteria uses overpressure endpoints at the high end of those included, with the caveat that there is a recommendation to evaluate "sensitive" buildings (as defined by AFMAN91-201) when located near IBD.

It is noted that HUD, EPA, and API 753 all relate to siting near petroleum and chemical plants. The explosion hazards there includes such events as vapor cloud explosions, boiling liquid expanding vapor explosions (BLEVEs), run-away chemical reactions, and pressure vessel bursts. Such events often (but not always) result in much longer duration

loads than do high explosive events typical of DoD accidents. Hence, this may explain why a lower overpressure value is adopted. The exception is NATO, which has adopted lower endpoints and would involve high explosive events.

Table 2. Criteria Summary

Criteria	Building Type	End Point
DDESB 6055.9 and AFMAN91-201	All Buildings	0.9 to 1.2 psi
	Sensitive Buildings	Assessment Required when near IBD
NATO AASTP-1	Brick buildings	0.73 pis
	Sensitive Buildings	0.3 pis
HUD-1060-CP	HUD wood-frame housing	0.5 psi
EPA-RMP	All buildings	1.0 psi
API 753	Light Wood Trailers	0.6 to 0.9 psi

2. Analysis

Limited analysis is offered here to demonstrate the vulnerability of some building and component types. A typical wood framed house with wood siding was analyzed for stud wall damage. In addition a typical annealed glass window breakage was evaluated.

2.1. Wood Stud Wall

The wall analysis was conducted using the methodology developed by the U. S. Army Corps of Engineers Protective Design Center (PDC) [1]. That methodology was used to develop Pressure-impulse (P-i) diagrams that can be compared to blast loads. The PDC report describes structural damage in terms of "Superficial:, "Moderate", "Heavy" and "Hazardous, which are bounded in P-i diagrams by response levels "B1, B2, B3, and B4" respectively. Table 3 summarizes these values and relates to damage level from the PDC methodology. Table 4 further describes these damage levels for wood framed homes with terminology developed by ABS Consulting. That terminology was selected to describe results in damage-related terms rather than focusing on repair/replacement used by the PDC (2006) in Table 3.

[1] USACE PDC technical report PDC-TR 06-08, Single Degree of Freedom Response limits for Antiterrorism Design. 20 October 2006.

Table 3. Component Damage Description

Response Limit Range	Component Damage Level	Damage Description
<B1	Superficial	Component has no visible permanent damage
B1 to B2	Moderate	Component has some permanent deflection. It is generally repairable, if necessary, although replacement may be more economical and aesthetic
B2 to B3	Heavy	Component has not failed, but it has significant permanent deflections causing it to be unrepairable
B3 to B4	Hazardous	Component has failed, and debris velocities range from insignificant to very significant

Table 4. Residential Wood Construction Damage Description

Response Limit Range	Component Damage Level	Wood Wall Construction Damage Description
<B1	Superficial	Non-structural damage only
B1 to B2	Moderate	Residential wood wall stud cracking
B2 to B3	Heavy	Widespread residential wood wall stud breakage
B3 to B4	Hazardous	Residential wood wall construction failure
Note: Damage description correlated to PDC Damage Descriptions		

Experience gained from past explosion events indicates that one of the most sensitive structural components of a typical wood framed home (i.e., break at lowest blast load) are the wood studs on walls facing the blast. Roof joist breakage can occur at or about the same blast level and would be expected to accompany wall failures. The analysis correlated structural damage to a typical residential wood stud wall which was based on 2X4 stud construction spanning 8 ft and spaced at 16 inches on center. While typical wood connections do not develop moment resistance, it was assumed that a partial moment carrying connection could be developed by the attachment between studs, siding, and the base-plate member at the floor level. Thus a fixed-pinned element was modeled to develop the P-I diagrams, which are presented in Figure 2, with the PDC (2006) Component Damage Level regions of B1, B2, and B3 identified.

Figure 2 also includes collections of P-i points for a range of NEWs at K40, K80, and K120, which correspond to IBD, 2 X IBD, and 3 X IBD respectively. (These P-i points are for normal reflected loading that would be experienced on walls facing the blast; hence are higher than free field loads.) It can be seen that at IBD (K40) even low NEWs (10^2 to 10^3 lbs) can cause damage while large NEWs (over 10^3 lbs) can cause stud wall failures on walls facing the blast (reflected loaded walls). At K80, only large NEWs (10^5 to 10^6) are capable of reflected wall failures. At K120 no failure are evident. This

analysis would suggest K80 may be a better candidate when considering distance to neighborhood housing of wood construction.

