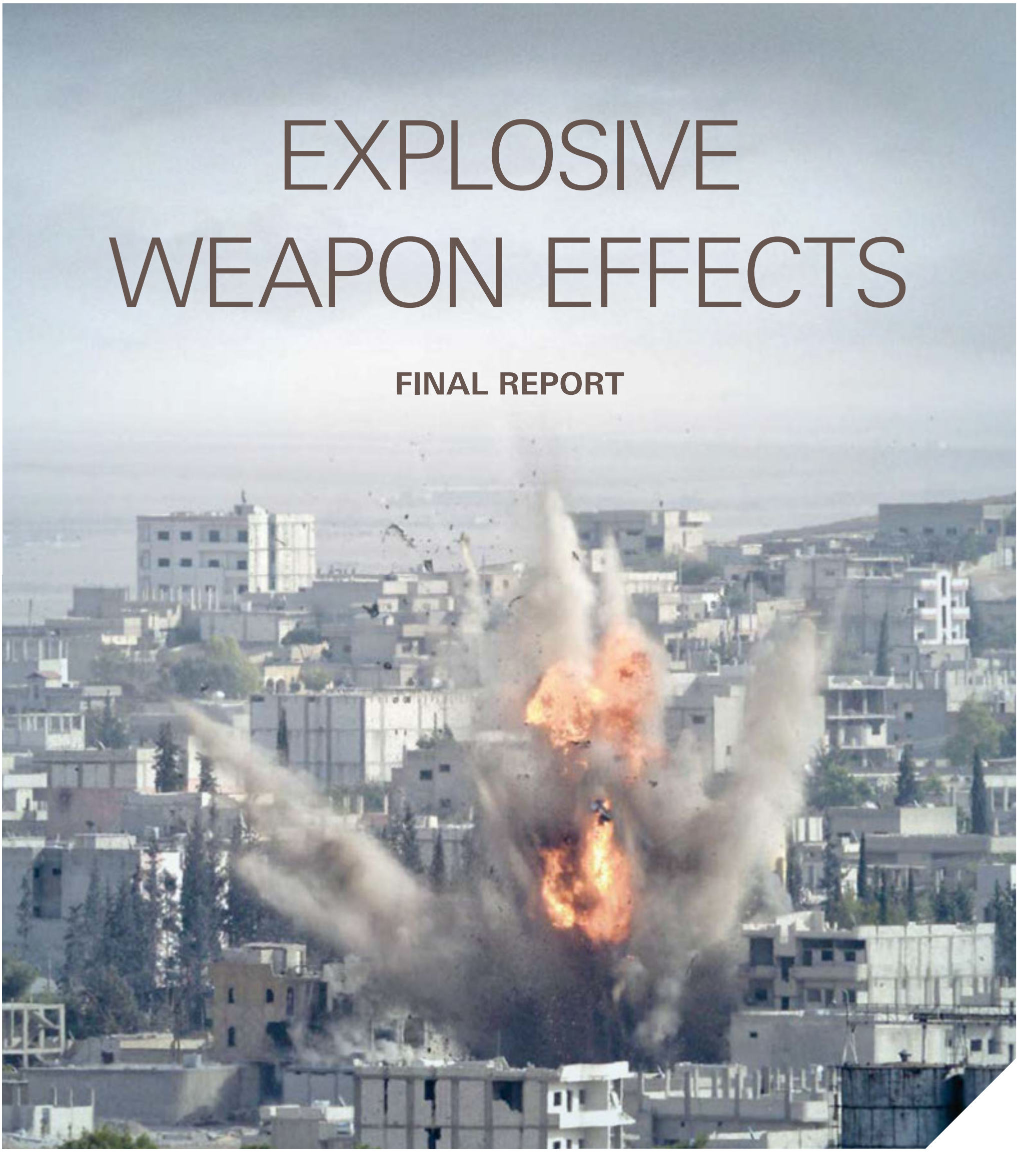
CHARACTERISATION OF EXPLOSIVE WEAPONS

EXPLOSIVE WEAPON EFFECTS

FINAL REPORT



GICHD

ABOUT THE GICHD AND THE PROJECT

The Geneva International Centre for Humanitarian Demining (GICHD) is an expert organisation working to reduce the impact of mines, cluster munitions and other explosive hazards, in close partnership with states, the UN and other human security actors. Based at the Maison de la paix in Geneva, the GICHD employs around 55 staff from over 15 countries with unique expertise and knowledge. Our work is made possible by core contributions, project funding and in-kind support from more than 20 governments and organisations.

Motivated by its strategic goal to improve human security and equipped with subject expertise in explosive hazards, the GICHD launched a research project to characterise explosive weapons. The GICHD perceives the debate on explosive weapons in populated areas (EWIPA) as an important humanitarian issue. The aim of this research into explosive weapons characteristics and their immediate, destructive effects on humans and structures, is to help inform the ongoing discussions on EWIPA, intended to reduce harm to civilians. The intention of the research is not to discuss the moral, political or legal implications of using explosive weapon systems in populated areas, but to examine their characteristics, effects and use from a technical perspective.

The research project started in January 2015 and was guided and advised by a group of 18 international experts dealing with weapons-related research and practitioners who address the implications of explosive weapons in the humanitarian, policy, advocacy and legal fields. This report and its annexes integrate the research efforts of the characterisation of explosive weapons (CEW) project in 2015-2016 and make reference to key information sources in this domain.

Cover image: an explosion during an airstrike on Kobane, Syria, as seen from the Turkish side of the border, near Suruc district, 13 October 2014, Turkey, Syria

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We recognise the work of the expert group established to steer and advise this project. Members of the group were consulted for their respective expertise and experience in the review of this report and its annexes. Namely, our gratitude goes to Simon Bagshaw (OCHA), Zsuzsanna Balogh (NATO HQ SACT), John Borrie (UNIDIR), Maya Brehm (Geneva Academy of International Humanitarian Law and Human Rights), Kimberly Brown (British Red Cross), Hannah Bryce (Chatham House), Judy Grayson (UNICEF), Eliot Higgins (Bellingcat), Benjamin King (Small Arms Survey), Colin King (Fenix Insight Ltd.), Clare Knock (Cranfield University), Kathleen Lawand (ICRC), Iain Overton (Action on Armed Violence), Thomas de Saint Maurice (ICRC), Robert Sheldon (Cranfield University), Alexander Stolz (Fraunhofer-EMI) and Christina Wille (Insecurity Insight). We thank Sean Moorhouse (independent) for the comprehensive research with the explosive weapon studies (annexes to this report). We appreciate the contributions of Stefan Elliott (ARES) and Yuri Lyamin (ARES) in providing technical information and significant data to this report. Finally, we are grateful to the Geneva Graduate Institute of International and Development Studies (IHEID) for assigning Prerna Bhagi, Kenneth Iannuzzi and Sofya Omelchenko to carry out global research on cases of use of the studied explosive weapons.

CONTENTS

LIST OF ABBREVIATIONS

AP
Armour-piercing (munitions)

BDA
Battle damage assessment

CDE
Collateral damage estimate

CEP
Circular Error Probable

CEW
Characterisation of explosive weapons

ERW
Explosive remnants of war

EWIPA
Explosive weapons in populated areas

HE
High explosive

HEAT
High explosive anti-tank

HE-FRAG
High explosive fragmentation

HESH
High explosive squash-head

HFD
Hazardous fragment distances

IHL
International humanitarian law

ISS
Injury severity score

JDAM
Joint direct attack munition

MBRL
Multi barrel rocket launcher

MPI
Mean point of impact

NEQ
Net explosive quantity

NEW
Net explosive weight

PGM
Precision guided munitions

PI
Percentage of incapacitation

RE
Relative effectiveness

RED
Risk estimate distances

REEF
Reverberating effects of explosive force

ROE
Rules of engagement

UAV
Unmanned aerial vehicle

UXO
Unexploded ordnance

ORGANISATIONS

HRW
Human Rights Watch

ICRC
International Committee of the Red Cross

ISIL
So-called Islamic State of Iraq and the Levant

MOD
Ministry of Defence (U.K.)

NATO
North Atlantic Treaty Organization

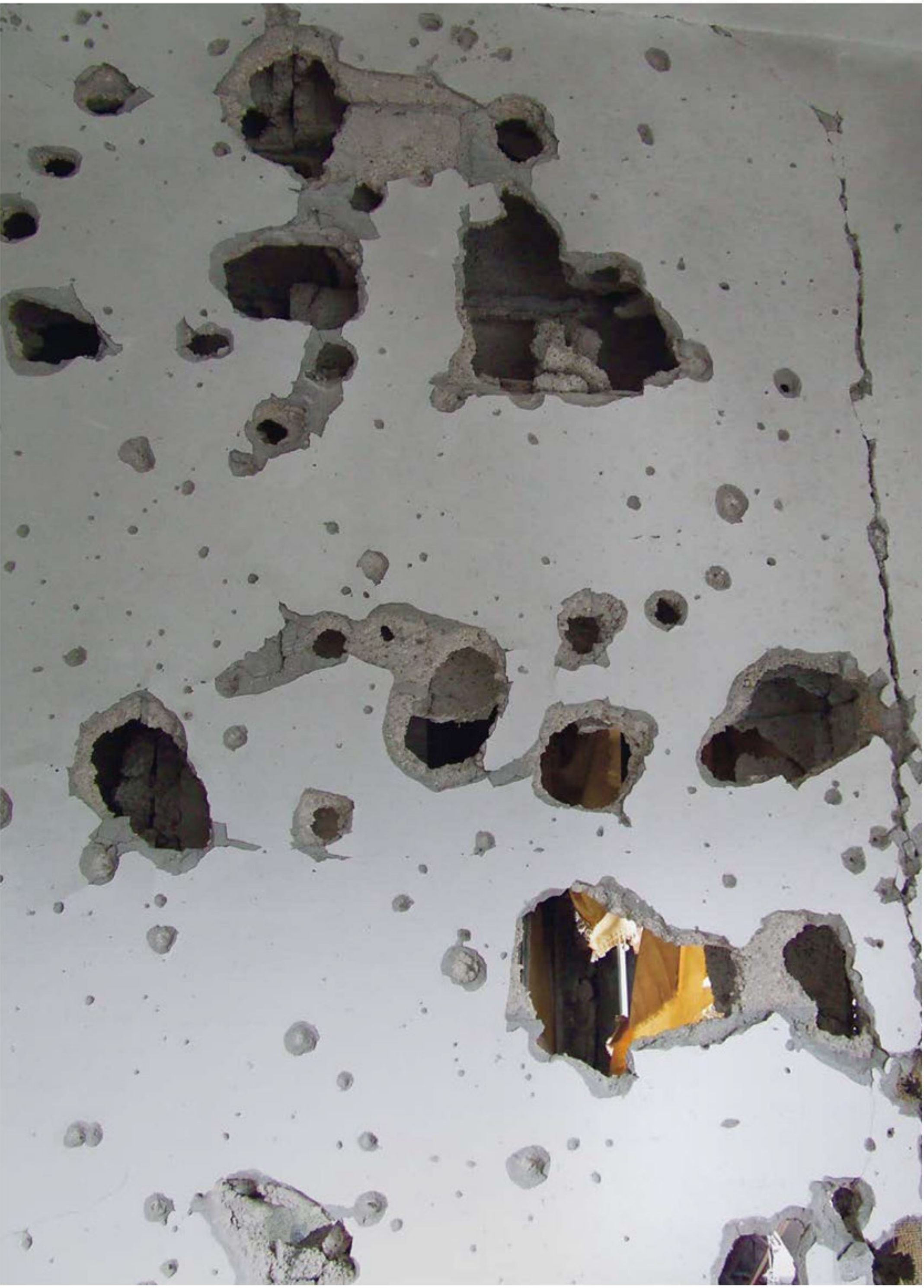
OSCE
Organization for Security and Co-operation in Europe

SCWSD
Air Force Safety Center Weapons Safety Division (U.S.)

UNIDIR
UN Institute for Disarmament Research

USDA
U.S. Department of the Army

USDAF
U.S. Department of the Air Force



EXECUTIVE SUMMARY

States, the United Nations and civil society organisations continue to raise concerns about the humanitarian impact caused by the use of explosive weapons in populated areas (EWIPA). This issue is currently being examined from political, legal, socio-economic and humanitarian perspectives. The GICHD has undertaken research to provide a technical perspective on the destructive effects of selected explosive weapons to inform the international debate.

The research project attempts to reduce an observed knowledge gap regarding EWIPA. It seeks to provide clarity concerning the immediate physical effects and terminology used when discussing explosive weapons. The project is guided by a group of experts dealing with weapons-related research and practitioners who address the implications of explosive weapons in humanitarian, policy, advocacy and legal fields.

Explosive weapons are generally designed specifically to kill and injure human beings and to destroy or otherwise incapacitate[1] vehicles and infrastructure. Whilst they carry out similar functions when used in populated areas as when they are employed elsewhere, the impact of their use may differ. Indeed, the use of explosive weapons in populated areas has resulted in significant civilian deaths and injuries. In addition to the human cost, our case studies confirm substantial damage to essential infrastructure, homes and businesses.

The research focuses on the inherent technical characteristics of the explosive weapon systems studied and their use in populated areas, examining both the methods and means of warfare. It draws on five technical studies on explosive weapon systems, each of which assesses a common type of weapon system present in contemporary conflict zones. The weaponry covered was chosen on the basis of its ubiquity, notoriety, widespread stockpiling and use in populated areas. The five weapon systems reviewed are 122 mm multi barrel rocket launchers, 81-120 mm mortars, 152-155 mm artillery guns, 115-125 mm tank guns and the Mk 82 aircraft bomb. The research's findings focus on the effects of the explosive munitions; inherent accuracy and precision of the five weapon systems employing them; and on their characteristic use including methods to mitigate the impact on civilians.

1 Including neutralise, suppress or harass the adversary, especially when used for indirect fire.

Effects of high explosive munitions in populated areas

The Mk 82 aircraft bomb and 122 mm rockets were found to have the widest area effect, although mortar and artillery projectiles were both responsible for single-munition explosions resulting in double-figure casualties. Of the weapons covered in the study, tank munitions were often found to have a more limited lethal area than others. Whilst there are measures the user can take to adjust the effects of an explosive weapon in terms of the way it functions, many systems such as multi barrel rocket launchers produce design-dependent effects intended to cause widespread destruction.

The effects of high explosive munitions within populated areas are influenced substantially by the presence of built structures and geographical features. Vehicles, housing, commercial property, factories, schools, hospitals, etc. may provide some protection from primary[2] and secondary[3] explosive weapon effects, but also amplify these due to the channelling and reflection of blast waves. Buildings and vehicles contribute bricks, concrete, glass and other debris to the fragmentation originating from the weapon. Any fuel sources or toxic chemicals within the munition's impact zone may pose a further deadly hazard to humans, as does the compromised structural stability of buildings which may be prone to collapse.

The intuitive reflex among humans to seek shelter from an explosive weapon attack in buildings, vehicles, narrow streets, tunnels and similar enclosed or semi-enclosed spaces poses a lethal risk. Besides the reflecting blast waves in such spaces, the intensification of the weapon effects occurs due to the presence of a large number of people and structures within the effective range of a munition(s), as well as sources of secondary fragmentation. This results in a higher proportion of fatalities than would be likely in open spaces.

Humans are particularly vulnerable to blast overpressure and reflected blast waves. Surviving an explosive weapon attack with only surface bruises visible does not exclude ruptured eardrums, damaged lungs, internal bleeding, brain damage, infections and poisoning, and bone fracturing. Depending on the layout

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2 Effects originating from the detonating munition i.e. blast overpressure, fragmentation, heat and light.

3 Effects originating from the objects affected by the detonation: secondary fragmentation, debris (i.e. pieces of masonry, plumbing, glass, wood, metal, bone fragments, etc.), firebrands, ground shock and cratering. See page 59.

of structures in a populated area and type of explosive weapon used in an attack, the probability of survival for a human may increase when away from the proximity of structures (prone on the ground in a small depression or narrow ditch).

Inherent accuracy and precision of the studied weapon systems

The accuracy and precision (See *Accuracy and precision*, p. 25) of the explosive weapon systems reviewed differ significantly, with tank guns and guided aircraft bombs being capable of use in an accurate and precise direct fire function when certain conditions are met. Artillery gun and mortar systems are capable of a relatively high level of accuracy in an indirect fire function. However, due to the lower precision inherent in their design, projectiles are typically spread over a wide area which increases with the distance to the target. Unguided artillery rockets are generally neither accurate nor precise.

The level of accuracy and precision can be unpredictable and inconsistent with any of the weapon systems studied, owing to factors such as the level of operator training, alignment and sighting of the weapon, the quality control of munitions, weapon maintenance and the practical experience of the firer in using the weapon in varying terrain and weather conditions. Most indirect fire systems used in conflicts of today are incapable of achieving the high degree of accuracy required to hit a small point target with the first round.

Characteristic use of explosive weapons and measures to control their impact

There are measures the user can take to adjust the wide area effects of explosive weapons. Competent target analysis and approval procedure, positive target identification, evaluation of the immediate physical environment and the selection of the most accurate and precise weapon available to the user are key factors in reducing collateral harm. If the impact of explosive weapons on civilian life and infrastructure is to be minimised, the decision on the method of employment[4] and timing of the attack, including the choice of optimal munition type and fuze configuration, will further assist in mitigating wide area effects.

As a general rule, armed forces should have thorough knowledge of the dynamic effects of the munitions in their inventories and should be able to predict fairly

4 i.e. direct, indirect or air-delivered fire method; selected based on a number of variables including access and physical proximity to the target, geography, weather, available weapon systems and collateral damage considerations.

accurately the extent of these effects in open terrain. However, there is less awareness of the effects of use in built-up areas. This is especially the case with regard to the impact of rebounding blast and sources of secondary fragmentation and debris. Whilst some militaries have the capability to model these hazards, this is far from common and carries limitations in terms of its ability to mimic reality accurately.

Observing the devastation in the majority of cases studied where explosive weapons were used in populated areas, it appears that the critical assessments of the probable damage to civilians and civilian infrastructure prior to their use was inadequate or recommendations generated by such assessments were not followed, resulting in substantial collateral damage.

Still, the use and acquisition of munitions may be changing in response to the challenges of using EWIPA. One example is the lesser use of Mk 84 (907 kg) aircraft bomb in contemporary conflict and the development of new, smaller bombs equipped with precision guidance systems such as the Very Low Collateral Damage Weapon (BLU-129/B, 227 kg) and Small Diameter Bomb (BLU-39, 110 kg). These developments imply increasing awareness of the substantial area effects of explosive weapons and may also suggest a gradual change in military doctrine concerning good tactical use of air-launched weapons, testifying to attempts better to control and reduce wide area effects by providing more appropriate tools in support of targeting policies (see *Weapon-target matching*, p. 65).

The key findings of the research project are presented in the section *Findings and conclusion* and exemplified in *Effects analysis*, with further evidence and examples in the five explosive weapon studies (Annexes A to E).

INTRODUCTION

This report attempts to characterise five explosive weapon systems: what they are, what they do, and how they are being used in populated areas, focusing on the analysis of key factors contributing to their effects on delivery. It is part of a project involving a series of studies that analyse the destructive effects of five commonly used explosive weapon systems. These are: the BM-21 122 mm multi barrel rocket launcher (MBRL); 152 mm and 155 mm artillery guns; 81 mm and 82 mm medium mortars and 120 mm heavy mortars; 115 mm, 120 mm and 125 mm tank guns; and the guided and unguided variants of the Mk 82 aircraft bomb.

After a brief overview of explosive weapon systems, their accuracy and precision qualities will be presented. The key terms and descriptions in the context will be introduced and the relevant concepts and modes of application. Thereafter, the various effects of detonating high explosive munitions, both on humans and structures will be examined, again with clarification of the technical language on the topic. These first sections of the report are to equip and familiarise the reader with the above concepts and terminology, so as to benefit fully from an increasingly technical analysis.

The report goes on to observe the contemporary use of explosive weapons, with emphasis on targeting practices and activities pertaining to the choice of a weapon and munition appropriate to the target, including fuze configuration. After this section, the five explosive weapon systems are presented and characterised from the perspectives of accuracy and precision, particular munitions' effects, and their typical role(s) in contemporary conflict. A technical comparison is made on the lethality of the munitions fired by each of these systems, and patterns of use are reviewed.

In the following analysis, findings are extracted from tens of case studies examining the actual use of each of the studied explosive weapon systems in conflicts around the world. Annexes A through E[5] of the report provide more detailed information about the weapon systems, common high explosive munitions employed, as well as presenting case studies[6] of their use in populated areas.

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5 Annex A: 122 mm BM-21 MBRL, Annex B: 152 mm & 155 mm artillery guns, Annex C: 81–120 mm mortars, Annex D: 115–125 mm tank guns, Annex E: Mk 82 aircraft bomb.

6 Case studies are referred to throughout this report with an alphanumeric designation, for example, D3 refers to Case Study 3 in Annex D: 115-125 mm tank guns.

Amid the significant challenges of measuring the overall extent of the wide area effects of high explosive munitions, the report draws conclusions from the findings of the case studies, and findings pertinent to the inherent characteristics, combination of effects and representative use of the studied explosive weapon systems. Attention is retained on the constituents of the various effects and the effects' interaction with each other, contributing to the impact on civilians. The research limits its considerations to the immediate effects of an attack involving these weapons and their munitions, rather than long-term consequences.

