A Semi-Quantitative Risk Analysis Approach for Determining the Level of Risk Involved in the Storage of Explosives

Dr Ali Ameri **WGCDR Gary Gibbs**

Directorate of Ordnance Safety, Explosive Ordnance Branch, Department of Defence

Scope

- QD Background and Limitations
- WHS Requirements
- QD Principles vs SFARP
- Managing Explosives Risks – ADF
- Risk Management Process

QD Background and Limitations

- NATO Quantity Distance (QD) principles was published in 1963, developed by France, Germany, the UK and the US.
- QD is defined as [1]:

“The separation distances between a potential explosion site and an exposed site that represent a ***compromise deemed tolerable*** *by the AC/326 Group of Experts between* ***absolute safety*** *and* ***practical considerations*** *including costs and operational requirements”*

- AASTP-1 Edition C vs DEOP 101: DFD, MCE, MWB, Non-explosive workshop
- The latest edition of QD published in AASTP-1 Edition C (2023) covers NEQ between 1 and 500K kg

[1] NATO, AASTP-1 Ed C V 1, *NATO Guidelines for the Storage of Military Ammunition and Explosives*, NSO, Brussels, March 2023

QD Background and Limitations

- What is the base of QD?

Risk = Likelihood X Consequence X Exposure

“QD are primarily consequence-based, which means that the occurrence of an accidental explosion is assumed. ***The probability of an event is thus not considered in a QD assessment****.”* [1]

- **Likelihood** of explosive initiation is not considered in QD,

IBD for EW = IBD for ECM

QD for storing new ammunitions = QD for storing dispose ammunitions

- **Consequence** in QD is not clear, is it the magnitude of the effects (blast, debris, thermal) or is it the damage resulted from the effects (building damage, injuries, fatalities)

[1] NATO, AASTP-1.1 Ed A V 1, *Manual for the Development of an Explosives Safety Site Plan Based on AASTP-1* ,”NSO, Brussels, March 2023

QD Background and Limitations

- **For HD 1.1**
- Blast effect (BD)
- Debris and Fragmentation (DFD): From ammunition (primary fragments) and from confining structure (secondary fragments-debris)
- Secondary debris are not considered for all HDs

At IBD - BD31:

*BD: is based on tolerable levels of **damage** expected from **a side-on overpressure of 5 kPa.*** [1]

BD → levels of damage for structures & magnitude of the effect

The level of damage at IBD is based on brick houses that were damaged during World War II - German bombings on London.

[1] NATO, AASTP-1 Ed C V 1, *NATO Guidelines for the Storage of Military Ammunition and Explosives*, NSO, Brussels, March 2023

QD Background and Limitations

BD31	D13	1 kg ≤ Q < 2500 kg	1.5*Q^2/3	2 m ≤ D < 277 m	(D/1.5)^1.5
		2500 kg ≤ Q < 4500 kg	5.5*Q^1/2	277 m ≤ D < 369 m	(D/5.5)^2
		4500 kg ≤ Q ≤ 500,000 kg	22.2*Q^1/3	369 m ≤ D ≤ 1763 m	(D/22.2)^3

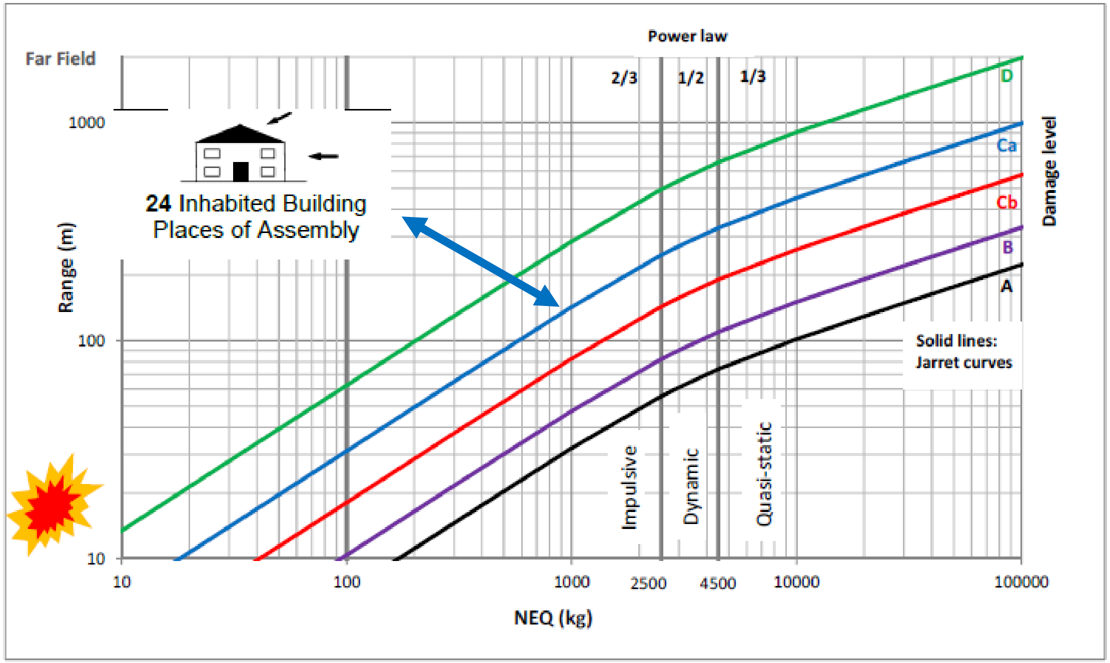


Figure 1: ACR to various damage levels based on Gilbert, Lees, and Scilly [1]

1.3.1.16. Inhabited Building Distances
These distances are the minimum permissible distances between PESs and **inhabited buildings** or **assembly places**. The distances are intended to prevent serious structural damage by blast, flame or projections to ordinary types of inhabited buildings or caravans/mobile homes and consequent death or serious injuries to their occupants.

What would be the vehicle damage due to blast at IBD for High Density Usage Roads?

[1] Voort et al. (2016), *Experimental and Theoretical Basis of NATO Standards for Safe Storage of Ammunition and Explosives*, 24th MABS, 2016

QD Background and Limitations

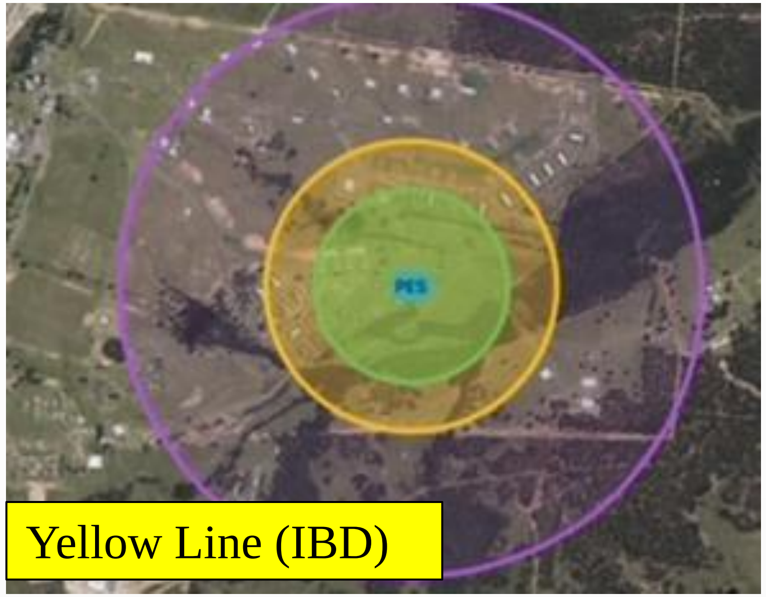


Figure 2: Example of a safeguarding map

2. <u>Expected Blast Effects</u>

   a. Unstrengthened buildings will suffer minor damage, particularly to parts such as windows, door frames and chimneys. In general, damage is unlikely to exceed approximately 5 % of the replacement cost but some buildings may suffer serious damage.

   b. Injuries and fatalities are very unlikely as a direct result of the blast effects. Injuries that do occur will be caused principally by glass breakage and flying/falling debris with injury severity a function of what part of the body is hit by that glass/debris.

Figure 3: Examples of inhabited buildings (houses)

QD Background and Limitations

- DFD were not calculated in previous editions of AASTP-1
- AASTP-1 Ed C introduced 21 DFD tables
- DFDs represent a significant advancement over previous set of minimum distances.