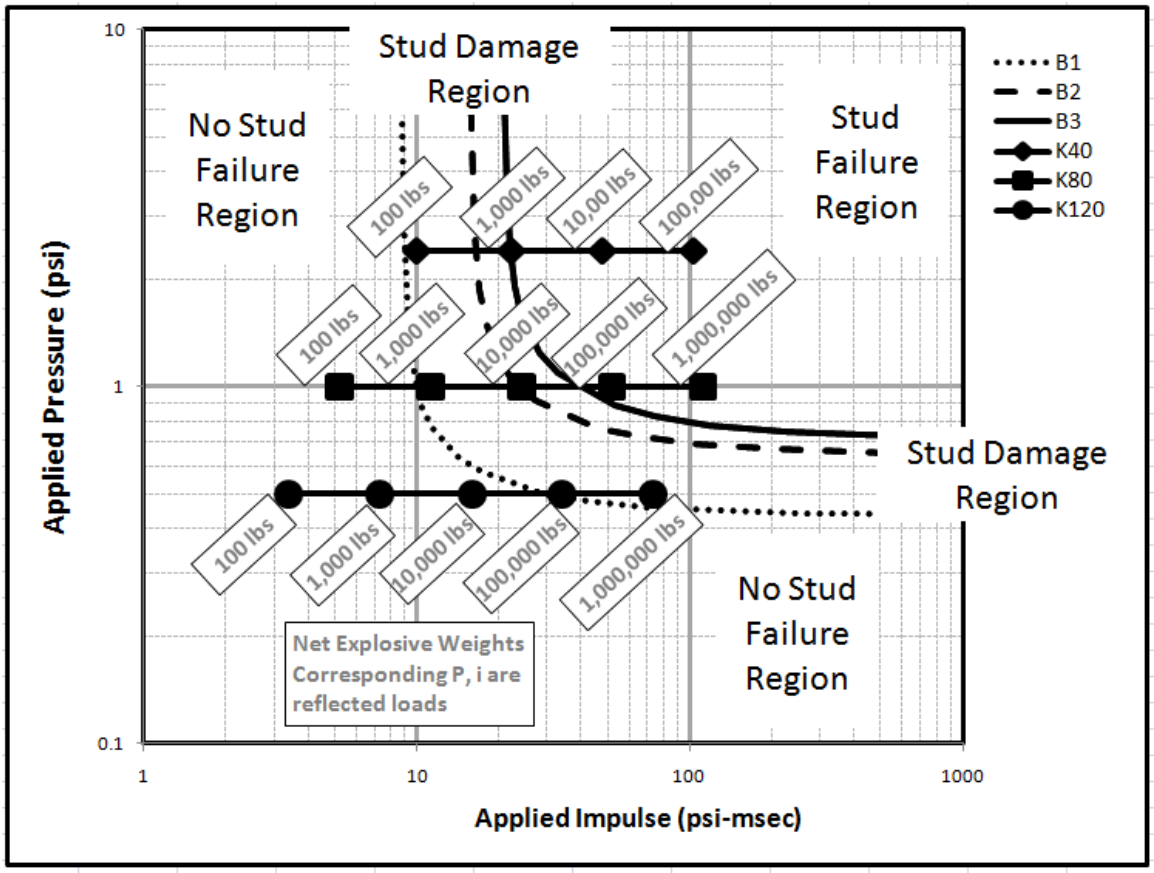


Figure 2. Residential Wood Stud Wall Free-Field P-i Diagram

2.2. Non-Structural Building Damage

Published technical information related to two significant past explosion events offer empirical-based damage models related to non-structural far-field explosion consequences to the community. Reed, Pape and Minor (1963) studied the San Antonio Medina Air Force Base explosion of November 13, 1963[2] and Reed and Zehrt (1998) studied the Pacific Engineering Company (PEPCON) explosion in Henderson, NV on May 4, 1988[3] both involved large explosions that impacted nearby communities and resulted in a large number of insurance claims, in particular to homes. Much of these claims occurred in the far-field and at relatively low blast pressure, consequently, insurance underwriters paid for engineering studies to help validate the claims. That work resulted in damage models to predict damage to single family residences and window breakage.

[2] Reed, J. W., Pape, B. J., "Evaluation of Window Pane Damage Intensity in San Antonio Resulting from Medina Facility Explosion in November 13, 1963", Sandia Laboratory and Southwest Research Institute.
[3] Reed, Jack; Zehrt, William. "Comparison of Actual Building Damage and Repair Costs from the PEPCON Explosion to Inhabited Building Distance Expectations" 1998.

Those damage models were selected because of the following

- They were developed from thorough engineering evaluations
- They are specific to community impact
- That work was widely published in several conference and symposia settings
- They included a large sample database in the analysis
- They address overpressure ranges specifically applicable to this paper

The Medina explosion caused non-structural damage covering several miles inside the city of San Antonio and the related work resulted in an empirical model of window breakage. The PEPCON explosion analysis included a large sample of residences that were damaged and resulted in an empirical model of home damage in terms of replacement cost. Further, results from the investigation of damage claims to the PEPCON explosion confirmed the Medina explosion model for window breakage.

2.2.1. Non-Structural Damage to Typical Homes

Reed and Zehrt (1998) were able to produce a correlation between free field overpressure and single-family residence damage as a percentage of the value of that residence. This relationship is presented in Figure 3. The damage estimates are normalized as a percentage of replacement costs; hence, there is no need to adjust the model for inflation, assuming that the percentages of replacement values are still applicable today. Non-structural damage to residences were predicted using the model in Figure 3 and Table 5, provides overpressure levels, damage descriptions and the approximate percentage of replacement values for low and intermediate blast overpressures.

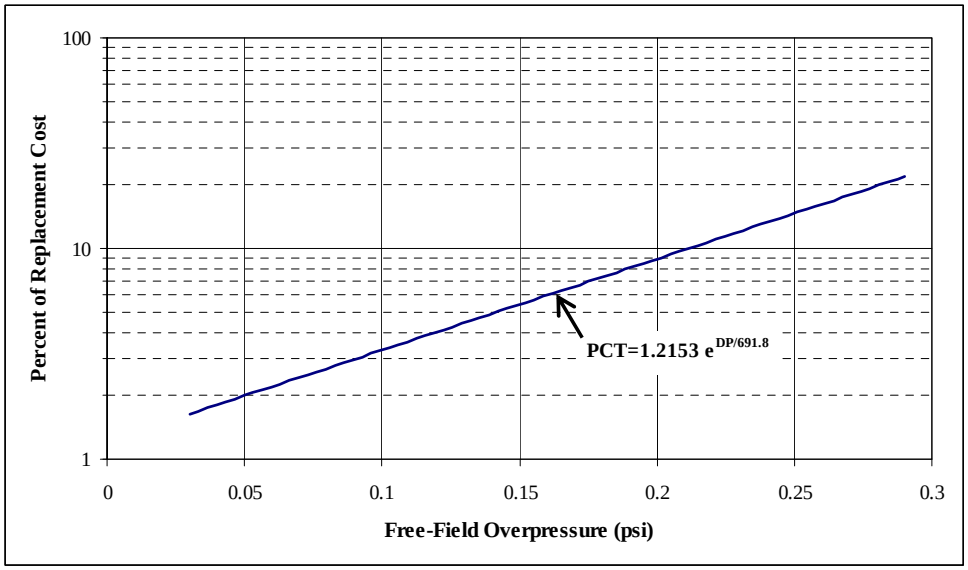


Figure 3. Total Single Family Residence Damage as a Percentage of Replacement Cost

Table 5. Approximate Off Site Damage as a Function of Free-Field Overpressure

Free Field Overpressure**	Non-Structural Damage to Single Family Residences as a function of value. Damage may include broken windows, damaged garage doors, entry doors, drywall damage and damage to soffits and siding.
0.03 psi	2% of Value
0.15 psi	5% of Value
0.20 psi	10% of Value
0.25 psi	15% of Value

As can be seen, non-structural damage alone can result in damage that is a relatively large percent of home value well beyond K40-50 (1.2 to 0.9 psi).

2.3. Non-Structural Damage to Typical Public, Commercial and Retail Buildings

Reed and Zehrt (1998) did not include a published correlation between free field overpressure and damage in terms of financial loss for typical public, commercial, and/or retail buildings. Use of the relationship by Reed and Zehrt (1998) may under-predict damage to typical public, commercial, and/or retail buildings for at least the following reasons:

- Building contents may include expensive items, inventories, and/or business-sensitive material that if lost result in significant business impact. These may be vulnerable to weather if the exterior envelope is compromised.
- Work loss time during clean up and repair is not addressed
- Employee injury claims not addressed
- Public, commercial, and/or retail buildings can include more significant glass usage than typical homes and, in particular, large windows and/or store fronts that have been shown by past incidents to be particularly vulnerable to blast.

Hence, use of the relationship described above concerning damage as a percentage of replacement cost can be expected to a minimum expected impact on businesses related to non-structural damage.

Because public, commercial, and/or retail buildings can include large windows and/or store fronts, an evaluation of window breakage is of value. Reed, Pape and Minor (1963) contains the following formulation for estimating window breakage, which was utilized in this report.

$$D = 3.71x10^{-3} A^{1.22} \Delta p^{2.78} \qquad \text{Equation 1}$$

Where: D is damage intensity in broken panes per 1000 panes of glass
A is the pane area in square feet
Δp is the free field overpressure in millibars

The above equation was used to estimate window breakage per 1000 panes for an explosion involving 1,000lbs TNT. This was based on a 42X36 inch window and the result plotted in Figure 4. We see that significant window breakage will occur out past two miles.