One of the goals of this report is to identify any knowledge gaps likely to have humanitarian consequences. The results should support efforts by policymakers, the drafters of military doctrine and the international community to better understand the ramifications of using explosive weapons in populated areas and encourage further research on their specific effects and targeting practices in these environments. The report and accompanying weapon studies can also be used to assist in more accurate recording of and reporting on the use and effects of explosive weapons.

METHODOLOGY AND SCOPE

The characterisation of explosive weapons (CEW) project is managed and implemented by the GICHD, and guided by a group of 18 experts from disciplines relevant to researching the effects of explosive weapons in populated areas. The experts volunteered to be consulted on a pro bono basis and shared their knowledge in a personal professional capacity. They come from specialised and international organisations[7] dealing with weapons-related research and include practitioners who address the implications of explosive weapons in humanitarian, policy, advocacy and legal fields.

This research was further supported by the Geneva Graduate Institute of International and Development Studies (IHEID). As part of the IHEID's Applied Research Seminar, three Masters students were seconded to carry out literature research on weapon effects, and map incidents of use of the selected weapon systems in conflict zones around the world. An independent consultant reviewed the case studies and provided five explosive weapon studies for the project, also directing the work of the students. The GICHD then engaged Armament Research Services (ARES), a specialist technical consultancy, to lend subject expertise and co-edit this report.

There are three phases to the CEW project, the first being to identify the scope of the research, establish stakeholders and partners, and assemble the group of subject experts. Once that was achieved, the GICHD, in close collaboration with the expert panel, determined the methodology and set the criteria for selection of the weapons to be studied. A list of terminology commonly used to describe EWIPA was mapped, compiled and clarified (see page 111).

This report marks the end of the second phase of the project, which involved technical research into five explosive weapon categories and the analysis of tens of case studies. The third and final phase of the project will use the raw data compiled by the project in a purpose-built computer simulation of explosive weapon effects

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7 In addition to the GICHD, these include: Action on Armed Violence (AOAV), Armament Research Services (ARES), Chatham House, Cranfield University, Fenix Insight Ltd., Fraunhofer-EMI, Geneva Academy of International Humanitarian Law and Human Rights, NATO Supreme Allied Commander Transformation (SACT), Insecurity Insight, International Committee of the Red Cross (ICRC), Small Arms Survey, Save the Children, UK, UN Children's Fund (UNICEF), UN Institute for Disarmament Research (UNIDIR), and UN Office for the Coordination of Humanitarian Affairs (OCHA).

in populated areas. All phases of the research will apply the same methods when compiling, formatting and presenting data, thus enabling a valid comparison to be made of the effects of different weapons on humans and infrastructure.

The weapon systems examined were selected on the basis of their ubiquity and frequency of use in recent and current conflict and in populated settings, as well as the availability of case study data. Furthermore, this report focuses on high explosive (HE) munitions that continue to be used in conflict and which remain commercially available, or are currently stockpiled in many countries. Several advanced versions of these are referenced, but not discussed in depth due to their few appearances in modern conflict, a relatively small number of users and in some cases, lack of available data. Examples of these are various precision guided munitions for indirect fire systems such as artillery guns, rockets and mortars.

While most of these weapon systems are also capable of delivering munitions that do not rely on HE content for their primary effects – such as illumination, smoke, kinetic energy penetrator, less-lethal, nuclear, chemical, and biological munitions – these lie outside the scope of this report. The report also does not address cargo munitions, which dispense HE submunitions[8] or mines[9] as these have already been addressed consistently in the framework of the Convention on Cluster Munitions and the Anti-Personnel Mine Ban Convention. It is important to distinguish between explosive munitions and incendiary munitions (see *Overview of explosive weapon systems*, p.19); this report does not address the latter.[10]

The case studies of each explosive weapon system included in this report were chosen to highlight their characteristics with an emphasis on the effects in a populated area. Many other case studies were undertaken, but the difficulty in obtaining reliable and accurate data from active conflicts and post-conflict areas meant that they did not meet the standards of this publication. The selection of the case studies was based on criteria of relevance, information verifiability and availability. While a representative selection was sought, the use of higher profile and publicly available examples were preferred.

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8 AKA ‘cluster munitions’. See Convention on Cluster Munitions, Dublin, 30 May 2008, in force 1 August 2010, 2688 UNTS 39.

9 See Protocol on Prohibitions or Restrictions on the Use of Mines, Booby-Traps and Other Devices as amended on 3 May 1996, Geneva, in force 3 December 1998, 2048 UNTS 93; and Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction, Oslo, 18 September 1997, in force 1 March 1999, 2056 UNTS 211.

10 See Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons, 10 October 1980, in force 2 December 1983, 1342 UNTS 171.

Not all of the desired information[11] was available for each case study, but the cross-comparison of multiple studies helped the identification of gaps in understanding. This information was further analysed to create a comprehensive characterisation of the typical design-dependent effects of each weapon system's use in a populated area.

Due to limitations on the types of conflict zones from which valid case studies could be drawn, there is a risk of unrepresentative sampling. The authors have done their utmost to abate this risk by examining the use of a particular explosive weapon in several conflict theatres and verifying the information from multiple sources.

This report does not seek to address the tertiary effects of explosive weapons use (i.e. reverberating, indirect and/or longer-term damage).[12] Instead, the focus remains on the primary and secondary effects of an attack. It is not the intention to discuss the moral or legal implications of using explosive weapon systems in populated areas, but to examine their effects from a technical perspective. Furthermore, this report does not seek to explain the development history, employment, sustainment and targeting of explosive weapon systems, although these are briefly addressed.[13]

11 Case studies, designated by annex and number (e.g. A1), include the following data fields: date/time of attack; location; a map of the area with impact points; the weapon system examined; number of munitions employed; range the munition was delivered from; the impact area size or dispersion area of multiple munitions; casualties; infrastructure damage; other damage; distance from detonation; sources and any other remarks.

12 For information on tertiary, or reverberating effects, see Wille & Borrie, 2016.

13 For information on these aspects, see Cross et al., 2016 and Dullum et al., 2016.

USE OF TERMINOLOGY

The characterisation process required in-depth research into the terminology used to describe explosive weapons, their various effects, and the environments in which they are used. What does a populated area, a 'town' or a 'village' actually refer to? What should be considered an 'explosive weapon', and what is excluded from that definition? What is a 'barrage' of projectiles? How effectively to communicate 'the various destructive effects' of an explosive weapon?

In order to ensure consistency in the use of terminology, the research team compared recognised sources of literature regarding munitions and their use. These included the NATO Glossary of Terms and Definitions (Allied Administrative Publication No. 6); British Ministry of Defence and Defence Safety Authority Explosives Regulations (Joint Service Publication No. 482); International Ammunition Technical Guidelines (United Nations, 2nd Edition 2015), International Mine Action Standards (United Nations 2014) and Convention on Certain Conventional Weapons (Protocols I, IV and V and Amended Protocols II and III). Reports were consulted also from the UN Institute for Disarmament Research (UNIDIR) and Armament Research Services (ARES).

Terms that were found effective for the purposes of the characterisation activity were selected and are included in the *Terminology of explosive weapons* table at the end of this report. In some instances there was no suitable term available to accurately describe a particular subject pertinent to explosive weapons. To reduce uncertainty and for completeness therefore, some existing terms were amended and fresh descriptions were developed (see *Terminology*, p. 111).

OVERVIEW OF EXPLOSIVE WEAPON SYSTEMS

‘Explosive weapon system’ is an informal term for any weapon system which delivers a munition with a primarily explosive payload. Explosive weapon systems differ substantially in their delivery mechanism, employment parameters and specific effects, but all use a munition to deliver an explosive payload to a target. The munition in question may be properly termed a bomb, rocket, missile or projectile, with some overlap or conflict between technical and lay terminology.

Explosive weapon systems have traditionally used munitions delivering significant quantities of high explosive compositions, commonly supplemented by fragmentation, to achieve a wide area effect. These munitions cause damage primarily via blast, fragmentation and thermal effects (see *Effects of high explosive munitions,* p. 41). Most explosive weapons are designed, developed and employed as area effect weapons, often fired at distance to achieve maximum effect against multiple targets. They may utilise either direct fire or indirect fire principles (see p. 30 and 35), depending on the system.

An important consideration in the design and use of explosive weapon systems is the need to ensure accuracy and precision[14] appropriate to the intended effects, to maximise the weapon’s efficiency and, increasingly, to minimise collateral damage. Historically, the difficulty of ensuring accurate and precise fire has led to doctrines which favour suppression of the enemy by overwhelming firepower. Explosive munitions used in such a way are commonly employed *en masse*[15] in salvo fire, and often in an indirect fire support role. The employment of explosive weapon systems in this manner within populated areas can put civilians and essential infrastructure at grave risk of harm.

In military terms, a ‘bomb’ is generally accepted to be a guided or unguided munition with no method of propulsion (such as an aerial bomb, or emplaced IED). A ‘projectile’ refers to a munition propelled under power from a weapon system, such as a gun. A ‘rocket’ is generally accepted to be an unguided munition propelled by a rocket engine, whilst a ‘missile’ is taken to mean any self-propelled guided munition. Guided munitions which employ rocket propulsion may be termed ‘guided missiles’; however, some missiles use forms of thrust other than rocket propulsion (Cross et al., 2016).

High explosive munitions are designed to destroy, damage, kill, injure or incapacitate the intended target. Multiple considerations are weighed when developing munitions for a particular use. Piercing the armour of personnel,

14 See *‘Accuracy and precision’* section in this report for description of these terms.

15 Several weapons firing a number of munitions simultaneously as a single group (in a mass, all together, as a group).

vehicles or structures, for example, may require a particular casing and fuze in order to optimise the intended effects. Anti-personnel requirements in open terrain may call for primarily fragmentation effects, whereas in enclosed environments (such as buildings and vehicles) they may make airburst high explosive, or thermobaric[16] warheads, a more effective choice.

In addition to their intended effects, munitions are designed according to various other constraints, including their delivery system(s), their working environment, available technology and materials, cost and legal restrictions. The design of munitions delivering similar effects and developed under similar constraints will still vary by delivery system. For example, artillery gun projectiles will commonly feature a thick munition casing to withstand the extremely high acceleration during the firing process and to produce significant fragmentation effects. General-purpose air-delivered bombs, by comparison, are only exposed to the airstream in the immediate vicinity of the delivery aircraft, and so do not require the structural rigidity of an artillery gun projectile. They will generally contain a higher proportion of explosive fill by weight (Cross et al., 2016).

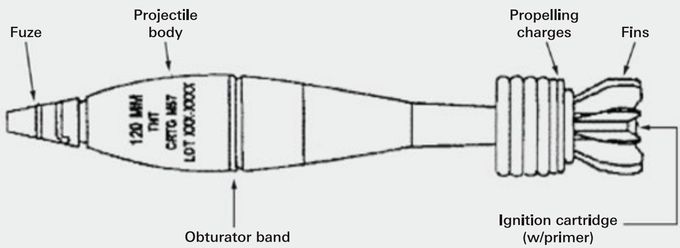

Figure 1. Arrangement of a typical mortar projectile (source: U.S. Department of the Army, 2007).

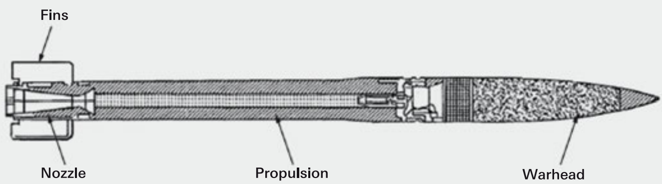

Figure 2. Arrangement of a typical artillery rocket (source: Dullum, 2010).

16 i.e. enhanced blast.

A high explosive munition is primarily intended to deliver a warhead[17] – a general term used to refer to the portion of a munition containing the payload[18]. All warheads contain, at a minimum, a fuze, the explosive fill and the warhead case. The type of warhead has a significant influence on the destructive effects, as the design may increase, for example, the blast or fragmentation effects of a munition.

Several types of explosive warhead exist; however, this report is primarily concerned with those that are both commonly held by states and non-state actors, and have the most substantial impact when employed in populated areas. These are the high explosive (HE) and high explosive fragmentation (HE-FRAG) types. Other warhead types which rely primarily on high explosive content to deliver their intended effects include high explosive anti-tank (HEAT), high explosive squash-head (HESH)[19], continuous rod; dense inert metal explosive (DIME); and the enhanced blast warheads – thermobaric and fuel-air explosive[20].

It is important to understand the distinction between incendiary and high explosive munitions. The former deflagrate, whilst the latter detonate.[21] The Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons[22] defines an 'incendiary weapon' as 'any weapon or munition which is primarily designed to set fire to objects or to cause burn injury to persons through the action of flame, heat, or combination thereof, produced by a chemical reaction of a substance delivered on the target'. Whilst explosive munitions often deliver a thermal effect, they are primarily intended to cause damage through blast and, typically, fragmentation.

Weapons may have both a 'maximum range', the farthest that a projectile will travel under optimal conditions, and an 'effective range'. The definition of the latter tends to vary by user, but is generally considered to be the maximum distance at which a weapon may be expected to be accurate and achieve the desired effect (DoD,

17 Term 'warhead' is typically associated with rockets and missiles; 'shell' with artillery and tanks guns; 'bomb' with mortars.

18 The distinction is blurred when referring to munitions with submunition payloads, or less-lethal or non-lethal payloads (Cross et al., 2016).

19 Known as high explosive plasticized or high explosive plastic (HEP) in the United States and elsewhere.

20 Thermobaric and fuel-air explosive munitions fall outside the scope of this report, but are increasingly employed by state and non-state actors in current and recent conflict zones. For information on these munitions, see Cross et al., 2016.

21 Note that some incendiary munitions may also contain high explosive bursting/anti-handling charges.

22 Convention on Conventional Weapons (CCW) Protocol III.

2016). The effective range should only be considered indicative. It varies with munition, training, sights used, whether the weapon platform is stable or mobile, weather conditions and other factors. The variations of these factors can contribute to civilian harm. For example, the Russian 115 mm 2A20 Molot tank gun fitted with the TSHS-41U telescopic sight and firing the 3OF18 HE-FRAG projectile has an effective range of 3000 m but its maximum range is 9500 m when fired at a gun angle of 16° (Nikolskiy, 1997). When used at night, firing with the TPN-1 night sight, its effective range is reduced to 800 m for all projectile types. This is a limitation of the sight, not of the munition but which has an impact on the projectile's effective range.

Finally, the introduction of precision guided munitions (PGM) and low-collateral damage weapons (see *Acknowledging wide area effects*, p. 94), particularly for air-delivered bombs, has substantially changed the way certain explosive weapon systems impact populated areas. The PGM are addressed in this report. PGM also exist for artillery gun and mortar projectiles, rockets (including those fired from MBRLs) and tank guns. These are not discussed in this report due to their rare appearance and employment in conflicts to date. PGM represent a marked difference in the employment criteria, effects and capabilities of explosive weapon systems. For those militaries with the ability to deploy such advanced technologies, PGM have led to substantial differences in the role of explosive weapon systems.

ACCURACY AND PRECISION

Achieving a high degree of accuracy and precision in firing an explosive weapon is of utmost importance if the objective is to deliver its effects on a specific target and hit nothing but the target. Whereas there are particular distinctions between the weapon's use in indirect and direct fire modes, in all situations, to hit a given target, the user must know the precise location (x,y) and elevation (z) of both the target and the weapon. Prior to firing the first round, the user must also be able to configure the weapon and the munition to correspond with the nature (size, type) of the target, and adjust variables pertinent to weather, distance and the weapon's alignment, among other factors.

The terms 'accuracy' and 'precision' have two distinct meanings, often understood respectively as the ability to hit a desired target, and the ability to hit that target consistently. The difference between accuracy and precision can be usefully understood in relation to archery. If an archer wielding a bow is accurate, after firing several arrows the 'grouping' of impacts will be centred on the target. However, the arrows may be dispersed and some – or all – may not strike the centre of the target (**Figure 3**, *example 3*). If an archer is precise, the arrows will impact closer together, in a tight grouping. However, this may not necessarily be close to the centre of the target (**Figure 3**, *example 2*). A good archer will therefore be both accurate and precise, ensuring that each arrow impacts close to the centre of the target and forms a tight group (**Figure 3**, *example 4*). An imprecise and inaccurate archer will shoot a loose grouping not centred on the target (**Figure 3**, *example 1*).

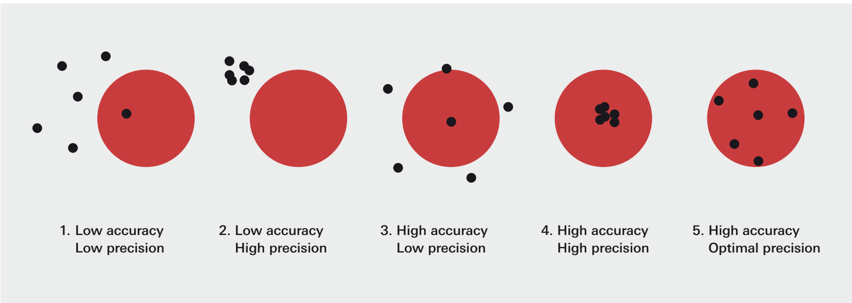

Figure 3. Accuracy and precision as affected by systematic and random errors. The red circle represents the desired area of effect (source: ARES).

Indirect fire weapon systems, however, are designed to have a natural dispersion to ensure that not all munitions strike the centre of the desired target[23] (**Figure 3**, *example 5*). In connection with explosive weapons therefore, accuracy refers

23 e.g. unguided rockets, artillery guns, mortars, unguided air bombs and any systems dispersing cluster munitions.

to a weapon's ability to strike a desired mean point of impact (MPI)[24], whereas precision is the measure of the standard deviation from the MPI, or 'dispersion'.

One common measure of weapon system precision is known as Circular Error Probable (CEP). The calculations used to determine the CEP for a weapon system are complex and require substantial modelling, field-testing, and statistical analysis of the fall of shot data under known conditions. It can be approximated to the radius of a circle centred around the MPI, the boundary of which is expected to include the impact points of 50% of the munitions in question (Sheedy, 1988). In simple terms, this means that half of the munitions fired, launched or dropped at a target would fall within the CEP of the weapon system; 93.7% will fall within twice the CEP radius and 99.8% will fall within three times the CEP radius from the MPI (see **Figure 4**).[25] A larger CEP therefore denotes increased uncertainty as to the precision of the weapon system.[26]

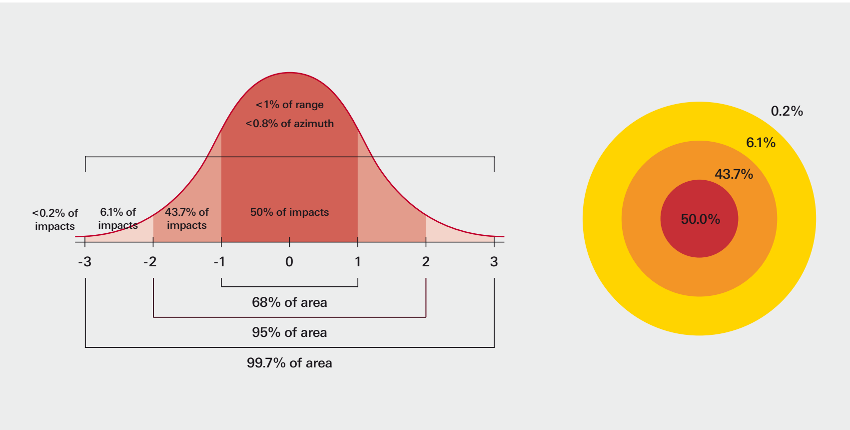

Figure 4. Error around the point of impact – Gaussian distribution and diagram of the Circular Error Probable (CEP) circular distribution (source: ARES).

24 Mean Point of Impact (MPI): the average impact position of a number of rounds (Dullum et al., 2016).

25 Figures given for CEP assume that munitions are deployed under standard testing circumstances, unless otherwise indicated.

26 The original concept of CEP was based on a circular bivariate normal distribution (CBN), with CEP as a parameter of the CBN, just as μ and σ are parameters of the normal distribution. Munitions with this distribution behaviour tend to cluster around the aim point, with the majority landing reasonably close together, then progressively fewer as the distance increases, and very few at long distance. That is, if CEP is *n* metres, 50% of rounds land within *n* metres of the target, 43.7% between *n* and *2n*, and 6.1% between *2n* and *3n* metres. The proportion of rounds that land farther than three times the CEP from the target is around 0.2% (Cross et al., 2016).

Many factors affect the accuracy and precision, such as the meteorological conditions at launch or along the ballistic trajectory, alignment and sighting of the weapon, or low standards in munitions manufacturing. In field applications munitions fired from the same system may have been manufactured in different factories – possibly even in different countries – leading to the potential for large variations in consistency and tolerance, which will introduce errors.

Systematic errors are consistent from round to round and affect accuracy, while random errors are unpredictable and affect precision (Taylor, 1997). Various features of different weapon systems may be designed to mitigate errors that affect precision or accuracy, or may contribute their own sources of error.[27] Precision guided munitions have a guidance system which allows course correction in-flight, enabling a target to be struck with a high level of precision and accuracy. They are designed to correct both systematic and random errors.

Systematic errors are consistent over a period of time and over multiple rounds. For example, an error in the estimation of the wind speed may result in a salvo's MPI being located to the right of the target. Similarly, a given batch of munitions may be consistently underweight, resulting in impacts prior to the target area. Both of these would lower accuracy, or create bias[28], in the impact pattern. This bias can be adjusted against for subsequent firings – the main reason indirect fire is 'walked' on to a target.