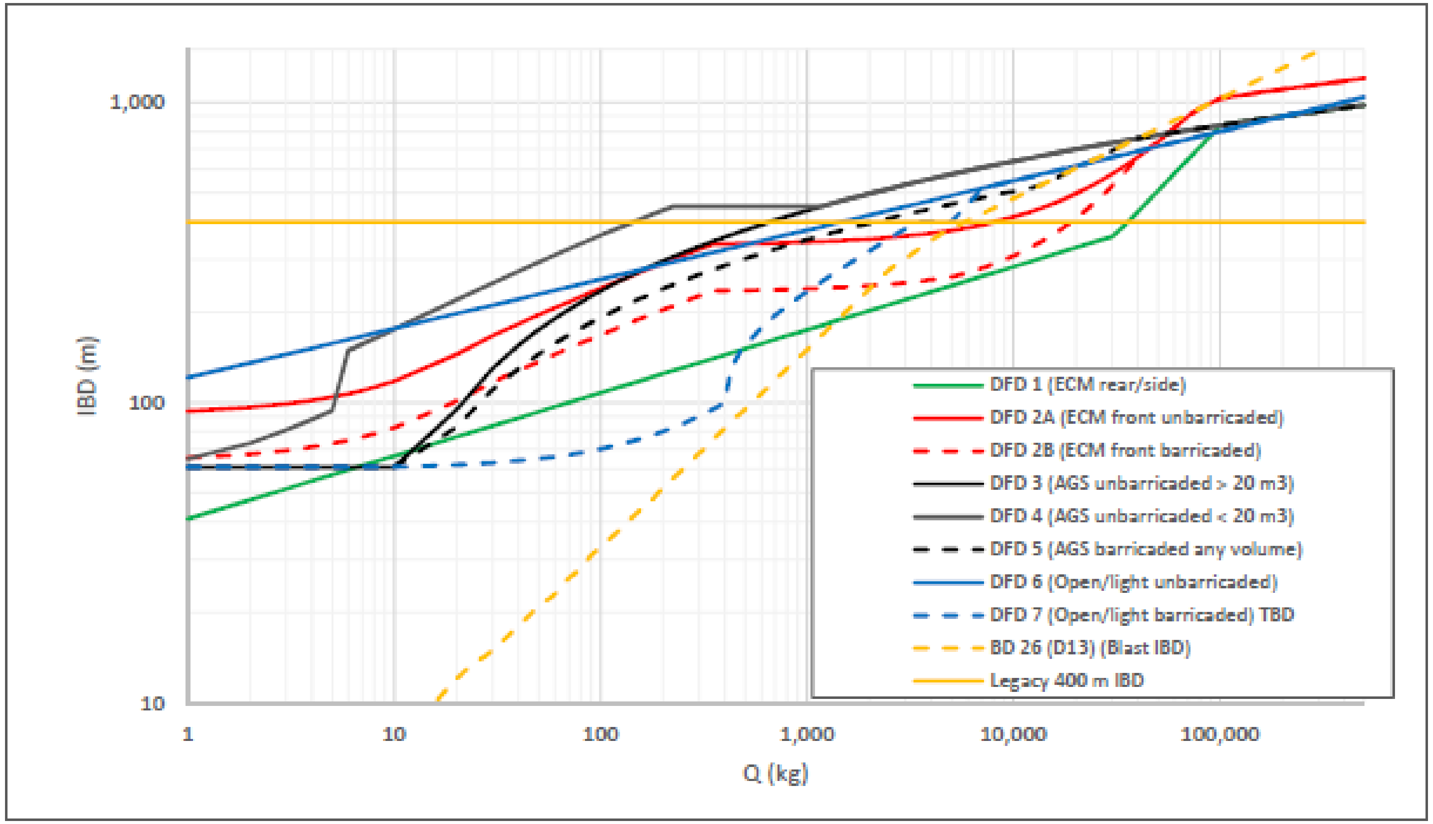


Figure 4: DFD curves for various PESs [1]

[1] NATO, AASTP-1.2 Ed A V 1, *Development of NATO Debris and Fragment Distance Curves for AASTP-1* , NSO, Brussels, March 2023

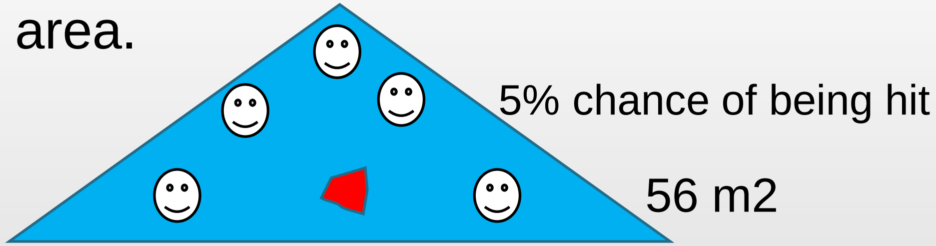
QD Background and Limitations

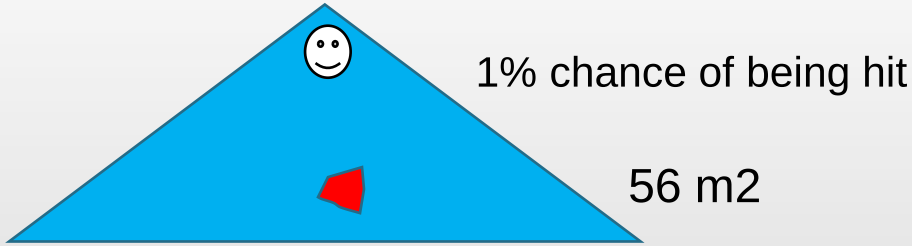
At IBD – DFD1-7 :

DFD (HFD) is only applied where individuals are exposed at ESs and determined based on **a single hazardous fragmentation** (79 J) per 56 m2

DFD → magnitude of the effect

- Based on this, there is ~ 1% chance of being hit by a hazardous fragment (the exposure area of a standing human is assumed to be 0.56 m2) and there is only one person present within this area.





- For HFD (79 J), the probability of lethality is ~2.3%, a major injury or worse is ~ 36.8%, and a minor injury or worse is ~ 99.2% [1].

[1] NATO, AASTP-1.2 Ed A V 1, *Development of NATO Debris and Fragment Distance Curves for AASTP-1* , NSO, Brussels, March 2023

QD Background and Limitations

At IBD – DFD1-7 :

- Lethal Fragment depends on: energy, shape, and impact location on the body
- Hazardous Fragment ≠ Lethal Fragment

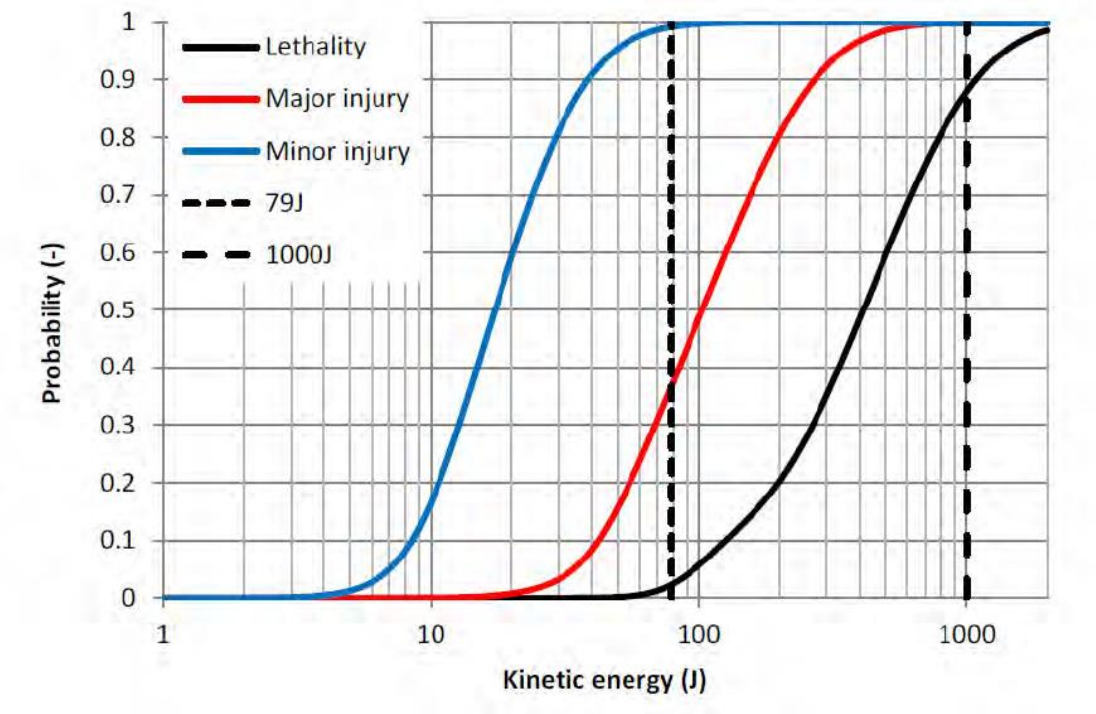


Figure 5: Probabilities of casualty given a debris impact for frontal exposure [1]

Limits for blunt impact injuries from [2]

LETHALITY DUE TO IMPACT ENERGY				
LETHALITY p %	IMPACT ENERGY / KINTETIC ENERGY (Joule)			
	HEAD	CHEST	ABDOMEN	LIMBS
1	55	58	105	155
5	65	90	140	240
20	79	140	200	380
50	100	230	280	620
99	200	850	850	2500

[1] NATO, *AASTP-1.2 Ed A V 1, Development of NATO Debris and Fragment Distance Curves for AASTP-1* , NSO, Brussels, March 2023
[2] NATO, *AASTP-1 Ed 1, Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives*, NSO, Brussels, May 2006

QD Background and Limitations

At IBD – DFD1-7 :

➢ DFD (HFD) ≠ Maximum Fragment Distance (MFD)

TABLE 11 - LOOK UP TAI

MASS	DEBRIS AI					
kg	DFD1	DFD2	DFD3	DFD4	DFD5	DFD6
1	41	94	61	65	61	121
2	48	97	61	74	61	136
3	52	100	61	82	61	145
4	55	102	61	88	61	152
5	58	105	61	94	61	158
6	60	108	61	150	61	163
7	62	110	61	157	61	167
8	64	113	61	164	61	171
9	66	116	61	170	61	174
10	67	118	61	176	61	177
20	77	145	95	221	83	198
30	84	168	131	251	111	212
40	89	183	156	275	130	222
50	94	196	175	294	146	230
60	97	207	191	311	158	237
70	101	217	205	325	168	243
250	131	310	316	450	255	300
275	134	317	324	450	261	304
300	136	325	332	450	267	309
325	139	331	339	450	273	313

AASTP-1

NEQ (kg)	MFD[1] (m)		NEQ (kg)	MFD[1] (m)	
	ROBUST[2]	NON-ROBUST[3]		ROBUST[2]	NON-ROBUST[3]
0.005	160.7	60.5	0.68	648.7	278.5
0.007	186.4	69.6	0.91	685.8	300.1
0.009	206.2	76.7	1.36	739.0	332.6
0.014	236.4	87.7	1.81	777.4	357.1
0.018	259.4	96.4	2.27	807.5	377.0
0.023	278.1	103.5	2.72	832.2	393.9
0.027	294.0	109.7	3.18	853.3	408.5
0.032	307.8	115.2	3.63	871.6	421.5
0.036	320.1	120.1	4.08	887.8	433.2
0.041	331.1	124.6	4.54	902.3	443.8
0.045	341.2	128.7	6.80	958.6	486.4
0.068	381.4	145.6	9.07	998.8	518.1
0.091	411.3	158.7	13.61	1055.7	565.1
0.14	455.4	178.7	22.68	1128.1	627.9
0.18	487.9	194.1	31.75	1176.0	671.4
0.23	513.8	206.7	45.36	1227.2	719.2
0.27	535.3	217.5	68.04	1285.8	775.7
0.32	553.9	227.0	90.72	1327.7	817.1
0.36	570.1	335.4	136.08	1387.4	877.0
0.41	584.5	243.1	226.80	1463.9	955.1
0.45	597.6	250.1	317.51	1515.3	1007.7

Table 7-2 – Default MFD Based on NEQ

[1] NATO, *AASTP-1 Ed C V 1, NATO Guidelines for the Storage of Military Ammunition and Explosives*, NSO, Brussels, March 2023

QD Background and Limitations

At IBD – DFD1-7 :

SciPan 4 test (Aug 2008) [1]

PES = Medium reinforced concrete/reinforced masonry structure, NEQ = 1,000 kg Flaked TNT

- Max. DFD =700 m along the 270° azimuth
  (Maximum Throw Distance = 1018 m)
- Average DFD = 307 m
- **DFD3 = 437 m (AASTP-1)**