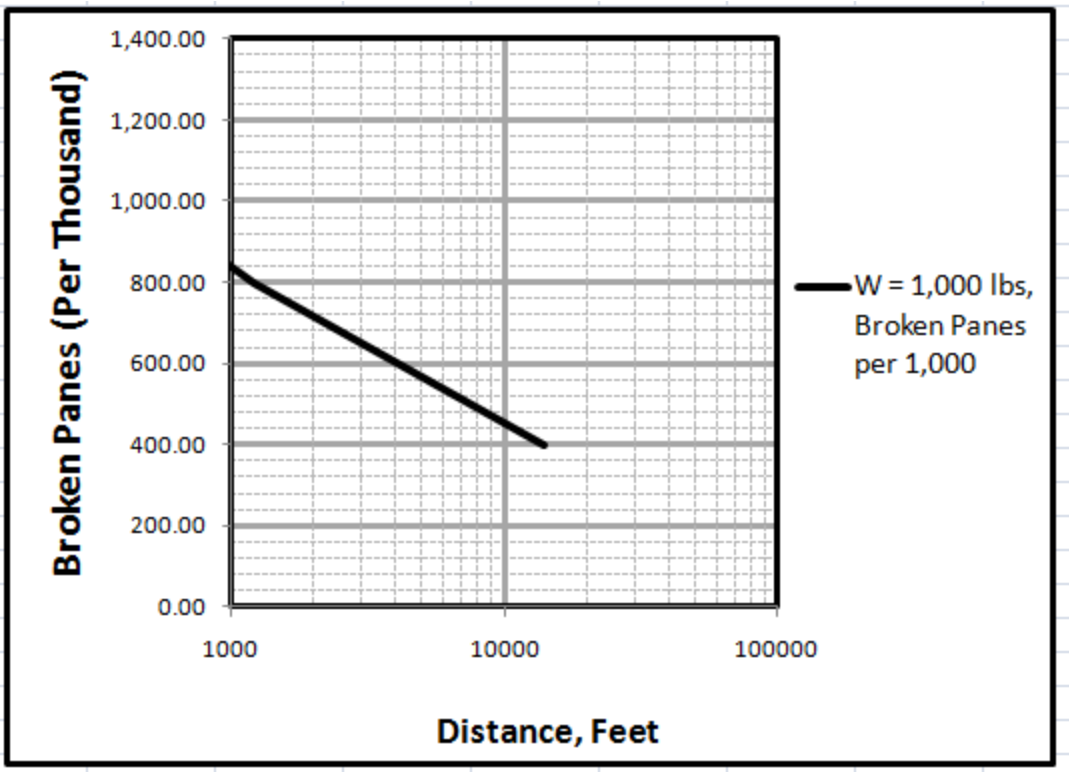


Figure 4. Window Breakage with Distance (per 1000) for 1,000 LB_{TNT}

3. Recommendations

The following recommendations are provided for DoD siting criteria, particularly when considering off-site impacts.

- More clearly discuss the potential hazards related to different types of construction. In particular modern construction and those most vulnerable to overpressure.
- Provide clear requirements for siting different types of construction, such as through a tiered K-Factor (i.e., higher K factors for weaker construction types.) The API 753 uses a system with 3 zones. A similar approach may work for DoD.
- Provide requirements for siting of buildings based on population and the potential for congregation of personnel.
- Consider separate criteria for residential areas.
- On-site, distinguish between buildings housing personnel necessary to directly support explosive mission and those housing other support personnel

Compare and Contrast Non-DoD Explosion Safety Rules to DoD Practices - Related to Off-site Impacts

Presenter and Author

Mark Whitney

Introduction

- DoD Explosive Siting Criteria
  - DDESB 6055.9
  - AFMAN91-201
- Several Non-DoD published criteria for blast overpressure
  - NATO - AASTP-1
  - HUD
  - EPA-RMP
  - API
- How do they compare with DoD when it comes to
  - Facility boundaries
  - Offsite Impacts
- Paper restricted to blast effects (not missiles, heat flux, etc.)
- Paper prompted by recent explosion events

DoD 6055.9 and AFMAN91-201

- Blast Criteria
  - Inhabited Buildings and Property Boundaries – K40
    - 1.2 psi (small explosions)
    - 0.9 psi (large explosions)
- Impact
  - *"Unstrengthened buildings can be expected to sustain damage that may approximate 5 percent of their replacement cost."*
  - *"Occupants of exposed, unstrengthened structures may be injured by secondary blast effects, such as falling building debris."*
- AFMAN91-201 also calls for a "baseline assessment" for all existing occupied buildings of a "Sensitive Nature" (e.g. schools, off-base buildings, on-base buildings with significant public access such as a commissary, buildings with large amounts of glass panels, etc.) inside or near IBD arcs.

NATO AASTP-1

- NATO IBD corresponds to 0.72 psi and states:
  - *"The distances are intended to prevent serious structural damage by blast, flame or projections to ordinary types of inhabited buildings (23 cm brick or equivalent) or caravans and consequent death or serious injuries to their occupants."*
  - 23 cm is approximately 9-inch
- NATO States the expected blast effects of such brick buildings to be:
  - *1) Unstrengthened structures are likely to suffer only superficial damage.*
  - *2) When large panes of glass are exposed so as to face the PES, 50 % or more breakages may occur.*
  - *3) Injuries and fatalities are very unlikely as a direct result of the blast effects. Injuries that do occur will be caused principally by flying glass.*

NATO AASTP-1, continued

- NATO has exceptions that address three types of buildings of vulnerable construction
  - 1) multi-story buildings with curtain walls of glass or lightweight brittle material
  - 2) multi-story buildings with more that 50% glazed
  - 3) buildings with non-load bearing curtain walls such as found in modern construction.
- For these situations NATO states that that IBD is
  - "*not sufficiently large to prevent breakage of glass and other frangible panels or cladding used in the three types of buildings of vulnerable construction. This broken glass, cladding etc. can cause injury to occupants and those in the immediate vicinity of the buildings.*
- NATO requires types 1) and 2) to be sited at 2 X IBD (about 0.3 psi)
- NATO requires type 3) to be evaluated but expects similar siting

NATO AASTP-1, continued

- NATO goes on to state that because "*even superficial damage may in some instances be unacceptable, <…> siting at <44.4 Q1/3> for facilities of especially vulnerable construction or public importance.*"

1) Large facilities of special construction of importance including:

- *Large factories of vulnerable construction.*
- *Multi-storey office or apartment buildings of vulnerable construction.*
- *Public buildings and edifices of major value.*
- *Large educational facilities of vulnerable construction.*
- *Large hospitals.*

2) Facilities of vulnerable construction used for mass meetings:

- *Assembly halls and fairs.*
- *Exhibition areas.*
- *Sports stadiums.*

3) Built-up areas which are both large and densely developed

HUD-1060-CP

- Blast Criterion
  - 0.5 psi free-field overpressure
- Impact
  - *"Research conducted by military services indicated that 0.5 psi is an acceptable level of blast overpressure for both people and buildings. At this level, people will probably not be injured (especially if located inside a building) and no major structural damage will result to buildings, with the exception of broken windows."*