Random errors are those which vary between munitions, or over very short periods of time between firing. Typically, random errors arise from poor quality control, or larger tolerances in the manufacturing process resulting in notable deviation between rounds. One source of random error is differences in the munitions' weight[29], or using a different type or amount of propellant than has been calculated for. This creates a larger deviation in the impact pattern, resulting in a much wider dispersion of impact points.

As the weapons covered in this report are used widely around the world, the weapons and munitions have been manufactured in a variety of countries and at different times and environments. Each of these factors will result in weapons that differ from the original design to varying degrees, meaning that the systematic

27 Each weapon system has sources of error that affect accuracy and precision differently, some quite particular to that system. Refer to Annexes A–E.

28 Bias is an error that only affects accuracy, resulting in a consistent offset in the MPI from the aim point or target.

29 Unless the difference is predictable, in which case it becomes a systematic error (Dullum et al., 2016).

errors of each copy will be slightly different from the original. Poor tolerances, insufficient maintenance and general wear and tear resulting from training, transport and use, increase the random errors of a weapon or a batch of munitions.

The operational life of each type of barrel is measured by the number of rounds it can fire before the wear exceeds acceptable tolerances. Each time an artillery gun, mortar or tank gun is fired, it is worn down. Increased barrel wear results in increased 'windage': the difference in projectile and bore diameter. When projectiles no longer fit tightly into barrels, this will adversely affect their accuracy, precision and range. Barrel wear can vary between guns in a formation, introducing inaccuracy and imprecision when these are fired *en masse*.

Inadequately resourced militaries may struggle to maintain the weapon systems and munitions correctly and in a systematic manner. Weapons and munitions often remain in service for much longer than their recommended operational lives (ARES, n.d.).

Other factors that could affect accuracy and precision include the quality of the information available to the operators; their ability to incorporate that information into the firing parameters; position and alignment of the weapon; environmental (meteorological and other) conditions; and storage and transportation of the munitions; all of varying levels of importance depending on the weapon system in question and its operational use.

The training of the operators is instrumental in accounting for and mitigating these factors. For example, a poorly trained or untrained crew may mix different batches of otherwise consistent munitions, leading to an increase in error. For those militaries seeking to source munitions for older weapon systems, the challenge can be to find homogenous batches that have been correctly packed, stored and transported since manufacture. Munition fabrication for modern military weapon systems is usually standardised and subject to strict quality inspections, resulting in increased precision and accuracy, but batches are still subject to changes over time due to changing conditions in storage, handling and transport.

A neat circular distribution of munition impact locations is rarely exhibited in the field, particularly with longer-range indirect fire systems such as artillery guns and rocket artillery. Impact distributions will typically exhibit a larger standard deviation (or error) along the line of fire than across. This results in an elliptical confidence distribution. Circular, or elliptical, Error Probable is only relevant for considering the precision of a weapon; it is not an estimate of a weapon's accuracy. However, for the purposes of discussing explosive weapon use in populated areas, it is an important characteristic for predicting potential collateral damage.[30] Manufacturers, militaries, NGOs and other stakeholders use the term CEP frequently in reference to weapon systems.

The CEP figures provided by armed forces or, especially, manufacturers typically assume perfect firing conditions, and a well-trained and experienced crew using munitions that have been both stored correctly and used before the end of their serviceable life. These conditions are often not present in practice, particularly among inadequately resourced militaries and non-state actors. Sometimes manufacturers' CEP figures are quoted but without details of the standard range at which the CEP is applicable, although in most cases with standard munitions the maximum range is used.

Measures of accuracy and precision can be notably degraded by adverse weather conditions. With indirect fire systems such as mortar, artillery gun and rocket systems, and unguided bombs, meteorological conditions such as wind and changes in prevailing air pressure[31] during the munition's flight play a substantial role in determining accuracy and precision. The further the munition must travel, the more significantly errors (both systematic and random) will affect its deviation from the intended MPI. In order to compensate for the prevailing weather effects, current readings from meteorological systems[32] may be used to adjust sighting and firing parameters, altering the trajectory of the munition. Accuracy and precision can be further improved by using modern, computer-controlled firing systems, especially in conjunction with smart fuzes and PGMs (Dullum et al., 2016). However, the latter option is not available for many of the older systems used in conflict zones, nor accessible to most non-state actors and many armed forces.

INDIRECT FIRE WEAPON SYSTEMS

When discussing explosive weapons, it is important to differentiate between direct and indirect fire systems. Direct fire systems are employed when the target is within the line of sight, with the weapon aimed directly at the target. The munition's trajectory closely follows the line of sight. Conversely, indirect fire weapon systems most commonly engage targets which are not within the direct

30 Precision guided munitions follow the same statistical laws as unguided munitions, but their CEP is much smaller. PGM generally have more 'close misses', and do not follow a Gaussian (normal) distribution (Dullum et al., 2016).

31 i.e. amount of air resistance, or drag, at different altitudes, and altering lift effect to the munition-in-flight.

32 e.g. a weather balloon.

line of sight. Yet, the term 'indirect fire' may also be used to describe fires delivered when the target is visible from the weapon system, but where the direct 'vision link' between the operator and target is not used for aiming (Ryan, 1982).

Indirect fire weapon systems include artillery guns, mortars, artillery rockets and many air-delivered munitions. Indirect fire may be employed to fire into defilade, out of defilade[33], or over forces or structures other than the target, in order to strike a target obscured by geographic or structural features, or by the curvature of the earth over long distances (see **Figure 5**).

Indirect fire weapon systems can be very accurate and quite precise under optimal conditions. However, adverse conditions, poor maintenance and inadequate training have a significant impact on the accuracy and precision of these systems. Over the long ranges that these weapon systems are typically employed, a slight deviation in accuracy can result in a complete miss. Adjusting fire procedures may be employed to account for random deviation in the impact location – to 'walk' the fire towards the target.

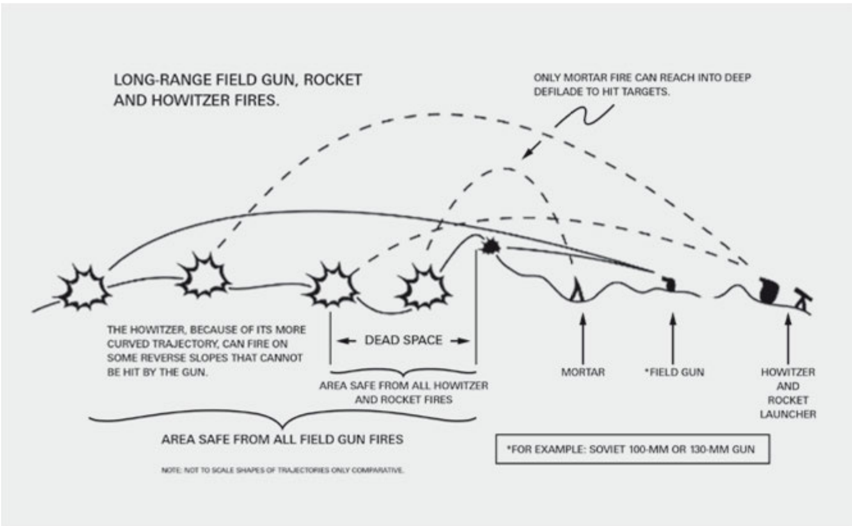

Figure 5. Comparative trajectories for indirect fire artillery systems (source: ARES / USAFAS).

33 The protection of a position against enemy observation or gunfire: see Figure 5.

Indirect fire weapon systems examples

MBRL type systems are often significantly less accurate and precise than guns or mortars. As the 122 mm BM-21 MBRL was developed to be an area weapon, accuracy and precision are not its primary strengths. When the BM-21 launches multiple rockets, these are launched some 0.5 seconds apart. As the launcher is vehicle-mounted, each launch causes the vehicle suspension to compress and rebound. The suspension movement causes fluctuations to the angle of the launching tubes, and subsequently greater inaccuracies in the delivery of the rockets. This means that rockets launched later in the salvo are likely to be less precise than those launched at the beginning (Dullum et al., 2016). The significant differences in vehicle types, weights and launcher mounting methods observed between BM-21 copies and variants makes this error very difficult to assess across different systems. Error induced from this process may be particularly pronounced when MBRL systems are mounted to lightweight vehicles with soft-suspension, such as civilian 4 x 4 pickup trucks.

With rocket artillery, meteorological conditions play a more significant role in determining accuracy and precision than with most other weapon systems – for example, wind may contribute an error ratio of some 2% at ranges of 20 km (Dullum, 2010). This is the equivalent of an error of 400 m from the desired MPI at a range of 20 km. Rocket artillery is also affected by a number of errors that do not affect other explosive weapon systems, such as tip-off due to launcher motion, and transverse wind during the boost phase of the rocket (Dullum et al., 2016).

Due to these factors, as well as others beyond the scope of this report, rockets launched from an MBRL of a design such as the BM-21 will typically be among the least accurate or precise explosive weapon systems commonly employed.

An estimation of the accuracy of the BM-21 must account for both systematic and random errors, as the combination of both determines the effectiveness of a strike. It is clear that the longer the range, the greater the margin for error and, therefore, the greater the CEP and bias. For errors across the line of fire, this can be described as an angular deviation, proportional to range fired, usually expressed in mils[34]; see **Table 1** for typical figures.

34 'One *mil* is approximately equal to a *milliradian*, which is an angle spanning out one metre at a distance of 1000 m – there are 6400 mils in a circle. An error measured in mils can be converted to metres by multiplying the given error (in mils) by the firing distance (in kilometres).' (Dullum et al., 2016).

TABLE 1 SAMPLE ACCURACY AND PRECISION FOR THE BM-21 GRAD

Accuracy and precision of selected multiple barrel rocket launchers (assumed values)

Values given as deviation in mils across x along the line of fire

System	Firing distance (km)	Random error (mils)	Systematic error (mils)	Total error (mils)[35]
122 mm BM-21	19	5.8 x 8.5	6.0 x 12.0	8.3 x 14.7

Source: Dullum, 2010.

When firing a 122 mm BM-21 rocket at a range of 20 km, for example, a sample probable error in deflection is 160 m, and a sample probable error in range is 300 m, representing ideal conditions (see **Figure 6**).

Figure 6. Probable error for a 122 mm rocket fired from a BM-21 Grad at a range of 20 km (source: ARES). These figures have been overlaid on a real-world example of BM-21 CEP. The map shows select, verified impact locations and approximate scale of an MBRL attack in Mariupol, Ukraine on 24 Jan 2015 (source: Human Rights Watch, 2015).

35 Ibid.

Artillery guns are generally considered to be a more accurate and precise indirect fire system compared to the studied mortars and rocket artillery, although the longer range of artillery systems (in comparison to the other systems examined) must also be taken into account. Artillery is still subject to errors induced by meteorological phenomena such as wind, and beyond a range of approximately 15 km these factors are generally the largest source of error. The ability to mitigate meteorological error is dependent on the accuracy and comprehensiveness of the information available to the ballistics computer and upon the accuracy of the ballistics model.

Approximate CEP values for 155 mm artillery guns are given in **Table 2**, below. The U.S. M777 towed and M109A6 self-propelled artillery guns, for example, have a maximum CEP of approximately 140 m when fired at 25 km (Knudson, 2008). The U.S. Army has previously designated 267 m as an acceptable CEP, at the maximum range of its 155 mm weapon systems. Various CEP figures given for 155 mm guns at 30 km are over 260 m, with variance for specific models (Watts, 2013).

TABLE 2 APPROXIMATE CEP VALUES FOR GENERIC 155 MM ARTILLERY GUNS

155 MM ARTILLERY ACCURACY	
Range	CEP
15 km	95 m
20 km	115 m
25 km	140 m
30 km	275 m

Source: Dullum, 2010; Hill, 2007.

NATO 120 mm HE mortar projectiles have a nominal CEP of approximately 136 m at their maximum range, without the use of an advanced fire-control system. The use of a fire-control system (such as the M95/M96 Mortar Fire-Control System (MFCS)) significantly reduces the CEP of conventional NATO 120 mm HE mortar projectiles (Super & Kundel, 2007). Improvements in the accuracy and precision for both medium and heavy mortars have been made, particularly in relation to the design of the munition.

DIRECT FIRE WEAPON SYSTEMS

Direct fire systems are those employed with an unbroken line of sight between the weapon system and the target. Under ideal circumstances, direct fire systems are very accurate and precise, and may be capable of achieving first-round hits. However, hitting the intended target does not negate the possible wide area effects of the munition. Collateral damage in populated areas remains likely when the target is small and the explosive yield of the munition is high.

Direct fire weapon systems examples

Tank guns are a typical example of a direct fire system. Unguided bombs dropped from aircraft have historically required the use of bombardment techniques more in line with those used by indirect fire systems, but this has changed with the introduction of advanced targeting and precision guided bombs. Modern aircraft-dropped bombs are employed in a manner that has more in common with tanks than artillery.

As tank guns are direct fire weapons, they do not suffer many of the difficulties inherent in indirect fire systems, and modern tank guns can be precise and accurate up to the maximum effective range of the gun. However, if a tank projectile misses its intended target, it is very likely to retain sufficient kinetic energy to continue for several kilometres beyond the target. Most tank guns can be fired from a moving platform, often whilst remaining accurate and precise, as the fire-control systems in modern tanks are able to measure a large number of different factors and adjust the aim accordingly. Modern tank fire-control systems measure, amongst other factors, the precise range to target, wind speed and direction, temperature, humidity, the angle of the target relative to the firing position, the angle of the ground, and the wear inside the barrel, in order to produce a very high first hit probability.

Under the guidance of a highly trained and competent crew, well-designed and well-built tank guns and munitions can have significant accuracy and precision. For example, a 120 mm Rheinmetall L55 gun is capable of landing five projectiles within an area measuring 9 cm high and 34 cm wide, from a distance of 2000 m[36] (Rheinmetall, n.d.). While modern tank guns rely on advanced fire-control systems to achieve these results, older tank guns are commonly employed with only rudimentary equivalents. As such, the gulf in accuracy and precision between legacy tanks and tank guns and their modern counterparts is significant.

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36 Firing the DM53 APFSDS round.

Figure 7. German Rheinmetall 120 mm smoothbore gun L44 and L55 (image credit: Thai Military and Asian Region).

PRECISION GUIDED MUNITIONS

Precision guided munitions (PGM) are designed to strike a precise target with the first shot by altering their trajectory during flight. In addition to the warhead, PGM also carry a seeker head, a processor and typically a servomotor assembly, with which to control small wings that are used to guide the munition to the target.[37] The CEP of modern PGM tends to be no greater than a few metres, even at their maximum range (Cross et al., 2016). While highly effective, the technology involved in producing PGM makes them very expensive to acquire, train with and employ. Precision guided projectiles may also employ rocket-assisted or base-bleed[38] designs in order to increase their effective range. PGM offer enhanced first-round hit probability and reduce the potential for collateral damage in situations where the target is of an appropriate size considering the explosive yield of the munition and the surroundings of the target. The introduction of PGM is increasingly resulting in the evolution of doctrine and employment procedures for the range of weapons they have been adapted for, as evidenced by the modern guided aircraft bomb.

By 1972, laser guided bombs had been developed and brought into service and were capable of delivering munitions with a CEP of approximately 23 feet (7 m), resulting in direct hits 48% of the time (Werrell, 1998). The effectiveness

37 Various other control surfaces and alternative methods are used to achieve course correction.

38 See Dullum et al., 2016.

of explosive weapons in achieving their desired aims is significantly affected by the accuracy of the munitions employed. One study of the performance of laser-guided bombs found that they were between 100-200 times as effective as conventional bombs against hardened targets and between 20-40 times as effective against soft and area targets (Blachly, Conine & Sharkey, 1973).

An example is the GBU-12 (an Mk 82 bomb fitted with a laser-guidance package): in 1991, 66 U.S. aircraft destroyed 920 Iraqi armoured fighting vehicles in only two weeks (Blackwelder, 1993). The accuracy of the GBU-12 depends entirely upon the guidance system of the munition being able to maintain the line of sight to the laser target designator. Multiple factors can cause target loss, including rain, cloud, fog, smoke and dust, causing loss of guidance. Likewise, any hardware problems with the sensor unit of the bomb or the laser target designator could result in a loss of guidance. If this were to happen, the bomb might cease altering its trajectory, potentially impacting hundreds of metres from its intended target. In a populated area, there would be a clear risk of civilian casualties and damage to civilian infrastructure. In part to mitigate this risk, more advanced guided bomb unit iterations were developed which incorporated other sensor inputs and redundancies, to lower the reliance on laser guidance.

The GBU-38, like many modern ‘smart bombs’, is guided by both differential GPS technology and an inertial navigation system (INS). It has a CEP of approximately 5 m, but this can be improved by the addition of further sensors designed to allow it to hit moving vehicles (Kopp, 2003). Unlike the laser-guided GBU-12, the GBU-38 is guided autonomously to the target once it has been dropped. There is no requirement for the GBU-38 to acquire a laser-marked target. Each individual GBU-38 can be assigned a different target by the systems of the delivery aircraft, meaning that one aircraft can accurately engage a number of targets simultaneously. The basic JDAM[39] guidance package can also be augmented by a range of other seeker heads, such as those using millimetre wave (MMW) imaging, referred to as Precision Terminal Homing Seekers. An example of a munition using an MMW imaging system is shown in **Figure 9**. The logical development of the guided bomb unit was to combine the laser-guidance of GBU-12 with the GPS/INS of the GBU-38. The manufacturer produced the GBU-49 in the 2000s and it first entered service with the British Royal Air Force in 2008. The combination of guidance units allows the bomb to have the accuracy of a laser-guided weapon with the flexibility of having an all-weather capability. It has a CEP of 1.1 m. The GBU-49 guidance unit cost US$ 42,000 in 2015 (Balle, 2015).

39 Joint Direct Attack Munition (JDAM): a guidance kit that converts unguided bombs into all-weather ‘smart’ munitions.

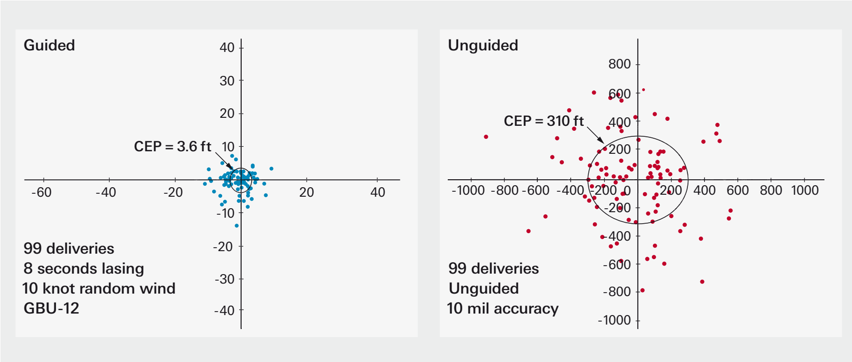

Figure 8. Comparative CEP of guided (GBU-12 Paveway II) and unguided Mk 82 aerial bombs, delivered from an altitude of 15,000 ft. (source: Raytheon, 2006).

TABLE 3 APPROXIMATE CEP FIGURES FOR MK 82 VARIANTS

MUNITION	CEP
Unguided Mk 82 variants	94.5 m
GBU-12 (laser-guided)	1.1 m
GBU-38 (GPS/INS guided)	5 m
GBU-38 (GPS jammed after release)	30 m
GBU-49 (enhanced GPS/INS and laser)	1.1 m (laser)

Source: Raytheon, 2006; 2016; U.S. Navy, 1999; 2001.

Whilst guided munitions for artillery guns, mortars and rockets are not as prevalent as their air-delivered counterparts, this is increasingly changing. PGM solutions for land service munitions provide increased firing accuracy, but also reduced munition consumption over their conventional counterparts, allowing for more fire missions and/or longer mission endurance before resupply becomes necessary. In-flight trajectory adjustments can be accomplished by a variety of methods, including fins, motor-control options and special pyrotechnic rotation charges (Jenzen-Jones, 2015).

Much like the 'bolt-on' guidance kits designed for conventional air-delivered bombs, many of the guidance solutions for land-based systems convert existing munitions into guided equivalents. For example, the U.S. military has introduced the XM1156 Precision Guidance Kit (PGK), which is a replacement fuze with course correction capability designed to significantly reduce the CEP of conventional 155 mm artillery munitions to 50 m or less at all ranges. The cost of the XM1156 is nowadays less than US$ 10,000, much less than the US$ 70,000 to US$ 130,000 of self-contained PGM equivalents (Gould, 2015). However, this is still considered to be too expensive for the majority of military forces, though inexpensive relative to precision guided missiles like the Joint Air-to-Surface Standoff Missile (JASSM) at some US$ 1,000,000 each (Watts, 2013).

For mortars, the U.S. military's precision guided mortar munition (PGMM) project has resulted in the development of the XM395 HE mortar projectile. The XM395 is a high explosive, GPS-guided 120 mm munition with a CEP of 10 m at its maximum range. As each XM395 costs about US$ 10,000 to manufacture, it is unlikely to replace conventional unguided mortar munitions (Calloway, 2011). Other countries are working on similar projects, but due to expense relative to the very low cost of conventional mortar projectiles, the deployment of these types of munitions will likely continue to be rare in the near term.[40]

A Russian equivalent to the PGMM is the Gran – a laser-guided, rocket-assisted mortar projectile with a range of approximately 9000 m fired from rifled mortars, and 7000 m from smoothbore mortars. The manufacturer claims that the Gran has an equivalent high explosive effect to that of the 152 mm HE projectile (Nuţu, 2011). The Gran can engage both stationary and moving targets and delivers a warhead containing 5.3 kg of high explosive.