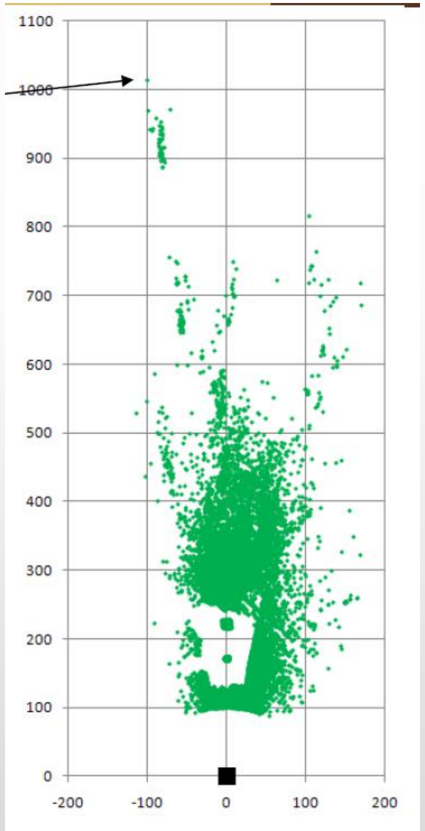


Figure 7: Distribution of all collected Debris @ 270°

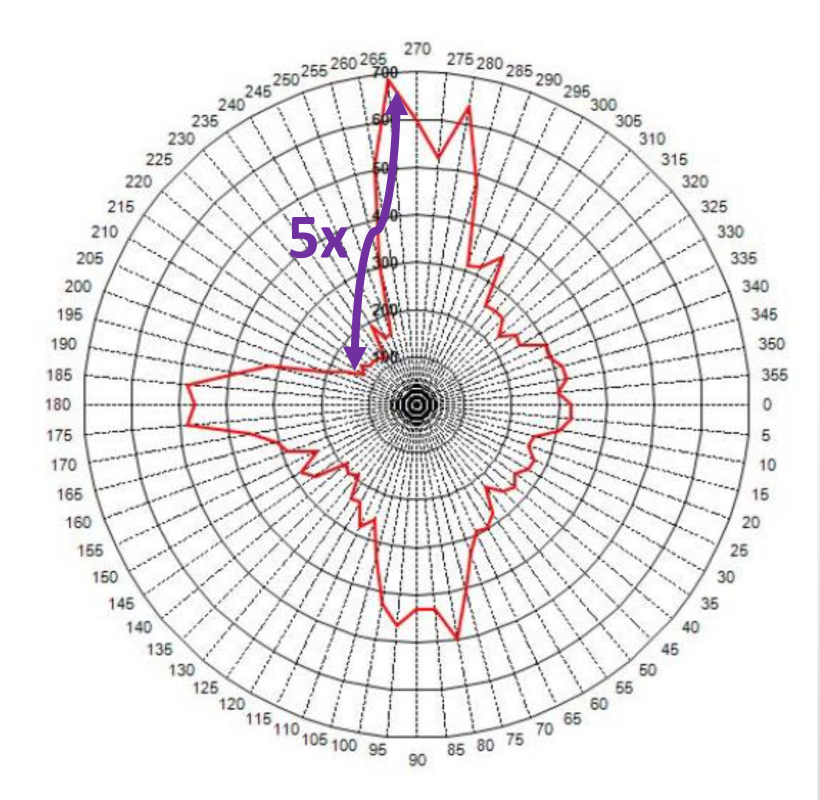


Figure 6: **SciPan 4 PTN Debris IBD**

[1] Conway et al. (2010), *SciPan 4: Program Description and Test Results*, 34th DDESB

QD Background and Limitations

- ❑ DFD is not yet perfect and there is still a substantial degree of uncertainty in predicted effects from fragmentation and debris.

- ❑ DFD limitations:

➢ Limited trial data and supporting evidence available.

➢ Generic approach across PES and ES types.

  - Not munition type specific.
  - Focused on injury not level of damage.
  - Formulae linked to NEQ to simplify QD distances assessments.

QD Background and Limitations

At EWD – BD18:

BD is based on the **peak side-on overpressure**, which is anticipated to be <20 kPa

BD → magnitude of the effect

DFD is taken as 2/3 or 1/2 of DFD for IBD

What is the risk/effect at 2/3 or 1/2 of DFD ?

1. Expected Blast Effects
   a. Buildings which are unstrengthened can be expected to suffer serious damage which is likely to cost above 30 % of the total replacement cost to repair.
   b. Serious injuries to personnel, which may result in death, are likely to occur due to building collapse or loose translated objects.
   c. There is some possibility of delayed communication of the explosion as a result of fires or equipment failure at the ES, direct propagation of the explosion is not likely.

- **Exposure** in QD is not consistent

PTRD varies with the number of the road users vs IBD is constant regardless of the number of the occupants

QD Background and Limitations

- QD are primarily consequence-based, which means that **the occurrence of an accidental explosion is assumed**. The **probability of an event is thus not considered in a QD assessment** [1].
- HFD is typically applied as a safety distance for **accidental events** such as in ammunition storage, whereas MFD is applicable to **intentional detonations** such as during demolition [2].
- Side-on overpressure:
  - IBD → 5 kPa (22.2 $Q^{1/3}$)
  - VBD → 2 kPa (44.4 $Q^{1/3}$)
  - Personnel withdrawal distance (demolition area) → 0.45 kPa (130 $Q^{1/3}$)

Likelihood value in QD = ?

[1] NATO, AASTP-1.1 Ed A V 1, Manual for the Development of an Explosives Safety Site Plan Based on AASTP-1 ,"NSO, Brussels, March 2023
[2] MSIAC (2021), Report 2021-AUS-3066 dated 29 Jul 21

WHS Requirements

- Defence must endeavour to ensure compliance with its duty under WHS to eliminate risks SFARP or, if not reasonably practicable to eliminate risks, to minimise risks SFARP.
- WHS Act 2011 [1]:

Subdivision 2—What is reasonably practicable

18 What is *reasonably practicable* in ensuring health and safety

In this Act, ***reasonably practicable***, in relation to a duty to ensure health and safety, means that which is, or was at a particular time, reasonably able to be done in relation to ensuring health and safety, taking into account and weighing up all relevant matters including:

(a) the likelihood of the hazard or the risk concerned occurring; and

(b) the degree of harm that might result from the hazard or the risk; and

(c) what the person concerned knows, or ought reasonably to know, about:

(i) the hazard or the risk; and

(ii) ways of eliminating or minimising the risk; and

(d) the availability and suitability of ways to eliminate or minimise the risk; and

(e) after assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk.

- DEOP 100 [2]: Principle 1 "*Defence must comply with applicable Explosives and WHS legislation and demonstrate means of compliance in a safety argument.*"

[1] Work Health and Safety Act 2011, Compilation No. 16, Compilation date: 1 July 2024
[2] DEOP 100, Defence Explosives Safety Regulatory Framework

QD Principles vs SFARP

- QD "*QD reflects a tolerable but non-zero level of consequence (and risk)*" [1]
- SFARP requires all practicable precautionary options to be tested for reasonableness, rather than to stop testing options once a 'tolerable' level of risk is reached.
- QD principles generally complies with the intent of ALARP (i.e., Go vs No-go)
- QD principles might **NOT** always satisfy SFARP
- To comply with SFARP, an ALARP judgement outcome (**i.e. QD outcomes**) needs further analysis (**an explosives risk assessment**) to determine if the risk is SFARP.

[1] NATO, AASTP-1.1 Ed A V 1, *Manual for the Development of an Explosives Safety Site Plan Based on AASTP-1* ,"NSO, Brussels, March 2023

Managing Explosives Risks - ADF

DEOP 101 [1]

- QD principles represent the base for siting and licensing Explosive Storage Facilities
- It is based on AASTP-1 Ed 1 and OPSMAN 3
- It is currently being updated to implement AASTP-1 Edition C (2023) requirements
- Explosive Risk Approach is a recognized approach in DEOP 101 to be used for:
  - Licensing Small Quantity Facilities (SQF) where NEQ is less than 50 kg
  - Licensing storage facilities in Area of Operations when QD rules cannot be applied
  - Licensing OLA in airfields of foreign countries when QD/AD rules cannot be applied
- The current policy (Regulation 5.3) on Explosive Risk Management is dated and it is not aligned with WHS and SAFETYMAN

[1] Department of Defence Explosives Regulations

Part 2

Risk Management Process

Stage 1: Establish Context

Stage 2: Risk Assessment

Stage 3: Risk Control Identification

Stage 4: SFARP Judgment

Stage 5: Residual Risk Assessment

Stage 6: Authorisations

Stage 7: Implementation

Step 8: Review and Maintenance

[1] Clayton UTZ (2015), Legal Advice to ADF - *Guidance on the Risk Management Process.*

Risk Management Process - Australia

Risk Assessment

Risk = Likelihood X Consequence X Exposure

Consequence reduction methods are to be the primary focus for risk minimisation. While likelihood controls and exposure may assist in lowering the risk, particularly in relation to the possibility of the event occurring and someone/asset being present, they don't lower the consequences should the event occur.

- ❑ **Define Hazards and Risks**
- ❑ **Evaluate Risk Elements**
- ➢ What is the likelihood of the risk?
- ➢ What is the harm/degree of harm that will arise from the risks (consequence)?
- ❑ **Prioritise the risks to be managed**
- ➢ How imminent is the risk?
- ➢ How necessary is the activity to which the risk attaches?
- ➢ How serious is the risk (likelihood v degree of harm)?

Likelihood vs Consequence controls

- Company appealed administrative decision by SafeWork NSW to decline the application for the variation of a licence (increase storage by 4500 tonnes) to store Ammonium Nitrate within facility in Newcastle.
- SafeWork NSW considered Quantity Distance requirements necessary and refused a Quantitative Risk Assessment.
- The court considered that a distinction needs to be made between steps which can be taken by a licensee to reduce the likelihood of an incident occurring and steps which can be taken to reduce the consequences of such an incident should it occur, even if that is unlikely.
- The company acknowledged at the hearing that administrative controls can fail (the sprinkler system could fail 10% of the time),
- The court view was steps which can be taken to ensure an equivalent level of safety, if separation distances can't be met, must relate to steps which can be taken if the controls which are put in place to prevent an explosion fail.
- The court was not satisfied that that the company has the appropriate facilities, systems and procedures for the safe and secure handling of additional 4,500 tonnes of ammonium nitrate.

https://www.caselaw.nsw.gov.au/decision/17efa9543e91326ab2b3c347

Consequence of Explosives Accident

LIKELIHOOD

What is the likelihood of the risk eventuating?