EPA-RMP

- Blast Criterion
  - 1.0 psi
- Impact
  - *"The endpoint of 1 psi is intended to be conservative and protective; it does not define a level at which severe injuries or death would be commonly expected. "*
  - *"An overpressure of 1 psi is unlikely to have serious direct effects on people; this overpressure may cause property damage such as partial demolition of houses, which can result in injuries to people, and shattering of glass windows, which may cause skin laceration from flying glass."*

API RP-752 – Permanent Buildings

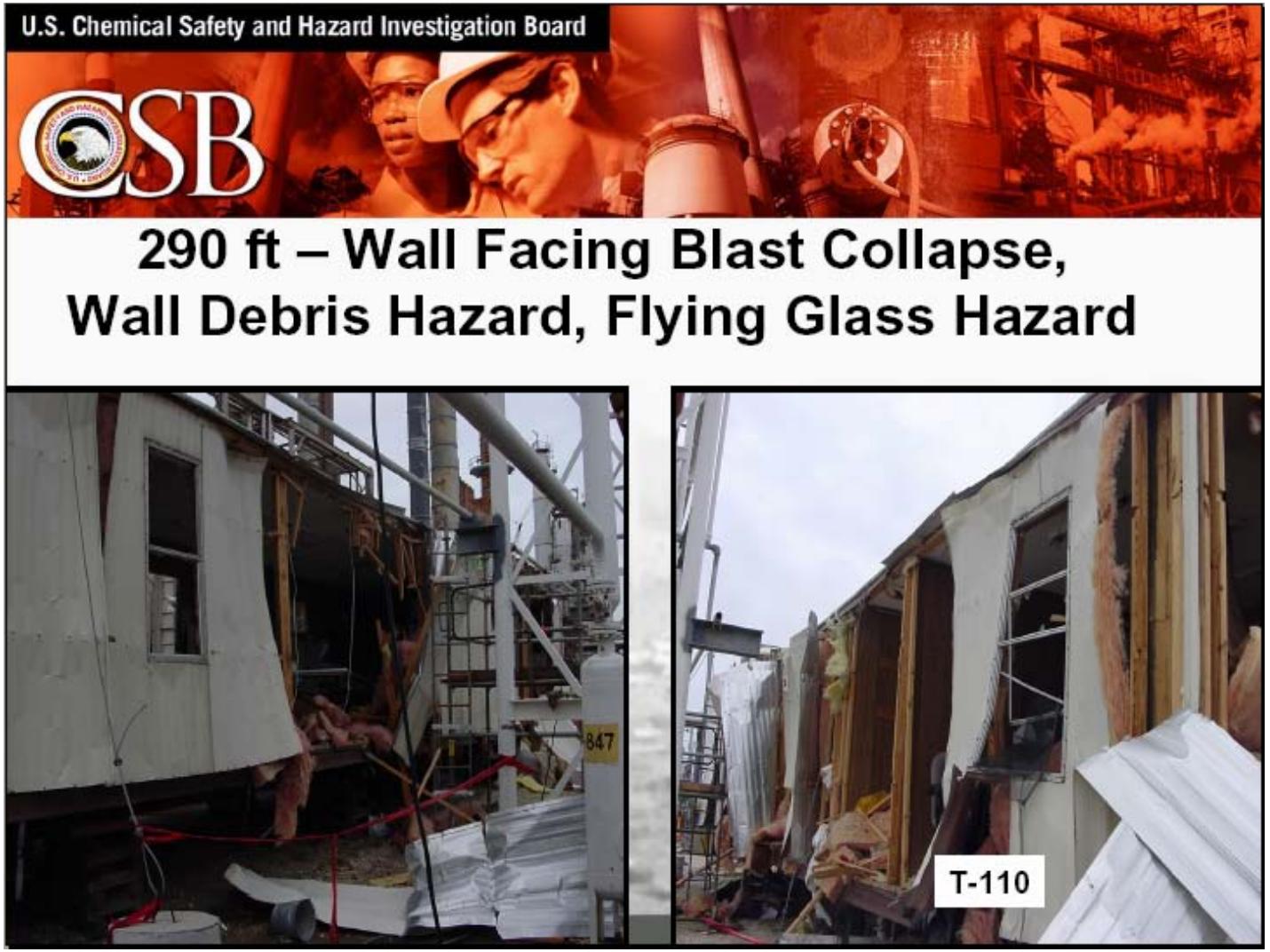
- American Petroleum Institute
  - Recommended Practice
  - Refineries, petrochemical and chemical operations
  - Vapor cloud explosions
- Requires Building Assessment for Blast Hazards
  - All buildings on site must be evaluated
  - No pressure endpoint provided
  - Specific warnings about brittle construction

API 753 – Temporary Buildings

- API 753 provides information for “Light Wood Trailers”
  - *“a portable building with a wall design consisting of “2X4” studs (nominal 1.5 inch by 3.5 inch) with a thin outer skin. This is generally representative of the weakest constructed portable building used in the processing industries.”*
- 0.6 psi or less:
  - Trailer is damaged in localized areas.
  - 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 to 0.9 psi:
  - Trailer damage is widespread, but structural collapse is not expected.
  - Wall components facing the blast sustain major damage and may fail
  - Window breakage and falling overhead items are expected.

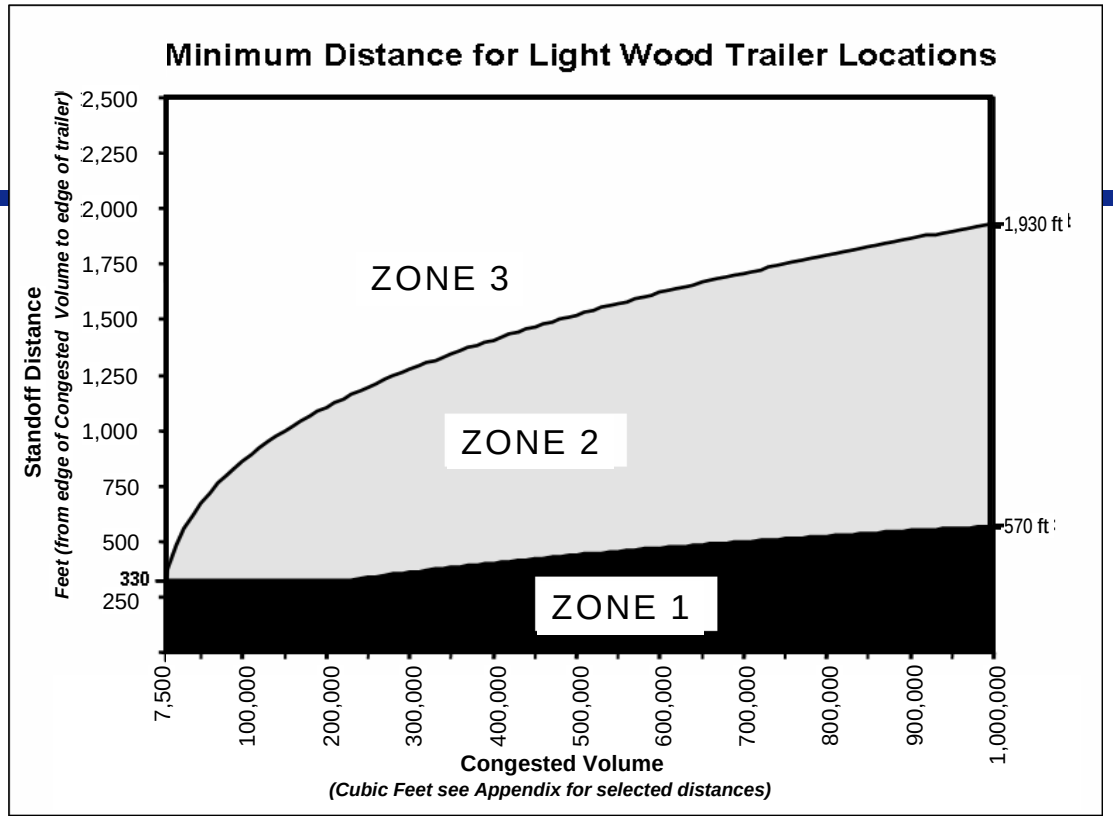
Typical Damage to Light Wood Trailers exposed up to 0.6 psi