Figure 9. XM395 precision guided mortar projectile (source: Orbital ATK).

40 For more information on guided mortar systems, refer to Annex C.

EFFECTS OF HIGH EXPLOSIVE MUNITIONS

The impact of explosive munitions can be broken down into the principal damage mechanisms and their primary effects, and the secondary and tertiary effects occasioned by these. This section of the report focuses on the primary damage mechanisms and secondary effects of explosive weapons in populated areas. Tertiary effects, which can be classified as damage to health, social and economic infrastructure and services that occur over a longer time scale, e.g. the lack of clean water caused by damage to water mains and sewers, or the loss of electrical and gas services, are beyond the scope of this report.[41]

Primary effects of explosive weapons are defined as those 'caused directly by the destructive effects that radiate from a point of initiation and include blast overpressure, fragmentation, heat and light' (GICHD, 2015b). These are attributed directly to the principal damage mechanism of an explosive weapon – blast, fragmentation and heat. The term 'blast' refers to a high-pressure blast wave moving at supersonic speed, referred to as the shockwave, which is followed by blast winds. Primary fragmentation comprises fragments that originate directly from the explosive munition. The third damage mechanism is the thermal energy released during the detonation of the explosive (Cross et al., 2016).

Most high explosive warheads are not designed to deliver an augmented incendiary effect and the thermal effect is limited to the immediate area of the detonation, as well as by its extremely short duration. Generally, the primary thermal hazard posed by an explosive weapon is less significant than the blast and fragmentation threats (SCWSD, 2011). As such, whilst it is acknowledged that thermal effects are present during the detonation of an explosive munition, and that they add to the total effects, these will not be addressed further in this report.

Secondary effects of explosive weapons derive from the environment in which the munition detonates. The most significant secondary effects include secondary fragmentation, firebrands, ground shock and cratering. Secondary fragmentation originates from objects that have been affected by the detonation, and can include such objects as pieces of masonry or glass from structures, or bone fragments from human or animal targets. Secondary fragments are generally larger than primary fragments and tend not to travel as fast, or as far (SCWSD, 2011).

Firebrands, or embers, consist of fragments heated to a very high temperature, are often on fire, and typically occur when an explosive munition detonates near flammable objects such as wooden structures or other munitions. Firebrands pose a hazard to other flammable material nearby, and can cause incendiary effects at a much greater distance than the primary thermal effects (Cross et al., 2016).

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41 For a fuller discussion of tertiary, or reverberating, effects, see Wille & Borrie, 2016.

They can ignite surrounding flammable materials, producing heat, toxic gases and choking smoke.

Ground shock results from the energy imparted to the ground by the shockwave caused by an explosion and can result from a detonation under or on the ground, or in the air above (Cross et al., 2016). Ground shock poses an additional threat to the structural integrity of buildings, as the ground conducts the shockwave into the foundations and walls. It can also damage subterranean constructions such as sewage and water pipes, gas and electricity lines, or underground tunnels.[42]

Cratering refers to the buckling and deformation of the ground around the detonation point (USDA, 2006). Both ground shock and cratering can cause substantial damage to underground critical infrastructure, including power, communications and water distribution. This may be a deliberate effect of explosive munitions optimised for cratering, intended to obstruct avenues of approach or to disrupt infrastructure. Such effects may have further humanitarian impacts. A cratering munition which prevents enemy use of a runway or airfield, for example, may also hamper the delivery of humanitarian aid by aircraft at a later date. If deep enough, cratering can also present a threat to underground structures.

Spalling presents an additional danger in urban environments. It is a stress wave effect most commonly observed in materials more brittle than metal. This occurs when an impact strikes the outer surface of a solid body, causing fragments to break off from the inside surface. The projectile or the fragment does not need to penetrate the solid body; merely striking the outer surface with sufficient energy may result in spalling. When considering the use of EWIPA, a possible scenario resulting in spalling is a brick wall being struck by a blast wave, or in some cases a projectile or a sufficiently energetic fragment, causing secondary fragmentation inside the building ('spall').

A significant hazard unique to urban environments is the risk of fatally compromised structural integrity of buildings caused by the blast waves. Any people in and around those buildings and structures may be crushed by their partial, or complete collapse.

42 For examples and additional information, refer to ICRC, 2015.

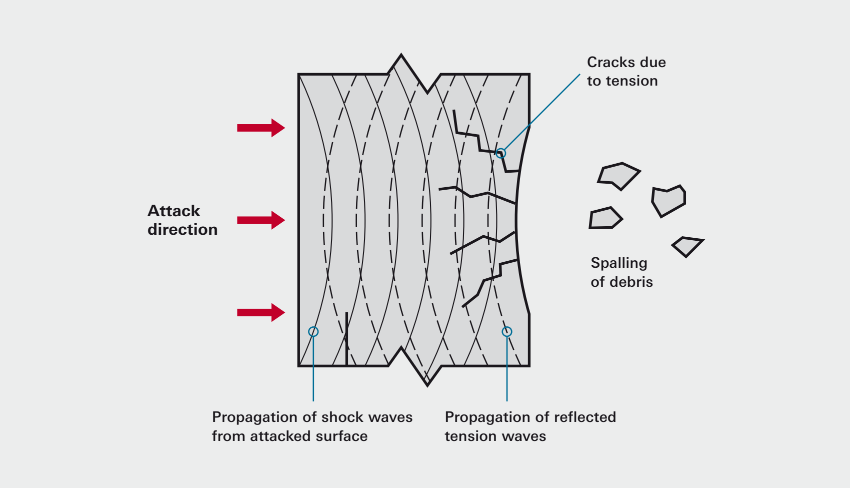


Figure 10. Propagation of shock waves through a concrete wall's media, and their reflection back as tension waves that crack the media and cause spalling of debris (source: Dynasystems Ltd. UK & GICHD).

BLAST EFFECTS

An explosive is a material that is capable of producing an explosion by releasing the potential energy contained within it. All high explosives produce heat and gas. The rapid expansion of gas is the primary medium for measuring the power of an explosion (Cullis, 2001). When a high explosive charge detonates, it produces a blast wave (overpressure) that consists of two parts: a shock wave and a blast wind. The blast wave pushes outwards from the core of the detonation at supersonic speed. The outer edge of the blast wave is made up of the compressed gases contained in the surrounding air. This layer of compressed air is more properly described as a shock wave or shock front.

In open air, the blast decays extremely quickly with time and distance; typically it can be measured in milliseconds (Cross et al., 2016). The effect of the blast is the least difficult to quantify in open terrain, as the pressure from an explosion can be calculated from the magnitude (size) and velocity of detonation of the explosive charge and the measured distance from the point of detonation. On the figure below, the impulse is shown as the area under the positive phase of the pressure versus time curve.

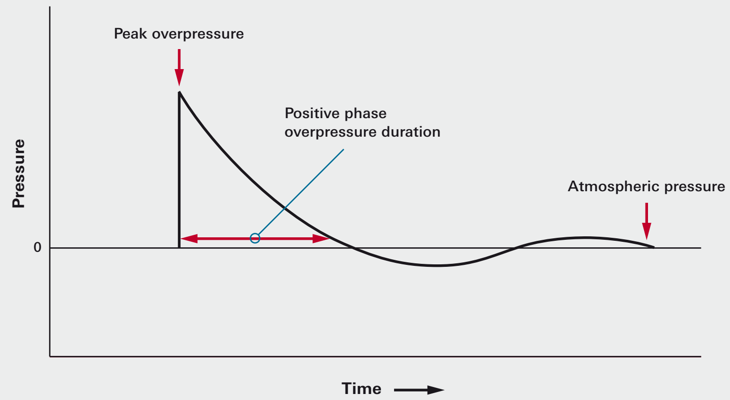


Figure 11. A visual representation of the blast wave, showing the pressure changes (source: Baskin & Holcomb, 2005; Dullum, 2010; GICHD, 2015).

The blast wave has two phases. The positive pressure phase pushes a large portion of the surrounding air away from the core of the detonation at supersonic speed, leaving a broad partial vacuum behind it. When the blast wave of the positive pressure phase loses momentum, the partial vacuum behind it causes the compressed and displaced gases to reverse their movement and rush inward to fill the void. The negative pressure phase moves less quickly than the positive phase and it generally lasts approximately three times as long (Cullis, 2001).[43]

The effect of the pressure wave upon a structure depends on what the structure is composed of and how it is built. In essence, it is dependent upon the structure's natural frequency of vibration compared with the duration of the blast wave (Cullis, 2001). When the supersonic shock front from a detonation encounters a solid structure, some of the energy is reflected, and some of the energy is transmitted into the structure; the relative amounts depend on the properties of the structure.

43 The physics of blast waves is a complex subject. More precise knowledge of blast behaviour in different circumstances and environments requires advanced computer modelling. This project is developing such a model to simulate primary and secondary effects of the studied explosive weapons.

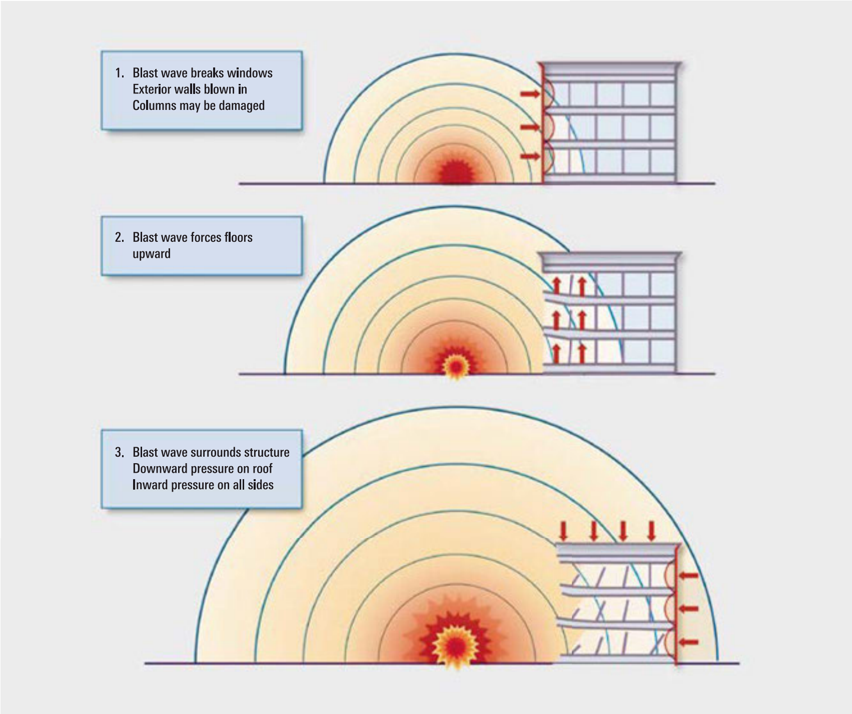


Figure 12. The effect of a blast wave on buildings and structures (source: FEMA et al., 2012).

In the process of striking the structure, the shock front will impart significant momentum to the exterior components. These components will be pushed towards the interior by the positive pressure wave, straining the resisting elements of the structure (such as support columns, building facades, etc.). Some of those resisting elements, windows in particular, will fail.

As the negative pressure phase of the pressure passes back through the structure, the direction of the energy is reversed. Unlike the reflection of sound waves, which have a negligible effect on the medium through which they are travelling, shock waves are moving at such high speed and contain so much energy that they change the medium itself.

When the shock wave hits the ground, it is reflected back into the still-advancing blast wind. This amplifies the blast overpressure anywhere up to 20 times[44] that of the initial detonation (Smith & Hetherington, 1994; UFC, 2014).

44 Against rigid surfaces.

In urban areas, the structures reflect the shock wave in different directions. Due to the densely packed structures typical of such areas, the blast wave cannot freely move outwards from the point of detonation. This results in the blast wave being partially absorbed, reflected and channelled in and around structures. In addition to being reflected, the shock wave can also wrap around structures, effectively squeezing them from all sides simultaneously (FEMA et al., 2012).

A blast wave can be quantified by its peak pressure and its duration. Multiplying the peak pressure by the duration gives a value known as the blast impulse. When considering the damage potential of a blast wave, the impulse of the wave is a key factor.

TABLE 4 EFFECTS OF BLAST OVERPRESSURE AND BLAST WIND ON STRUCTURES AND HUMAN BODY

PEAK OVERPRESSURE	MAXIMUM WIND SPEED	EFFECTS ON STRUCTURES	EFFECTS ON THE HUMAN BODY[45]
7 kPa	17 m/s	Window glass shatters	Light injuries from fragments occur
14 kPa	31 m/s	Moderate damage to houses (windows and doors blown out and severe damage to roofs)	People injured by flying glass and debris
21 kPa	46 m/s	Residential structures collapse	Serious injuries are common, fatalities may occur
34.5 kPa	73 m/s	Most buildings collapse	Injuries are universal, fatalities are widespread
69 kPa	131 m/s	Reinforced concrete buildings are severely damaged or demolished	Most people are killed
138 kPa	224 m/s	Heavily built concrete buildings are severely damaged or demolished	Fatalities approach 100%

Pressure units converted from pounds per square inch (PSI) to kilopascal (Pa), and speed units from miles per hour to metres per second (source: Zipf & Cashdollar, n.d.).

45 For a fuller discussion on the effects of explosive weapons on the human body, see Brevard, Champion, & Katz, 2012.

Blast effects example (MK 82 aircraft bomb)

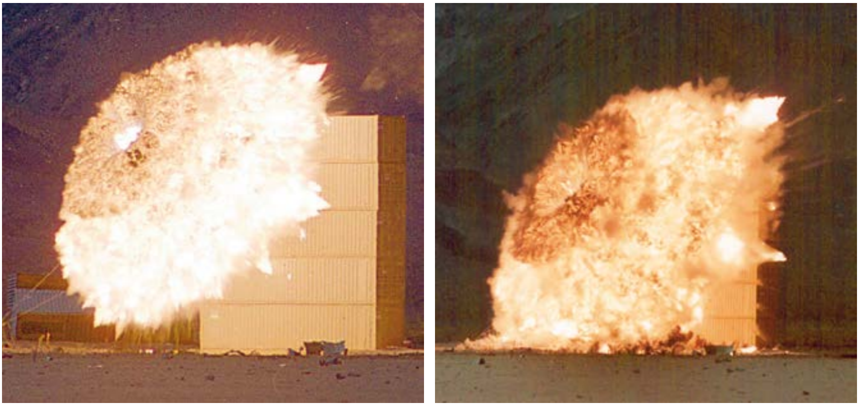


Photo 1. An Mk 82 bomb detonation in a test environment (photo credit: Federation of American Scientists).

In its simplest configuration, the standard Mk 82 bomb contains approximately 89 kg of high explosive in a forged steel body weighing 142 kg (Glass et al., 1997). According to one manufacturer, the detonation of a Mk 82 aircraft bomb produces a peak overpressure of 117 kPa at 16 m from the point of detonation. The design fragment from this weapon is less than 20 grams travelling at 2400 m/s, and at this distance the natural fragments generated by the detonation will penetrate up to 32 mm of steel armour plate. After 16 m the velocity is reduced below 1900 m/s. It will then be capable of penetrating up to 200 mm of concrete (ConWep, 2016).

The peak overpressure reduces to 34 kPa at a distance of 31 m (Ordtech, n.d.). Assuming that the point of detonation is the centre of a circle, a radius of 31 m produces a circle with an area of 3019 m^2. Within this area, a Mk 82 aircraft bomb will cause the collapse of most buildings, severely damage heavily built concrete structures and produce injuries to all persons present, killing the majority of them. Depending on the type of ground it hits, the angle of impact and other factors, the Mk 82 will produce a crater with a diameter of between 4.6 to 10.7 m and depth between 0.76 and 4.27 m (Ordtech, n.d.).

FRAGMENTATION

Primary fragmentation originates from the casing of the typically metallic[46] warhead surrounding the high explosive charge. Fragments can take a variety of shapes and sizes, and are primarily effective in an anti-personnel capacity. When a warhead has not been treated for pre-fragmentation, the detonation of the high explosive will cause the warhead to splinter, resulting in what is known as natural fragmentation.

Some warheads are scored, or treated with heat or chemicals, to encourage the metal casing to fragment along pre-determined stress lines. Pre-fragmented munition casings can result in a denser spread of fragments than might occur with munitions relying on natural fragmentation. Consistency in fragmentation can greatly enhance the lethality and efficiency of munitions. Pre-formed fragments are increasingly preferred in many munition designs. Such fragments are often held in a matrix of polymer or light metal, and provide even greater consistency than pre-fragmented designs. The inclusion of pre-formed fragments is often combined with pre-fragmented outer casings on munitions.

The type of steel used in the manufacture of the warhead plays a significant role in determining the nature of the natural fragmentation that is produced. High explosive warheads are typically made from either forged or cast steel or iron (Ryan, 1982). Cast metals are melted down and poured into moulds to form the shape of the projectile, whereas forged steel projectiles are formed by beating red-hot steel ingots into the desired shape.

In 1968, the Norwegian Defence Research Establishment carried out a series of trials to establish the lethal area for 81 mm and 120 mm HE mortar projectiles.[47] It was discovered that when the explosive within a forged steel projectile detonates, it produces fewer fragments than would be produced by a cast steel body of the same dimensions. When calculating the lethal area for prone human targets, cast iron cases produced approximately three times as many fragments as forged steel casings (Jacobsen & Strømsøe, 1968). A smaller number of fragments from the same total mass indicates that the fragments will generally be larger than those produced by a cast warhead. Such larger fragments would be more effective against lightly armoured targets, but the smaller number of fragments would generally make forged steel warheads less lethal against softer targets (i.e. human beings) than cast warheads.

46 Conventional ordnance casings made from non-metallic materials, whilst rare, have been employed in conflict zones (Jenzen-Jones, 2016). Non-metallic fragmentation may also be used in conjunction with conventional ordnance and improvised explosive devices (IEDs).

47 Refer to Annex C for additional information regarding mortar lethal effects.

Table 5 gives the hazardous fragment distances (HFD) in metres for a nominal munition with a given net explosive quantity (NEQ) in kg TNT equivalent – one of the models used to assess fragmentation hazards. The HFD represents the distance at which the density of fragments in the air will likely reduce to 1 per 55.7 m^2. The HFD distance is one with a low probability of being hit by a hazardous fragment, and if one were hit after all, the impact would not be lethal (SCWSD, 2011).[48] Note that the HFD does not represent the maximum range that fragments may travel – individual fragments can be found more than 3048 m further than the HFD (U.S. DoD, 2008).

TABLE 5 HAZARDOUS FRAGMENT DISTANCES (HFD) FOR GIVEN NET EXPLOSIVE QUANTITY (NEQ)[49]

NEQ (KG)	HFD (M)	NEQ (KG)	HFD (M)
0.45	87	11.35	164
0.91	104	22.70	180
1.36	113	34.05	190
2.27	126	45.40	197
4.54	142	113.50	304

Source: U.S. Department of the Army, 2013.

In order to calculate the effectiveness of a warhead against a given target area, it is necessary to calculate the hit probability for the fragmentation that is produced. The fragmentation effect can be quantified by the two-dimensional function p(x,y), which is the probability of being affected by the weapon when the position of the target is given by the ground coordinates (x,y). Once the injury probability function has been established, the effect of the munition can be stated as a single quantity called lethal area. The probability that a given target is hit by at least one fragment reduces with distance. The further a target is from the point of detonation, the less likely it is to be hit by the fragmentation produced.

48 A hazardous fragment is one having an impact energy of 58 ft-lbs or greater (SCWSD, 2011). Hazardous fragments with an impact energy between 15 J and 79 J are considered capable of causing 'serious injury', whilst fragments of 79 J or greater 'severe injury or death' respectively (U.S. Department of Energy, 2012).

49 Table adapted from the USDA; units converted from imperial (pounds, feet) to metric (kilograms, metres).

At a given distance a larger target is more likely to be hit. Military modelling assumes that the targeted soldiers are in the prone position and present an area of 0.5 m^2. As described in *Risk estimate distances* (RED) *for selected munitions* (**Table 10**, p. 84), *RED* represent the expected percentage of incapacitation (PI) for unprotected personnel, with for example 10 PI being the equivalent of 10% of the affected soldiers rendered unable to continue fighting (U.S. Army, 2007). *RED* are primarily derived from the fragmentation radius of a given munition, as well as the characteristics of the delivery system; that is, both the effects and the precision of the system in question. It associates this combination with a percentage representing the likelihood of incapacitation.

Buildings can provide a degree of protection from primary fragmentation. Primary fragmentation may penetrate some surfaces, such as those made from softer materials, but generally loses a significant amount of energy and often proves less lethal after it penetrates certain materials. The fragments may, however, ricochet off hard, thick surfaces and may continue to pose a risk to people in the open.

Nonetheless, the majority of the fragment's energy would likely be absorbed in the initial impact, rendering it less hazardous as a result. A modern urban environment, composed of brick, stone and concrete structures, would provide a much greater level of protection from primary fragmentation than the weaker structures often found for example in shanty towns or refugee camps.

The weight of each fragment is a significant factor in determining the amount of damage it can cause, as well as its likely lethal range. The less mass the fragment has, the lower its momentum.

Secondary fragments are generally larger than primary fragments and typically do not travel as far or at as high a velocity as primary fragments (often at hundreds, rather than thousands of feet per second) (USDAF, 2011). However, urban environments may generate a range of secondary fragmentation effects not found on the open battlefield.