- The integrity of current risk control measures (if any) that have been implemented to control the risk.
- The skills and training of the personnel involved in the activity.

EXPOSURE (People/ Asset)

Who and How long are exposed?

- Workers (directly involved) and non-workers (not directly involved).
- Important Assets.
- Duration of the hazard.

CONSEQUENCE

BLAST

FRAGMENTATION

FATALITY or DAMAGE

DEBRIS

THERMAL RADIATION

Likelihood of Explosives Accident

❑ Likelihood

Hazards linked with the Activity that can directly or indirectly on the munitions

Examples:
- EO handling errors
- Incorrect testing

Hazards linked to munitions design or condition state

Examples:
- Sensitive to environmental conditions such as heat or water.
- Unserviceable munitions

Internal and external hazards linked to the location

Examples:
- Safety threat
- Environmental factors (thunderstorm)

Consequence of Explosives Accident- Blast

CONSEQUENCE- BLAST

- ❑ **Incident (Side-on peak) Overpressure (positive phase)**
- ❑ Impulse
- ❑ Dynamic pressure (blast wind)
- ❑ Negative pressure (suction phase)→duration = ~ 3X positive phase

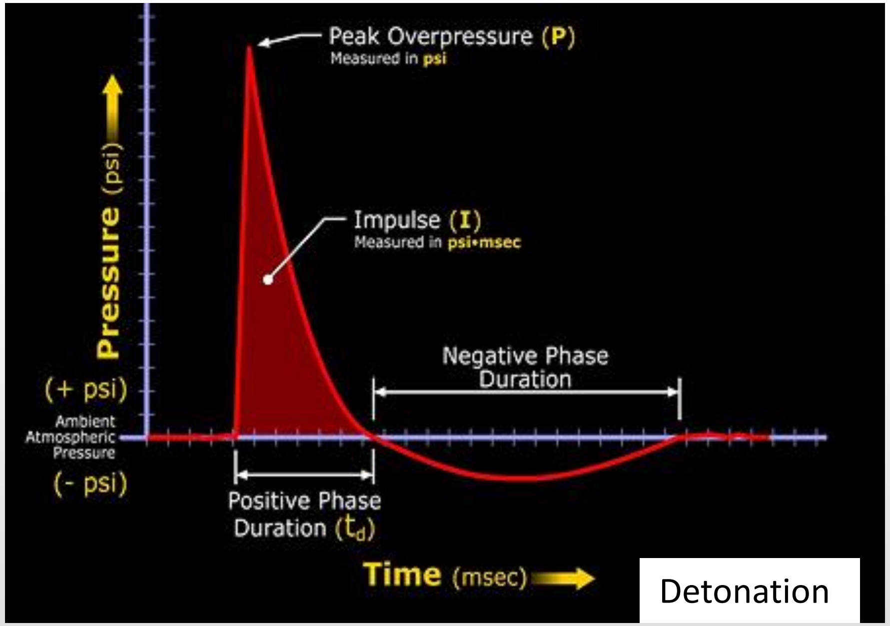


Figure 7: Typical blast wave profile

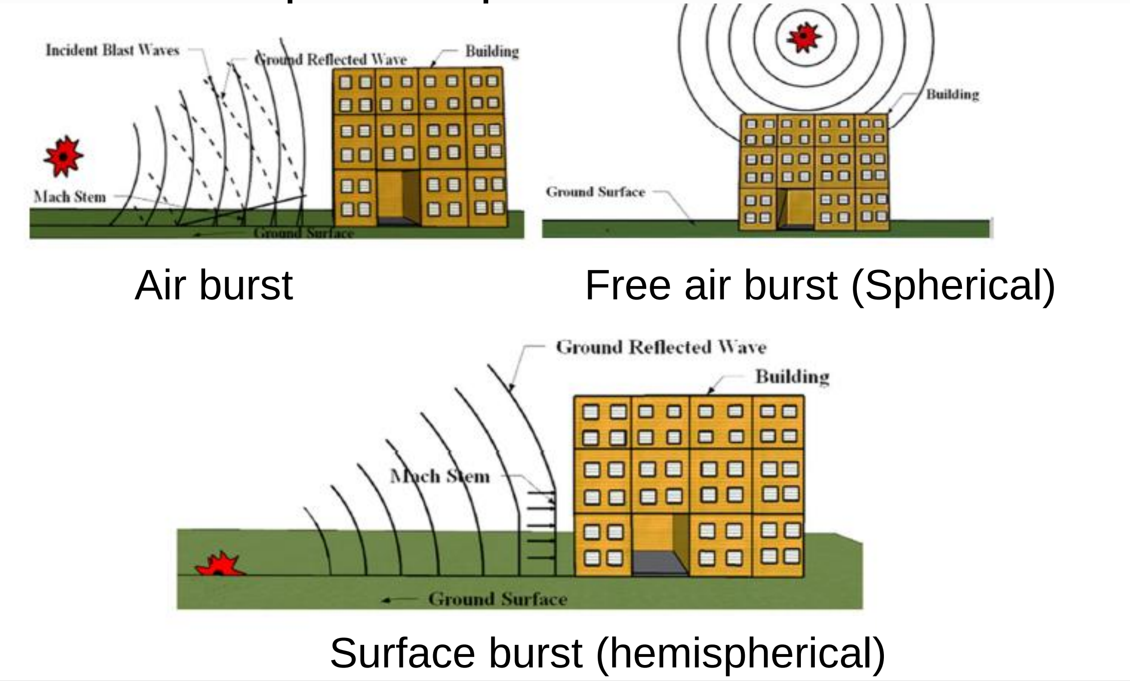


Figure 8: Types of Explosions

Shirbhate et al. (2021), *A critical review of blast wave parameters and approaches for blast load mitigation*, *Archives of Computational Methods in Engineering*, *28*(3), 1713-1730.

Consequence of Explosives Accident- Blast

FACTORS AFFECTING BLAST LOADING [1]

- ❑ Type of EO
- ❑ Explosive Weight
- ❑ Distance between PES and ES
- ❑ Casing Effects (case weight, material and thickness)
- ❑ Charge Geometry
- ❑ Terrain Effects (Pressures α + slope)

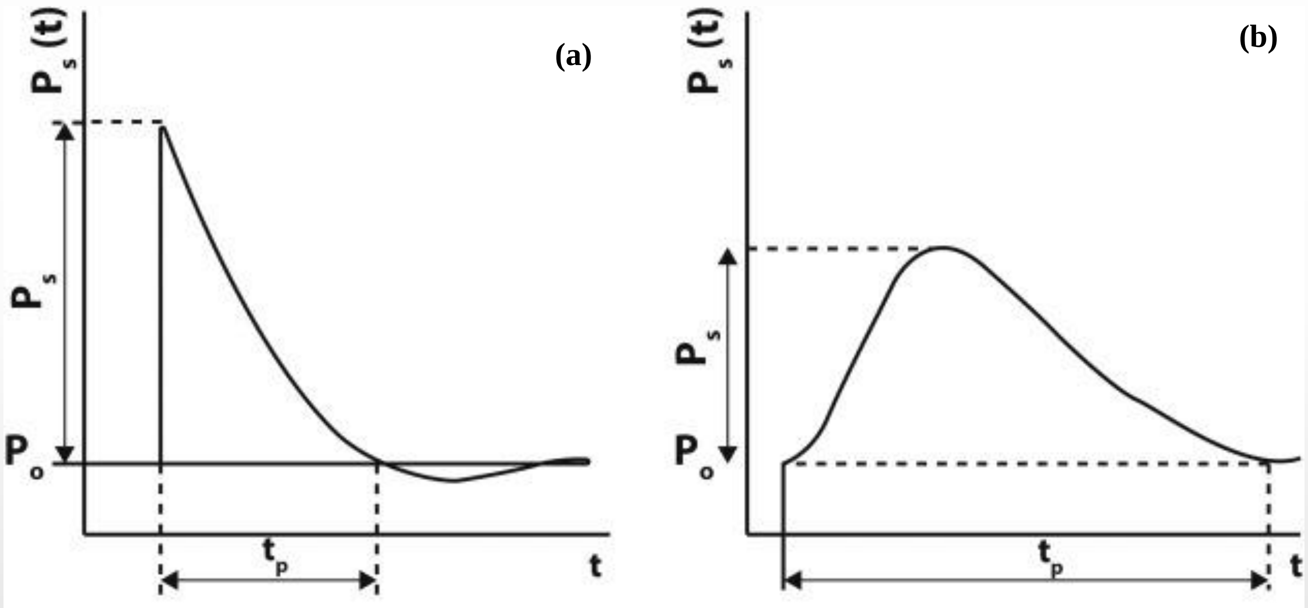


Figure 9: (a) typical blast wave profile (detonation), (b) pressure wave (deflagration)

[1] NATO, "AASTP-4 Ed 1 V 4 Explosives Safety Risk Analysis, Part II Technical Background," NSO, Brussels, published in 2016.

Consequence of Explosives Accident- Blast

BLAST EFFECT

❑ Incident (Side-on peak) Overpressure

- Well validated model (*AASTP-4 and TP 20*)
- For Z < 1 $m/kg^{1/3}$ the curves are not supported by any data
- For Z < 1 $m/kg^{1/3}$ (near-field blast), loading profile is very complex

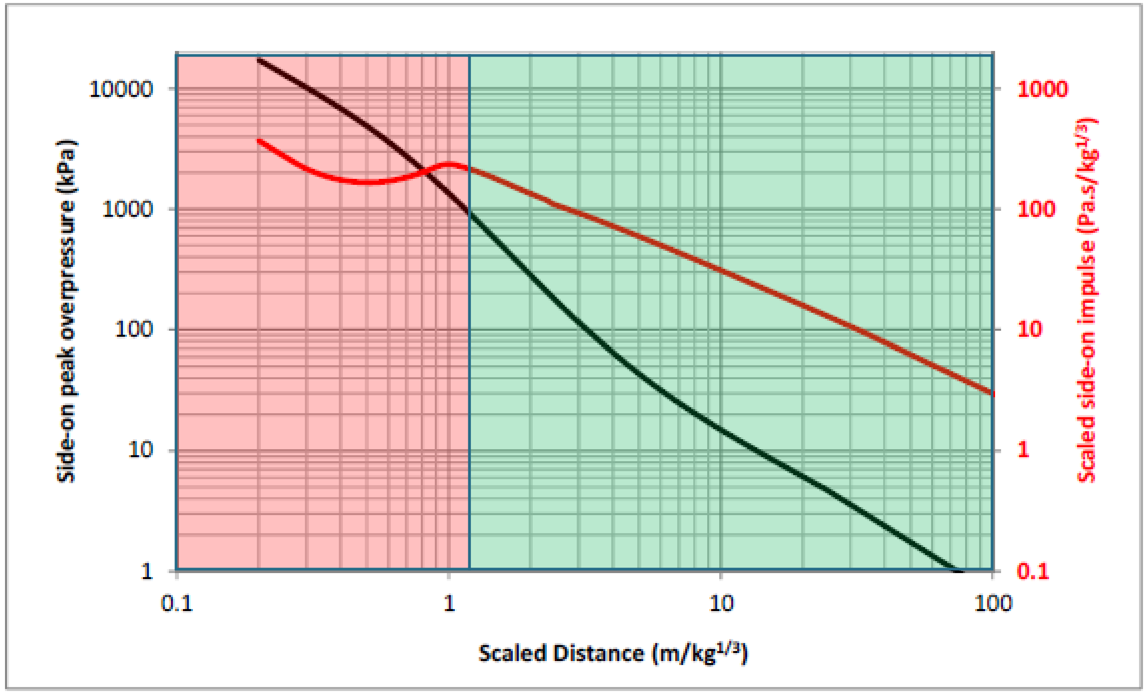


Figure 10 : The side-on peak overpressure and scaled side-on impulse as a function of scaled distance for a hemispherical surface burst.

