INTERNATIONAL AMMUNITION TECHNICAL GUIDELINES

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Formulae for ammunition management

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Warning

The International Ammunition Technical Guidelines (IATG) are subject to regular review and revision. This document is current with effect from the date shown on the cover page. To verify its status, users should consult www.un.org/disarmament/ammunition

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Foreword

Ageing, unstable and excess conventional ammunition stockpiles pose the dual risks of **accidental explosions at munition sites** and **diversion to illicit markets**.

The humanitarian impact of ammunition-storage-area explosions, particularly in populated areas, has resulted in death, injury, environmental damage, displacement and disruption of livelihoods in over 100 countries. Accidental ammunition warehouse detonations count among the heaviest explosions ever recorded.

Diversion from ammunition stockpiles has fuelled armed conflict, terrorism, organized crime and violence, and contributes to the manufacture of improvised explosive devices. Much of the ammunition circulating among armed non-State actors has been illicitly diverted from government forces.[1] In recognition of these dual threats of explosion and diversion, the General Assembly requested the United Nations to develop **guidelines for adequate ammunition management**.[2] Finalized in 2011, the International Ammunition Technical Guidelines (IATG) provide voluntary, practical, modular guidance to support national authorities (and other stakeholders) in safely and securely managing conventional ammunition stockpiles. The UN SaferGuard Programme was simultaneously established as the corresponding knowledge-management platform to oversee and disseminate the IATG.

The IATG also ensure that the United Nations entities consistently deliver high-quality advice and support – from mine action to counter-terrorism, from child protection to disarmament, from crime reduction to development.

The IATG consist of 12 volumes that provide practical guidance for 'through-life management' approach to ammunition management. The IATG can be applied at the guidelines' **basic, intermediate, or advanced levels**, making the IATG relevant for all situations by taking into account the diversity in capacities and resources available. Interested States and other stakeholders can **utilize the IATG for the development of national standards and standing operating procedures**.

The IATG are reviewed and updated at a minimum every five years, to reflect evolving ammunition stockpile-management norms and practices, and to incorporate changes due to changing international regulations and requirements. The review is undertaken by the UN SaferGuard Technical Review Board composed of national technical experts with the support of a corresponding Strategic Coordination Group comprised of expert organizations applying the IATG in practice.

The latest version of each IATG module can be found at www.un.org/disarmament/ammunition.

[1] S/2008/258.

[2] See also the urgent need to address poorly-maintained stockpiles as formulated by the United Nations Secretary-General in his Agenda for Disarmament, *Securing Our Common Future* (2018).

Introduction

The nature of ammunition and explosives with their potential for unplanned, violent reaction makes it necessary to develop recommendations and guidelines for safe conventional ammunition management stockpile management. This requires, by necessity, a risk-based approach[3], which should be based on sound explosive engineering and science.

Risk management decisions based on more complete knowledge can be made if the likelihood of an explosives accident can be taken into account as well as the consequences. This requires knowledge of the range of scientifically accepted formulae that can be used to support decision-making and risk management during conventional ammunition stockpile management.

In this document a survey of the best practice models for estimation of the consequences of explosions is given.

Formulae are taken basically from two documents, which represent the state-of-the art of explosion modeling, since these documents have been developed by leading experts, who have access to the most elaborate experimental data on this topic as well as to the adequate modeling background.

These documents, which are listed in annex A are

- AASTP-1 by NATO CNAD AC326, Ammunition Safety
- DDESB Technical Paper TP-14 by US DoD Explosives Safety Board

Risk analysis is a three-step process

1) Determination of the effects of the explosion

IATG 1.80 is addressing
- ✓ Airblast
- ✓ Debris
- ✓ Ground shock
- ✓ Thermal effects

2) Determination of the consequences

IATG 1.80 is addressing
- ✓ Damage to buildings by air blast (structural damage and window breakage)
- ✓ Human vulnerability by air blast
- ✓ Human vulnerability by debris (debris from PES, debris from windows of ES, structural damage of ES)
- ✓ Damage to buildings and equipment by ground shock
- ✓ Human vulnerability by thermal effects

3) Determination of the likelihood of the consequences

IATG 1.80 is addressing
- ✓ Probability of breakage of windows and collapse of structures
- ✓ Probability of fatality, major and minor injury by air blast
- ✓ Probability of consequences for people in an ES
- ✓ Probability of consequences by debris hit, differentiating between fatality, major and minor injury

[3] IATG 02.10 *Introduction to Risk Management Principles and Processes* contains further information on risk-based approaches to conventional ammunition stockpile management.

The risk analysis is to be supported by software-tools implementing the suite of formulae.

A **level-1 toolkit** provides the blast-data of a free field air blast. Consequences are modelled on simple empirical correlations using free field blast wave peak-parameters. A level-1 tool is not capable to provide debris densities caused by a PES.

A **level-2 toolkit** is capable to provide simple modifications of the blast wave by structures (PES, barricades, ES). It is also capable to provide information on PES-related debris based on empirical correlations.
The blast wave is not only characterized by peak-values but also the decay of the blast wave is taken into consideration on calculations.
Empirical correlations are used for calculation where detailed physical modelling cannot be realized properly with reasonable efforts due to complexity.

A **level-3 toolkit** is using full mathematical and physical modelling of all parameters regarded as relevant to describe an effect or consequence.

The **SAFERGUARD toolkit** provides a complete level-1 toolkit for level-1 risk assessment.

IATG 1.80 provides all information necessary for implementation of a level-2 toolkit, which could be based on EXCEL-spreadsheets. Only AASTP-1 and DDESB TP-14 have to be consulted for some details regarding algorithms and tabulated data for empirical calculations.

Examples of such calculations are provided in ***Annex C*** on solving the ***reference scenarios.***

Formulae for ammunition management

1 Scope

This IATG module introduces and summarises scientifically proven and sound formulae that may be used to support the decision-making and risk management processes essential for the safe, efficient and effective stockpile management of conventional ammunition. Guidance on their appropriate use is either contained within this IATG module or the complementary IATG software normative references.

The following referenced documents are indispensable for the application of this module. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2 Normative references

A list of normative references is given in Annex A. These documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

A further list of informative references is given in Annex B in the form of a bibliography, which lists documents that contain additional information related to the contents of this IATG module.

Annex C contains reference scenarios which are solved by means presented in this IATG 1.80

3 Terms and definitions

For the purposes of this module the following terms and definitions, as well as the more comprehensive list given in IATG 01.40 *Glossary of terms, definitions and abbreviations,* shall apply.

In all modules of the International Ammunition Technical Guidelines, the words 'shall', 'should', 'may' and 'can' are used to express provisions in accordance with their usage in ISO standards.

a) **'shall' indicates a requirement**: It is used to indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

b) **'should' indicates a recommendation**: It is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form, 'should not') a certain possibility or course of action is deprecated but not prohibited.

c) **'may' indicates permission**: It is used to indicate a course of action permissible within the limits of the document.

d) **'can' indicates possibility and capability**: It is used for statements of possibility and capability, whether material, physical or casual.

4 Introduction - Physical effects of an explosion

When dealing with the description of the physical effects of an explosion, they are usually described as a set of several primary effects in the following way:

Air blast

This effect is made up of two events in extremely quick succession. A detonation is creating the physical phenomenon of a shock wave, which is subject to complex shock reverberations on reflection of surrounding surfaces. The generated and expanding hot gases of an explosion are producing a blast wind, which is creating a dynamic pressure on the surroundings.

Projection

This effect summarizes various sources of fragments created during an explosion. Fragmentation is generally considered to be of two types:

Primary fragments result from the shattering of material in direct contact with the explosive (eg. casing). These fragments are usually small and are launched with velocities up to 2000m/s.

Secondary debris stems from structures and other items in close proximity to the explosion, which get destroyed or just accelerated by the blast wind or from crater ejecta. This debris is usually larger in size than the primary fragments and is launched at velocities up to hundreds of m/s.

Ground shock

Ground shock is the result of coupling of the energy of explosion into the ground. Ground shock leads to localized movement of the ground or structures.

Thermal effects

Thermal effects are associated with the fireball of an explosive event and might lead to secondary fires. Thermal effects are usually less severe than damage caused by air blast and fragmentation, and therefore play only a minor role in the explosion consequence analysis.

5 Modelling of effects

5.1 Air blast

The air blast of a free field explosion of a certain TNT- equivalent on the ground is commonly the base for any further evaluation of many of the prediction models.

5.1.1. Hopkinson-Cranz scaling law

Free field TNT-air blast has thoroughly been studied by extensive trials in the past. Free field air blast follows a QD-rule, which is also well known as the Hopkinson-Cranz cube-root scaling law (table 1).

It is the basis of much of the work on the estimation of appropriate quantity and separation distances. Many States use rules based upon the explosives, their quantity, and the distance from the explosive to where people are at risk. For HD 1.1. ammunition the QD-concept is based on a pressure-related correlation.

Certain effects are associated with a certain scaled distance, which is directly related to a certain level of overpressure, determined by the Hopkinson-Cranz Scaling law (table 2). This approach is used in the QD-siting concept described in AASTP-1.

However, limitation of this approach is evident by the fact that the impulse of the blast wave is not a direct function of the scaled distance, as it is the pressure (table 3).

$(R_1/R_2) = (W_1/W_2)^{1/3}$ $R = Z.W^{1/3}$	R = Range (m) Z = Constant of Proportionality (dependent on acceptable blast overpressure) W = Explosive Weight (kg)

Table 1: Hopkinson-Cranz Scaling Law

Examples of the constant ‘Z’ used in explosive storage safety[4] are shown in table 2:

Z	Purpose	Remarks
8.0	Used to predict separation distances between ammunition process buildings (APB) within an explosive storage area (ESA).	▪ Additionally minimum safe distances further apply if R is below a certain level, which differs for each ‘Z’ function.
14.8	Used to predict separation distances between an explosive storehouse (ESH) and a public traffic route with civilian access.	
22.2	Used to predict separation distances between an explosive storehouse (ESH) and a building inhabited by civilians.	
44.4	Used to predict separation distances between an explosive storehouse (ESH) and a vulnerable building inhabited by civilians (e.g. a school).	

Table 2: Examples of Constant ‘Z’

[4] These are the default ‘Z’ settings in the IATG Software, although the software does allow the user to input alternative ‘Z’ values.

Further details on the practical use of this formula are contained within IATG 02.20 *Quantity and separation distances*. A complementary IATG software can be found on the UN SaferGuard Website[5].

Amount of explosive [kg]	Distance [m]	Scaled distance	Incident pressure [bar]	Incident impulse [bar ms]	Positive phase duration [ms]
1000	222	22,2	0,054	1,43	61,1
8000	444	22,2	0,054	2,87	122
64000	888	22,2	0,054	5,74	244

Table 3 – Example of application of the scaling rules

The overpressure is calculated with empirical formulae for the description of a blast-wave. The most recognized approaches used in engineering tools are either the formulae developed by Kingery and Bulmash[6] or the formulae by Kinney and Graham. The Kinney-Graham[7] formulae are validated for larger scaled distances, up to Z=500; whereas the Kingery-Bulmash data set is limited to Z=40.

The formulae developed by Kingery and Bulmash for hemispherical surface burst are well established in engineering tools, and are implemented in popular engineering tools as well as the AASTP-1 QD-concept. The Kinney-Graham approach is also scientifically recognized, but the data are derived from spherical air bursts.

Therefore, the Kingery-Bulmash description of a hemispherical surface burst is chosen for the description of relevant blast wave parameters in IATG 1.80.