Window glass for instance, often forms a significant proportion of the secondary fragmentation.[50] These fragments are caused by the high-pressure blast wave moving through the air and shattering windows, rather than the transmission of the shockwave through a solid medium. Structures making significant use of glass – increasingly commonplace in urbanised areas – can be particularly sensitive to the effects of high explosive detonations (Balogh, 2010). One example of how

50 For further information on the effects of blast on glass, refer to Balogh, 2010.

dangerous glass can be as a form of secondary fragmentation can be seen from analysis of the 1996 bombing of the Khobar Towers in Saudi Arabia: 95% of the survivors suffered injuries from fragmentation; of these, 88% were injured by glass (Thompson, Brown, Mallonee, & Sunshine, 2004).

Calculating the effects of primary fragmentation is more complicated than the blast effect, owing to the number of known unknowns. In many cases, the initial velocity (speed and impact angle) of the warhead at the time of detonation is not known, nor is the exact shape, weight and aerodynamic performance of each fragment. Warheads utilising pre-formed fragmentation or pre-fragmented munitions casings will be easier to predict, generating more consistent fragmentation effects. The type of fuze will also affect the fragmentation pattern (See *Fuzing*, p. 66 and *Fuze selection*, p. 96). Due to the greater variation in the size and number of fragments caused by the explosion, natural fragmentation is more difficult to predict and model. The effect of fragmentation on human targets is particularly unpredictable, as the amount of exposed body area and the posture of the target can have a marked influence on the potential harm.

The angle at which a munition impacts the target has a significant bearing on the size and shape of the lethal area. In simple terms, the higher the angle (toward vertical 90°) of fall, the larger the lethal area will be.[51] In order to maximize lethal area, at higher angles of fall (45-90°) the optimal height for detonation is approximately 2 m above ground, although even at just above ground, the lethal area is increased (Jacobsen & Strømsøe, 1968). The 5 February 1994 attack on Markale market, Sarajevo (Case Study D1), is indicative of the devastation which can be caused by a single munition falling at high angle and detonating above ground level. The size of the Markale market, approximately 1000 m^2 with tall buildings surrounding it from all sides, makes it a relatively small, enclosed space. Such a space, coupled to a high density of people in it, makes it particularly vulnerable to a fragmenting warhead falling from above.

Primary fragmentation effect example (9M22)

An example of the fragmentation effects of a high explosive munition can be seen in the common 122 mm artillery rocket type BM-21, model 9M22. The warhead of this munition contains 6.4 kg of TGAF-5[52] high explosive composition and generates 3,920 representative fragments from scored diamond patterns on the

51 See Annex C for a more complete explanation, along with a table of the lethal area relative to angle of fall.

52 TGAF-5 is comprised of 40% TNT, 40% RDX, 17% Aluminium powder and 3% phlegmatiser (Nitrochem, 2015). Later, these munitions used A-IX-2 (Karpenko, 2010).

inside of the munition casing (USSR Ministry of Defence, 1971). The figures below show an example of natural fragmentation (**Figure 13**) and controlled fragmentation (**Figure 14**).

Figures 13 and 14. Natural fragmentation (left) from a mortar projectile recovered in Baghdad, Iraq in Jan 2006 (photo credit: Bryan G. / U.S. Army), and a section of pre-fragmented munition casing (right) (source: USDA, 2006, p. 20).

The warhead of the rocket 9M22 is designed to produce some 1,640 fragments, each weighing approximately 2.4 g, and 2,280 fragments of approximately 2.9 g, for a total of 3,920 fragments. In reality, there will be a much larger total number of fragments, some of them microscopic, and a smaller number of those weighing approximately 2.4 g and 2.9 g. This is because the detonation and resulting blast cannot be evenly distributed throughout the warhead, resulting in uneven fracturing. Although there may be fewer optimally sized fragments than intended, some of these will be significantly heavier. The heavier fragments will carry more momentum than the smaller fragments, which will increase the range at which they are capable of causing damage to people, vehicles and structures. The area forward of where these rockets land will be struck with significantly more fragmentation than the area behind, owing to the angle of incidence and ballistic inertia of the rocket.

It is important to consider that MBRL such as the 122 mm BM-21 are commonly used to deliver salvo fire, and that a full barrage from just one system – meaning forty 122 mm rockets – would deliver 256 kg of high explosive composition and produce a total of approximately 156,800 controlled fragments and some 60 kg of additional natural fragmentation, spread over a lethal area of 600 x 600 m (Jelic et al., 2013).

With a range of 20 km, an impact angle of 32° (up from horizontal), a velocity of 333 m/s, and a rotation of 600 rpm, the detonation of a single 9M22 rocket will produce the fragmentation patterns shown in **Figure 16**. The image on the left shows the probable distribution of natural fragmentation; the area affected by the explosion (measured in metres); and a colour code wherein red denotes 80-100% potential lethality and dark blue 0-20%. The image on the right shows the same for a pre-fragmented munition.

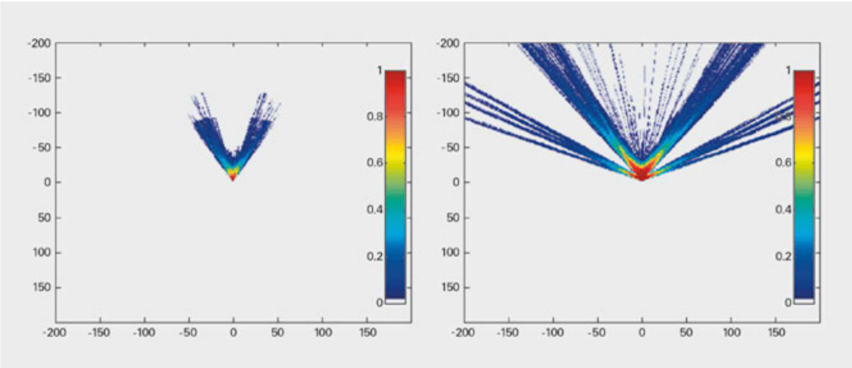


Figure 15. The figure on the left illustrates the distribution of natural fragmentation and on the right, the fragments generated from pre-fragmented material. The attack direction is from the bottom (source: Jelic et al., 2013).

The fragmentation effect of a full salvo of forty 122 mm rockets has been modelled in **Figure 16**, which assumes that an impact fuze has been used.

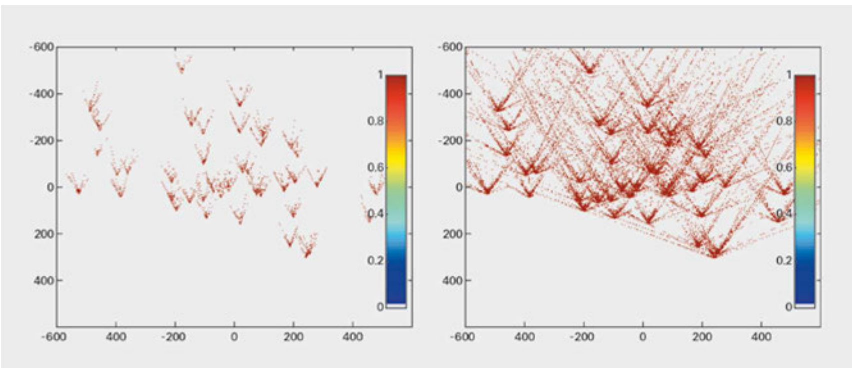


Figure 16. Simulated distribution of primary fragmentation in an open area for natural (left), and pre-fragmented (right) munition. The attack direction is from the bottom (source: Jelic et al., 2013).

As it can be observed, there is a very high hit probability at short distances from the point of detonation and the probability drops steeply as the distance increases.

Figure 17 shows only the hit probability for the primary fragmentation generated by the pre-fragmented warhead of a single 122 mm 9M22 Grad rocket. The rocket will also generate approximately 1.5 kg of natural fragmentation, but the number of fragments likely to be formed from this cannot be accurately predicted (Jelic et al., 2013).

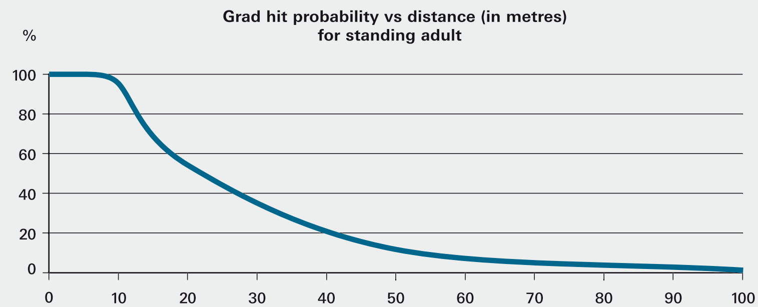


Figure 17. Hit probability for fragmentation from a 122 mm 9M22 rocket (source: Jelic et al., 2013).

The lethal area for a 122 mm Grad rocket is given as 700 m^2 for each high explosive warhead that detonates upon striking the ground (Dullum, 2010). 700 m^2 is roughly equivalent to a circle with a radius of 15 m. When the lethal area is known, it is possible to estimate the probability of being incapacitated at a given distance from the point of detonation. It should be acknowledged that this only considers the detonation of a single munition; when multiple munitions impact across an area, there will commonly be overlap of the lethal areas. **Table 6** presents the probability of incapacitation at different distances from the detonation point of one 9M22 type rocket.

TABLE 6 PROBABILITY OF INCAPACITATION OVER DISTANCE (122 MM 9M22 TYPE ROCKET)

DISTANCE FROM POINT OF IMPACT	PROBABILITY OF INCAPACITATION
3 m	96%
6 m	85%
10 m	64%
15 m	36%
20 m	17%

Source: Dullum, 2010.

BLAST EFFECTS ON THE HUMAN BODY

Reflected blast waves are significantly more damaging to the human body than incident overpressure.

A study from 1996 compared incidences of detonations in buses (enclosed areas) to those in open areas and demonstrated that there was a significantly higher number of deaths in enclosed spaces[53] (Leibovici et al., 1996) and that the injuries suffered by those in enclosed areas were more severe than those in the open. It concluded that there was '*significantly increased morbidity and mortality among those in confined-space bombings compared to those in open-space attacks*' (Brevard, Champion, & Katz, 2012).

Blast injuries to the eyes and limbs are rare, but result in quite serious injuries. When blast waves remove limbs, the patient is unlikely to survive the loss of blood. In cases where the patient does survive such a traumatic amputation, the limbs can rarely be reattached.

53 It should be noted that the attacks studied involved IEDs rather than conventional high explosive weapons, which would have different patterns and types of fragmentation.

In open spaces, 8% of those affected died, compared to 49% for enclosed spaces (see below **Table 7**).

TABLE 7 INJURIES AND DEATHS CAUSED IN OPEN VS. ENCLOSED SPACES

	OPEN SPACE	ENCLOSED SPACE
Deaths		
	8%	49%
Injuries		
• Primary Blast Injuries	34%	77%
• Burns (total body surface area)	18%	31%
• Injury Severity: (median value using Injury Severity Score)	4 (minor)	18 (moderate/severe)

Source: Leibovici et al., 1996.

The severity of the injuries sustained can be evaluated using the injury severity score (ISS), which is an anatomical scoring system for classifying the severity of wounds on patients with multiple injuries (Stevenson et al., 2001). In open spaces, the injuries suffered had a median score of 4 on the ISS, which is considered to be minor. For people injured in closed spaces, the effects were more serious, with the injuries suffered having a median score of 18 on the ISS, considered to represent moderate to severe injuries (see above **Table 7**) (Leibovici et al., 1996).

The fact that detonations in enclosed spaces cause generally more significant primary blast and fragmentation injuries than those that occur in the open is predominantly caused by the reflection and subsequent intensification of blast waves within the enclosed space. The blast effects are capable of causing significant injuries to the human body.

The lungs are particularly vulnerable to blast effects. An overpressure of 0.25 MPa (approx. 2.4 atmospheres) is associated with possible lung injury and at 0.5 MPa the probability of serious lung injury is 50%. The risk is magnified in confined spaces such as rooms or vehicles. Detonations in open spaces cause fewer lung injuries, and those injuries caused tend to be less serious than those in closed spaces (Brevard et al., 2012).

Some lung injuries are immediately apparent, while others appear over a period of hours or days. The X-ray on the right shows severe bruising of the lung (pulmonary contusion) on the right of the picture, as a result of a blast injury. This is the lighter, triangular-shaped area in the lower part of the lung. As a result of this type of injury, blood and other types of body fluids gather in the tissues of the lungs, preventing the lung from absorbing its normal amount of oxygen. This can have serious, sometimes fatal, consequences (Baskin & Holcomb, 2005).

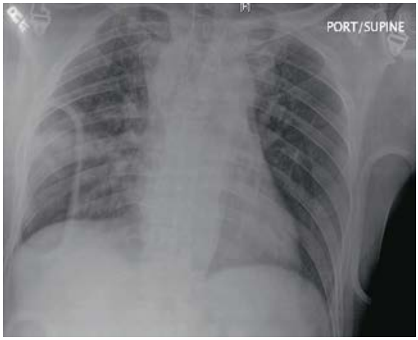


Photo 2. X-ray of severe bruising of the lung (right) as a result of a blast injury (source: Brevard et al., 2012).

Blast also causes other types of injury. Unlike buildings and structures, which can sustain varying amounts of damage from both the positive and negative phases of the blast wave, the human body sustains the majority of injuries during the positive phase.

The blast wave causes a rapid compression and then expansion of the gases contained in hollow organs, such as the gastro-intestinal tract, lungs and ears. The blast overpressure damages air-filled human organs, causing bruising, tearing and puncturing of the organ walls. The pressure wave can rupture the eardrum and fracture the delicate bones inside the ear.

The rapid compression and then re-inflation of these organs may result in tearing which is principally caused by the acceleration of organ and muscle tissue at different rates due to their different densities. Solid organs, such as the kidneys and liver, are not as susceptible to direct damage from blast waves as hollow organs, but the shear force imparted by blast waves can cause these to be torn from their attachment points within the body (Hernad, 2013).

The brain can be damaged by being suddenly accelerated and then decelerated. This often damages the brain's occipital and frontal lobes, in what is known as a coup-contrecoup contusion (Cernak & Noble-Haeusslein, 2010). Some brain injuries, known as traumatic brain injuries (TBI), may not be immediately apparent and victims will present no physical symptoms. The mechanisms of these injuries are not yet fully understood, but apparently even mild TBI can result in cases of post-traumatic stress disorder (PTSD). One study of American troops returning from Iraq and Afghanistan showed that 44% of personnel who suffered what appeared to be a mild TBI, but lost consciousness later, suffered from PTSD (Xydakis, Robbins, & Grant, 2008).

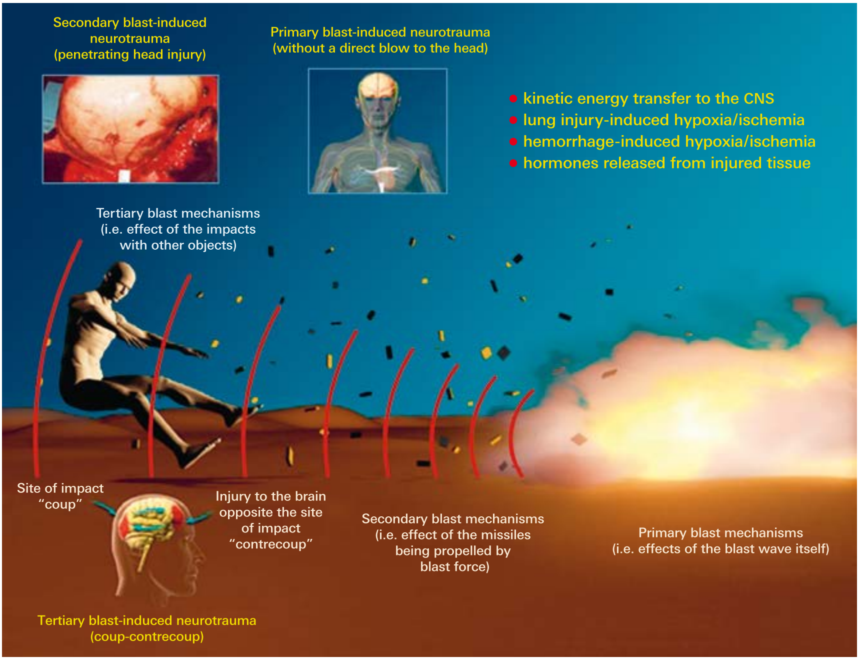


Figure 18. Blast-induced trauma to the brain (source: Cernak & Noble-Haeusslein, 2010).

FRAGMENTATION EFFECTS ON THE HUMAN BODY

When examining the effects of fragmentation on the human body, it is important to note that these vary significantly based on the amount of body area exposed to the fragmentation and the posture of the victim when struck. A similarly sized piece of fragmentation could kill one person but only lightly injure another, depending on its impact location and each person's unique physiology. Low-velocity fragments may tumble on impact with a body, which causes a larger wound track with irregular tearing that is difficult to repair. Bigger fragments travelling at lower velocities can crush large areas of human tissue and cause more damage than the same fragment travelling at a high velocity. This runs counter to the previously accepted notion that fragments travelling at a higher velocity will always result in a more severe wound (U.S. DoD, 2004).

Most of the people injured by explosive devices suffer from multiple penetrating fragment injuries to more than one area of the body. The fragments produced by the detonation of a high explosive warhead are often irregularly shaped.

This means that the aerodynamic drag of each fragment is different, and therefore the velocity of each fragment is also different. This is an important consideration when determining the effect these fragments can have on the human body. The impact of a small fragment in the torso of a human being is likely to prove fatal at velocities in excess of 600 m/s (Bowyer, Cooper, & Rice, 1996). When high explosive munitions are involved, initial velocities of primary fragments can be as high as 2500 m/s.

The risk of injury from blast overpressure is represented by a smaller radius than the risk of fragment injury, as blast pressure drops much more rapidly than the rate that fragments lose velocity. For detonations that occur in open spaces, the majority of injuries will be caused by fragmentation (see **Table 8**).

TABLE 8 INJURIES IN OPEN SPACE FROM A TYPICAL HE 155 MM PROJECTILE AT VARIOUS DISTANCES[54]

DISTANCE FROM DETONATION	MORBIDITY AND MORTALITY	
	Blast injury	Fragmentation injury
0 to 15 m	Death, eardrum rupture	Death
15 to 25 m	Eardrum rupture	Death
25 to 40 m	Temporary hearing injury	Injury
40 to 550 m	None	Possible injury

Source: Champion, Holcomb, & Young, 2009.

Secondary fragmentation can cause significant medical complications by further fragmenting on impact, leaving many small fragments embedded in the body. The eyes are particularly vulnerable to secondary fragmentation injuries from small particles of shattered glass or metal: approximately 10% of all blast injury survivors are left with significant eye injuries of this nature (Lemonick, 2011). The wounds usually contain dust, dirt and small parts of clothing. Large explosions may cause buildings to collapse and crush people, or expose them to the risks inherent in inhaling large quantities of fine dust particles.

54 Table adapted and units converted from imperial (feet) to metric.

Photo 3. Example of the density of multiple primary and secondary fragmentation wounds on a human body (source: O'Brien PJ, Cox MW – CC).

TARGETING AND USE

Whilst this report is primarily concerned with the well-known, design-dependent effects of particular weapon systems and munitions, the circumstances under which such systems are used can have a significant impact on their actual effects. The specific influence of these circumstances on precision and accuracy cannot be predicted for each use. Nonetheless, it is well established that explosive weapons are often used in conditions other than optimal. Acceptable margins of deviation from optimal conditions can be observed in standing targeting policies and rules of engagement, including weapon-target matching, described below. When assessing the impact of explosive weapons in populated areas, it is therefore important to consider the manner in which such systems are used and the targeting procedures, which may or may not have taken place.

In modern military forces, weapon systems are employed according to a series of rules and regulations. These range from a targeting policy, set at the highest level by policymakers and their military staff, down to the rules of engagement (ROE) that govern individual soldier's actions in conflict. Targeting policy defines how targets are engaged within the confines of national and international law, in pursuit of national politico-military objectives. ROE directly inform the tactical and operational employment of individual weapon systems. They can vary across different geographic areas, over time within a conflict, and according to the system or munition used (Dullum et al., 2016). Targeting policies and ROE vary between different national forces. Such frameworks are often noticeably absent from the actions of non-state actors; however, some groups may follow their own targeting 'code' which may limit their combat actions.

The targeting of a given weapon system is conducted either deliberately, or in contact with the enemy.[55] Strategic and operational targets are often subject to deliberate targeting, tactical targets far less so. Deliberate targeting is a formal and complex process. It requires planning in advance of the employment of a system, approval from the appropriate higher authority and a formal collateral damage estimate (CDE). CDE are conducted to predict unintended or incidental damage to persons and/or objects which are not the intended target and which are not otherwise lawful targets (U.S. DoD, 2013). Targets are almost invariably on a target list, which may include 'strike' and 'no strike' lists, each with their own parameters. Common target lists include a master target list, joint target list, no-strike list and restricted target list (MoD, n.d.).

55 This may not mean that the unit operating the weapon system is in contact; it may be that a battery of artillery guns, for example, is responding to a call for fire support from a unit in contact.