[1] Voort et al. (2016), *Experimental and Theoretical Basis of NATO Standards for Safe Storage of Ammunition and Explosives*, 24th MABS, 2016

Consequence of Explosives Accident- Blast

STRUCTURES RESPONSE UNDER BLAST

- ❑ **Incident (Side-on peak) Overpressure**
  - **Reflected blast wave** is the dominate element in defining the damage level for structures

Pr = Pi X Cr

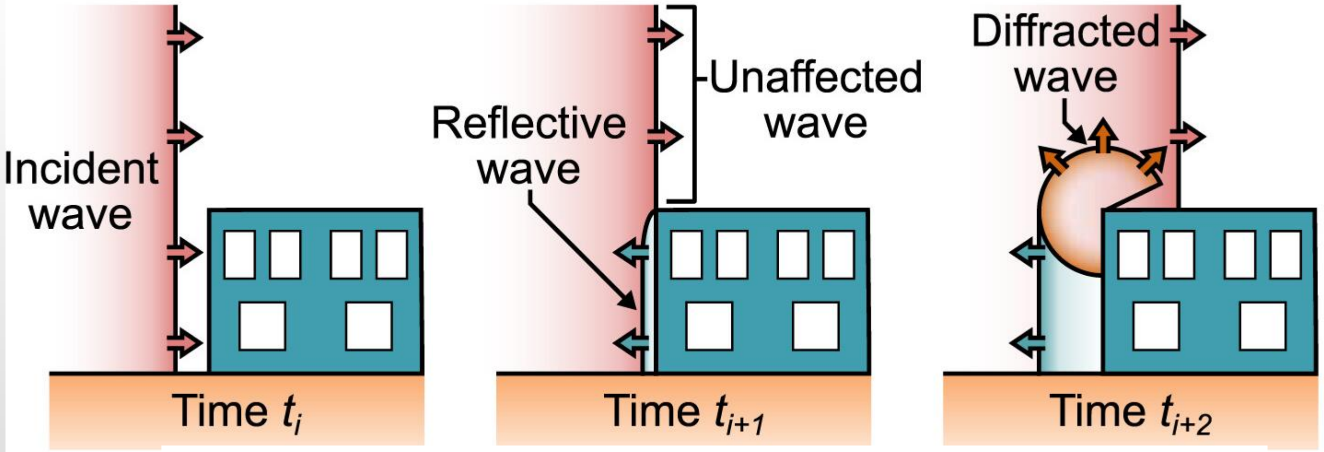


Figure 12: Blast wave interaction with a building.

Ref [10]

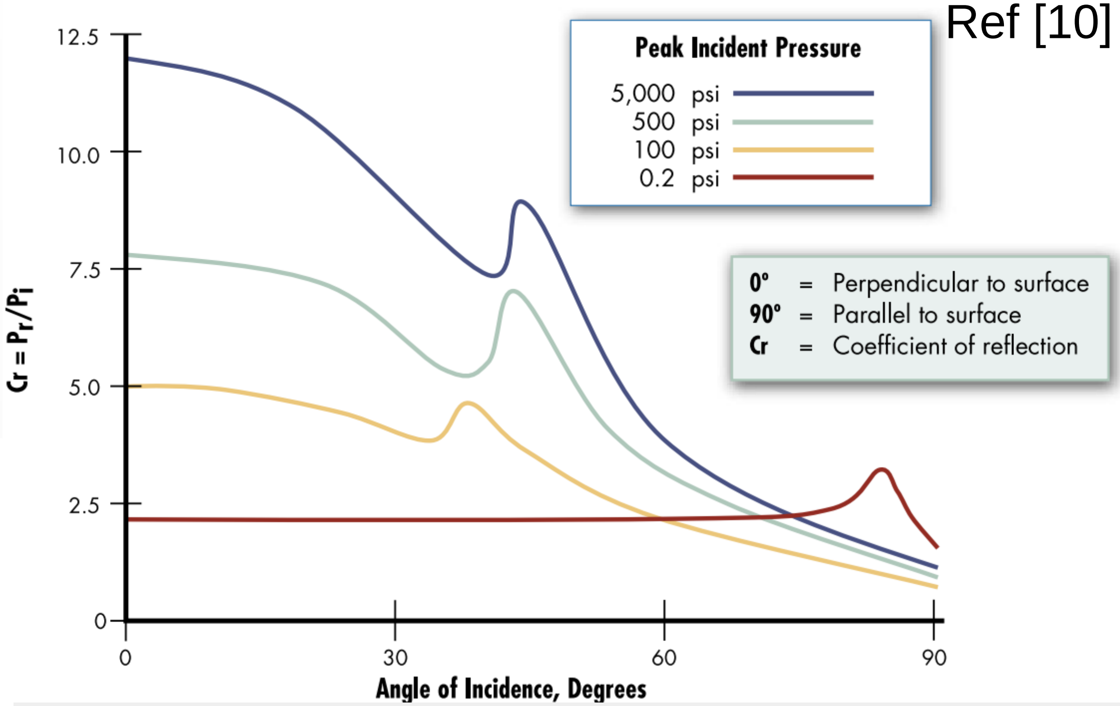


Figure 11: Coefficient of reflection for different peak incident pressure at different incident angles.

Cr depends on the incident angle and magnitude of the incident pressure

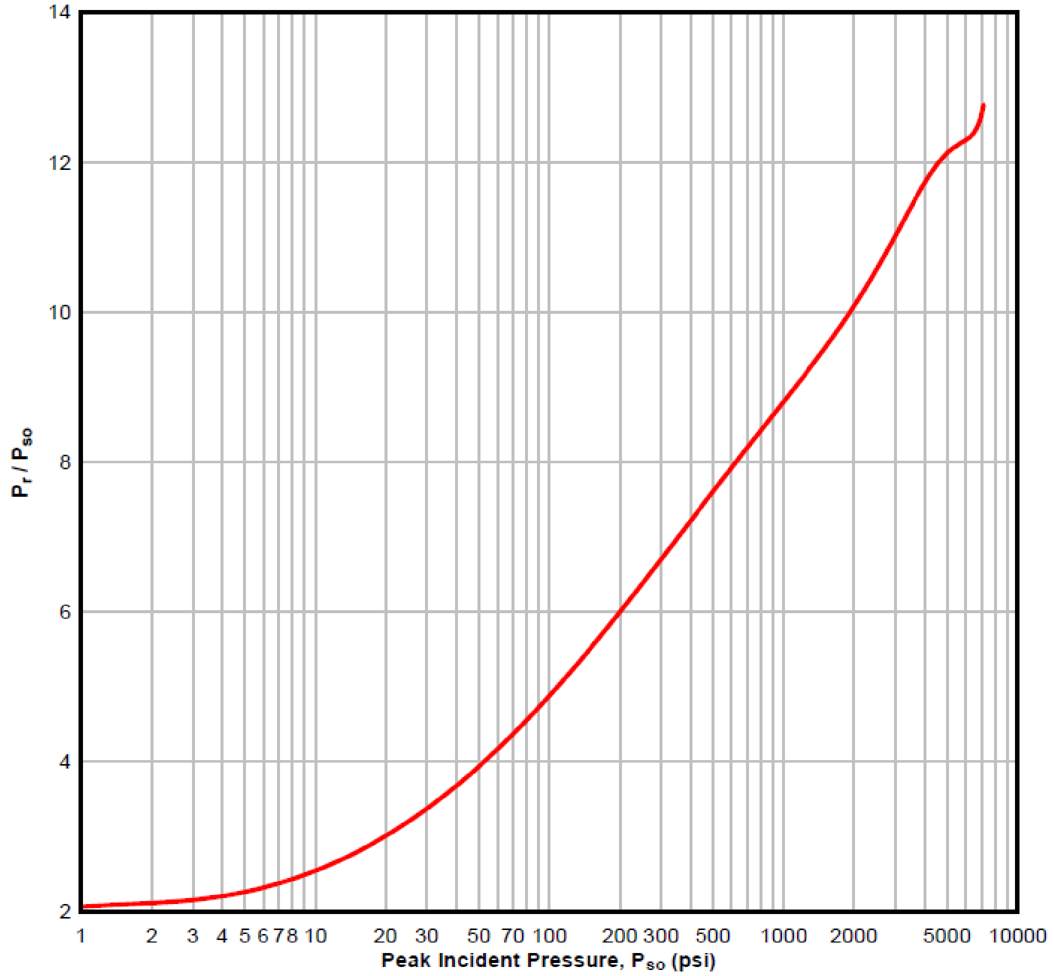
Shirbhate et al. (2021), *A critical review of blast wave parameters and approaches for blast load mitigation*, *Archives of Computational Methods in Engineering*, *28*(3), 1713-1730.

Consequence of Explosives Accident- Blast

STRUCTURES RESPONSE UNDER BLAST

- 90º Reflection can result in Cr value of ~ 13
- If the building can withstand the value of the incident wave (e.g. rigid wall), the reflected wave must be considered

Figure 13: **Peak Incident Pressure versus the Ratio of Normal Reflected Pressure/Incident Pressure for a Free-Air Burst**



US Army Corps of Engineers, *Structures to Resist the Effect of Accidental Explosions, UFC 3-340-02*," Unified Facilities Criteria, December 2008.