5.1.2. Blast wave description by Kingery and Bulmash

The characteristic parameters of a blast wave which are needed for further calculation of blast effects are:

Incident pressure: this is the peak pressure of the freely expanding blast wave

Reflected pressure: this is the pressure an object is experiencing, which is situated in front of a large obstacle perpendicular to the direction of expansion of the blast wave

Dynamic pressure: this is the additional pressure an object positioned in the flow of the blast wave is experiencing, due to the forces exerted by the blast wind caused by the expanding gases.

Incident impulse and **reflected impulse** are the corresponding acting impulses of the blast wave.

Further characterizing parameters provided by the Kingery-Bulmash empirical equations are the **time of arrival of the shock front** at a certain distance, the **duration of the positive phase of the blast wave** and the **velocity of the shock wave.**

These essential physical parameters of the blast wave have been made readily available by empirical formulae developed by Kingery and Bulmash. These equations are widely accepted as engineering

[5] https://www.un.org/disarmament/un-saferguard/

[6] Kingery, C. N. and Bulmash, G., Airblast Parameters From TNT Spherical Air Bursts and Hemispherical Surface Bursts, ARBRL-TR-02555, April 1984.

[7] G. Kinney, G. Graham. Explosive Shocks in Air, 1985, Springer.

predictions for determining free-field pressures and loads on structures and form the basis of the US Conventional Weapons Effects Programme (CONWEP) software. Their report[8] contains a compilation of data from explosive tests using charge weights from less than 1kg to over 400,000kg. There are datasets for a spherical burst in free air and for a hemispherical surface burst. The airblast of a ground detonation, as an incident at a storage facility would be, is described by the hemispherical surface burst data which are given below.

The authors used curve-fitting techniques to represent the data with high-order polynomial equations (see Table 4), which are included in the accompanying software to the IATG[9] for ease of application.

T = common logarithm of the distance in m **$U=K_0+K_1*T$** **$Y = C_0 + C_1U + C_2U^2 + C_3U^3 \ldots\ldots\ldots C_nU^n$**	Y = Common Logarithm of the Air Blast Parameter (metric) *(Pressure or Impulse)* $C_{0,1,2\ etc}$ = Constant $U = K_0 + K_1T$ $K_{0,1\ etc}$ = Constant T = Common Logarithm of the Distance (m)

Table 4: Kingery and Bulmash general polynomial form

The coefficients for calculation of the blastwave-parameters are provided in AASTP-1, table 5-5. Examples of results of the calculation are provided in table 5 below.

Amount [kg]	**1000**	**10000**	**100000**
Distance [m]	50	50	50
Scaled distance	5	2,32	1,078
Incident pressure [bar]	0,43	2,02	11,5
Incident impulse [bar ms]	5,9	25,2	106
Dynamic overpressure [bar]*)	0,062	1,12	17,9
Reflected pressure [bar]	1,01	6,8	66,5
Reflected impulse [bar]	12,6	65,5	372
Duration of positive phase [ms]	37,9	46,8	93
Arrival time of shock wave [ms]	82,4	48,1	24,8
Velocity of the shock wave [m/s]	398	559	1114

*) the dynamic overpressure is derived from the relation in table 6

Table 5: Examples of calculated blast wave parameters by Kingery-Bulmash formulae

[8] *Charles N Kingery and Gerald Bulmash*. Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst, US Technical Report ARBRL-TR-02555. Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, USA. April 1984.

[9] https://www.un.org/disarmament/un-saferguard/kingery-bulmash/

$P_{dyn}=5/2*P_i^2/(7*P_a+P_i)$	P_{dyn}=dynamic pressure P_i = incident pressure P_a=ambient pressure

Table 6: Calculation of dynamic pressure

5.1.3. Scaling law for atmospheric conditions

In the case of blast waves from explosions produced at altitude, where ambient conditions can be very different from those at sea level, the most commonly used scaling law is that due to Sachs.[10] The application of the Sachs scaling law leads to the formulation of altitude scaling factors.

Scaled Distance at Altitude 'z' $S_{dz} = (P_0/P_z)^{1/3}$ *Scaled Pressure at Altitude 'z'* $S_{pz} = (P_z/P_0)$ *Scaled Impulse at Altitude 'z'* $S_{iz} = (P_z/P_0)^{2/3} \cdot (T_0/T_z)^{1/2}$ *Scaled Impulse at Altitude 'z'* $S_t = (P_0/P_z)^{1/3} \cdot (T_0/T_z)^{1/2}$	S_{dz} = Scaled Distance at Altitude 'z' (m) P_0 = Ambient Pressure (kPa) (101.33kPa) P_z = Pressure at Altitude 'z' (kPa) S_{pz} = Scaled Pressure at Altitude 'z' (kPa) S_{iz} = Scaled Impulse at Altitude 'z' (kg.m/s) T_0 = Ambient Temperature (K) (288.16^{0}K) T_z = Temperature at Altitude 'z' (K) S_t = Scaled Times at Altitude 'z' (s)

Table 7: Sachs scaling factors

Example: 100000kg at 50m distance in altitude 2000 (Table 8):

Amount of explosive [kg]	100000	100000
Distance [m]	50	50
Altitude above sea [m]	0	3000
Scaled distance	1,08	1,08
Incident overpressure [bar]	11,5	7,99
Incident impulse [bar ms]	106	86,1
Dynamic overpressure [bar]*)	17,9	12,4
Reflected overpressure [bar]	66,5	46,0
Reflected impulse [bar]	372	301
Duration of positive phase [ms]	93	109

Table 8: Altitude correction of blast parameters by Sachs scaling law

[10] *Sachs R G*. The dependence of Blast on Ambient Pressure and Temperature. Technical Report 466. Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, USA. May 1944.

5.1.4. Pressure reflexion coefficient dependency on angle of incidence

The calculated reflected pressure is valid for a surface perpendicular to the direction of the wave, which is the most severe case in terms of loading.

The reflected pressure decreases with increasing angle of incidence but not monotonically. It is a function of the height of the pressure and the incident angle. Reflection coefficient dependency on angle of incidence is provided in UFC-3-340-02[11], table 2-193.

For small overpressures (incident pressure below 1bar) there is a maximum at higher incident angles, which can exceed the perpendicular reflected pressure by 50%.
For higher overpressures there is a maximum of the reflection factor in the region between 40-50° For these cases the use of the perpendicular reflected overpressure is a save conservative assumption.

Amount of explosive [kg]	1000	1000	1000	1000
Distance [m]	5	10	20	50
Scaled distance	4,93	15,65	46,05	234
Incident overpressure [bar]	50	5,0	0,50	0,05
Incident angle	Refl. Overpressure [bar]			
0° (perpendicular)	**408**	22,5	**1,18**	**0,10**
10°	390	22,0	1,18	0,10
20°	363	21,1	1,17	0,10
30°	330	20,1	1,17	0,10
40°	296	20,2	1,17	0,10
45°	**358**	17,1	1,32	0,10
50°	312	13,6	**1,41**	0,10
55°	227	11,2	1,37	0,10
60°	150	9,6	1,17	0,11
70°	65	7,3	0,87	**0,14**
80°	50	6,0	0,66	0,098
85°	50	5,4	0,58	0,069

Table 9: Dependency of the reflected pressure on angle of incidence and pressure level – example for a 1000kg explosion

5.1.5. TNT equivalence

The formulae for blast wave characterization have been developed for TNT. In the explosives community it is a common strategy to determine a TNT-equivalent for the type of explosive of concern to use the Kingery-Bulmash TNT-blast formulae.

TNT-equivalency is not a precisely defined property, however. There exist coefficients derived by experiment as well as theoretically justified approximations. To provide a standardized approach, TNT-equivalents for several types of explosives are tabulated below (table 10), taken from AASTP-1, Table 5-2.

[11] UFC-3-340-02, *Structures to Resist the Effects of Accidental Explosions*. US Department of Defense. 05 December 2008; Change 2, 01 September 2014

Explosive	TNT Equivalent Mass		Pressure Range (MPa)
	Peak Pressure	Impulse	
ANFO	0,82	0,82	0.007 – 0.700
Composition B	1.11	0.98	0.035 - 0.350
Composition C4	1.37	1.19	0.070 - 0.700
H-6	1.38	1.15	0.035 -0.700
Octol 75/25	1.06	1.06	Estimate
Pentolite	1.42	1.00	0.035 - 0.700
PETN	1.27	1.11	0.035 - 0.700
RDX	1.14	1.09	--
RDX / TNT 60/40 (Cyclotol)	1.14	1.09	0.035 - 0.350
Tetryl	1.07	--	0.021 - 0.140
TNT	1.00	1.00	Standard
Torpex II	1.23	1.28	--
Tritonal 80/20	1.07	0.96	0.035 - 0.700

Table 10: TNT Equivalence (data taken from AASTP-1, Table 5-2)

A TNT-equivalent based on tabulated heats of detonation is provided in UFC-3-340-02, Table 2-1. To give an impression on variability of TNT-equivalence depending on the approach, table 11 is provided below.

Explosive	TNT Equivalent Mass	
	Heat of detonation	TNT equiv.
Baratole	1.04	0,53
Composition B	2.15	1,09
Composition C4	2.22	1,13
HMX	2.27	1,15
Pentolit 50/50	2.14	1,09
PBX 9407	2.24	1,14
PETN	2.31	1,17
RDX	2,27	1,15
Tetryl	2,11	1,07
TNT	1,97	1,00
NQ	1.49	0,76
NG	2.22	1,13

Table 11: TNT Equivalence (data taken from UFC-3-340-02, Table 2-1)

5.2 Modification of blast by Potential Explosion Site (PES)

If a detonation occurs within a building, the propagation of the blast wave will be obviously reduced, as part of the energy is consumed by damaging the surrounding structure.

Based on analysis of large data sets, empirical correlations for attenuation of a blast wave by surrounding structures have been derived for certain types of buildings, which are provided in DDESB TP-14, chapter 4.2.2. The amount of explosive is adjusted by a weight coefficient derived from table A-5 and the pressure and impulse is recalculated with the adjusted weight. For hollow clay tile buildings ad pre-engineered buildings are assumed to provide no blast reduction.

DDESB TP-14 assesses the following types of PES buildings:

Open	
ECM small concrete arch	ECM=earth covered magazine
ECM medium concrete arch	
ECM large concrete arch	
ECM small steel arch	
ECM medium steel arch	
ECM large steel arch	
AGBS small	AGBS=above ground brick structure
AGBS medium	
AGBS large	
PEMB	PEMB=Pre-engineered metal building
Hollow clay tile	
OB small concrete building	OB=office building
OB medium concrete building	
HAS	HAS=Hardened aircraft shelter
Small ship	
Medium ship	
OB medium concrete weak front	
ISO Container	

Table 12: PES building types defined in DDESB TP-14

5.3 Modification of blast by an exposed site (ES)

5.3.1. Blast load on a cuboid structure without significant venting openings

For determination of the blast effect on a nearby building, also several modifying effects have to be considered.

The forces imparted to an above ground structure can be divided into four general components:

- Forces resulting from the incident pressure
- Forces associated with the dynamic pressure
- Forces resulting from the reflection of the incident pressure impinging upon an interfering surface
- Pressures associated with the negative phase of the shock wave.

A simplified approach for the positive pressure phase is provided in AASTP-1, which is outlined below. A more detailed approximation for the total pressure history is given in UFC-3-340-01, chapter 2.15-3.