Conversely, targeting which takes place whilst in contact is time-sensitive in nature; if it includes a CDE, it will be expedient in nature, known as a field CDE (Cross et al., 2015; Dullum et al., 2016). Some military doctrines consider that there is an absolute right of self-defence in the face of a direct attack or immediate threat of one. Under international humanitarian law, the prohibition of indiscriminate attacks and the rule of proportionality and distinction in attack must be respected at all times, even under conditions of self-defence[56] (ICRC, 1987). Air-delivered munitions are more likely to be used under deliberate targeting parameters, whereas the other systems addressed in this report are more likely to be employed in contact.

Where the risk of collateral damage is high, the decision on whether to engage a target may be referred up the chain of command. This can happen at the tactical level, with an individual combatant seeking approval from a squad leader, up to the strategic level, where political approval may be required. This process may also be conducted on a formal basis, according to predetermined requirements and parameters, or informally under field conditions. ROE directly inform this approvals process and will specify which actions by an adversary permit the use of force. It may also place limitations on the method of the attack, including the type of fuze or munition used, or the weight of fire applied (Dullum et al., 2016). The desired and permissible effects are achieved by correct weapon-target matching, taking into account the factors outlined in previous sections concerning precision and accuracy.

WEAPON-TARGET MATCHING

At a fundamental level, weapon systems and their munitions are selected for an attack based upon the effects the combatants wish to impose on a given target. The process of weapon-target matching, also known as 'weaponeering', seeks to ensure that the correct platform, system and munition are assigned to achieve the desired aims (Cross et al., 2016). Weaponeering may take place under deliberate targeting conditions, wherein it is constrained by political and military requirements and restrictions informed by a robust CDE, or as part of a response to friendly forces in contact, in which case the process may be significantly abbreviated. In both cases, and especially when taking place in an abbreviated form, weapon-target matching is limited by the assets available to the planner or operator.

56 In relation to the definition of 'attack', 1987 ICRC Commentary to Additional Protocol I to the Geneva Conventions states that 'the restrictions imposed by humanitarian law on the use of force should be observed both by troops defending themselves and by those who are engaged in an assault or taking the offensive'.

Weapon-target matching begins by determining which weapon system of those available from a given range of platforms is appropriate for the objective at hand. A battery of artillery guns firing unguided projectiles, for example, is unlikely to be suitable for engaging a point target in a populated area. An air-delivered PGM may be deemed a more appropriate choice for such a target, assuming that the selected munition's explosive yield does not enable primary and secondary explosive weapon effects beyond the target limits.

Weaponeering is also concerned with selecting the correct munition and fuze combination, which can dramatically change the effects of a system. There are many ways to attack a target beyond the standard high explosive projectile and point detonating fuze (Dullum et al., 2016). Whilst this report is concerned with the use of high explosive munitions, it is important to understand the range of options that may be available to certain belligerents.

FUZING

A fuze is a mechanical or electronic initiating device designed to function a munition. The way a fuze functions has a direct relationship with the nature of the effects of the munition it is fitted to. The fuze serves three main roles: (1) ensuring a munition can be safely handled during the loading process and in transit; (2) arming the munition at a given time or position; and (3) ensuring the munition functions at a given time or position (King, 2011). For most systems currently in service, the fuze must be selected at the time it is fitted to the munition. However, some modern multi-function fuzes offer a variety of fuzing options, and a subset of these may allow the operator to select the desired mode of operation immediately prior to use (King, 2011). Most fuzes have an arming sequence initiated by inertia, or other forces or mechanisms occasioned by the firing, launch or release of the munition. The three common types of fuzes are defined by their firing function: impact, time and proximity.

The most common fuze typically used with explosive munitions is the impact, or point-detonating[57], fuze. Impact fuzes are generally simple in operation, detonating on the direct impact or rapid deceleration (caused by impact) of the munition. Whilst many impact fuzes detonate almost immediately upon impact, other examples often incorporate a delay of milliseconds or more (USAFAS, 2004). A short delay allows for a munition to explode inside a target (e.g. A concrete

57 Base-detonating fuzes also exist, as do 'all-ways impact' fuzes. The latter functions without regard to the orientation of the munition during impact and is most commonly seen in use with explosive submunitions.

bunker), or underneath it (i.e. subsurface). If a point-detonating fuze is designed for an instantaneous explosion it is known as a 'super quick' fuze[58] (King, 2011).

Time fuzes function after a predetermined delay, rather than relying on a physical input such as impact. The three most common varieties are mechanical time, electronic time or powder train time fuzes.[59] Time fuzes are most commonly used in conjunction with cargo munitions, however they can be used with high explosive munitions, such as when seeking to achieve an airburst effect. Time fuzes operate in seconds, minutes, hours or days – orders of magnitude greater than the very short delay incorporated into some impact fuzes (Dullum et al., 2016). Certain time fuzes incorporate backup impact fuzing options.[60]

Proximity, or 'variable time' fuzes detonate a munition at a specific distance from the target. A proximity fuze generally uses radio waves[61] to determine when to detonate the munition. When employed against ground targets, proximity fuzes are most often used to 'airburst' a munition (USAFAS, 2004), i.e. detonate before the impact in the air, at a set distance from the target.

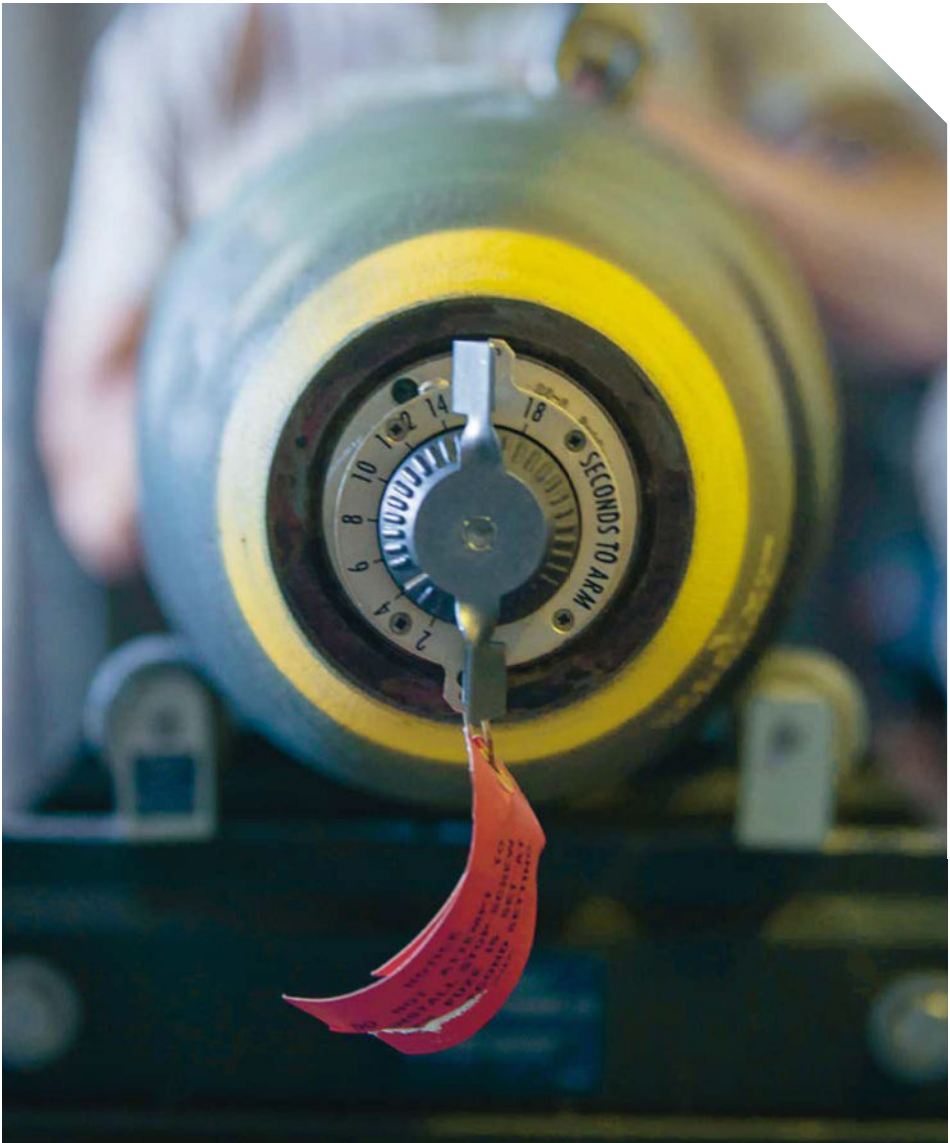
The choice of fuze is critical in understanding how militaries make choices in tailoring a weapon's effects during the targeting process (Cross et al., 2016). When assessing how a fuze influences collateral effects, consider a concentration of enemy troops in a populated area. Munitions fitted with proximity or time fuzes set to deliver an airburst effect may be used to enhance the blast and fragmentation effects against personnel or other comparatively fragile targets. An airburst fuze on a conventional munition can increase its area effect by up to 100% (Naval Surface Warfare Center, n.d.), which in broad terms means that fewer munitions are required to achieve the desired aim. Employing airburst munitions in a densely populated area will potentially significantly increase civilian harm.

58 Many common point detonating fuzes for projectiles allow the operator to select either the super quick action, or a short delay allowing, typically, a high explosive projectile to penetrate the target prior to detonating.

59 Chemical and material fatigue delay mechanisms also exist, but these have fallen out of favour with modern militaries due to reliability issues (Dullum et al., 2016).

60 These are commonly 'time super quick' and 'mechanical time super quick' (USAFAS, 2004).

61 Optical, acoustic, magnetic influence, infrared and other types have also been developed (Dullum et al., 2016).



FIVE STUDIED EXPLOSIVE WEAPON SYSTEMS AND THEIR MUNITIONS

This section introduces the studied 122 mm BM-21 multi barrel rocket launcher (MBRL); 152 mm and 155 mm artillery guns; 81 mm and 82 mm medium mortars and 120 mm heavy mortars; 115 mm, 120 mm and 125 mm tank guns; and the guided and unguided variants of the Mk 82 aircraft bomb. After a brief introduction of each system's technical characteristics, utility and typical roles in conflict theatres, common high explosive munitions employed by these weapon systems are presented and compared with each other. Among the specifications for each munition type, the comparison shows their relative energetic payloads delivered, allowing an estimation of their hazardous ranges in open space. The annexes A through E[62] of the report provide more detailed information about the weapon systems and common high explosive munitions employed, as well as presenting the case studies[63] of their use in populated areas.

122 MM BM-21 TYPE MULTI BARREL ROCKET LAUNCHER (MBRL)

Photo 4. A BM-21 Grad type multi barrel rocket launcher firing rockets, Devichki, Ukraine (photo credit: Popsuievych / Shutterstock.com).

62 Annex A: 122 mm BM-21 MBRL, Annex B: 152 mm & 155 mm artillery guns, Annex C: 81–120 mm mortars, Annex D: 115–125 mm tank guns, Annex E: Mk 82 aircraft bomb.

63 Case studies are referred to throughout this report with an alphanumeric designation, for example, D3 refers to Case Study 3 in Annex D: 115-125 mm tank guns.

Since its introduction in the early 1960s, the presence and use of 122 mm BM-21 Grad (Град; 'Hail') type multi barrel rocket launchers has been prevalent in conflict zones throughout the world. Its simplicity, combined with the ability to deliver massive firepower from a relatively light mobile platform, has led to its rapid, widespread adoption. This weapon system has been widely copied and these copies, variants and derivatives can be found in the inventories of over 50 state armed forces, as well as numerous non-state armed groups (Schroeder, 2014; IISS, 2010).

As the BM-21 is a relatively old design, first developed in the late 1950s, some of these variants have resulted in the inclusion of more modern weapon characteristics, such as advanced fire-control systems and more advanced aerodynamic properties for the rockets themselves. This report limits itself to the study of the original BM-21 (the 9K51 in Soviet service) and those copies and variants which closely approximate the characteristics of the BM-21. 122 mm variants of the BM-21 that are significantly more modern than the original design have not been widely employed in conflict zones, and are not addressed in this report.

The Russian nickname 'Hail' is an appropriate moniker for a weapon system that can launch up to forty 122 mm rockets in just under 20 seconds, at ranges of up to 20 km[64]. Designed to deliver its munitions over an area rather than at a point target, the BM-21 is not a precision weapon; at a range of 20 km, when a full salvo of 40 rockets is fired, the lethal area extends up to 600 m x 600 m (Jelic et al., 2013). When the rockets impact, they produce a substantial fragmentation effect.

The multiple instances of its use in populated areas across the world have resulted in significant numbers of civilian deaths and injuries.[65] In addition to the human cost of using 122 mm MBRLs in populated areas, there has been devastating damage to civilian objects including residential buildings, businesses and critical infrastructure.

For more information on 122 mm BM-21 type MBRLs, refer to Annex A.

64 The most modern Russian rockets can extend this range to 40 km (Splav, n.d.).

65 See Annexes A–E, and, for example, *Four Years of Harm: Explosive Violence Monitor 2011-2014* by Action on Armed Violence (AOAV).

152 MM & 155 MM ARTILLERY GUNS

Photo 5. U.S. Army 155 mm M777 towed artillery gun in Iraq
(photo credit: Defense Industry Daily).

Artillery guns are designed to provide fire support for armour and infantry forces by firing munitions at greater distances than small arms and light weapons. Artillery guns typically operate as a unit, or 'battery', and are intended to deliver salvo fire against an area target. They can either be towed or self-propelled, and can be armoured or unarmoured. Modern artillery systems primarily exist to deliver indirect fire onto targets. In this report, the term 'artillery gun' is used to refer specifically to self-propelled, towed and emplaced guns (i.e. not man-portable) of a calibre greater than 57 mm, which are designed for an indirect fire role and capable of hitting targets at a considerable range (Ferguson et al., 2015).

Artillery guns in 152 mm or 155 mm calibres can be found in the majority of current and recent conflicts that involve at least one regular army, and many that involve primarily non-state actors. The Warsaw Pact nations selected guns chambered for the 152 mm calibre developed in the Soviet Union, while NATO members and other 'western' forces chose to adopt the 155 mm calibre. The two calibres are broadly similar in capability; both are able to deliver a projectile of approximately 40 kg to ranges of 17-40 km. There are many different models of 152/155 mm artillery guns; however this report focuses on models that have been widely used, or are currently being used, in conflict zones.

152 mm and 155 mm artillery guns form a staple in nearly all state armed forces of moderate size or larger. Non-state actors such as the Liberation Tigers of Tamil Eelam (LTTE) in Sri Lanka and the so-called Islamic State of Iraq and the Levant (ISIL) in Iraq and Syria have captured artillery guns from conventional military forces and employed these in support of their own aims. ISIL is reported to have captured fifty-two 155 mm towed artillery systems provided by the U.S. military to the Iraqi Army, although some of these have since been recaptured by Kurdish forces or destroyed by coalition air strikes (Ernst, 2014).

For more information on 152 mm and 155 mm artillery guns, refer to Annex B.

81 MM, 82 MM & 120 MM MORTARS

Photo 6. French soldiers firing an 81 mm medium mortar, Mali (photo credit: http://gunrunnerhell.tumblr.com).

Mortars are generally smoothbore, muzzle-loading, indirect fire weapons. Conventional mortars do not have recoil mechanisms, with the main recoil force being transmitted directly to the ground via the baseplate. Additionally, most mortars are restricted in elevation, and are only capable of firing at high-angle trajectories (above 45°), meaning that they cannot be used in a direct fire support role.[66]

66 There are a small number of mortar systems which have uncommon features such as rifling, recoil mitigation systems, or which are breech-loaded and some mortars are capable of low-angle fire (Jenzen-Jones, 2015; Ryan, 1982).

Mortar projectiles often impact the target at a very steep angle, making mortars ideal weapons for firing over, into, or out of defilade. Sometimes referred to as 'the poor man's artillery', they are simple to manufacture and operate, rugged, portable, cheap and versatile, although generally less accurate than artillery (Dullum et al., 2016).

There are a number of different designs in various calibres; this report highlights some of the most commonly encountered varieties of conventionally designed mortars; specifically 81 mm and 82 mm medium mortars, and 120 mm heavy mortars. Mortars are generally one of the most responsive of indirect fire weapons, capable of engaging targets quickly and at shorter ranges than many artillery guns or rocket systems. Generally speaking, medium mortars can fire at ranges of 100 m to 5500 m, while heavy mortars have a range of some 500 m to 7000 m (Gander & Hogg, 1993; Isby, 1988).

Mortars are found in the inventories of almost all state armed forces, and a majority of larger non-state armed groups. They are comparatively simple to operate and are employed frequently in current and recent conflict zones. A single 120 mm mortar projectile was fired into a market in the February 5, 1994 attack in Sarajevo, killing 68 and injuring approximately 144 civilians (Hansen, 2006; Allsop, 2012).

For more information on 81 mm, 82 mm, and 120 mm mortars, refer to Annex C.

115 MM, 120 MM & 125 MM TANK GUNS

Photo 7. Russian Tank T-90MS-V firing its main gun (photo credit: Photobucket / bhenkz2).

Tanks are mobile, armoured, heavy weapons platforms that have been used in the majority of conflicts since World War II. Tank guns differ from the other land based weapon systems detailed in this report by primarily employing direct fire; that is to say, when firing its main gun, the gunner can see the target and aims directly at it, rather than firing at an indirect trajectory. Although, due to technological advances, modern tanks far exceed the performance of their predecessors, simultaneous developments in anti-tank systems mean that most remain vulnerable to countermeasures employed by both conventional military forces and non-state actors using asymmetric warfare techniques. This influences the employment tactics of modern tanks in contemporary conflict.

This report covers tank guns of 115 mm, 120 mm and 125 mm in calibre, which encompasses the majority of tanks guns that have been produced since 1961, when the Soviet Union introduced the T-62 main battle tank (MBT). It is necessary to limit the scope of this study, and the increase of Soviet tank gun calibres from 100 mm to 120 mm in 1961 provides an appropriate cut-off point in time. Although the T-62 partially replaced the earlier T-55 model with its 100 mm main gun, T-55 tanks remain commonly encountered today. The majority of tank gun munitions employed by modern militaries are dual-purpose, designed to destroy enemy armoured fighting vehicles or structures, while also offering a fragmentation effect for use in an anti-personnel role. Tank guns of Russian design commonly use HE and HE-FRAG munitions.

Tanks often take on a high-profile role in modern conflicts. Capable of very high precision in their direct fire role, tanks have been involved extensively in attacks within populated areas. As an example, a bus in Chechnya containing displaced people was struck by a single tank projectile on 5 October 1999, resulting in 28 deaths and 17 injuries (HRW, 1999).

For more information on 115 mm, 120 mm and 125 mm tank guns, refer to Annex D.

MK 82 AIRCRAFT BOMB

Photo 8. A Paveway II practice bomb being dropped from an F-35 aircraft (photo credit: U.S. Air Force).

Air-delivered munitions may provide the ability to destroy ground and naval targets without risking a large number of military personnel on the ground, even when operating deep within enemy territory. The Mk 82 aircraft bomb and its guided variants have been used extensively throughout the world and are one of the most common families of air-delivered munitions ever produced.

The Mk 82 and its variants are 500-pound (227 kg) class[67], low-drag, general-purpose aircraft bombs containing 89 kg of high explosive. Originally dropped as an unguided bomb (sometimes referred to as an 'iron' or 'dumb' bomb), these versions of the Mk 82 exhibited a Circular Error Probable (CEP, explained in pp. 27-36 of 94.5 m when released from an altitude of 15000 ft. (4572 m).

Guided versions of the Mk 82, such as the GBU-12 and the GBU-49, now have a CEP of 1.1 m (Raytheon, 2006), indicating very high precision (see **Figure 8**). During Operation Desert Storm in 1991, the laser-guided GBU-12 was reported as striking its targets 88% of the time, with most targets being single vehicles

67 Air-delivered bombs are often classified by weight, although this classification does not necessarily indicate the precise weight of the complete munition or its payload; rather, these are approximate weight 'classes' (Cross et al., 2016).

(Blackwelder, 1993). Although 12% of the targets were still missed, the introduction of PGM meant that targets could be destroyed with a relatively small and precise strike. This reduced the number of explosive weapons and munitions previously required to achieve the military objective and the number of aircraft needed to carry the munitions, reducing the risk of aircrew losses.

The Mk 82 has been used by the U.S. military and various other nations since the 1950s, and saw extensive deployment in South East Asia during the Vietnam War.[68] The Mk 82 remains relevant in current and recent conflicts. During the 1991 Gulf War, more than 4,500 Mk 82 bombs configured as laser-guided GBU-12 model PGM were used by the U.S. and its allies (Friedman, 1997). In 2016, various configurations of the Mk 82 were used in a number of countries and territories, including Afghanistan, Gaza, Iraq, Libya, Syria and Yemen (ARES, n.d.).

For more information on Mk 82 bombs and variants, refer to Annex E.

MUNITIONS' EFFECTS COMPARISON

Comparative information on the characteristic high explosive munitions used by the studied weapon systems is presented in **Table 9**. The table provides key data relating to the high explosive payloads of a variety of HE and HE-FRAG munitions of differing design and origin, showing explosive fill weight, explosive fill as a percentage of the total munition weight, explosive composition, relative effectiveness (RE) factor and net explosive quantity (NEQ).[69] This table allows for a comparison of the relative energetic payloads delivered by each munition type. The RE factor is a measurement of an explosive's power for military, logistical, safety and other purposes. It is used to compare a given explosive compound's effectiveness relative to TNT[70] by weight. The definition of TNT equivalency is complex, as there are many experimental bases for comparison of explosives (heat, brisance, detonation velocity, etc.). For more information on relative effectiveness factors see, for example, Maienschein (2002).