Consequence of Explosives Accident- Blast

- NEQ = 400 kg
- Distance = 35 m
- K = $\frac{35}{\sqrt[3]{400}}$ = 4.75 m/kg$^{1/3}$ → Pi= ~ 47 kPa, Cr = 2.5 → Pr = ~ 118 kPa
- Simulation results: Pi = 52 kPa and Pr = 126 kPa

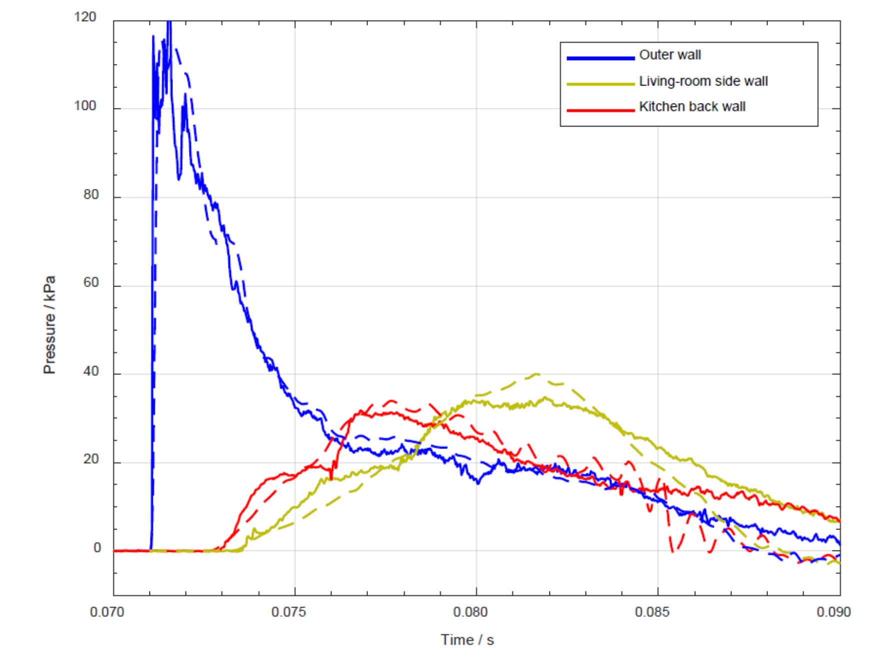


Figure 15: Pressure-time history

Figure 14: Photo of the ES before the explosion

K. B. Holm (2018), *Blast injuries to people inside buildings*, Norwegian Defence Research Establishment (FFI)

Consequence of Explosives Accident- Blast

Figure 16: Photos of the ES after the explosion

K. B. Holm (2018), *Blast injuries to people inside buildings*, Norwegian Defence Research Establishment (FFI)

Consequence of Explosives Accident- Blast

STRUCTURES RESPONSE UNDER BLAST

❑ Impulse

- Structural response depends on the duration of the positive incident overpressure
- It is recommended to consider P-I diagram in defining the damage rather than the peak incident pressure

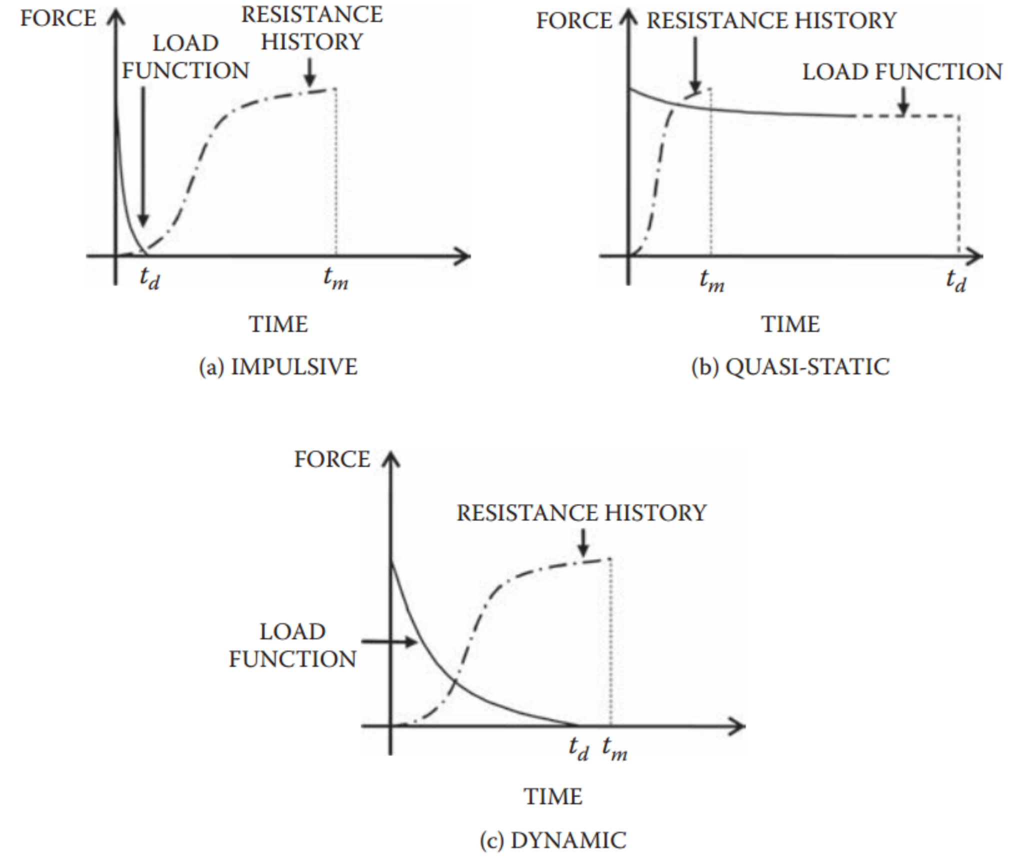


Figure 17: Comparison of response time loading regimes.

Theodor Krauthammer (2008), *Modren protective Structures*, CRC Press

Consequence of Explosives Accident- Blast

STRUCTURES RESPONSE UNDER BLAST

- **Impulse**

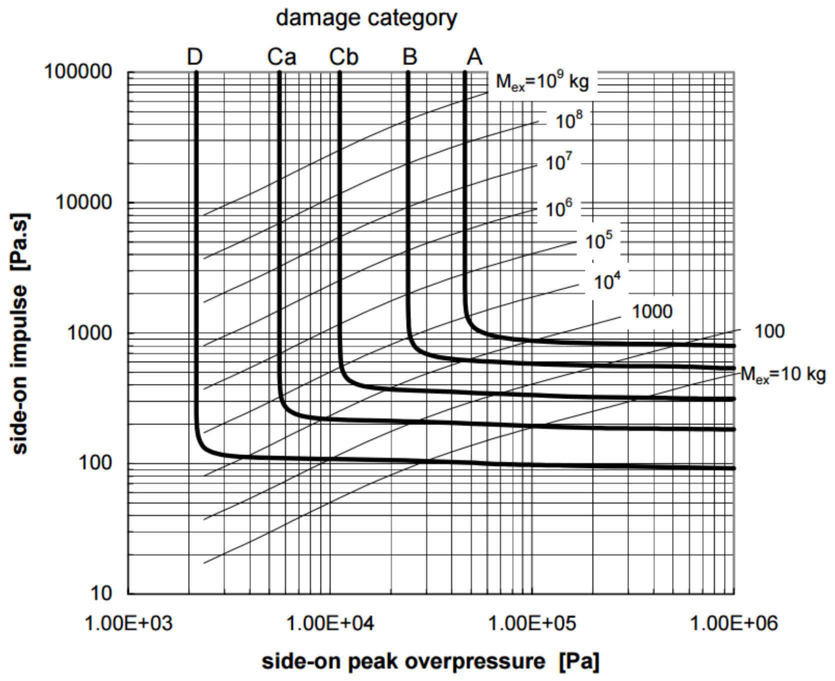
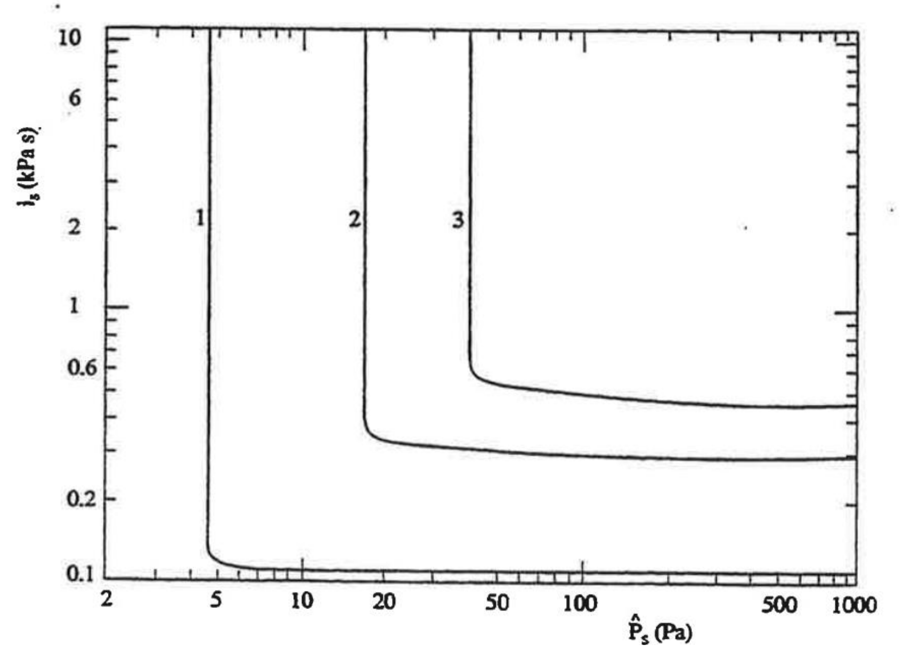


Figure 18: P-I diagrams for various damage levels of houses [1]



1 Threshold for minor structural damage. Wrenched joints and partions.
2 Threshold for major structural damage. Some load bearing girders fail.
3 Threshold for partial demolition. 50 to 75% of walls destroyed or unsafe

Figure 19: P-I diagrams for masonry building damage[2]