Assumptions for the following calculations are (see also figure 1):

- ✓ The structure has a rectangular shape
- ✓ The structure is in the region of the Mach stem and the Mach stem is extending the height of the building, which means that the blast wave can be assumed as a uniform perpendicular wave approaching the structure

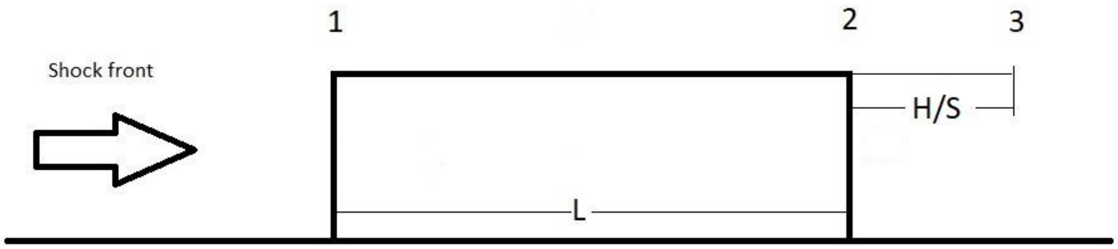

Figure 1 – Blast load on a cuboid structure

The characteristic air blast parameters needed (Kingery-Bulmash equations) at Position 1, 2, 3 (Figure 1) are (x…Position 1 ,2 or 3)

- ✓ Incident peak pressure ($P_{i,x}$)
- ✓ Incident impulse ($I_{i,x}$)
- ✓ Reflected peak pressure ($P_{r,x}$) (position 1 only)
- ✓ Reflected impulse ($I_{r,x}$) (position 1 only)
- ✓ Time of arrival ($t_{a,x}$)
- ✓ Duration of positive phase ($t_{o,x}$)
- ✓ Shock front velocity (U_x)
- ✓ Blast wave length of positive phase ($L_{w,x}$) (approximated as U_x*$t_{o,x}$)

Parameters of the building:

L…length of building
D…position of maximum loading of structural element (usually midpoint of span of element)
H…height of building
W…building width
S…clearing distance (height or 0,5*W, whichever is the smaller value)

Front face load:

$t_{of,1}=2*I_{i,1}/P_{i,1}$	$t_{of,1}$=fictitious duration of positive phase
$L_{w,1}=U_1*t_{o,1}$	
$t_r=2*I_{r,1}/P_{r,1}$	tr=duration of reflected pressure
$q_{o,1} = 5/2*P_{i,1}{}^2/(7*P_a+P_{i,1})$	$q_{o,1}$=dynamic pressure at point 1 P_a=ambient pressure (1,023bar)
$I_{q,1}=0,5*q_{o,1}*t_{of,1}$	$I_{q,1}$=dynamic impulse at point 1
$I_d=C_{D1}*I_q$	C_{D1}=drag coefficient (=1,0)
$t_s=MIN\ (t_{s*},t_c)$ $t_{s*}=(P_{r,1}*t_{r,1}-(P_{i,1}+C_{D1}*q_{o,1})_{*to,1}/(P_{r,1}-(P_{i,1}+C_{D1}*q_{o,1})$ $t_c=3*S/U_1$	t_s= time at point of intersection between reflected pressure and combined side-on/drag pressure t_c=clearing time (of reflected pressure)
$Ir*=0,5*(P_{r,1}-P_{i,1}-C_{D1}*q_{o,1})*t_s$ $I=I_{s,1}+I_d+I_{r,1}$	
Pressure waveform: **$0\leq t<t_s$: $P_{(t)}=P_{r*}*(1-1/t_s)+(P_{i,1}+C_{D1}*q_{o,1})*(1-1/t_{of,1})$** $P_{r*}=P_{r,1}-P_{i,1}-C_{D1}*q_{o,1}$ **$t_s\leq t\leq t_{of,1}$: $P_{(t)}=(P_{i,1}+C_{D1}*q_{0,1})*(1-t/t_{of,1})$**	

Table 13: Calculation of front wall load

Side wall (at midpoint):

$t_{of,2}=2*I_{i,2}/P_{i,2}$	
$t_{2,eff}=t_{a,2}-t_{a,1}+t_{of,2}$	$t_{2,eff}$=effective duration of positive phase
$L_{w,2}=U_2*t_{o,2}$	
$C=L_{w,2}/L$ $\mathbf{C_2}=0{,}0048*C^5-0{,}0584*C^4+0{,}2817*C^3-0{,}6963*C^2+0{,}9551*C+0{,}2433$ $D/L=0{,}0098*C^5-0{,}1203*C^4+0{,}5682*C^3-1{,}3207*C^2+1{,}6217*C-0{,}0774$ $\mathbf{D}=L*D/L$ $t_{d2}=D/U_2$	
$q_{o,2} = 5/2*P_{i,2}^2/(7*P_a+P_{i,2})$	
$P_o=C_2*P_{i,2}+C_{D2}*q_{o,2}$ $I_s=0{,}5*P_o*t_{2,eff}$	$C_{D2}=-0{,}4$ (Drag coefficient)
Pressure waveform: $\mathbf{0\leq t<t_{d2}: P_{(t)}=P_o*t/t_{d2}}$ $\mathbf{t_{d2}\leq t\leq t_{2,eff}: P_{(t)}=P_o*(1-t*t_{d2}/(t_{2,eff}-t_{d2}))}$	

Table 14: Calculation of side wall load

Rear wall:

$t_{of,3}=2*I_{i,3}/P_{i,3}$	
$t_{3,eff}=2*H/(U_2+U_3)+t_{of,3}$	$T_{3,eff}$=effective duration of positive phase
$L_{w,3}=U_3*t_{of,3}$	
C=Lw,3/H $\mathbf{C_3}=0{,}0048*C^5-0{,}0584*C^4+0{,}2817*C^3-0{,}6963*C^2+0{,}9551*C+0{,}2433$ $D/L=0{,}0098*C^5-0{,}1203*C^4+0{,}5682*C^3-1{,}3207*C^2+1{,}6217*C-0{,}0774$ $\mathbf{D}=H*D/L$	
$t_{d3}=D/U_2$	
$q_{o,3} = 5/2*P_{i,3}^2/(7*P_a+P_{i,3})$	
$P_o=C_3*P_{i,3}+C_{D3}*q_{o,3}$ $I_s=0{,}5*P_o*t_{3,eff}$	$C_{D3}=-0{,}4$ (Drag coefficient)
$\mathbf{0\leq t<t_{d3}: P_{(t)}=P_o*t/t_{d3}}$ $\mathbf{t_{d3}\leq t\leq t_{3,eff}: P_{(t)}=P_o*(1-t*t_{d3}/(t_{3,eff}-t_{d3}))}$	

Table 15: Calculation of rear wall load

5.3.2. Blast inside of an exposed building

DDESB TP-14 provides also a method for estimation of the pressure inside a building, described in chapter 4.2.3. A reduction level for pressure is calculated from the percentage of glass of the building walls and the percentage of damage to the windows. This model does not discriminate between different type or quality of windows.

The maximum reduction level is assumed with 50% if all windows remain undamaged, and is gradually reduced to 0% at 25% percentage of glass.

As a building parameter, the vent area to building volume ratio is introduced. The slope of the reduction is determined from a function of pressure and explosive weight.

The following information on ES building is required:

- ✓ Building type
- ✓ Percentage of glass
- ✓ Floor area

DDESB TP-14 assesses the following types of ES:

Small reinforced concrete	
Medium reinforced concrete	
Large reinforced concrete tilt-up	
Small reinforced masonry	
Medium reinforced masonry	
Small unreinforced brick	
Medium unreinforced masonry	
Large unreinforced masonry	
Small PEMB	PEMB=Pre-engineered metal building
Medium PEMB	
Large PEMB	
Small wood frame	
Medium wood frame	
Medium steel stud	
Wood frame trailer/building	
Moving vehicle	
Stationary vehicle	

Table 16: ES building types defined in DDESB TP-14

5.4 Blast reduction by barriers

AASTP-1 gives a short notice on blast reduction by barriers: significant shielding effects are only occurring up to scaled distances of about 1 $m/kg^{1/3}$ and the effects are difficult to quantify.

On the other hand, there is documentation of shielding effects of buildings in certain configurations leading to blast reduction up to 50% at the front side of the shielded building and vice-versa enhancement by reflection effects on the rear wall of the shielding building[12].

Zhou and Hao[13] have developed an empirical model based on analysis of an experimental database and validation with CFD-methods. Parameters are:

- W=amount of explosive, ranging from 10 to 10000kg,
- R= distance between PES and ES, ranging from 5 to 50m,
- H_{ES} = height of ES, from 3 to 40m
- H_B = height of the blast wall from 1 to 4 m; thickness in the dimension of 0,25m
- L = distance between PES and barrier, ranging from 1 to 40m.

The L/R ratio of the database ranged from 0,2 to 0,8.

The model provides information of distribution and peak values of reflected pressure and impulse on the front side of a building, effected by a barricade.

Input parameters are incident pressure and impulse, reflected pressure and impulse for the free-field configuration (derived for W and D from Kingery-Bulmash equations) distance between PES and ES (D), height (H_B) of barricade, height of building (H_{ES}), and distance L between PES and barricade.

AP_{max}=-0,1359+(0,3272+0,1995*lg(H_B/R))*lg Z – 0,5626 *lg(H_B/R)+ +0,4666*L/R	AP_{max}=maximum pressure reduction coefficient Z=R/$W^{1/3}$ lg=common logarithm
AI_{max}=0,0274+(0,4146+0,2393*lg(H_B/R))*lg Z – 0,5044*lg (H_B/R)+ +0,2538*L/R	AI_{max}=maximum impulse reduction coefficient
(HP_{min}-H_B)/R = -0,4275+0,0366*lg Z-0,4043*lg(H_B/R)-0,1709*lg(L/R)	HP_{min}=height of minimum of pressure
AP_{min}/AP_{max}=-0,0284+0,244*lgZ-0,4302*lg(H_B/R)-0,3475*lg(L/R)	AP_{min}=reduction coefficient for pressure minimum
(HI_{min}-H_B)/R=-0,2474+0,1084*lgZ-0,2450*lg(H_B/R)-0,2377*lg(L/R)	HI_{min}=height of minimum of impulse
AI_{min}/AI_{max}=0,3196+0,2154*lgZ-0,3171*lg(H_B/R)-0,2013*lg(L/R)	AI_{min}=reduction coefficient for impulse minimum
HP_{max}/R=1,0995-0,0105*lgZ+0,7806*lg(H_B/R)-0,4109*lg(L/R)	HP_{max}=maximum height of pressure reduction
HI_{max}/R=1,1994-0,0843*lgZ+0,8329*lg(H/R)-0,1841*lg(L/R)	HI_{max}=maximum height of impulse reduction

Table 17: Calculation of pressure and impulse reduction by barricades

[12] *A. Remennikov*, The state of the art of explosive loads characterization,2007, 1-25. https://ro.uow.edu.au/engpapers/4245.

[13] *X.-Q. Zhou, H. Hao*, Prediction of air blast loads on structures behind a protective barrier, International Journal of Impact Engineering, 35(5), 363-375, 2008.