68 More than 8.5 million Mk 82 bombs were dropped by the USAF in South East Asia during the period 1963-1973 (Berger, C. 1977).

69 NEQ describes the total explosives content of a particular munition (in this case, restricted to the warhead of the munition) (MoD, 2013).

70 Trinitrotoluene, a common type of military explosive.

TABLE 9 HIGH EXPLOSIVE PAYLOAD COMPARISON FOR SELECTED MUNITIONS

Munition	Country of origin	Make	Model	Total munition weight	Explosive fill weight	Explosive fill % of total weight	Explosive composition	RE factor	Net explosive quantity (NEQ)[71]	Source
Mortar projectiles										
81 mm	United States	American Ordnance	M821	4.06 kg	0.72 kg	17.70 %	Comp-B[72]	1.33	0.96 kg	U.S. Army, 2003
81 mm	Bulgaria	Arcus Co.	AR-M81	4.15 kg	0.75 kg	18.10 %	TNT	1.00	0.75 kg	Arcus, n.d.
81 mm	Serbia	Krušik a.d.	M72	3.05 kg	0.68 kg	22.20 %	TNT	1.00	0.68 kg	Krušik, n.d.
81 mm	Bosnia & Herzegovina	Pretis d.d.	M91	4.10 kg	0.85 kg	20.70 %	Comp-B/TNT	1.33/1.00	1.13 kg/0.85 kg	Pretis, n.d.
82 mm	Bulgaria	Arcus Co.	VO-832DU	3.10 kg	0.40 kg	13.00 %	TNT	1.00	0.40 kg	Arcus, n.d.
82 mm	Bulgaria	Arsenal JSCo.	HE 82M	3.10 kg	0.42 kg	13.50 %	TNT	1.00	0.42 kg	Arsenal, n.d.
82 mm	Hungary	Fort Hungary LLC	HE-82LD	4.15 kg	0.75 kg	18.10 %	TNT	1.00	0.75 kg	Fort, n.d.
82 mm	Bosnia & Herzegovina	Pretis d.d.	M74	3.05 kg	0.68 kg	22.30 %	TNT	1.00	0.68 kg	Pretis, n.d.
120 mm	Serbia	Krušik a.d.	M62P8	12.60 kg	2.45 kg	19.40 %	Comp-B/TNT	1.33/1.00	3.26 kg/ 2.45 kg	HK 'Krušik' a.d, n.d.
120 mm	Belgium	MECAR	M530A1	15.20 kg	2.60 kg	17.10 %	Comp-B	1.33	3.46 kg	MECAR, n.d.
120 mm	Norway	Nammo AS	120 mm HE	13.00 kg	2.00 kg	15.40 %	TNT	1.00	2.00 kg	Nammo, 2016
120 mm	Pakistan	Pakistan Ordnance Factories	HEM44A2	13.00 kg	2.60 kg	20.00 %	TNT	1.00	2.60 kg	POF, n.d.(a)
120 mm	Bosnia & Herzegovina	Pretis d.d.	M62P3	12.60 kg	2.25 kg	17.90 %	TNT	1.00	2.25 kg	Pretis, n.d.

71 In some cases, RE factors are calculated to approximate equivalency, drawing on various sources. See Crawford & Dobratz, 1985; Maienschein, 2002; Pirospravka, 2012.

72 Composition B, a mixture of RDX and TNT.

Munition	Country of origin	Make	Model	Total munition weight	Explosive fill weight	Explosive fill % of total weight	Explosive composition	RE factor	Net explosive quantity (NEQ)	Source
Artillery rockets										
122 mm	Soviet Union[73]	JSC 'NPO' Splav	9M22U	66.60 kg	6.40 kg	9.60 %	TGAF-5	1.30	8.32 kg	Splav, n.d.; Karpenko, 2010
122 mm	Serbia	Krušik a.d.	GRAD-2000	68.30 kg	6.40 kg	9.40 %	TGAF-5 equiv.	1.30	8.32 kg	Krušik, n.d.
122 mm	Romania	Romarm	122 Rocket	65.00 kg	6.00 kg	9.20 %	TGAF-5 equiv.	1.30	7.80 kg	Tohan, n.d.
122 mm	Pakistan	Pakistan Ordnance Factory	Yarmuk HE	66.00 kg	6.00 kg	9.10%	Comp-B	1.33	7.98 kg	POF, n.d.(b)
122 mm	Turkey	Roketsan	TR-122	65.90 kg	6.00 kg[74]	9.10 %	Comp-B	1.33	7.98 kg	Roketsan, n.d.
Artillery projectiles										
152 mm	Russia	JSC NIMI	3OF64	43.56 kg	7.80 kg	18.00 %	A-IX-2	1.54	12.01 kg	ICDTS[75], 2006; NIMI, n.d.
152 mm	Soviet Union[76]	JSC NIMI	3OF45	43.56 kg	7.65 kg	18.00 %	A-IX-2	1.54	11.78 kg	ICDTS[77], 2006.
152 mm	Slovakia	ZVS (MSM Group)	152 mm HE ER-HB	43.56 kg	8.10 kg	18.60 %	TNT	1.00	8.10 kg	ZVS, n.d.
152 mm	Bosnia & Herzegovina	Pretis d.d.	OF-540	42.93 kg	5.85 kg	13.60 %	TNT	1.00	5.85 kg	Pretis, n.d.
155 mm	Italy	Simmel Difesa	L15A1	43.50 kg	11.30 kg	25.00 %	Comp-B/TNT	1.33/1.00	15.00/11.30 kg	Nexter Group, n.d.
155 mm	Italy	Simmel Difesa	M107	43.00 kg	6.98 kg	16.20 %	TNT	1.00	6.98 kg	Nexter Group, n.d.
155 mm	Norway	Nammo AS	155 mm HE-ER	44.40 kg	9.00 kg	20.00 %	TNT/Comp-B	1.00/1.33	9.00/11.97 kg	Nammo, 2016
155 mm	United States	American Ordnance	M795	46.90 kg	10.79 kg	23.00 %	TNT	1.00	10.79 kg	American Ordnance, n.d.
155 mm	India	Indian Ordnance Factories	HE M/77B	42.60 kg	8.00 kg	18.80 %	TNT	1.00	8.00 kg	IOF, n.d.

73 Later produced in Russia.

74 Estimated.

75 Information Centre of Defence Technologies and Safety.

76 Later produced in Russia.

77 Ibid.

Munition	Country of origin	Make	Model	Total munition weight	Explosive fill weight	Explosive fill % of total weight	Explosive composition	RE factor	Net explosive quantity (NEQ)	Source
Tank gun projectiles										
115 mm	Soviet Union	Various	3UOF37	17.82 kg	3.13 kg	17.60 %	A-IX-2	1.54	4.82 kg	ICDTS, 2006.
115 mm	Egypt	Heliopolis Company, Chemical Industries	3OF18 copy	17.86 kg	2.80 kg	15.70 %	TNT	1.00	2.80 kg	ICDTS, 2006.
120 mm	France	Nexter Munitions	HE F1	16.00 kg	3.00 kg	18.70 %	Comp-B	1.33	3.99 kg	Nexter Group, n.d.
120 mm	Norway	Nammo AS	IM HE-T	16.00 kg	3.20 kg	20.00 %	OSX-8	1.30	4.16 kg	Nammo, 2016
120 mm	Israel	Israeli Military Industries	HE-MP-T 120 M339	17.00 kg	2.70/3.00 kg	15.9/17.6 kg	TNT/CLX663	1.00/?	2.70/- kg	Schirding, 2011
125 mm	Soviet Union[78]	JSC NIMI	3OF26	23.00 kg	3.40 kg	14.80 %	A-IX-2	1.54	5.24 kg	ICDTS, 2006; NIMI, n.d.
125 mm	Pakistan	Pakistan Ordnance Factory	125 mm H.E.FS TK	34.15 kg	4.00 kg	11.70 %	TNT	1.00	4.00 kg	POF, n.d.(c)
125 mm	Soviet Union	Various	3OF19	23.00 kg	3.15 kg	13.70 %	TNT	1.00	3.15 kg	ICDTS, 2006.
125 mm	Bosnia & Herzegovina	Pretis d.d.	M86	23.30 kg	3.15 kg	13.70 %	Comp-B/TNT	1.33/1.00	4.19/3.15	Pretis, n.d.
Aircraft Bombs										
500 lb	United States	Ordtech Industries	Mk 82	241.00 kg	87.00 kg	36.10 %	TNT	1.00	87.00 kg	Ordtech, n.d.
500 lb	Serbia	Krušik a.d.	FAB-250 M79	240.00 kg	105.00 kg	43.80 %	TNT	1.00	105.00 kg	Krušik, n.d.
500 lb	Romania	S.C. Mechanical Plant 'Mija'	BM-250E	250.00 kg	97.00 kg	39.00 %	TNT	1.00	97.00 kg	Mija, n.d.
500 lb	Pakistan	Pakistan Ordnance Factory	AC 500	241.00 kg	90.00 kg	37.30 %	Comp-B	1.33	119.70 kg	POF, n.d.(d)
500 lb	United States	General Dynamics	BLU-111	241.00 kg	87.00 kg	36.10 %	PBXN-109	1.17	101.80 kg	Ordtech, n.d.

78 Later produced in Russia.

Table 9 is supported by **Table 10**, which gives sample risk estimate distances *(RED)*[79] for each of the five broad types of munitions studied. These figures are visually represented in **Figure 19**.

TABLE 10 RISK ESTIMATE DISTANCES FOR SELECTED MUNITIONS

MUNITION TYPE	RED 0.1 (M)	RED 10 (M)
1 Medium calibre (81 mm / 82 mm) mortar projectile[80]	175 m	80 m
2 Tank gun (120 mm) projectile[81]	250 m[82]	90 m[83]
3 120 mm mortar projectile[84]	400 m	100 m
4 Artillery gun (152 mm / 155 mm) projectile[85]	450 m	125 m
5 122 mm artillery rocket[86]	500 m[87]	150 m[88]
6 500 lb. class aircraft bomb[89]	425 m	250 m

Sources: DoD, 2008; Karpenko, 2010; Locking, 2011; Maienschein, 2002; Pirospravka, 2012; U.S. Army, 1997; 2011; USMC, 1998; 2009.

79 In U.S. military use, *RED* applies to combat only. Minimum safe distances (MSD) are used in training environments.

80 Calculated using M821 81 mm projectile.

81 Calculated using IM HE-T 120 mm projectile.

82 No *RED* data available; estimated.

83 No *RED* data available; estimated.

84 Calculated using M329A2 120 mm projectile.

85 Calculated using M107 155 mm projectile.

86 Calculated using 9M22U 122 mm rocket.

87 No *RED* data available; estimated.

88 No *RED* data available; estimated.

89 Calculated using Mk 82 aircraft bomb.

RED are defined as the minimum distance friendly troops can approach the effects of friendly fire without suffering appreciable casualties of 0.1 per cent PI (one person in one thousand likely to be incapacitated; *RED* 0.1) or 10 per cent PI (one person in ten likely to be incapacitated; *RED* 10) (U.S. Army, 2007; 2011). The U.S. Army bases its lethal area calculations (and PI) on a prone male soldier in winter clothing being physically unable to respond to an assault for a 5-minute period after the attack (U.S. Army, 2006). Where *RED* figures were not available for given munitions, they have been estimated by comparing the net explosive quantity (NEQ), relative effectiveness (RE) factor, explosive fill type, dimensions and munition weight of a given munition with several similar munitions and calculating the average among them.

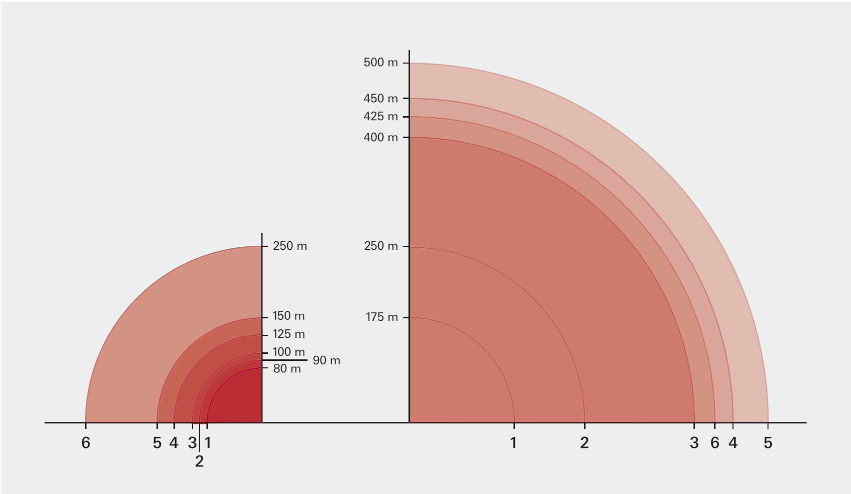


Figure 19. Comparative *RED* 10 (left) and *RED* 0.1 (right) for the six munitions outlined in **Table 10** (Source: ARES / GICHD).

EFFECTS ANALYSIS

This section provides an analysis of the various physical effects, practices in use and terminology of the studied explosive weapons. There are patterns emerging, presented later in the section *Findings and Conclusion*. The case studies quoted in this section exemplify explosive weapon use in recent and continuing conflicts, each demonstrating the use of one type of weapon in a populated area. The research team sought as much objective, publicly accessible data on the studied cases as possible to allow for open comparisons between case studies and the weapons used.[90] Forty case studies, selected from more than 100 produced in this project, are included in Annexes A through E of this report. These have been condensed to include only the information pertinent to this study.

In the majority of studies, the number of people killed and injured during these attacks is stated. These figures have been included, but they only offer one dimension of the situation, and should not be viewed as the sole metric for characterising the effects of the explosive weapons involved.

The medical terminology used to identify the exact nature of the wounds sustained has been omitted, on the grounds of brevity and verifiability. The analysis and classification of damage to infrastructure is more situational, and therefore more difficult to compare. In some cases, it was reported incompletely, or not at all. This should not be taken to mean that reporting organisations and media do not appreciate the importance of infrastructure damage, as it is highlighted where verifiable information could be included.

Table 11 on next page lists one case involving each explosive weapon system studied, selected to highlight the use and effects of the particular weapon. The five case studies cover the period from February 1994 to January 2015. Though illustrative of the potential impact of the weapon systems covered, they should not necessarily be perceived as typical, as all munitions effects are context-dependent due to the many variables inherent to the use of explosive weapons in populated areas.

90 Non-publicly accessible (closed source) information was excluded, as transparency was a requirement to appropriately contextualize traditional and social media discourse on these events.

TABLE 11 CASE STUDIES SELECTED FOR EACH EXPLOSIVE WEAPON SYSTEM

CASE STUDY	WEAPON TYPE	DATE	LOCATION	DEATHS	INJURIES
A17	122 mm grad	24 Jan 2015	Mariupol, Ukraine	29	~93
B4	152 mm artillery	16 Aug 2012	Aleppo, Syria	60	79
C1	120 mm mortar	05 Feb 1994	Sarajevo, BiH	68	144
D5	120 mm tank gun	20 Jul 2014	Ash Shijaiyah, Gaza City	65	~100
E1	227 kg guided Mk 82[91]	05 Apr 2003	Basra, Iraq	17	5

EFFECTS ON STRUCTURES

The use of explosive weapons in populated areas can have a profound effect on physical structures such as vehicles, housing, commercial property, factories, school, hospitals etc. Consequently, though it might be an intuitive response of persons perceiving an explosive threat, seeking shelter in vehicles, houses and cellars is extremely risky. Whilst such structures offer some protection from the primary fragmentation effects of explosive weapons, they are also a source of debris and secondary fragmentation, such as shards of window glass or concrete, metal rods, plumbing pipes, or marble from the facades of modern buildings. Case study A13 includes an unverified doctor's report that all 14 survivors out of 21 total casualties presented evidence of injuries from secondary fragmentation. Secondary fragmentation injuries from window glass are a common occurrence; for example, they accounted for 88% of the total injuries suffered by survivors of the Khobar Towers bombing in 1996 (Thompson, Brown, Mallonee, & Sunshine, 2004).

Moreover, if there is enough explosive force applied to compromise the structural integrity of a building, the latter will collapse, crushing those people who took shelter inside it. The 24 July 2014 case study from Beit Hanoun, Gaza (D2), demonstrates the effects of several 120 mm tank projectiles fired at a school. Similarly, the 20 July 2014 case study from Ash Shijaiyah, Gaza (D5), and Deir el Balah, also Gaza (D1), covered multiple tank gun projectiles fired into residential areas, including Al Aqsa Martyrs Hospital. In both cases, it was necessary to extract civilian casualties from collapsed buildings.

91 Specific Mk 82 model is not known.

Although no data was available for the structural design, construction techniques and materials concerning the structurally compromised buildings, it is worth noting that multi-purpose tank munitions are often designed to penetrate structures before delivering their effects. This can lead to munitions penetrating multiple rooms, or destroying structural elements in buildings that may otherwise be expected to be more resistant to explosive weapons, such as steel girders and foundations.

The effects of an explosive weapon used in one populated environment may be very different in another area, depending on the building design, engineering and materials. There appears to be insufficient data on the subject and therefore more research is necessary to explore what effect explosive weapons might have on populated areas characterised by buildings built with different materials and according to different standards.

EFFECTS ON CRITICAL INFRASTRUCTURE

Some illustrative examples of damage to critical infrastructure, such as electrical and water supply systems, and economically vital businesses can be seen in case studies A8 (1 February 2014, in Al Kufrah, Libya) in an attack on the Sarir Power Station, and in case study A5 (31 July 2011, Misrata, Libya) on the Al-Naseem Dairy. Both these attacks were carried out using BM-21 type MBRL systems and had a significant broad impact. The damage to the Sarir power station caused power cuts in Tripoli and Benghazi and the attack on the dairy forced the closure of the largest private employer in the country, with 750 jobs lost. The estimated costs to restart production at the dairy were in excess of US$ 20 million.

The 23 January 2015 case study from Mosul, Iraq (A16), examining an attack that damaged a water sterilisation plant, presents an example of how a critical infrastructure object can be impacted by explosive weapons, causing subsequent civilian casualties. Primary and secondary explosive weapon effects on the water sterilisation plant resulted in the release of a cloud of toxic chlorine gas, which went on to kill an unspecified number of people. In this case, both artillery guns and rocket launchers were used, and it is not possible conclusively to define the roles of each weapon system in causing the damage.

EFFECTS IN ENCLOSED URBAN SPACES

When explosive munitions detonate in a populated and urban environment, the reflected blast waves, coupled with primary and secondary fragmentation, can cause very high casualties. The 5 February 1994 attack on Markale, Sarajevo (C1), is an example of the potentially devastating effect of explosive weapons in an enclosed or semi-enclosed public space. A single 120 mm mortar projectile fell into a crowded market in Sarajevo, in what is now Bosnia and Herzegovina, killing 68 people and injuring an additional 144. This is a rather unusual event, as a single HE mortar projectile is unlikely to cause so many casualties. There is a lack of information regarding the specific nature of the injuries.

However, in a second attack on the same location the following year (C2), doctors reported a large number of brain injuries. This type of trauma would be consistent with injuries caused by blast waves. The market place itself is relatively small, and surrounded by tall buildings. This would have had the effect of reflecting the energy of the blast wave back into the crowd of people, thus amplifying the overall impact. Had this attack occurred in the open, it is highly unlikely that so many people would have been killed or injured.

In line with Israeli research into the effects of attacks on buses, a 5 October 1999 case study from Chechnya, Russia (D4), shows the increased lethal effect of explosions in, or near, enclosed vehicles.[92] From the case study, it is notable that a single tank projectile is thought to have caused 28 deaths and 17 injuries, when it detonated inside a bus.

This effect occurs with other explosive weapon types, and is not necessarily limited to munitions which explode inside the vehicle. In the 13 January 2015 case study from Volnovakha, Ukraine (A12), one 122 mm rocket detonated close to a bus, killing 12 and injuring 17. The impact point of the rocket was approximately 10 m away from the bus, but the pattern of lethality is consistent with the Israeli research, and with the tank projectile case studies.

Based on the injury patterns, it is most probable that the large number of casualties caused by a single projectile is a result of the reflection of the blast wave inside the bus, followed by primary and secondary fragmentation and crushing debris in the confined space. A similar effect would occur if a projectile detonated inside the room of a house, or any other similar enclosed space.

92 It should be noted that the attacks that were studied involved IEDs, rather than conventional high explosive weapons, which would have different patterns and types of fragmentation (Leibovici et al., 1996).

For larger explosive munitions, such as Mk 82 aircraft bomb variants, enclosed spaces can be a series of interconnected spaces, or even entire buildings. The intensification of the primary effect is mainly due to the reflection of the blast wave, but also because of secondary fragmentation. This will result in a higher proportion of fatalities than would be likely in open spaces.

EFFECTS IN OPEN URBAN SPACES

Where crowds of people have been caught outside without warning or cover, the effects of munitions in populated areas are substantial. In these instances, a single munition can cause a large number of deaths, as can be seen in the 16 August 2012 case study from Aleppo City, Syria (B4), when 60 people were killed and 79 injured while they were queuing for bread.

Whilst significant casualties are often seen as a result of munitions which strike enclosed or semi-enclosed spaces, case study E3 represented an exceptionally high casualty rate despite the open nature of the strike site. Three GBU-12 (Mk 82) precision guided munitions were dropped in Majer, Libya, destroying three houses, resulting in 16 deaths and 23 injuries. The houses were partially reduced to rubble, which was being searched for survivors when another bomb was dropped some 10-20 minutes later. The final bomb proved to be more lethal than the previous three munitions combined, killing another 18, and injuring 15.