Typical Damage to Light Wood Trailers exposed up to 0.9 psi (Trailer was Unoccupied)



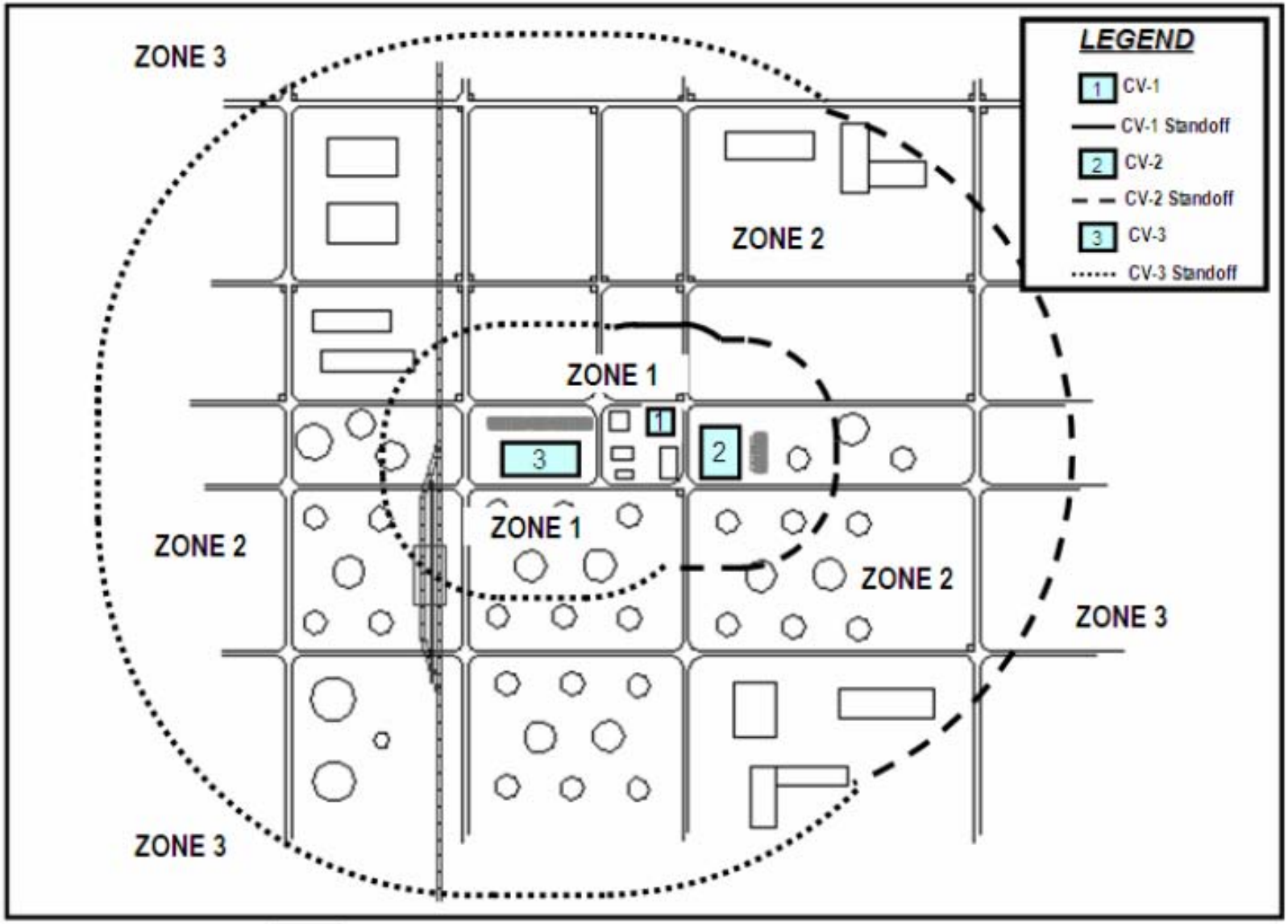
API 753, continued

- Uses zoning approach
- Addresses
  - Building type
  - Occupancy



¤	Light·Wood·Trailers¤	Portable·Building·other·than·Light·Trailers¤	Occupancy·Restrictions¤
Zone·1¤	Not·Allowed¤	¤	House·only·Essential·Personnel¤
Zone·2¤	Detailed·Analysis·Required¤	Detailed·Analysis·Required¤	No·Restrictions¤
Zone·3¤	No·Restrictions¤	No·Restrictions¤	No·Restrictions¤

Petrochem Facility with Zones per API 753



Discussion

- DoD endpoints at high end of scale
- NATO for specifically address different building constructions
- HUD, EPA, and API for industrial explosions which tend to be longer duration events. Can compare with K-50