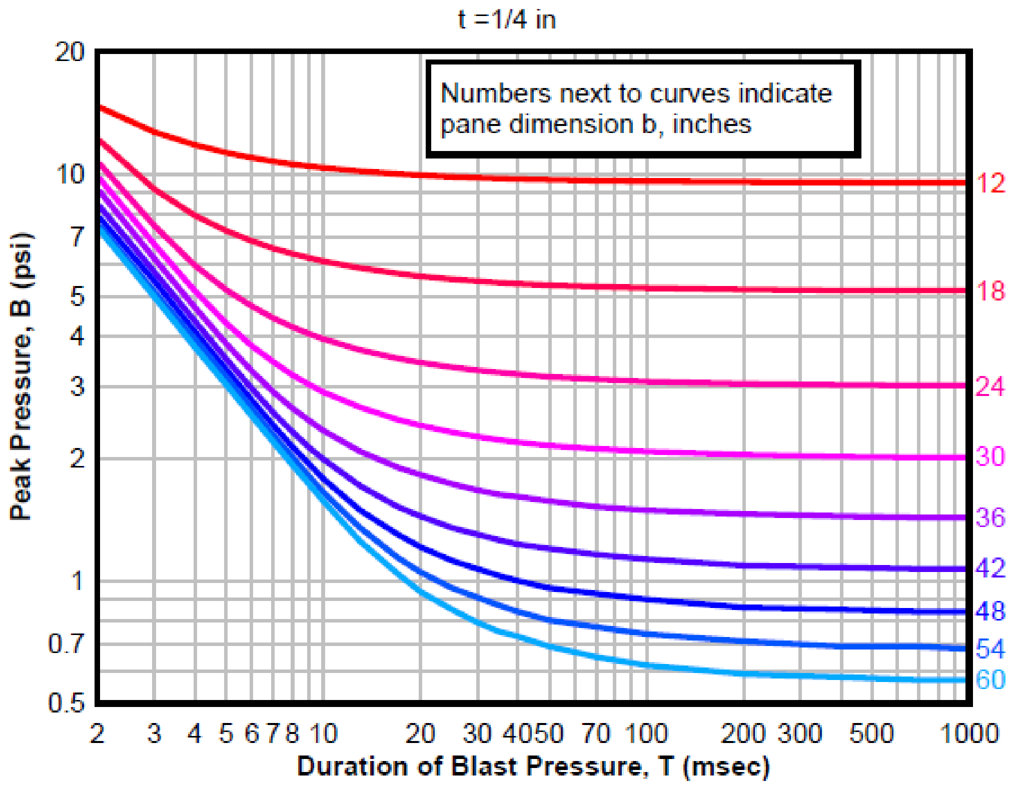
[1] Publicatiereeks Gevaarlijke Stoffen 1 (PGS 1-2B): *Effecten van explosie op constructies," Ministerie van Verkeer en Waterstaat, December 2003.*
[2] TNO, *Methods for the Determination of Possible Damage*, Green Book, Report No. CPR 16E (1989).

Consequence of Explosives Accident- Blast

GLASS RESPONSE UNDER BLAST

- ❑ Glass fragments are a major cause of injuries from accidental explosions
- ❑ Failed window glazing → higher internal pressure
- ❑ Glass window failure depends on:
- ➢ Loading profile (pressure and impulse)
- ➢ Type of glazing,
- ➢ Glazing setting,
- ➢ Dimensions of the window,
- ➢ Mechanical properties of the frame

Figure 20 Peak Blast Pressure Capacity for Tempered Glass Panes (*a*/*b* = 1.00, *t* = 1/4 and 5/16 in) [1]



[1] US Army Corps of Engineers, *Structures to Resist the Effect of Accidental Explosions, UFC 3-340-02*," Unified Facilities Criteria, December 2008.

Consequence of Explosives Accident- Blast

Human RESPONSE UNDER BLAST

- ❑ **Eardrum Rupture**
- ❑ **Lunges Injuries**

Figure 21 Human Ear Damage Due to Blast Pressure

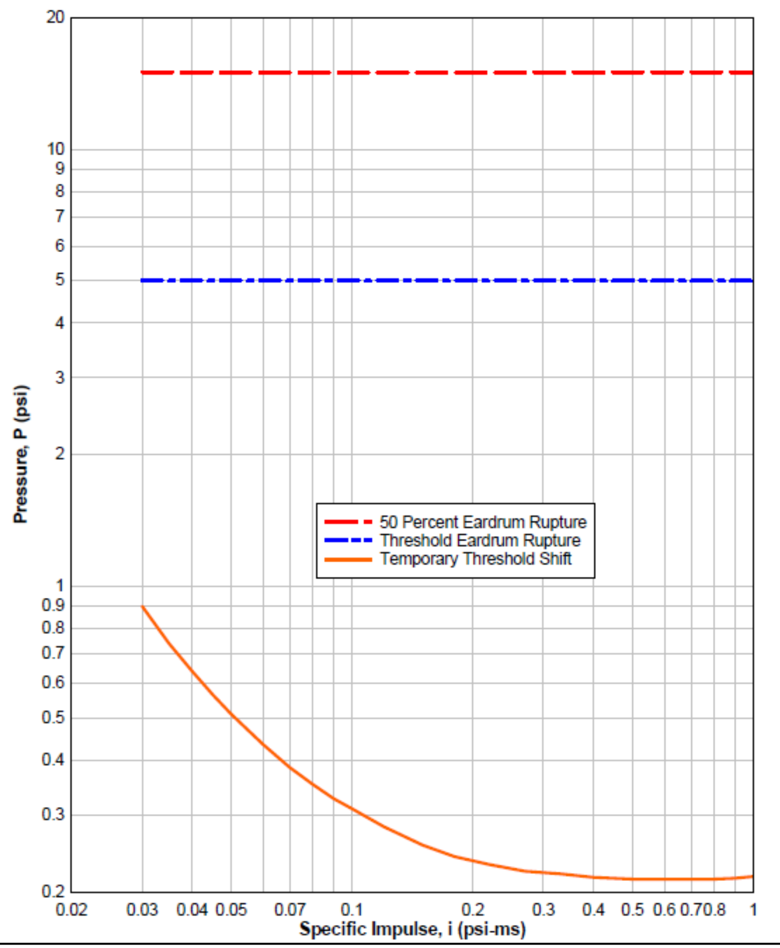
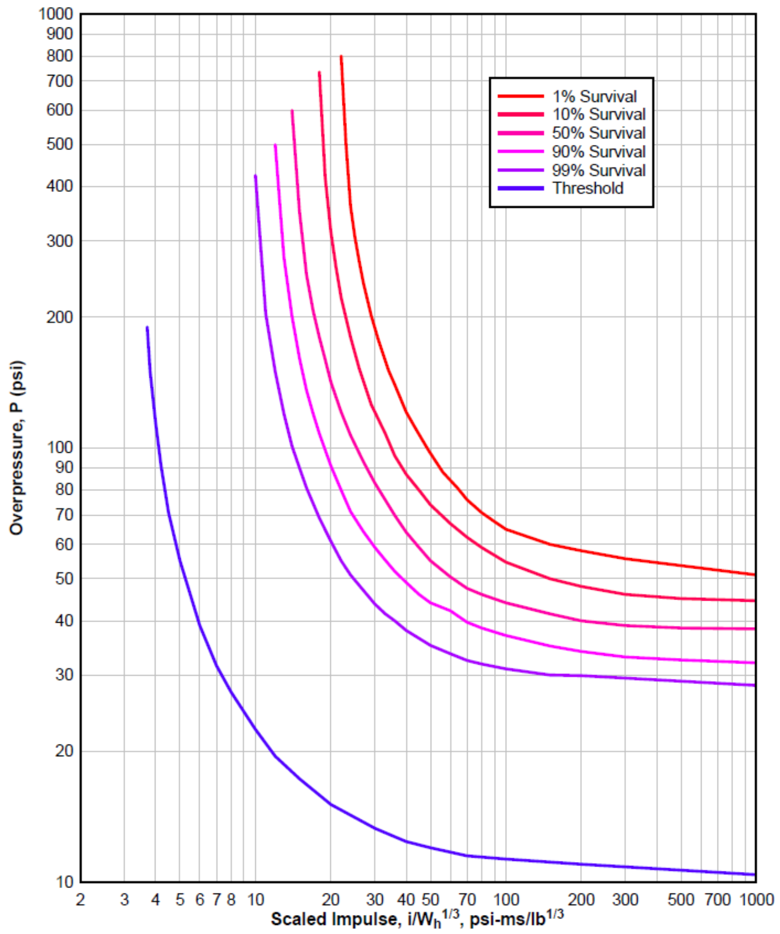


Figure 22 urvival Curves for Lung Damage, Wh = Weight of human being (lbs)



US Army Corps of Engineers, *Structures to Resist the Effect of Accidental Explosions, UFC 3-340-02*,” Unified Facilities Criteria, December 2008.

Consequence of Explosives Accident- Blast

Human RESPONSE UNDER BLAST

- ❑ **Skull Damage**
- ❑ **Body Movement**

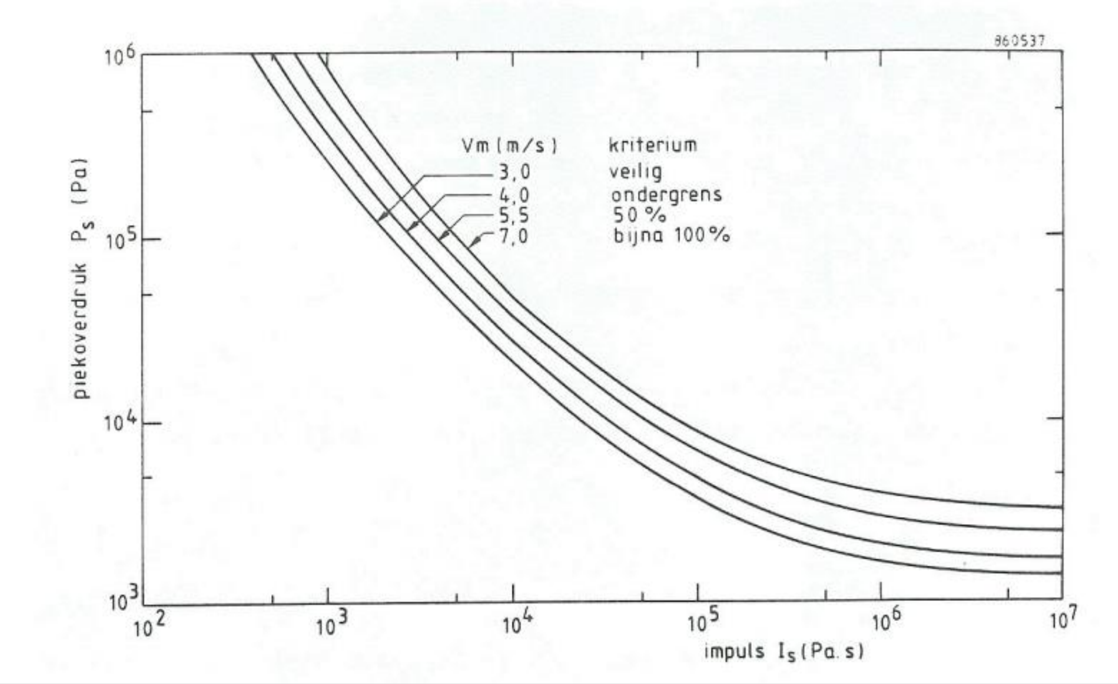


Figure 23: PI diagram for lethality from skull fracture [1].