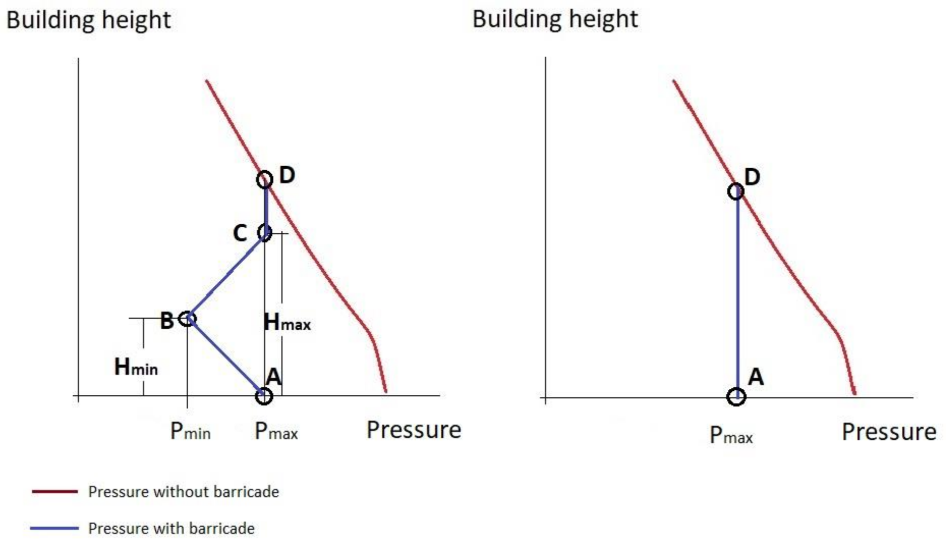

Figure 2 – Simplified profile of pressure and impulse reduction by barricades

For $(R\text{-}L)/H_B<4$, a local minimum of blast load occurs and the pressure and impulse profile on the building front is approximated by a curve according to the left side of figure 2.

For $(R\text{-}L)/H_B>4$ there is no local minimum and the pressure and impulse profile is following the curve on the right side of figure 2.

5.5 Fragments and debris

The throw of fragments and debris is often a dominant effect in explosion events. The Q-D concept for determination of safe distances is based on blast levels only. The throw of fragments and debris is only considered indirectly, as a certain hazard from throw is related in a very generalized way with a certain amount of explosive.

Therefore, models are needed for a more detailed characterization of fragments and debris generated by an explosion.

One tool is the calculation of trajectories for a representative choice of fragments and debris.

5.5.1. Trajectory calculation

Trajectories can be calculated by basic physical equations:

The model used in the ECA-tool (to be provided) takes into account gravity and drag forces and is considering dependency on density of air and of drag-coefficient on velocity. The tool is meant for irregularly shaped objects accelerated by explosion and does not consider spin-stabilized projectiles. The drag coefficient for natural fragments as provided in AASTP-1(Table 5-9) is chosen as a default.

Mach number	Drag coefficient
0.1 – 0.2	0.85
0.2 – 0.4	0.86
0.4 – 0.6	0.90
0.6 – 0.8	1.10
0.8 – 1.0	1.25
1.0 – 1.1	1.33
1.1 – 1.2	1.415
1.2 – 1.3	1.42
1.3 – 1.4	1.40
1.4 – 2.8	1.29
2.8 – 5.6	1.15
5. – 11.2	1.115

Table 18: Drag coefficient dependency on Mach number for natural fragments (fom AASTP-1, table 5-9)

Parameters to be provided for calculation are:

- ✓ Initial velocity of the fragment
- ✓ Shape of the fragment (approximated as a cuboid)
- ✓ Density of the fragment (or weight)
- ✓ Drag coefficient (to be chosen from given selection)

A full trajectory calculation needs to solve the following coupled differential equations.

General equation: $dU/dt=1/m*(F_{drag}+F_g)$	F_{drag}=drag force F_g=Gravity U=current velocity of the fragment (vector) t=time of travel of the fragment m=mass of the fragment
With u as the radial and v as the vertical component of the velocity vector U the equation can be written as two coupled differential equations:	
$du/dt=-\kappa*(u^2+v^2)^{1/2}*u$ $dv/dt=-\kappa*(u^2+v^2)^{1/2}*v-g$	K=ballistic coefficient (kg/m³) g=gravity constant
$K=S_n*\rho_a*C_D/(2*\rho_m^{2/3}*m^{1/3})$	S_n=shape number (2 for irregularly shaped fragments) ρ_m =material density of the fragment m=mass of the fragment C_D=drag coefficient (depending on velocity, see table 18)

Table 19: Trajectory calculation

5.5.2. Initial Fragment velocity

The *Gurney Equations*[14] are a range of formulae used in explosives engineering to predict how fast an explosive will accelerate a surrounding layer of metal or other material when the explosive detonates. This determines how fast fragments are released on detonation of an item of ammunition. This initial fragment velocity can then be used with other ballistic equations to predict either danger areas or fragment penetration. A popular model for the prediction of launching velocity of ammunition casing is the Gurney equation. The model assumes a material with high tensile strength, cast iron as a brittle material is not really covered by the model; according to literature the velocity for brittle iron achieves only 80% of the calculated values.

Cylindrical Charge Equation[15] $(V/\sqrt{2E}) = ((M/C_{exp}) + \frac{1}{2}))^{-1/2}$ *Spherical Charge Equation*[16] $(V/\sqrt{2E}) = ((M/C_{exp}) + 3/5))^{-1/2}$	V = Initial Fragment Velocity (m/s) √2E = Gurney Constant for a given explosive (m/s) M = Total mass of casing (kg)[17] C_{exp} = Explosive Charge Mass (kg)

Table 20: Gurney Equations[18]

The Gurney Constant √2E is usually very close to 1/3 of the Detonation Velocity of the explosive. Table 21 contains the Gurney Constants for a range of high explosives:[19]

[14] *Gurney, R. W*. The Initial Velocities of Fragments from Bombs, Shells, and Grenades, BRL-405. Ballistic Research Laboratory, Aberdeen, Maryland. USA. 1943.

[15] First order approximation for most high explosive artillery shells, mortar bombs and missile warheads.

[16] Use for military grenades and some cluster bomblets.

[17] For an artillery shell this is usually the base for which an estimate of mass is made from the total body mass.

[18] There are other Gurney equations for symmetrical, asymmetrical, open faced and infinitely tamped sandwiches. These are beyond the scope of this IATG and have hence been excluded.

[19] Densities and detonation velocities are approximate as explosive mixtures vary.

Explosive [20]	Density (kg/m³)	Detonation Velocity [21] (m/s)	Gurney Constant √2E (m/s)
Composition B	1.61	7,620	2,774
Composition C4	1.71	8,200	2,530
Octol 75/25	1.81	8.640	2,896
PETN	1.78	8,260	2,926
RDX	1.81	8,700	2,926
RDX / TNT 60/40 (Cyclotol)	1.68	7,800	2,402
Tetryl	1.71	7,570	2,499
TNT	1.61	6,900	2,438
Tritonal 80/20	1.70	5,480	2,316

Table 21: Gurney Constant for different explosives

5.5.3. Mass distribution of the fragments of ammunition casings

The Mass distribution of the fragments of ammunition casings is described by Mott´s equation, one of the earliest models. The model deals with a grenade as an expanding cylinder causing tensile stress and experiencing a tensile relief on fracture surfaces. Readily available data usually refer to mild steel as a casing material.

$N(m) = M_o/2*M_K^2*\exp(-m^{1/2}/M_K)$	N(m)=Number of fragments with mass larger than m M_o= Mass of the metal cylinder (lbs) M_K…..distribution factor
$M_K = B*t^{5/16}*d^{1/3}*(1+t/d)$	B=specific constant for a given explosive-metal pair (Mott Constant) t…wall thickness (inch) d…inside diameter of a cylinder (inch)
$N_t=M_o/2/M_K^2$	N_t=total number of fragments
$M_{av}=2*M_K^2$	M_{av}=average mass of the fragments

Table 22: Calculation of fragment distribution by Mott´s equation

Table 23 contains the Mott Constants for a range of high explosives:

[20] Details on a wide range of explosives can be found in the App “eXdata”.

[21] The detonation velocity will vary dependent on the methodology used to measure it. This column includes examples.

Explosive [22]	**Mott coefficient for Mild Steel Cylinders ($lb^{1/2}in^{-7/16}$)**
Composition B	0.0554
H-6	0.0690
Pentolite	0,0620
RDX	0.0531
Tetryl	0.0682
TNT	0.0779

Table 23: Mott´s Constant for different explosives

5.5.4. Launch velocity and mass distribution of debris (reinforced concrete)

5.5.4.1. Launch velocity

The launch velocity as well as the mass distribution of debris of reinforced concrete structures, demolished by the blast can be estimated according to the formula developed by Van der Voort and Weerheijm[23].

$DLV = C *(NEQ/V^{2/3}/t/\rho)^{1/2}$	DLV=Debris Launch Velocity C=Constant (525m/s) T=wall thickness NEQ=net explosive weight (TNT-equivalent) V=room volume ρ = density of wall material

Table 24: Launch velocity of concrete debris

5.5.4.2. Length distribution of debris

The length distribution of concrete debris from exploding reinforced concrete structures can be described by a generalized Mott distribution (Van der Voort and Weerheijm).

$N(L)=N/L_{av}*\exp(-L/L_{av})$	N(L)=Number of fragments with length larger than L L_{av}=average length of debris
$M_{av}=6* \rho*L_{av}^3$	M_{av}=average mass of debris ρ= material density of debris
$N=M/M_{av}$	M=total mass of debris

Table 25: Length distribution of concrete debris

[22] Details on a wide range of explosives can be found in the App "eXdata".

[23] *M.M. van der Voort, J. Weerheijm*, A statistical descriptionn of explosion produced debris disperion, Inteernational Journal of Impact Engineering, 59, 29-37, 2013.

The essential parameter L_{av} has been determined by numerous large and small scale internal detonation experiments. The dependency of L_{av} on the relevant parameter combination is classified information and therefore not accessible, however.

Representative values might be deduced by use of accessible experimental data sets (KASUN[24], and SCIPAN[25] trials).

5.5.5. Calculation of Debris and fragment hazards by an empirical model

5.5.5.1. Empirical model of DDESB TP-14

Determination of fragment hazards by trajectory calculations is a very tedious process and beyond the scope of this IATG.

IATG 1.80 recommends a simpler estimation by an empirical model, which is in detail described in DDESB TP-14.

The US DoD tool SAFER is a software-tool based on the data provided in DDESB TP-14.

DDESB TP-14 provides an empirical method for calculation of debris generated by explosions of a choice of ammunition items in a selection of generalized building types.

Fragments are categorized by mass and energy bins and divided into fragments stemming from ammunition and the building. For building there is a discrimination between debris from concrete and from metal (stemming from constructive elements).

Bin	Kinetic energy MIN [ft lbs]	Kinetic energy average [ft lbs]	Kinetic energy MAX [ft lbs]	Average fragment mass, steel [lbs]	Average fragment mass, concrete [lbs]
1	100000	173000	<300000	35,7	75,4
2	30000	54000	100000	14,9	31,5
3	10000	17000	30000	6,34	13,4
4	3000	5000	10000	2,66	5,61
5	1000	1700	3000	1,13	2,38
6	300	547	1000	0,473	1,0
7	100	173	300	0,199	0,42
8	30	54	100	0,0852	0,18
9	10	17	30	0,0379	0,08
10	3	5	10	0,0142	0,03

Table 26: Mass and energy bin concept used in DDESB TP-14

The debris is divided into direct flying fragments, which will hit an ES on a side wall with residual velocity related to the trajectory, and high angle fragments, which will hit the ES from above with terminal velocity of free fall.

[24] *R. Forsen, R. Berglund, G.A. Groensten,* The effects of cased ammunition explosions confined in concrete cubicles-KASUN-III, 34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

[25] *R. Conway, J. Tatom, M. Swisdak*, SciPan4: Program description and test results, 34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

The direct flying fragment are further split into fly-through fragments and side impact fragments, which have reached terminal velocity and are falling when they hit the wall of the ES.

The algorithms are considering effects of degree of destruction of the PES and the dependency of number and size of fragment of the loading density of explosive within the building,

The algorithm is further considering the shielding effect of a barrier and the shielding of the ES in terms of energy reduction due to energy loss by penetrating work of the debris.

In the end the algorithm provides a table with number of fragments for each energy bin and finally values for probabilities of fatal hits, hits causing major injuries and hits causing minor injuries.