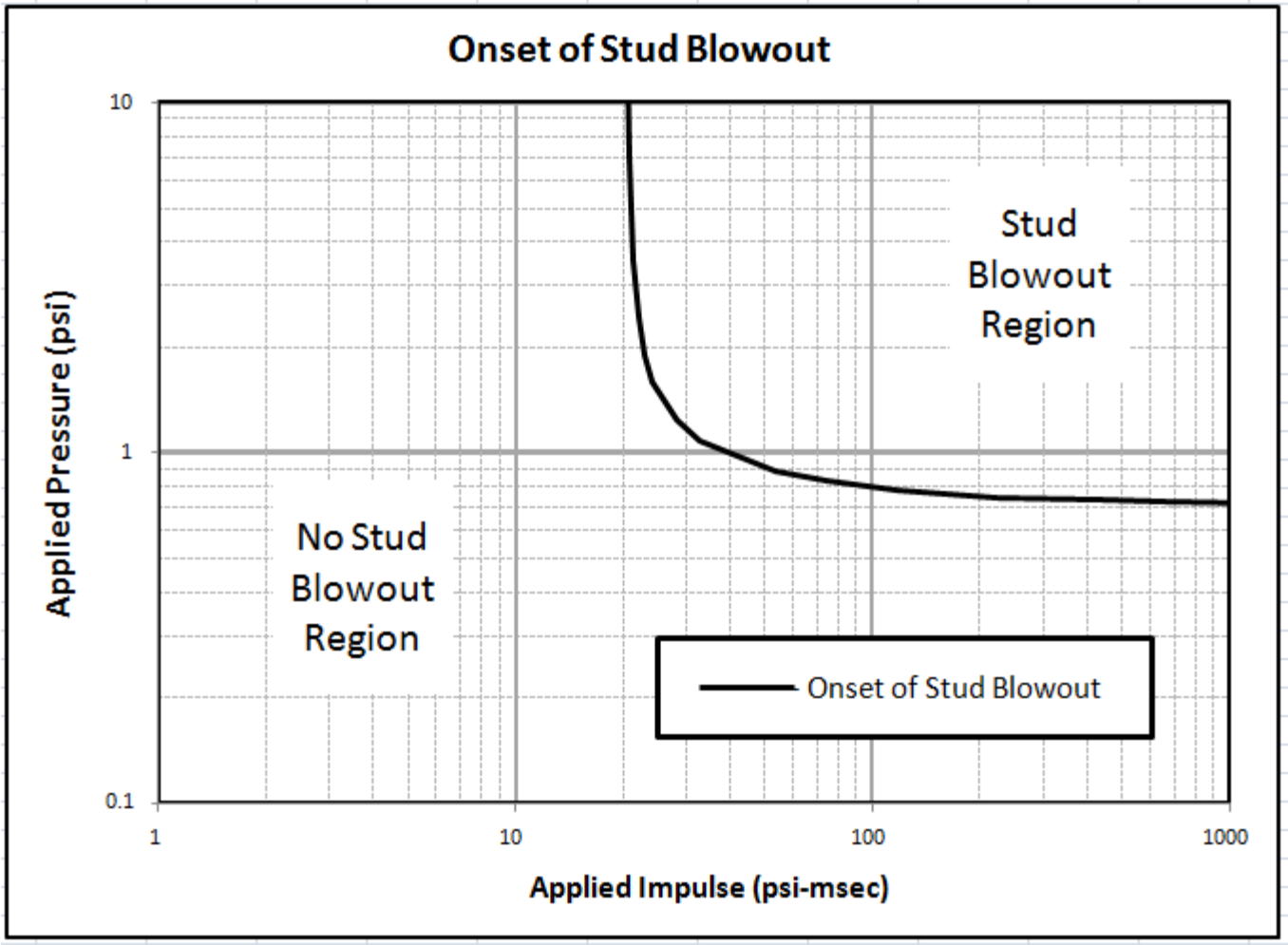
Criteria	Building Type	End Point
DDESB 6055.9 and AFMAN91-201	All Buildings	0.9 to 1.2 psi
	Sensitive Buildings	Assessment Required when near IBD
NATO AASTP-1	Brick buildings	0.73 pis
	Sensitive Buildings	0.3 pis
HUD-1060-CP	HUD wood-frame housing	0.5 psi
EPA-RMP	All buildings	1.0 psi
API 753	Light Wood Trailers	0.6 to 0.9 psi

Analysis

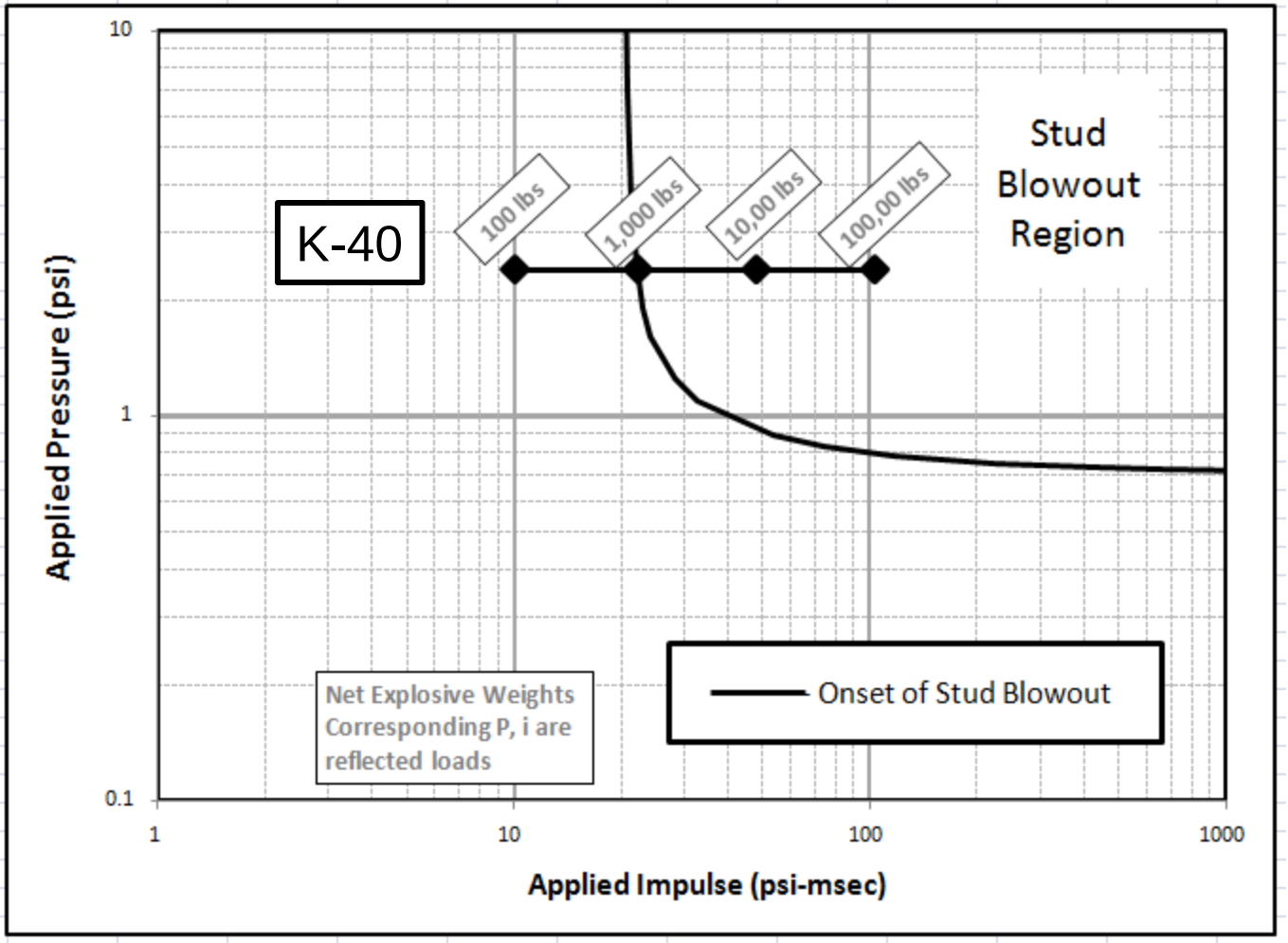
Analysis

- Analyzed typical house
  - wood stud wall with wood siding
  - SBEDS – P-i diagram approach
- Compared with various K-factors
- Reflected loading