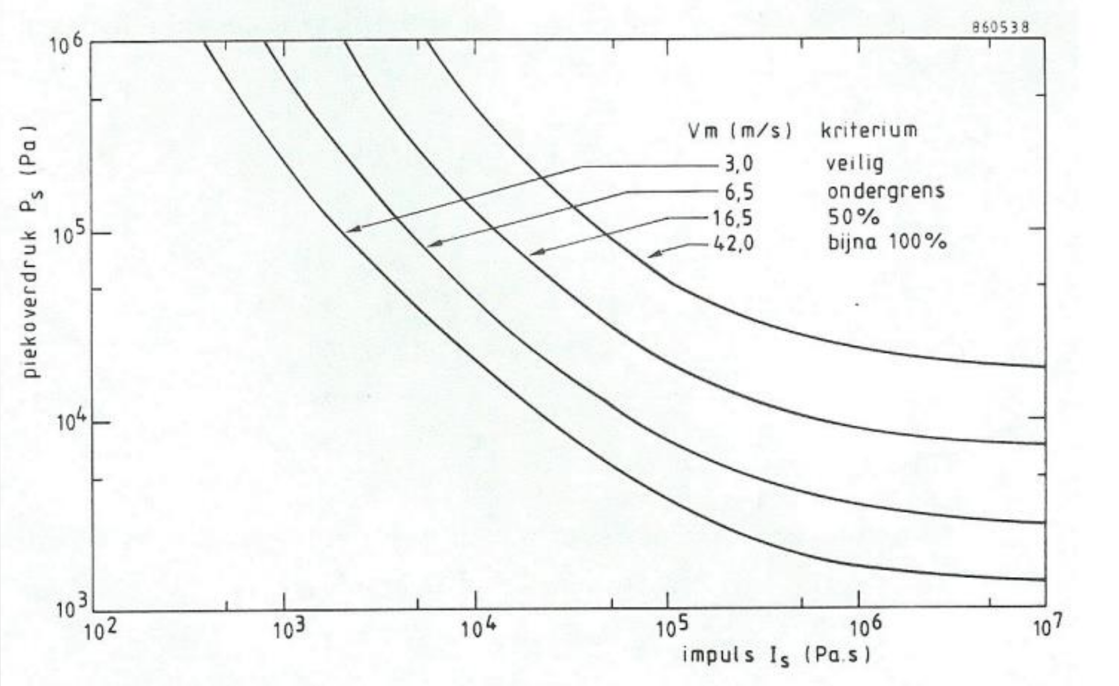


Figure 24: PI diagram for lethality from body impact [1].

[1] Publicatiereeks Gevaarlijke Stoffen 1 (PGS 1-2A): *Effecten van explosie op personen," Ministerie van Verkeer en Waterstaat, December 2003.*

Consequence of Explosives Accident- Debris

Source of Fragmentations

- **Primary Fragmentation:** Ammunition packing material (launched velocities ~1000 m/s → 1st effect reaches to the ES)
- **Secondary Fragmentation (Debris):** Structure surrounding the ammunition (storage building, container, etc.). Velocity varies from several 10 m/s up to several 100 m/s
- **Secondary Debris:** Structures far away from Ammunition (result of blast/fragmentation interaction with other structures)

Trajectory of Fragmentations

- **Low Angle:**
  - **Source:** packing and wall
  - **Velocity:** High velocity
  - **Mitigation:** Barricades

- **High Angle:**
  - **Source:** packing and roof
  - **Velocity:** terminal velocity
  - **Mitigation:** heavy roof

PES Door:

- Significantly reduce the launch velocities of the fragmentation in that direction
- Large pieces debris or a single piece

Consequence of Explosives Accident- Debris

Fragmentations Effects

- Fragmentation impact buildings cause local damage (i.e. no building collapse)
- Fragmentation impact people can serious injuries even when the fragment kinetic energy < 5 J

Threshold Of Serious Injury To Personnel Due To Fragment Impact [1]

Critical Organ	Weight (g)	Fragment Velocity (mps)	Energy (J)
Thorax	1134	3	5.4
	45	24	13.6
	0.5	122	3.4
Abdomen and limbs	2722	3	12.2
	45	23	12.2
	0.5	168	6.8
Head	3629	3	16.3
	45	30	21.7
	0.5	137	4.1

US Army Corps of Engineers, *Structures to Resist the Effect of Accidental Explosions, UFC 3-340-02*," Unified Facilities Criteria, December 2008.

Consequence of Explosives Accident- Debris

Calculating Debris and Fragmentation Risk

- Due to the complexity of determining DF risk, DFD rules in AASTP-1 will be utilised
- If individuals are located at a distance less than DFD, the severity of injuries will increase
- If the outcome of this analysis is deemed not enough, DF risk can be analysed using AASTP-4 or UFC 3-340-02

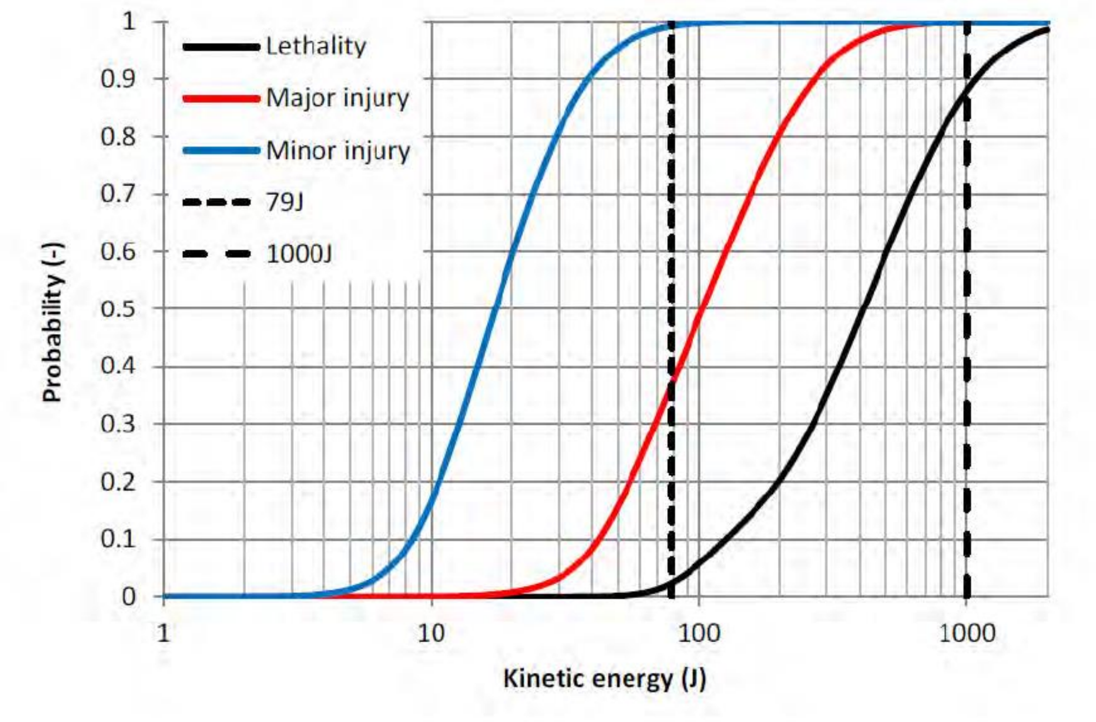


Figure 5: Probabilities of casualty given a debris impact for frontal exposure

Consequence of Explosives Accident- Debris

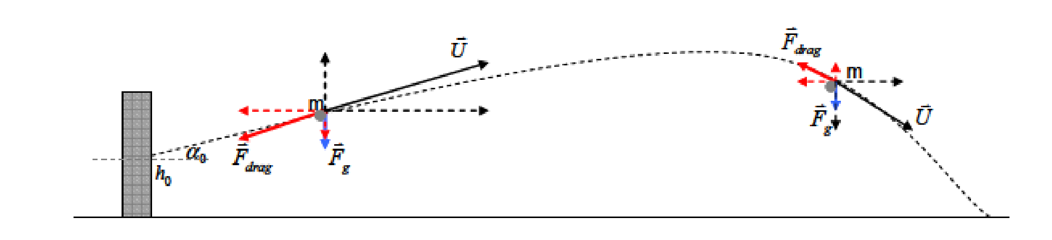
Calculating Debris and Fragmentation Risk

1) **Number of Fragments:** Fragment mass distribution is represented in the form of the cumulative distribution of the number of fragments **Nf,** individually heavier than a defined mass **Mf**, as a function of **Mf**. Such a function may be derived directly from the results obtained by testing or determined analytically using the Mott distribution.

2) **Fragment Ballistics**: If the mass distribution, angles of departure and initial velocities of fragments at the point of origin are known, trajectories, impact parameters and distribution density of the fragments can be determined. Gravity and atmospheric drag are essential parameters affecting the trajectory, which should be taken into account.

3) **Hazard Potential**: The probability of impact **Pf** of an individual fragment or a fragment flux is calculated using the area density **qf** . The impact process is assumed to be uniformly random in the vicinity of the target point, so that fragment impact is equally probable on all equal area elements in the vicinity of the point. The probability of impact **Pf** of one or more fragments of a mass **Mf** or greater on a given target area.

4) **Injury Criteria.** A variety of functions of impact velocity and fragment mass have been proposed as injury criteria. NATO-wide, a lethal fragment is defined as a fragment with a kinetic energy exceeding the critical value of **79** Joules.



NATO, *AASTP-1 Ed 1, Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives*, NSO, Brussels, May 2010

Conclusions

- QD principles are a compromise between absolute safety and NATO accepted Tolerable Risk. That risk is ‘*subjective’ and not clearly defined’.*
- QDs do not specify PES or ES in great detail so consequence outcomes will vary in terms of actual damage or injury estimations.
- The introduction of DFDs represents a significant advancement over previous set minimum distances but still have limitations.
- For the ADF, WH&S Act requires an SFARP determination, which implies a form of Risk Assessment to be conducted. (**QD is not always SFARP**)
- The proposed Risk Assessment represents the 1st step to improve the current policy in DEOP 101 (considering impulse effects, considering blast wave reflection, considering fragments and debris effects).

Questions


Satellite image ©2024 Maxar Technologies
MAXAR


MAXAR
Satellite image ©2024 Maxar Technologies (Courtesy Image)