For details and data refer to DDESB chapter 4.4 .1 to 4.4.9. and associated tables.

Table 27 shows one example of a fragment table.
Assumptions: 103 items of MK 82 bombs, representing 9600kg explosive, stored in an earth covered magazine. The table shows the fragment density in the open with a barricade of 5m height at 5 m distance to the ECM, and without, at a distance of 200m.

Debris density at 200m PES: ECM NEQ: 9600 kg	**without barricade**	**with barricade (5m height at 5 m distance to ECM)**
High angle debris table	pieces/m^2	pieces/m^2
Bin1 (234,6 kJ)	2,10E-02	2,10E-02
Bin2 (73,2 kJ)	1,50E-02	1,50E-02
Bin3 (23 kJ)	2,75E-02	2,75E-02
Bin4 (6780 J)	4,53E-02	4,53E-02
Bin5 (2300 J)	5,87E-02	5,87E-02
Bin6 (742 J)	8,32E-02	8,32E-02
Bin7 (235 J)	9,74E-02	9,74E-02
Bin8 (73 J)	2,09E-01	2,09E-01
Bin9 (23 J)	6,17E-01	6,17E-01
Bin10 (6,8 J)	6,37E+00	6,37E+00
Low angle debris table	pieces/m^2	pieces/m^2
Bin1 (234,6 kJ)	3,36E-04	1,49E-04
Bin2 (73,2 kJ)	6,13E-04	4,12E-04
Bin3 (23 kJ)	1,18E-03	9,98E-04
Bin4 (6780 J)	2,28E-03	2,14E-03
Bin5 (2300 J)	1,10E-02	5,64E-03
Bin6 (742 J)	4,49E-02	7,97E-03
Bin7 (235 J)	1,79E-01	9,25E-03
Bin8 (73 J)	5,72E-01	1,07E-02
Bin9 (23 J)	7,07E-01	1,53E-02
Bin10 (6,8 J)	6,27E-01	3,18E-02

Table 27 – Example of empirical fragment density estimation following the algorithm of DDESB TP-17

The table shows, that the barricade reduces the density of critical fragments (NATO criterion 79J; critical density is 1 piece/$56m^2$) from 77 pieces/$56m^2$ to 33 pieces/$56m^2$.

AASTP-1 Estimation of fragment densities from ammunition stacks

AASTP-1 gives simple estimations on maximum fragment densities for fragments from ammunition stacks.

$q_f=Q_o/R^2*\exp(-(2M_f/M_o)^{1/2})$ If the critical mass M_{cr} is chosen, then q_f delivers the density of critical fragments (q_{cr})	R=distance Q_o=total number of fragments per unit solid angle emitted in target direction by an ammunition item. For spherical distribution: $Q_o=N_t/4/\pi$ (see Mott distribution 4.2.3) N_t=total number of fragments M_f=fragment mass under consideration (=all fragments with this and larger mass are under consideration
The critical mass M_{cr} can be estimated by an iterative procedure: $M_{cr\ (low\ angle)}=2*E_{cr}/V_i^2$ $M_{cr\ (high\ angle)}=(2*E_{cr}/9{,}81/L)^{3/4}$ $V_i=V_o*\exp(-R/L)$ $L=2*k^{2/3}/C_D/\rho_a$ Whichever gives the smaller value of $M_{cr\ (low\ angle)}$ and $M_{cr\ (high\ angle)}$ is used as M_{cr} for calculation of critical fragment density	E_{cr}=critical energy (79J) k=shape factor (4,74g/cm³) V_o=launch velocity (Gurney, see chapter 4.3.3) C_D=drag coefficient (see table 18) ρ_a=density of air L=length of flight path traveled after which the fragment velocity drops to the $(1/e)^{th}$ part
$Q_{o,eff}=Q_o*N_E$	$Q_{o,eff}$=effective value of Q_o
Stack in the open: $N_E=0{,}9*N_S+0{,}1*N_T$ Stack in an earth-covered magazine: $N_E=0{,}7*N_S+0{,}1*N_T$	N_S=number of items of ammunition on the side of the stack facing the potential target N_T=number of items of ammunition in the top layer of the stack

Table 28: simple estimation of critical fragment densities from ammunition stacks

5.6 Ground shock

Ground shock can be differentiated in shock induced by air blast and directly induced ground shock.

A simple approach for surface and near surface bursts is outlined in AASTP-1 (chapter 2.5.4.1 to 2.5.4.3, table 5-12 and table 5-14), which is recommended for rough estimations.

Usually the damage caused by ground shock is by far outreached by direct blast effects and damage by debris.

The formulas are evaluated for the range 0,2<Z<24 for masses from 0,5 to 500.000kg

The ground shock consists of an air blast induced component and a direct induced component. Both shock components act independently of each other. In the vicinity of the point of burst the air blast induced ground shock reaches the exposed side before the direct ground shock, with increasing distance the direct component catches up, resulting in superposition of both shock waves and finally with the leading direct induced wave at greater distance.

Airblast induced **Ground shock**	**Displacement D** **[m]**	**Velocity V** **[m/s]**	**Acceleration A** **[g]**
Vertical	D_v=Ii/(cp rho)	V_v=P_i/(cp rho)	A_v=122*P_i/(cp rho)
Horizontal	take vertical values as worst case		
Ii=incident impulse [Pa s] Pi=incident pressure [Pa]		c_p rho = acoustic impedance (see table 29)	

Table 29: Calculation of air blast induced ground shock (AASTP-1, table 5-12)

Soil description	**c_p rho (acoustic impedance) [kg/m²s]**
Heavy saturated clays and clay-shale	954000
Shale and marl - min	273000
Basalt	283000
Granite	457000
Limestone	605000
Sandstone	2686000
Volcanic rock min	3712000
Weathered rocks min	4175000

Table 30: Acoustic impedance for various types of soil (from AASTP-1, table 5-13)

Direct induced Ground shock, Vertical	**Displacement D_v [m]**	**Velocity V_v [m/s]**	**Acceleration A_v [g]**	
Rock	$(R*Q)^{1/3}/(37000*Z^{1/3})$	$0,95/Z^{1,5}$	1200/(Z*R)	R=distance Z=scaled distance Q=mass of explosive
Dry soil	$(R*Q)^{1/3}/(1000*Z^{1/3})$	$0,95/Z^{1,5}$	1200/(Z*R)	
Wet soil	$(R*Q)^{1/3}/(1000*Z^{1/3})$	$0,95/Z^{1,5}$	1200/(Z*R)	

Table 31: Calculation of direct induced ground shock, vertical direction (AASTP-1, table 5-14)

Direct induced Ground shock, Horizontal	**Displacement D_h [m]**	**Velocity V_h [m/s]**	**Acceleration A_h [g]**	
Rock	$0,5*D_v$	V_v	A_v	see table 30!
Dry soil	D_v	V_v	$0,5*A_v$	
Wet soil	D_v	V_v	A_v	

Table 32: Calculation of direct induced ground shock, horizontal direction (AASTP-1, table 5-14)

5.7 Thermal effects

Thermal effects might be the limiting threat for 1.3 ammunition, particularly propellant charges. AASTP-1 gives a rough estimation on the criterion of an energy flux of 167 kJ/m², which is reached at a certain distance R, to prevent propagation.

Distance of heat energy flux limit of 167kJ/m²	
$R=NEQ^{0,44}$	R(m) NEQ (kg)

Table 33: Heat flux limit for propagation (AASTP-1, chapter 2.5.6.2)

For estimation of thermal effects, the models of Baker et al.[26] and models presented in AASTP-4 (Swiss and Norwegian model have been harmonized using experimental data from M. Williams (Cranfield University)[27]. Calculation of thermal flux is done either with a point source model (if relation of fireball diameter and distance can be approximated by this assumption) or by use of diagrams provided by Baker et al.

Fireball characterization (Baker)	
Diameter of fireball [m]: $d=3,86*Q^{0,32}$	Q=burning mass [kg]
Duration of fireball [s]: $t=0,299*Q^{0,32}$	
Correction of burning temperature	
Factor for d: $f_d=(T_x/T_r)^{1/3}$ Factor for t: $f_t=(T_x/T_r)^{10/3}$	Reference burning temperature (T_r): 3600K Burning temperature of propellants (T_x): 2500K
Efficient duration of fireball [s]: $t_{eff}=t/f_t$	

Table 34: Fireball characterization

Thermal flux: point source model	
$q=0,4*Q*H_c/4/\pi/t_{eff}/R/R$ [kW/m²]	q=thermal flux H_c=heat of combustion (4600 kJ/kg for propellants) 0,4=radiation fraction of heat
Thermal energy $Q_{th} = q*t_{eff}$ [kJ/m²]	
Thermal dose: $q^{4/3}*t_{eff}$ [(kW/m²)$^{4/3}$s]	

Table 35: Calculation of thermal flux and thermal dose

[26] *W. E. Baker et al*. Explosion Hazards and Evaluation, Elsevier, (ISBN 0 444 42094 0). Amsterdam, 1983.

[27] *M. Williams*, Measuring radiated thermal output from pyrotechnics and propellants, Cranfield University, 2008.

6 Modelling of consequences

6.1 Simple correlations for planning of destruction of ammunition by open detonation[28]

6.1.1. Range safety distances

The following simple safety distances can be used to estimate range danger areas when planning the destruction of ammunition by open detonation. They may be used for 'quick planning' on demolition ranges with existing danger areas. If used on demolition areas with no formal danger areas the user should remember that the distance produced by these equations is that distance outside which no more than one fragment would be expected to fly. They are NOT absolutely safe.

For fragmenting munitions when public access is possible to the demolition range area. **$D = 634(AUW)^{1/6}$** *For bare exposed explosive only.* **$D = 130(AUW)^{1/3}$**	D = Distance (m) AUW = All Up Weight of Ammunition or Bare Explosives (kg)

Table 36: Simple Range Safety Distances

An Explosion Danger Area Calculator that uses these equations can be found in the IATG Implementation Support Toolkit[29].

The Australian Defence Science and Technology Organisation (DSTO) conducted research in March 1997 into multi-item demolition of ammunition and explosives. They concluded that fragmentation explosion danger areas for multi-item demolitions can be reduced to that of the largest Net Explosive Quantity single munition in the demolition . Underlying assumptions are:

a) the ordnance is arranged in a linear array and NOT a stack;

b) the ordnance is detonated simultaneously; and

c) the items are GREATER than one charge diameter apart.

$D = 370(AUW)^{1/5}$	D = Distance (m) AUW = All Up Weight of Ammunition or Bare Explosives (kg)

Table 37: Simple Range Safety Distances (Alternative)

6.1.2. Vertical danger areas

The equations to estimate the vertical danger areas necessary to warn air traffic of demolitions taking place on the ground differ slightly from Clauses 9.1 and 9.2 as no ballistic parabola needs to be taken into account.

[28] See Technical Note for Mine Action (TNMA) 10.20/01 *Estimation of Explosion Danger Areas* (Version 2.0). Geneva. GICHD. Further details on their use are available there.

[29] https://www.un.org/disarmament/un-saferguard/explosion-danger-area/

For single ammunition item only. **$D = 314(AUW)^{1/3}$** *For multi-item fragmenting munitions.* **$D = 470(AUW)^{1/5}$**	D = Distance (m) AUW = All Up Weight of Ammunition or Bare Explosives (kg)

Table 38: Vertical danger Areas

A Vertical Danger Area Calculator can be found in the IATG Implementation Support Toolkit[30].