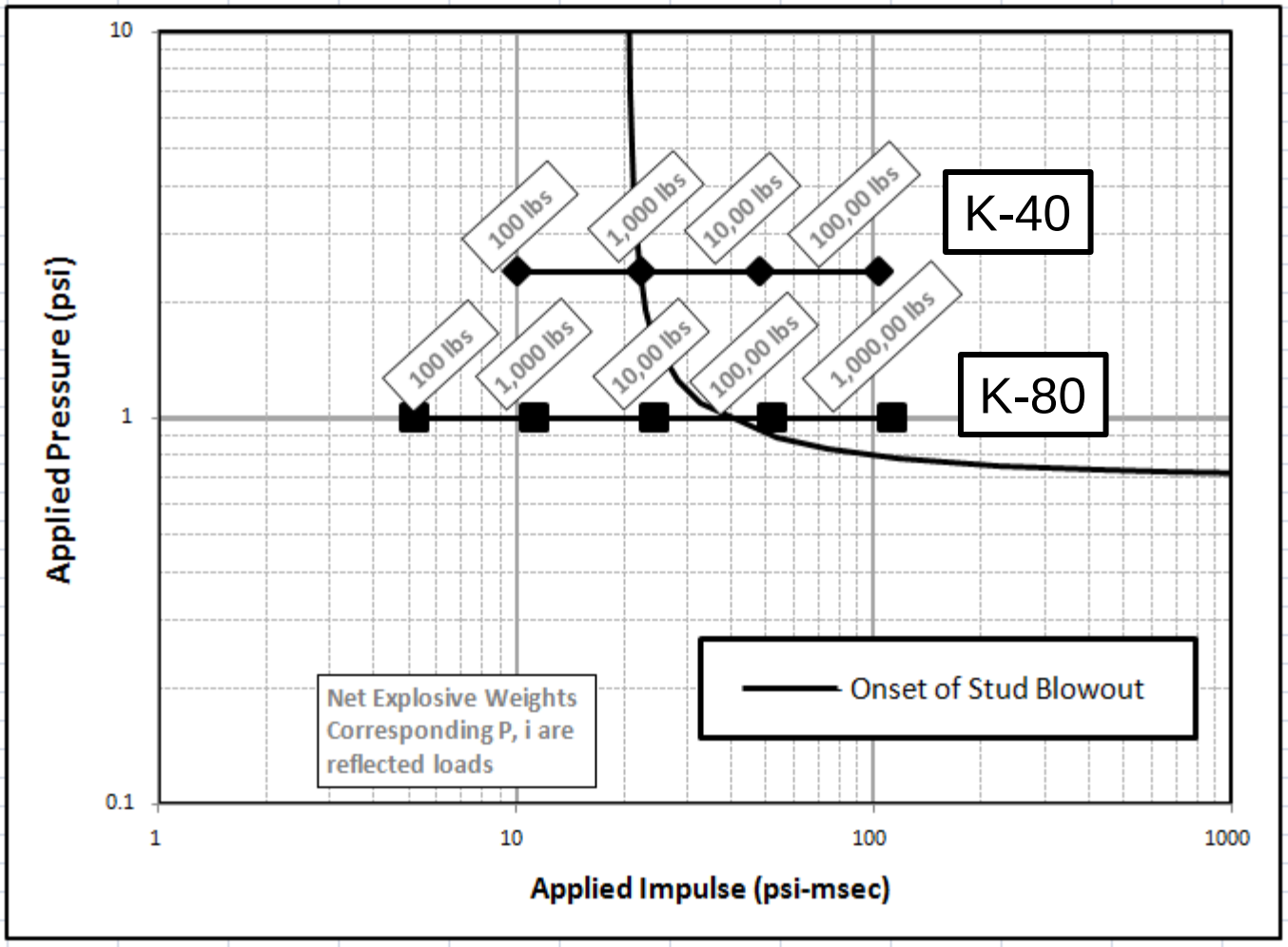
P-i Diagram


Onset of Stud Blowout
10
1
0.1
Applied Pressure (psi)
Stud
Blowout
Region
No Stud
Blowout
Region
Onset of Stud Blowout
1
10
100
1000
Applied Impulse (psi-msec)