6.1.3. Simple noise prediction

The following equation[31] can be used to predict the distance at which 140dB[32] of sound could be expected to be achieved, which is regarded as a critical level for impulse noise:

$D = 215\ (M_{exp})^{1/3}$	D = Distance (m) M_{exp} = Mass of Explosive (kg)

Table 39: Simple Noise Prediction

A simple calculator that uses this equation can be found in the IATG Implementation Support Tool[33]

[30] https://www.un.org/disarmament/un-saferguard/vertical-danger-area/

[31] Source: QinetiQ Shoeburyness, UK. 1999.

[32] The EU maximum permissible noise level for a single event.

[33] https://www.un.org/disarmament/un-saferguard/noise-prediction/

6.2 Blast effects on structures

The prediction of weapons effects on structures is a complex undertaking due to the large number of variables involved[34] and the impact that these variables have on structural response to blast loading.

6.2.1. Model by Scilly

Rough estimates for structural damage due to air blast may be obtained from empirically derived models based on an analysis of accidents, trials and war damage data. This analysis correlates the structural damage with the distance from the explosion and the charge mass involved.

The most extensive data is available for brick-built structures due to studies undertaken in World War 2. Explosion induced damage categories for brick built housing have been developed[35] which may be used in explosion consequence analysis to illustrate the potential severity of the effects of an undesirable explosion:

Category	Definition	Remarks
A	Houses completely demolished.	▪
B	Houses so badly damaged they are beyond repair and require demolition.	▪ 50% - 75% of external brickwork destroyed. ▪ Remaining walls have gaping cracks that are un-repairable.
C_B	Houses rendered uninhabitable but can be repaired with extensive work.	▪ Partial or total collapse of roof structure. ▪ Partial demolition of walls up to 25% of the whole. ▪ Severe damage to load bearing partitions necessitating demolition and replacement.
C_A	Houses rendered uninhabitable but can be repaired reasonably quickly.	▪ Does not exceed minor structural damage. ▪ Partitions and joinery wrenched from fittings.
D	Houses requiring repairs to remedy serious inconvenience but remain habitable.	▪ Damage to ceilings and tiling. ▪ Minor fragmentation effects on walls and glazing.

Table 40: Brick Built Housing Damage Categories

The data analysis used to produce Table 40 led to an empirically derived formula to estimate damage range (Table 41).

$R_x = (K_x \,.\, M_{exp}^{1/3}) \,/\, (1 + (3175/M_{exp})^2)^{1/6}$	R_x = Range for Damage Level ‘x’ (m) K_x = Constant for Damage Level ‘x’ (See Table 29) M_{exp} = Mass of Explosive (kg)

Table 41: Damage Range to Buildings Estimation

[34] For example: 1) structure type; 2) structure material strength, elasticity and ductility; 3) structural response to blast loading; 4) diffraction loading effects; 5) drag loading effects; 6) building orientation to blast loading; 7) local topography etc.

[35] Through the work of: 1) *Scilly N F* and *High W G.* The blast effect of explosions. Loss prevention and safety promotion 5. 1986; and 2) *Jarrett D E*. Derivation of the British Explosives Safety Distances. Annals New York Academy of Sciences, 152, Article 1. 1968.

Values for K_x were initially derived by *Jarrett* and subsequently revised by *Gilbert, Lees and Scilly.*[36] The revised values take account of the casing factor, which is the degree of energy imparted to the primary fragments from the casing, thereby reducing the air blast energy available.

K_x for Damage Category	Jarrett	Gilbert, Lees and Scilly
A	3.8	4.8
B	5.6	7.1
C_B	9.6	12.4
C_A	28.0	21.3
D	56.0	42.6

Table 42: 'K' Factors for Table 41

6.2.2. US method for building damage based on composite PI-diagrams

The method is comprehensively described in DDESB TP-14. Pressure-Impulse diagrams are provided showing iso-damage curves for various degrees of destruction (DDESB TP-14, attachment 7, figures A7-1 to A7-16). The data were developed by ACTA for fifteen low-rise structure types. The diagrams are valid from yields ranging from 453,6kg to 2.268.000kg. Input parameters are incident pressure and incident impulse.
The types of ES-buildings assessed in DDESB TP-14 are tabulated in table 16.

Figure 3 provides one example.

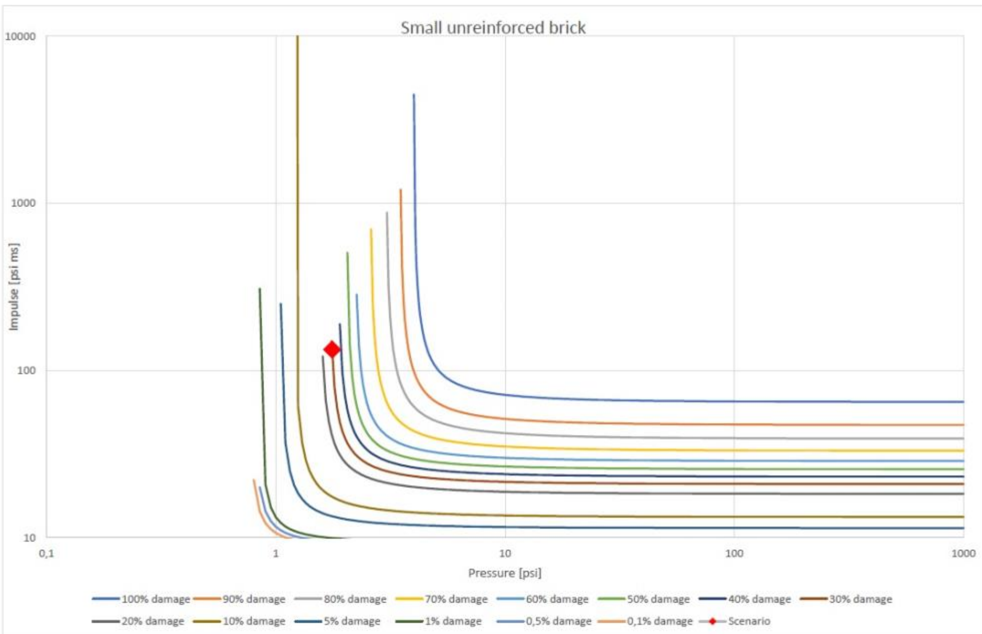

Figure 3 – Example of damage assessment by PI-diagrams (50000kg open detonation at 400m distance)

[36] *Gilbert S M, Lees F P and Scilly N F.* A Model Hazard Assessment of the Explosion of an Explosives Vehicle in a Built-Up Area. Minutes of the 26th US Department of Defense Explosives Safety Board Seminar. Miami. USA. 1994.

6.2.3. Breakage of windows

The breakage of windows by air-blast has been modelled in various research programs. The response of windows is obviously very much depending on construction and type of glass and is therefore also subject to regional building regulations and traditions.
In comparison of several available models the deviations are in a reasonable bandwidth.
The Swiss model[37] is easy to use and covers the whole width of model deviations. It was therefore chosen for implementation in the ECA-tool.
Nominally the model was adopted for the following specifications:

- ✓ Dual pane window
- ✓ Glass thickness 4-6mm
- ✓ Normal glass (annealed)
- ✓ Modern windows, less than 30 to 40 years old
- ✓ Size: Small: <1 m² Medium: 1-3m² Large: > 3m²

Degree of breakage is assessed by use of PI-diagrams which are constructed by a generic equation.

Figure 4 shows an example of a calculation.

(P-A)*(I-B)=C	P=actual pressure [kPa] I=actual impulse [kPa ms] A, B are constants defined by probit functions for each window type (see table 42)
C=exp(1,3+2,23*ln(A))	C=curvature of the PI-hyperbolas

Table 43: PI-diagrams for assessment of glass breakage by blast wave

Window size	Function (Pr=Probit)
Small	Pr=-1,013+3,356*ln(A) Pr=-2,558+1,932*ln(B)
Medium	Pr=0,796+3,356*ln(A) Pr=-0,788+1,932*ln(B)
Large	Pr=2,674+3,356*ln(A) Pr=0,983+1,932*ln(B)

Table 44: Probit functions for PI-diagrams for assessment of glass breakage by blast

Degree of damage (%)	**99,9**	**99**	**90**	**70**	**50**	**30**	**10**	**1**	**0,13**	**0,011**
Probit (Pr)	8,09	7,33	6,28	5,52	5,00	4,48	3,72	2,67	2,00	1,30

Table 45: Relation of Probit and degree of damage

[37] P. Kummer, Glass breakage and injury – yet another new model? 31st DDESB Explosives Safety Seminar, San Antonio, 2004.

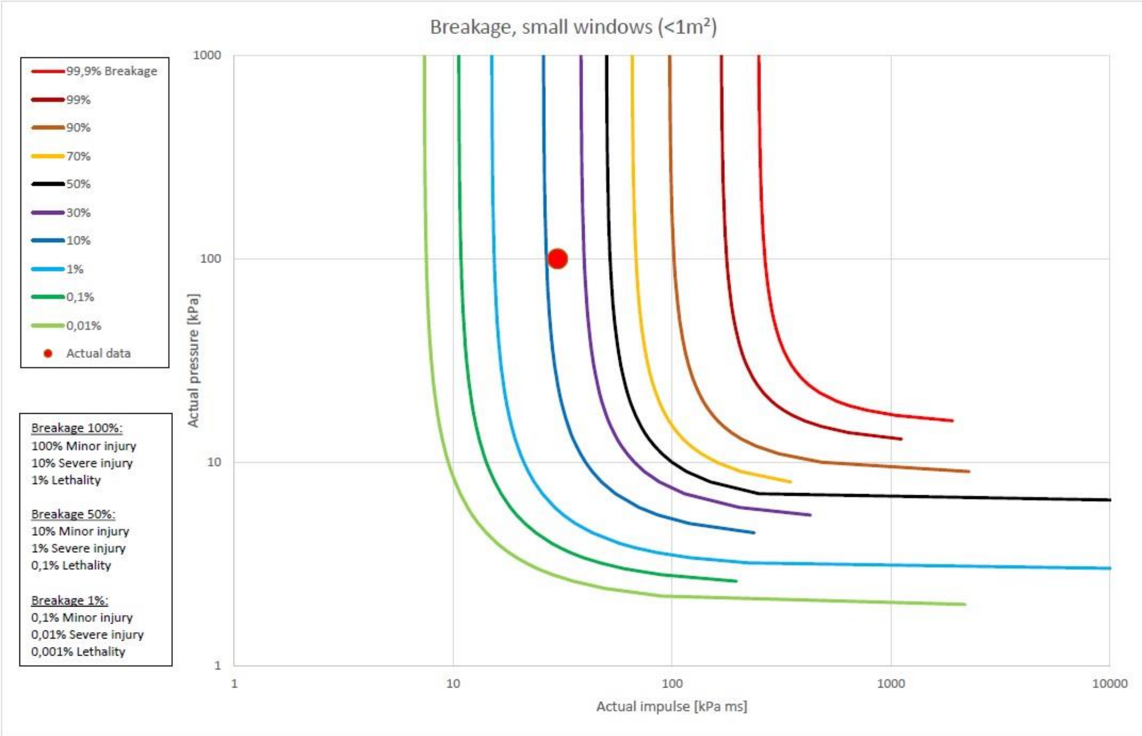

Figure 4 – Example of a calculation

The degree of breakage is related to a probability of an injury level in a generalized way according to table 46 below, as well as to more complicated probit functions.

Breakage	Minor injury	Major injury	Lethality
100%	100%	10%	1%
50%	10	1%	0,1%
1%	0,1%	0,01%	0,001%

Table 46: Degree of window breakage and injury levels

A second model provided is the empirical correlation on PI-diagrams provided by DDESB TP-14. Table A-19 in DDESB TP-14 is providing the coefficient for construction of the PI-curves, differentiating between dual pane, windows, annealed glass windows, and tempered glass windows. Note, that this approach does not take into account the size of the windows!

The degree of breakage is related to a probability of an injury level, described in section 4.3.1.1 in DDESB TP-14.

6.2.4. Ground shock damage

Ground shock is usually not the limiting cause for damage. The propagation of ground shock is very much depending on local discontinuities of the ground material.

A rough estimation of damage is provided by AASTP-1 in tables 5-20 to 5-25 (see also table below).

Degree of damage	V [m/s]
no	<0,05
minor/medium	0,05-0,14
heavy	0,14-0,19
complete	>0,19

Table 47: Damage related to oscillating velocity of ground shock (AASTP-1)

Type of building	Critical oscillating velocity [m/s]
Historical buildings	0,004
Dwelling and business building	0,008
Braced buildings	0,030

Table 48: Critical oscillating velocity to prevent damage (AASTP-1)

Equipment	A [g] no damage	A [g] heavy damage
Heavy weight machinery (engines, generators) >2000kg	10	80
Medium weight machinery (pumps, condensers)500-2000kg	15	120
Light weight machinery (small engines) <500kg	30	200
Duct work, piping	20	280
Electronic equipment	2	28

Table 49: Critical acceleration of ground shock for equipment (AASTP-1)

6.3 Personnel consequences

6.3.1. Blast

The evaluation of blast effects is traditionally linked to the criteria lung damage and eardrum rupture by direct blast and to injuries due to whole body-displacement by the blast wave (e.g. skull-fracture)[38].

There is strong indication on negative influences on the brain and central nervous system by blast effects but too little is known so far about mechanisms to set up criteria on evaluation of these effects[39].

The lung injury criterion is used as a lethality key-parameter. The correlation is dating back to trials in the 1960 with animals[40]. This is still the most comprehensive set of data and was subject to deeper evaluations several times over the years[41].

The recommended formula is taken from the TNO Green Book, 2nd edition[42].

$Pr=5,0+5,7*\ln(V)$	
$V=P_{scaled}/(4,17-0,00164*\ln(t)/t+0,0161/t)$	P_{scaled}=actual scaled overpressure t=scaled positive phase duration [s]
$P_{scaled}=P/po$	P=actual overpressure [Pa] po=ambient pressure [Pa]
$t=t_o*(C_9/m)^{1/3}*/p_o/p_{ref})^{1/2}$	p_{ref}=reference ambient pressure ($1,013*10^5$ Pa) C_9=70 (reference body weight [kg]) M= body weight [kg] t_o=duration of positive pressure wave [s]

Table 50: Probability of fatal lung injury by direct blast

The linkage of probit values to lethality is given in table 45.

[38] "Green Book"; Methods for the determination of possible damage to people and objects resulting from release of hazardous materials, CPR 16E; The hague: Directorate-General of Labour of the Ministry of Social Affairs and Employment; 1992 (ISBN 90-5307-052-4), chapter 3.

[39] *R.K. Gupta, A. Przekwas*, Mathematical models of blast induced TBI: current status, challenmges, and prospects, Frontiers in Neurology, Vol.4, 1-21, 2013.

[40] N. Bowen, E. Fletcher, D. Richmond, Estimate of Man´s tolerance to the direct effects of air blast, DASA 2113, Lovelace Foundation, Albuquerque, 1968.

[41] *K. Holm*, Beregning av doedelighet fra luftsjokk, FFI-rapport 2007/01896.

[42] Green Book"; Methods for the determination of possible damage to people and objects resulting from release of hazardous materials, CPR 16E; The hague: Directorate-General of Labour of the Ministry of Social Affairs and Employment;2nd Edition, 2005.

A more recent well recognized model is the single-degree of freedom approach by Axelsson[43].
It describes the chest wall response of a human exposed to a given blast wave.
Originally it was developed on input of 4 pressure transducers in a blast device with 4 independent differential equations to solve. A simplified approach is just using a single point field pressure.
Figure 5 gives a visualization of a calculation example.

$M*d^2x/dt^2+J*dx/dt+K*x=A*(p(t)-p_{lung}(t))$ $P_{lung}(t)=p_o*(V_o/(V_o-A*x))g$ $v(t)=dx/dt$ $V=\Sigma v(t)$	M= effective mass (2,03 kg) A= effective area (0,082m²) V_o=lung gas volume at x=0 (0,00182m³) J=damping factor (696 Ns/m) K=spring constant (989 N/m) p_o=ambient pressure p(t)=blast loading pressure g=polytropic exponent for gas in lungs (1,2) x(t)=chest wall displacement v(t)=chest wall velocity V= chest wall velocity predictor
$ASII=(0{,}124+0{,}117*V)^{2{,}63}$	ASII=injury level for internal organs

Table 51: Single point lung injury model (Axelsson)

Injury level	ASII	V(m/s)
No injury	0,0 – 0,2	0,0 -3,6
Trace to slight	0,2 – 1,0	3,6-7,5
Slight to moderate	0,3 – 1,9	4,3-9,8
Moderate to extensive	1,0 – 7,1	7,5-16,9
>50% lethality	>3,6	>12,8

Table 52: Injury levels for internal organs in relation to Axelsson´s chest wall velocity predictor

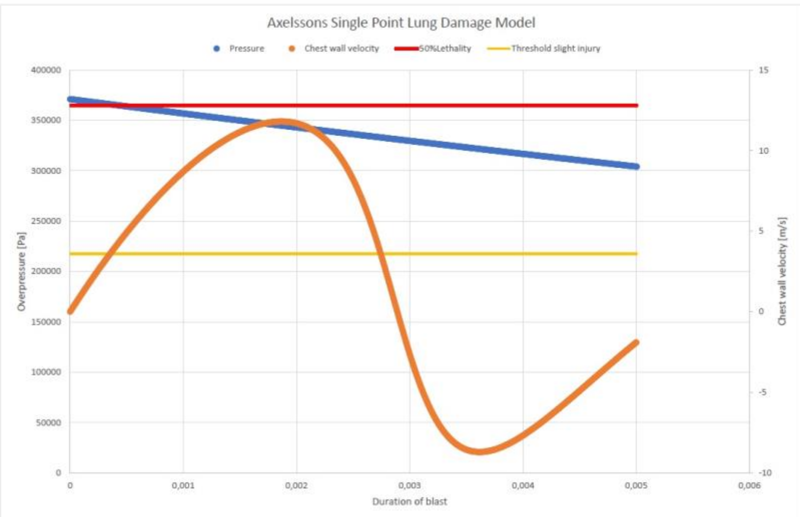

Figure 5 – Calculation example of Axelsson SP-model

43 *J. Teland, J. van Doormaal, M.van der Horst,E. Svinsas*, A single point pressure approach as input for injury models with respect to complex blast loading conditions,34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

FFI has developed PI-diagrams on combined primary and secondary blast injuries.

Figure 6 is showing an example corresponding to the scenario (Incident peak pressure P_i=1,27 bar, duration of positive phase t_o=56,5ms) for calculation of the Axelsson Single point model in figure 5.

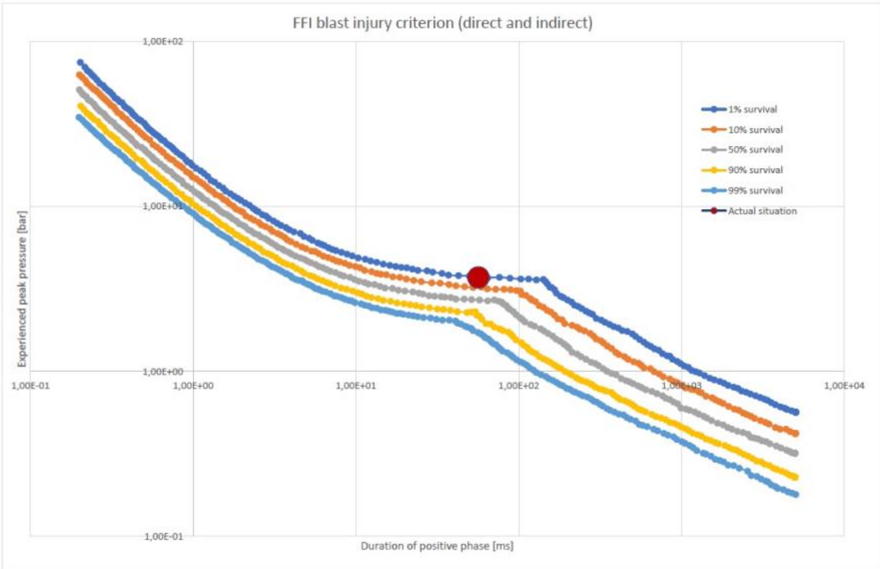

Figure 6 – Calculation example of FFI blast injury model

Table 53 gives a comparison of the different approaches for this scenario.

Criterion	Result
Bowen´s Criterion (lung injury)	50%survival
Axelsson´s Criterion (chest wall velocity)	Moderate to extensive injury
FFI Criterion (combined indirect and direct blast injury)	1%survival
TNO-criterion for direct blast lethality	11% lethality

Table 53: Comparison of different blast injury criteria

6.3.2. People in collapsing structures

Gilbert, Lees and *Scilly* developed probability values for building occupants suffering fatal, serious or light injuries. These are shown in Table 54.[44]

Damage Category	Damage Definition	Probability (Fatality)	Probability (Fatality or Serious Injury)	Probability (Fatality, Serious Injury or Light Injury)
		P(K)	P (K + I)	P (K + SI + LI)
A_a	Houses totally demolished.	0.96	1.0	1.0
A_b	Houses almost completely demolished.	0.57	0.66	0.82
A	Houses demolished.	0.62	0.71	0.84
B	Houses so badly damaged they are beyond repair and require demolition.	0.096	0.15	0.38
C_b	Houses rendered uninhabitable but can be repaired with extensive work.	0.009	0.043	0.13
C_a	Houses rendered uninhabitable but can be repaired reasonably quickly.	0	0.002	0.006
D	Houses requiring repairs to remedy serious inconvenience but remain habitable.	0	0	0

Table 54: Probability Values for Secondary

DDESB TP-14 also provides in section 4.3.1.2 an empirical correlation of probability of fatality, major and minor injury with degree of building damage.

[44] These equate to the damage levels at Table 51, with the addition of A_a for complete demolition and A_b for almost complete demolition.

6.3.3. Fragment and debris

AASTP-1 gives a simple estimate of probability of a hit by a critical fragment from debris stemming from open detonation of ammunition.

$P_f=1-\exp(-q_f*A_T)$	P_f=probability of impact of a fragment of mass M_f or greater (see also section 4.2.5.2) A_T=target area (e.g. 0,56m² for a person)

Table 55: Probability of hit from open stack fragments (AASTP-1)

A more elaborate empirical correlation is provided by DDESB TP-14, section 4.4.9.

It provides assessment of probability of fatal hits or hits causing a major injury or a minor injury on debris density calculated as described in IATG 1.80, 4.2.5.1.

A *concern area* for different degrees of injuries (fatal, major, minor) is defined, reflecting the critical body areas for different severity of a hit.

Each bin is further weighted by a so-called *vulnerability value*, which characterizes the potential of threat for the fragments represented by a bin.

The probability for a hit can be calculated for each type of consequence and every combined high-angle and low-angle debris table according to formula in table 56 below.