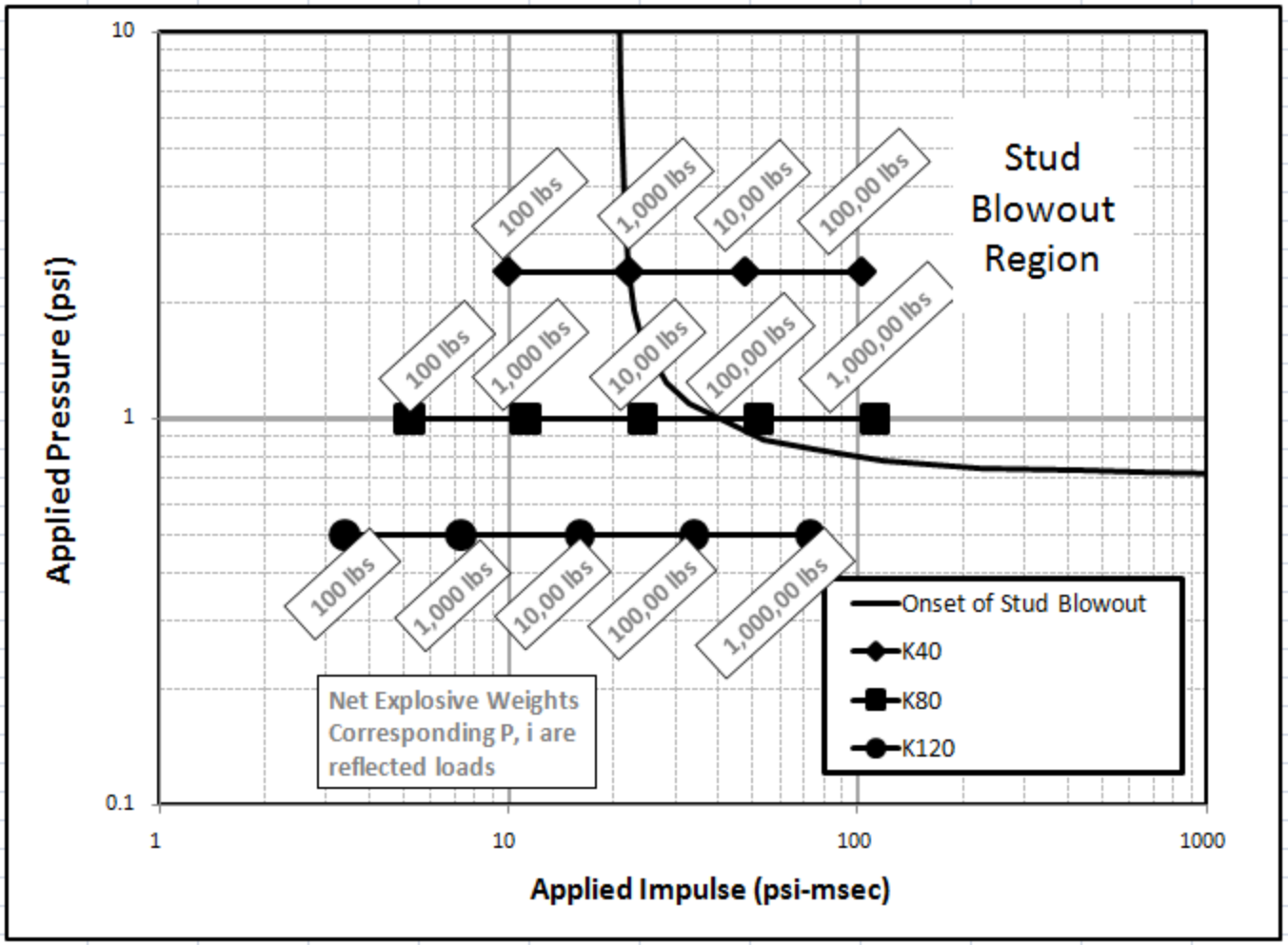
Reflected Load for K 40



Add K-80

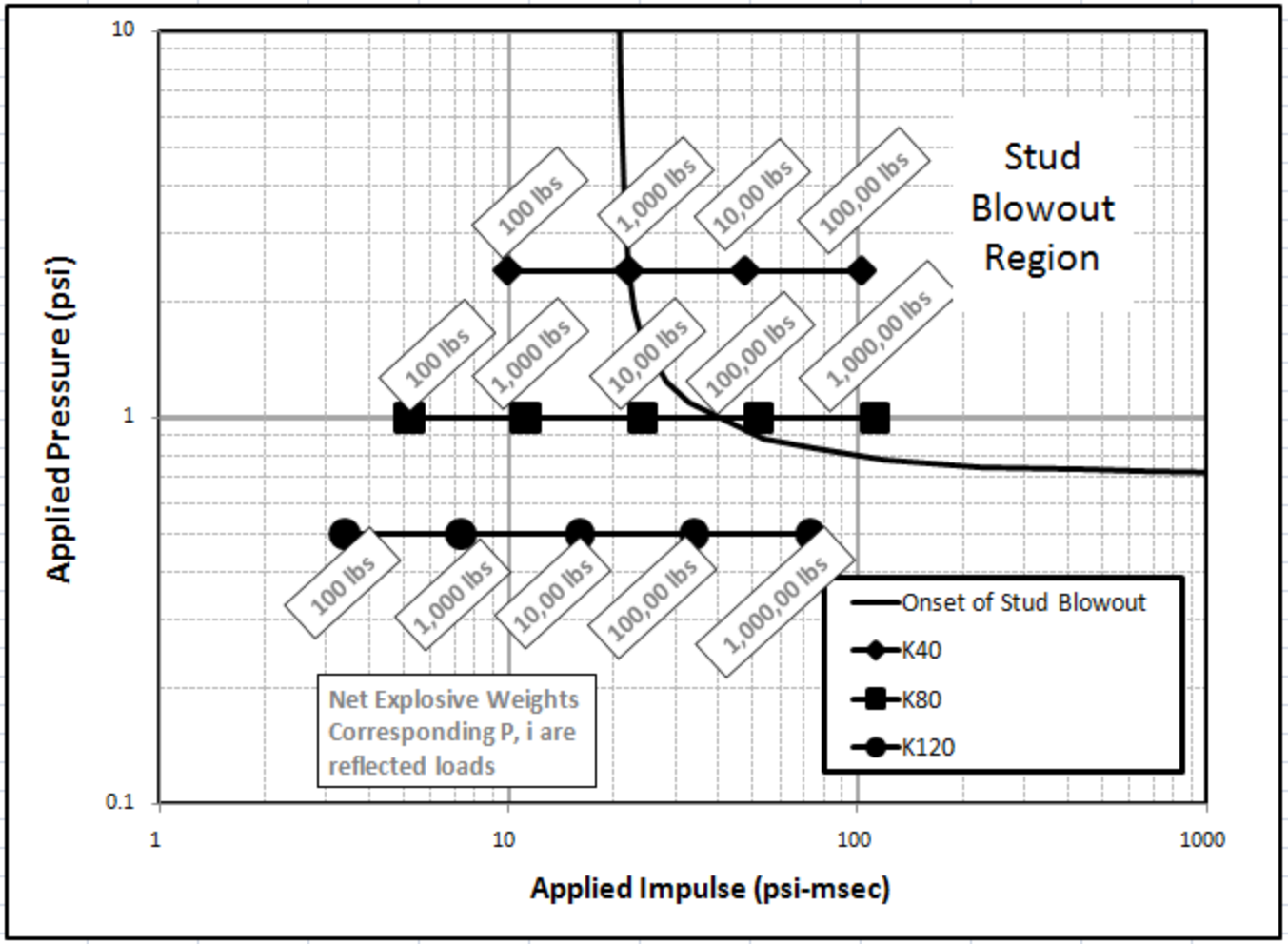

10
1
0.1
1
10
100
1000
Applied Pressure (psi)
Applied Impulse (psi-msec)
100 lbs
1,000 lbs
10,00 lbs
100,00 lbs
1,000,00 lbs
K-40
K-80
Net Explosive Weights Corresponding P, i are reflected loads
Onset of Stud Blowout

Add K-120


Applied Pressure (psi)
10
1
0.1
1
10
100
1000
Applied Impulse (psi-msec)
Stud Blowout Region
100 lbs
1,000 lbs
10,00 lbs
100,00 lbs
1,000,00 lbs
Net Explosive Weights Corresponding P, i are reflected loads
Onset of Stud Blowout
K40
K80
K120

Analysis

- @ K40, blowout for over 10^3 lbs
- @ K80, only large NEWs (10^5 to 10^6) are capable of reflected wall failures.
- @ K120 no failures



Non-Structural Building Damage

- Addressed in the paper
- Includes
  - Total Single Family Residence Damage as a Percentage of Replacement Cost
  - Window Breakage
- Based on work by Jack Reed and Bill Zehrt
- Concludes
  - Damage to homes as a percent of value much greater than discussed previously
  - Expect window breakage for miles even for moderate events
- Explosion Accidents

Recommendations for DoD

- More clearly discuss the potential hazards related to different types of construction.
  - In particular modern construction and those most vulnerable to overpressure
  - Provide clear requirements for siting different types of construction, such as through a tiered K-Factor. The API 753 uses a system with 3 zones.
- Consider requirements for siting of buildings based on population and the potential for congregation of personnel.
- Consider separate criteria for residential areas.
- On-site, distinguish between buildings housing personnel necessary to directly support explosive mission and those housing other support personnel