$P_{(x)(bin)}=V_{bin}*1-\exp(-C_{Abin}*N_{bin})$	$P_{(x)(bin)}$=probability of a consequence (fatality, major or minor injury) by a certain bin C_{Abin}=concern area for a bin V_{bin}=Vulnerability value for a bin N_{bin}=number of fragments of a fragment bin (10 bins for high-angle and 10 bins for low-angle fragments)

Table 56: Calculation of probability of consequences of fragment hit (DDESB TP-14)

The total probability is calculated using the additive rule for the union of non-mutually exclusive events (table 57):

$P_{(x)angle}=P_{(x)bin1}+P_{(x)bin2}*(1-P_{(x)bin1})+P_{(x)bin3}*(1-P_{(x)bin1})*(1-P_{(x)bin2})+\ldots$	$P_{(x)angle}$=probability of a consequence (fatality, major or minor injury) by a fragment category (high-angle or low-angle)
$P_{(x)total}=P_{(x)high\text{-}angle}+P_{(x)low\text{-}angle}*(1-P_{(x)high\text{-}angle})$	$P_{(x)totale}$=probability of a consequence (fatality, major or minor injury)

Table 57: Calculation of total probability of consequences of fragment hit

6.3.4. Thermal effects

The representative parameter for evaluation of thermal effects to human is the thermal dose (see table 35).

Criteria are taken from HSE[45].

Effect	Thermal dose [(kW/m²)$^{4/3}$s]	
	Mean	Range
Pain	92	86-103
Threshold first degree burn	105	80-130
Threshold second degree burn	290	240-350
Threshold third degree burn	1000	870-2600

Table 58: Thermal effects on human skin by heat radiation

Baker[46] has provided a diagram with an empirical correlation for pain threshold with relation to duration and intensity of thermal flux (figure 7).

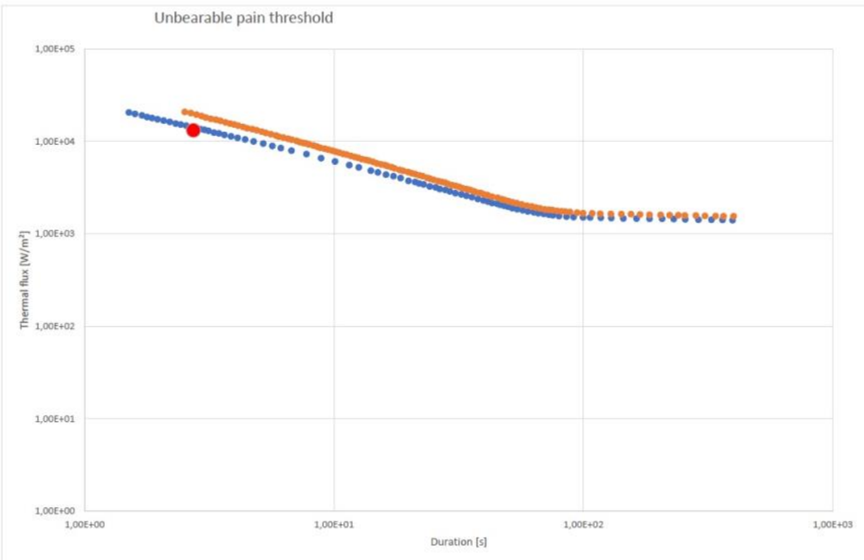

Figure 7 – Pain threshold in relation to thermal flux and duration (Baker et al.)

[45] *S. O´Sullivan, S Jagger*, Human Vulnerability to Thermal Radiation Offshore, Health&Safety Laboratory, HSL 2004/04.

[46] *W. E. Baker et al*. Explosion Hazards and Evaluation, Elsevier, (ISBN 0 444 42094 0). Amsterdam, 1983

Annex A
(normative)
References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this part of the guideline. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of the guideline are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO maintain registers of currently valid ISO or EN:

a) IATG 01.40 Glossary of *terms, definitions and abbreviations*. UNODA. 2020.

b) AASTP-1, Edition B, Version 1, *NATO Guidelines for the Storage of Military Ammunition and Explosives*. NATO Standardization Office (NSO). December 2015.

c) AASTP-4, Edition 1, Change 4, *Explosives Safety Risk Analysis*. NATO Standardization Office (NSO). September 2016. (Note: Part 2 has restricted distribution);

d) Technical Paper 14. *Approved Methods and Algorithms for DoD Risk-Based Explosives Siting*. Revision 4. US Department of Defense Explosives Safety Board (DDESB), Alexandria, Virginia, USA. 17 March 2017;

The latest version/edition of these references should be used. The UN Office for Disarmament Affairs (UNODA) holds copies of all references[47] used in this guideline and these can be found at: www.un.org/disarmament/un-saferguard/references/. A register of the latest version/edition of the International Ammunition Technical Guidelines is maintained by UNODA, and can be read on the IATG website: www.un.org/disarmament/ammunition. National authorities, employers and other interested bodies and organisations should obtain copies before commencing conventional ammunition stockpile management programmes.

[47] Where copyright permits.

Annex B
(informative)
References

The following informative documents contain provisions, which should also be consulted to provide further background information to the contents of this guideline:

a) IATG 02.10 *Introduction to Risk Management Principles and Processes*. UNODA. 2020;

b) *Selection and Use of Explosion Effects and Consequence Models for Explosives.* UK Health and Safety Executive. (ISBN 0 7176 1791 2). UK. 2000; and

c) UFC-3-340-02, *Structures to Resist the Effects of Accidental Explosions*. US Department of Defense. 05 December 2008; Change 2, 01 September 2014. www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-340-02

d) “Green Book”; Methods for the determination of possible damage to people and objects resulting from release of hazardous materials, CPR 16E; The hague: Directorate-General of Labour of the Ministry of Social Affairs and Employment; 1992 (ISBN 90-5307-052-4).

e) *Kingery, C. N. and Bulmash, G.,* Airblast Parameters From TNT Spherical Air Bursts and Hemispherical Surface Bursts, ARBRL-TR-02555, April 1984.

f) *G. Kinney, G. Graham.* Explosive Shocks in Air, 1985, Springer.

g) *Sachs R G*. The dependence of Blast on Ambient Pressure and Temperature. Technical Report 466. Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, USA. May 1944.

h) *A. Remennikov*, The state of the art of explosive loads characterization,2007, 1-25. https://ro.uow.edu.au/engpapers/4245.

i) *X.-Q. Zhou, H. Hao*, Prediction of airblast loads on structures behind a protective barrier, International Journal of Impact Engineering, 35(5), 363-375, 2008.

j) *Gurney, R. W*. The Initial Velocities of Fragments from Bombs, Shells, and Grenades, BRL-405. Ballistic Research Laboratory, Aberdeen, Maryland. USA. 1943.

k) *M.M. van der Voort, J. Weerheijm*, A statistical descriptionn of explosion produced debris disperion, Inteernational Journal of Impact Engineering, 59, 29-37, 2013.

l) *R. Forsen, R. Berglund, G.A. Groensten,* The effects of cased ammunition explosions confined in concrete cubicles-KASUN-III, 34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

m) *R. Conway, J. Tatom, M. Swisdak*, SciPan4: Program description and test results, 34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

n) *W. E. Baker et al*. Explosion Hazards and Evaluation, Elsevier, (ISBN 0 444 42094 0). Amsterdam, 1983.

o) *M. Williams*, Measuring radiated thermal output from pyrotechnics and propellants, Cranfield University, 2008.

p) Technical Note for Mine Action (TNMA) 10.20/01 *Estimation of Explosion Danger Areas* (Version 2.0). Geneva. GICHD. Further details on their use are available there.

q) *Scilly N F* and *High W G.* The blast effect of explosions. Loss prevention and safety promotion 5. 1986.

r) *Jarrett D E*. Derivation of the British Explosives Safety Distances. Annals New York Academy of Sciences, 152, Article 1. 1968

s) *Gilbert S M, Lees F P and Scilly N F.* A Model Hazard Assessment of the Explosion of an Explosives Vehicle in a Built-Up Area. Minutes of the 26th US Department of Defense Explosives Safety Board Seminar. Miami. USA. 1994.

t) P. Kummer, Glass breakage and injury – yet another new model? 31st DDESB Explosives Safety Seminar, San Antonio, 2004.

u) *R.K. Gupta, A. Przekwas*, Mathematical models of blast induced TBI: current status, challenmges, and prospects, Frontiers in Neurology, Vol.4, 1-21, 2013.

v) N. Bowen, E. Fletcher, D. Richmond, Estimate of Man´s tolerance to the direct effects of air blast, DASA 2113, Lovelace Foundation, Albuquerque, 1968.

w) *K. Holm*, Beregning av doedelighet fra luftsjokk, FFI-rapport 2007/01896.

x) Green Book"; Methods for the determination of possible damage to people and objects resulting from release of hazardous materials, CPR 16E; The hague: Directorate-General of Labour of the Ministry of Social Affairs and Employment;2nd Edition, 2005.

y) *J. Teland, J. van Doormaal, M.van der Horst,E. Svinsas*, A single point pressure approach as input for injury models with respect to complex blast loading conditions,34th DDESB Explosive Safety Seminar, Portland, OR, 2010.

z) *S. O´Sullivan, S Jagger*, Human Vulnerability to Thermal Radiation Offshore, Health&Safety Laboratory, HSL 2004/04.

The latest version/edition of these references should be used. The UN Office for Disarmament Affairs (UNODA) holds copies of all references[48] used in this guideline and these can be found at: www.un.org/disarmament/un-saferguard/references/. A register of the latest version/edition of the International Ammunition Technical Guidelines is maintained by UNODA, and can be read on the IATG website: www.un.org/disarmament/ammunition. National authorities, employers and other interested bodies and organisations should obtain copies before commencing conventional ammunition stockpile management programmes.

[48] Where copyright permits.

Annex C

Reference scenarios

The following scenarios have been chosen for reference of the application of the formulae:

Scenario A:

Earth covered magazine containing 1200 pieces of 155mm shells with 6,85 kg Composition B as explosive filling. The side of the magazine is facing an ammunition process building at a distance of 100m. The building is 15x15m in area and 4m high and doesn´t have a protected roof. On each of the side walls and the rear wall of the building there are two small windows (0,6 x 1,0m) of 4mm annealed glass.

In the moment of the explosion one person is standing close to the wall facing the earth covered magazine and one close to the back wall.

At a distance of 400m in the opposite direction, there is a sanatorium building, with 30% window area on the side facing the magazine.

There is a barricade surrounding the magazine at a distance of 6m with 5m height.

Scenario B:

Ammunition process building, containing 1000kg TNT, subject to accidental detonation. A large office building is situated at 600m distance; designed with large windows representing 50% of the wall area.

A Public traffic route is passing at 100m distance. One person is passing in free field at 50m distance.

Scenario C:

Open detonation of 1000kg Nitropenta. A brick building, two storeys high, of the dimension 20m width, 30m length and 7m height, is situated at 500m distance, designed with medium sized windows representing 20% of the wall area facing the explosion at an angle of 45 degrees. One person inside and one on the rear side of the building.

Scenario D:

Open detonation of 64 155mm shells, arranged in an array of 8x8, and open burning of 1000kg propellant. The safety requirements have to assessed.

Amendment record

Management of IATG amendments

The IATG are subject to formal review on a five-yearly basis. This does not preclude amendments being made within these five-year periods for reasons of operational safety, efficacy and efficiency or for editorial purposes.

As amendments are made to this IATG module they will be given a number, and the date and general details of the amendment will be shown in the table below. The amendment will also be shown on the cover page of the IATG by the inclusion of the amendment number and date.

As the formal reviews of each the IATG module is completed, new editions will be issued. Amendments will be incorporated into the new edition and the amendment record table cleared. Recording of amendments will then start again until a further review is carried out.

The most recently amended, and thus extant, IATG module is posted on www.un.org/disarmament/ammunition

Number	Date	Amendment Details
0	01 Feb 15	Release of Edition 2 of IATG.
1	31 March 21	Release of Edition 3 of IATG.