Whereas the primary effects of the Mk 82 could have caused all deaths, the initial three bombs had a 41% lethality rate, with a total of 14 killed, while the final bomb had a 55% lethality rate, with 18 killed. Although precise medical information was not available in this instance, it is unlikely that the blast effect of the Mk 82 was more lethal in open air, even considering the significant effects of primary fragmentation as part of its total effects. It is possible that secondary fragmentation was a significant contributing factor to the lethality of the bomb in this instance or that there was a high concentration of people in the vicinity trying to rescue those affected by the earlier bombs.

EFFECTS DUE TO TARGETING

There are undoubtedly limitations on accuracy and precision placed upon the use of explosive weapons in indirect fire in particular. Such limitations can be due to lack of training or access to advanced technology, old weapons and inconsistent munitions, and bad weather for example. However, the research found several examples (cases A2, A3, A12, A15, A16, A17, B5), in recent and ongoing conflicts where explosive weapons appeared to be targeted and used *en masse*, over an area, without this resulting in a clear military objective being achieved. Therefore, when examining causality of harmful effects in populated area, it is important not to mix issues pertinent to targeting with those related to accuracy and precision.

EFFECTS DUE TO HIGH EXPLOSIVE YIELD IN MUNITION

Some munitions pose particular targeting concerns. A single Mk 82, for example, contains 89 kg of high explosive. It creates a tremendously powerful blast, making collateral damage mitigation measures a complex task in a populated area. Owing to the powerful blast wave it produces, it can destroy reinforced concrete structures within 16 m of the point of detonation, and will easily flatten the houses and apartment buildings that civilians inhabit. Non-reinforced buildings offer almost no protection from a direct hit from a Mk 82. This is clear from the 5 April 2003 case study from Al-Tuwaisi, Basra (E1), when an attempt was made to kill a high-value individual in his house. The house was destroyed, but so were the houses on either side, killing 17 people and injuring another 5.

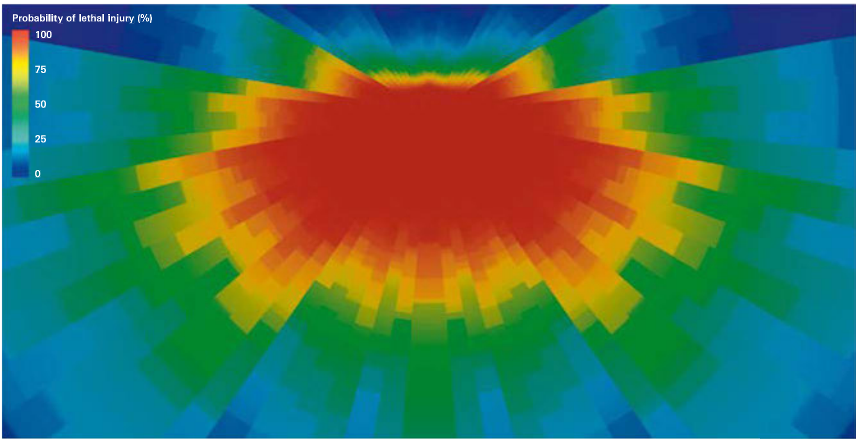


Figure 20. Butterfly-shaped pattern of the blast and fragmentation effects of a typical 227 kg (500 lb) HE aircraft bomb. The red area measuring approx. 32 m (from left to right) indicates 100% lethality: a preliminary result of the explosive weapon effects modelling software being developed under this project (source: Fraunhofer-EMI).

ACKNOWLEDGING WIDE AREA EFFECTS

The use and acquisition of munitions may be changing in response to the challenges of employing explosive weapons in populated areas. For example, the fact that variants[93] of the Mk 82, one of the smallest[94] guided bomb units in NATO's inventory, are used so often in preference to the larger Mk 83 (454 kg) and the Mk 84 (907 kg), suggests increasing awareness of the substantial area effects of explosive weapons. The development of new bombs such as the BLU-126/B Low Collateral Damage Bomb and the BLU-129/B Very Low Collateral Damage Weapon may also imply a change in military doctrine of good tactical use of air-launched weapons, testifying to attempts better to control and reduce wide area effects by providing more appropriate tools in support of targeting policies (see *Weapon-target matching*, p. 65).

EMPLOYMENT PRACTICES

The most modern artillery systems can achieve remarkable accuracy at all ranges, but many forces most likely to be using artillery guns in populated areas will also tend to use older designs, which often cannot achieve the same levels of accuracy. In some cases, adjusting fire techniques are employed. This means that a single round (sometimes a practice round or other less-lethal type) is fired, its impact point recorded, and adjustments made, before a second round is fired. This continues until the rounds are impacting exactly where the observer wants them to go. The rounds are 'walked' onto the target. Military forces often 'register' their guns in advance, and deliberately adjust fire in designated zones. However, in the case of some forces, this procedure will take place within populated areas, using one or more HE projectiles. Multiple rounds will fail to impact the target area, and will pose a threat to civilians and civilian objects (Dullum et al., 2016).

The Aleppo City study (B4) is particularly illustrative of how indirect fire can be 'walked' on to a target to achieve a precise strike, alas in a manner which adversely impacts civilians. Witnesses observed a fired artillery projectile strike near a Free Syrian Army (FSA) facility. After a few minutes this was followed by another two projectiles striking apartment buildings nearby, close to a local bakery, followed by a fourth and final projectile which struck 'a few metres from the breadline, where several hundred people were waiting in line' (Human Rights Watch, 2012).

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93 The Small Diameter Bomb (GBU-39, 110 kg), for example, entered into service in 2006 (Boeing, 2012).

94 Mk 82 weighs 227 kg, including approximately 89 kg of high explosive.

It is important to note that if the intended target of the artillery was indeed the bakery, then an observer would likely have advised the artillery gun crews of the impact locations of the first three projectiles in order to compensate for bias, 'walking' the fire to the target.

Another example of employment practices concerns tactics of use of indirect fire *en masse*, prevalent in a number of case studies. Military doctrines for mortars, artillery rockets and field artillery in particular continue to encourage *en masse* delivery of indirect fire, with an objective to achieve maximum concentration of the effects on an area at a given time (Dullum, 2010). Such tactics, and explosive weapons, were developed in an era when precision of weapons and consistency of munitions were unattainable and not a characteristic requirement. It allowed compensating for their poor accuracy and precision, *de facto* using the area weapons in the very function they were designed for (Dullum, 2010). However, technological developments in the past decades have introduced higher precision and accuracy characteristics for many explosive weapon systems; military objectives can be achieved with fewer munitions fired yet delivering the desired effects. The suitability of use of indirect fire en masse therefore, in certain scenarios such as in populated areas, is questionable and a review of standing military doctrines should be considered.

As noted earlier, the 122 mm BM-21 MBRL was not designed to be a precision weapon. With its powerful warhead and the common practice of firing a barrage of rockets from one or more launch platforms, the effects of this system are not confined to a small area. Multiple rockets were fired in the following case studies: A2 to A5, A7 to A17, A19 and A20.

In some cases, such as the 24 January 2015 attack in Mariupol, Ukraine (A17), it is difficult to differentiate between different rocket artillery systems employed in the same attack. According to the Mariupol City Council, multiple BM-21 systems fired their full complement of rockets, and the Organization for Security and Co-operation in Europe (OSCE) Special Monitoring Mission (SMM) reported that the BM-27 Uragan 220 mm MBRL was also used in this attack. It is not surprising, given the similarities between systems and areas of overlapping effects, that the damage was not distinguishable between the two rocket artillery systems from the limited public data.

On the other hand, most modern tank guns are able to achieve remarkable accuracy and precision, relative to the other unguided weapon systems covered in this report. When tank guns cause harm to civilians and civilian objects, it is more often a result of the manner in which they are employed, and the targets against which they are used, i.e. as a result of target selection, identification and engagement practices. This has been largely driven by the need for a 'one shot, one kill' weapon platform that can neutralise an enemy tank before it has the opportunity to respond and neutralise the attacker.

However, if a tank were to miss its target with its main gun, the projectiles may have sufficient kinetic energy to continue for several kilometres beyond their intended target, potentially placing civilians and civilian objects at risk when employed in, or near populated areas.

115–125 mm HE projectiles[95] are powerful explosive munitions with a wide area effect. An accurate hit in the centre of the intended target will still affect the area around the target and may cause collateral harm if improperly employed. Some tank projectiles have been designed with multiple fuze settings, including delay functions which can be set to function very shortly after impact, with the specific intention of detonating the projectile inside the target.

An analysis of the relative explosive quantity (expressed by NEQ), fragmentation weight and expected patterns, and *RED* figures for each of the five types of weapon system assessed in this report clearly illustrate how the design-dependent precision and effects of these weapons vary. As anticipated, with an NEQ of at least 87 kg, the Mk 82 aerial bomb is the single most destructive munition studied herein. However, as discussed, Mk 82 series munitions are now generally employed as part of a PGM, greatly enhancing delivery accuracy. By way of contrast, the 9M22U 122 mm rocket has an NEQ of less than 8.5 kg. Nonetheless, significant fragmentation generated from the pre-fragmented and partially pre-fragmented munitions casing combined with an imprecise delivery system result in a relatively high *RED*.

FUZE SELECTION

The vast majority of HE munitions are fitted with point-detonating fuzes, which are designed to detonate on impact. This is especially the case when mortar projectiles are being fired at targets that are protected, such as trenches or bunkers. In addition to the spread of fragmentation, the shockwave will travel through the ground or structure. Evidence gathered from the craters at the Markale market (case studies C1 and C2) indicates that the projectiles used were fitted with point-detonating fuzes. The angle of fall, estimated at 60-65°,

95 Includes multi-purpose munitions, or High Explosive Anti-Tank (HEAT), which is the most common type of tank munition deployed internationally (Defense Update, 2004).

would place the estimate for the lethal area at between 290-380 m^2 (ICTFFY, 2003). This would mean that up to 38% of the market's area was within the lethal area of the warhead, without considering primary fragmentation and secondary effects. The increased lethality of the resulting explosion in an enclosed or semi-enclosed area explains the number of casualties caused by the attacks.

Photo 9. Structural damage caused by explosive munitions in the northern Gaza Strip, August 2014 (photo credit: APA Images).

AVAILABILITY OF TECHNOLOGY

As noted, less advanced weapon systems, munitions and fire control systems may require additional projectiles to be fired to establish an impact point, so that adjustments can be made to hit the required target. If more advanced laser or GPS-guided munitions (PGM) were used instead, indirect fire weapon systems would become more accurate and precise. However, such PGM are currently expensive, and will not be replacing unguided munitions in the foreseeable future.

Standardisation and quality control of available conventional munitions should also be taken into account. The BM-21 is a good example of a weapon system that has been widely copied. As a result, there are notable inconsistencies in the rocket materials, the engineering of components and assembly, and in storage environments, which may further compromise the weapon's accuracy and precision. Rockets that have been manufactured under less than ideal conditions, or in environments without adequate quality control, may be less accurate than those produced in advanced facilities.

The availability of weapon systems of varying levels of technological advancement directly impacts the effects of those systems in populated areas. For example, when examining the impact of tank guns, it is important to consider the wide range of battle tanks in service around the world. Some modern military doctrines have diminished the role of tanks, particularly in urban environments where they can be more vulnerable to developments in anti-tank technology. Some militaries, for their part, continue to use older generation tanks and technology because those are what they can afford and have access to. Such older tank systems may be readily available on the market at a fraction of the cost compared to a modern system. This has led to a proportional increase in the number of older generation tanks deployed in conflict zones. The use of older tanks can be seen in the 18 March 2011 case study from Central Misrata, Libya (D3), where second generation tanks such as the T-72 were used. As the tanks currently fielded by militaries in certain countries continue to age, the precision of these tanks may decline, as maintenance and replacement guidelines may not be adhered to. Their performance will be significantly less precise than that of the newer generation III or IV Merkava tank, or the third generation T-90 tanks currently being fielded by other militaries (D1, D2, D5).

Similarly, the information presented in this report with regard to the accuracy of 122 mm BM-21 type MBRL refers primarily to the original and improved Russian designs. These figures and tables should not be used as a benchmark for the less-advanced BM-21 variants. More advanced variants may be capable of greater precision and accuracy, but there are technical limits to what can be achieved by unguided rockets fired from this type of system, particularly when fired *en masse*.

PRECISION GUIDED MUNITIONS

Modern warfare is frequently asymmetric, where a professional military force fights against an insurgency with only a very limited ability to wage a conventional war. This often sees belligerents on one side dispersed among the local population. Precision guided munitions (PGM), combined with real-time intelligence from various sources, including advanced unmanned aerial vehicles (UAV), allow a small number of military forces to strike targets accurately in populated areas and, depending on the specific weapon's explosive yield, and other factors considered in this report, may reduce the likelihood of causing civilian casualties or significant damage to civilian objects. However, precision guidance does not obviate a munition's wide area effects. It is important to stress this point, as the modern usage of the Mk 82 aircraft bomb with a comparatively high explosive yield (89 kg) sees them deployed as PGM.

Moreover, though none of the Mk 82 case studies which all employ PGM demonstrated inaccuracy of the weapon system, civilian casualties caused in these cases typically resulted from poor intelligence and targeting. Therefore, while the destructive effect of the Mk 82 can manifest itself in significant collateral damage, as seen in case study E1, this should not necessarily be interpreted as an indication of a failure in accuracy.

The negative impact of poor intelligence is evident in the 4 September 2009 case study from Amerkheil, Kunduz, Afghanistan (E2), in which two fuel tankers hijacked by Taliban militants became bogged down. An Afghan informant incorrectly asserted that the hundreds of civilians who had come to siphon fuel from the tankers were all militants, and they were subsequently targeted by two GBU-38 PGMs delivered by a NATO F-16, killing 142. It is likely that the presence of the flammable material and secondary fragmentation from the tankers contributed to the large number of civilian deaths.

MULTI BARREL ROCKET LAUNCHERS

MBRL systems have specific considerations and limitations that should be addressed. The MBRL was designed to produce a wide area of effect, as opposed to striking precise targets. When an MBRL such as the 122 mm BM-21 fires rockets at a range of approximately 14 km in close to ideal conditions (i.e. in even terrain, with good weather conditions, a trained crew and an appropriate target profile, calculations and firing tables), each rocket still has a probable error of 100 m in range, meaning it could land as far as 100 m beyond the target, or 100 m before it.

The rocket also has a probable error of 80 m in deflection, which means that it could land 80 m to the left, or 80 m to the right of its aiming point. When the BM-21 is fired at that range, then there is an elliptical probable error such that 50% of rockets fired will land somewhere in an ellipse measuring approximately 200 x 160 m. At 20 km, this increases to an ellipse measuring approximately 600 x 320 m. At a range of 20 km, a full salvo of 40 BM-21 rockets would create a lethal area of up to 600 x 600 m, which goes some way to explaining the dispersion patterns evident in the case studies.

The system lacks both precision and accuracy, dispersing munitions over a significant lethal radius. It is possible to aim at a single point inside a populated area, but multiple rockets are required for a statistically probable chance to deliver the desired destructive effects to the target. Without advanced guidance systems, the attacker has very few technical means to reduce, or limit, the damage around the approximate target area. These characteristics suggest that 122 mm BM-21 type MBRL and other MBRL with similar characteristics are unsuitable for use in populated areas.

Even a single rocket can cause significant numbers of casualties, as can be seen in the 14 April 2011 case study from Misrata, Libya (A4). In this case, one of six rockets fired killed ten people as they waited in line for bread. Similarly, in a case study from 14 October 2014 in Sartana, Ukraine (A13), seven people in a funeral procession were killed and another fourteen wounded by a single rocket. The other three rockets fired in the attack caused no casualties. As there are so many instances of single rockets causing multiple casualties, there can be no doubt as to the lethality of these warheads, even when they are not deployed *en masse*. When it is not clear where the rockets will impact, it also shows that the extent of destruction and the number of potential civilian casualties is difficult if not impossible to predict with sufficient accuracy. Consequently, without that accuracy in prediction, a realistic collateral damage estimate would have to come up with a very large impact area.

Photo 10. Buildings destroyed by bombing on July 20, 2006, Beirut, Lebanon (photo credit: Sadik Gulec / Shutterstock.com)

FINDINGS AND CONCLUSION

This report examined the characteristics of five explosive weapon systems encountered in contemporary conflicts in built and populated environments. The research compiled case studies to analyse the selected weapon systems and demonstrated prevailing practices in their use and their effects on humans and structures. Information to support the research was drawn from the case studies, external publications and expert interviews, with the objective of understanding and advancing knowledge on key characteristics of these weapons. On the basis of this analysis, the report draws findings on their accuracy and precision, multitude of immediate effects, and practices in their use, as follows:

1. Inherent accuracy and precision of the studied explosive weapon systems

1.1 The level of accuracy and precision of the studied explosive weapon systems differ significantly, with tank guns and guided aircraft bombs being capable of use in an accurate and precise direct fire function. However, their potential effects will be influenced by a given munition's explosive yield, i.e. A precision guided Mk 82 bomb may still retain a wide area effect due to its tremendous power.

1.2 Modern versions of artillery guns and mortars are capable of a relatively high level of accuracy in an indirect fire role within their effective ranges. However, due to design-dependent low precision of these systems, projectiles generally spread over a sizable area which increases as the distance to the target increases. This limits their technical suitability for use against smaller or moving targets, especially in populated areas. Most indirect fire weapon systems used in today's conflicts are incapable of achieving the high degree of accuracy required to hit a small point target with the first round.

1.3 Unguided artillery rockets are neither accurate, nor precise. Owing to its design as an area weapon, at maximum range the studied 122 mm BM-21 multi barrel rocket launcher could not reliably impact an area smaller than 600 x 320 m, within which humans and structures will be impacted.

1.4 Most Mk 82 aircraft bombs found in contemporary conflicts are guided versions. Precision guidance systems fitted to the Mk 82 can increase its accuracy from well above 100 m CEP to less than 5 m CEP in most weather conditions. However, accurately and precisely striking a target with a large munition such as a 227 kg (500 lb.) class bomb does not obviate its significant area effects and potential impact on civilians and civilian objects.

1.5 The level of accuracy and precision can be unpredictable and inconsistent with any of the weapon systems studied owing to factors such as the design of the weapon system in question, level of operator training, alignment and sighting of the weapon, the quality control of munitions, weapon maintenance and the practical experience of the firer in using the weapon in varying terrain and weather conditions. Old designs of the weapon systems, as well as munitions that are past their effective shelf life, continue to be employed in conflicts by crews with limited or otherwise inadequate training on their operation, resulting in poor accuracy and precision.

2. Effects of high explosive munitions in populated areas

2.1 The main effects of high explosive munitions comprise blast, heat and fragmentation originating from the munition, plus the secondary fragmentation and debris generated in the impact, or explosion of the munition, travelling at high velocity to considerable distance. These effects are compounded by firing a salvo of munitions simultaneously or sequentially and by their use in populated areas, which often results in large areas experiencing significant damage, as opposed to damage to a cluster of unconnected and localised points.

2.2 The effects of high explosive munitions within populated areas are influenced substantially by the presence of built structures and geographical features. Structures may provide protection from primary and secondary explosive weapon effects, but also amplify these effects due to the channelling and reflection of blast waves. Buildings and vehicles may contribute bricks, concrete, glass and other debris to the fragmentation originating from the weapon. Any fuel sources (liquid and gas) or toxic chemicals within the munition's impact zone may pose a further hazard to humans, as does the compromised structural stability of buildings which may be prone to collapse.

2.3 The intuitive reflex among humans to seek shelter from an explosive weapon attack in buildings, vehicles and similar enclosed spaces poses a lethal risk. The intensification of the weapon effects in a populated area is mainly due to the reflecting blast waves and presence of a number of people and structures within the amplified effective range of a munition(s), as well as sources of secondary fragmentation. This results in a higher proportion of fatalities than would be likely in open spaces.

2.4 Humans are particularly vulnerable to blast overpressure and reflected blast waves. Surviving an explosive weapon attack with only surface bruises visible does not exclude ruptured eardrums, damaged lungs, internal bleeding, brain damage, infections and poisoning, and bone fracturing. Depending on the layout of structures in a populated area and type of an explosive weapon used in an attack, the probability of survival for a human may indeed increase when away from the proximity of structures (prone on the ground in a small depression or narrow ditch).

2.5 Mk 82 aircraft bombs and 122 mm rockets were found to have the widest area effect in the study, although mortar and artillery projectiles were both responsible for single-munition explosions resulting in double-figure casualties. Tank munitions were often found to have a more limited lethal area. Explosive weapon systems such as the 122 mm BM-21 multi barrel rocket launcher produce design-dependent effects intended to cause widespread destruction.

2.6 Given regional differences observed regarding structural design and building materials, more technical research is needed to characterise explosive weapon effects in different target environments. For example, the significance of sources of debris in different populated areas and the implications of the presence of secondary hazards including but not limited to chemicals, have not yet been adequately researched.

3. Characteristic use of explosive weapons and measures to control their impact

3.1 As a general rule, armed forces should possess in-depth knowledge of the dynamic effects of the weapon systems and munitions in their inventories and should be able to accurately predict the extent of these effects in open terrain. However, our research suggests that there is less awareness of the effects of use in built-up areas, especially with regard to reflecting blast and sources of secondary fragmentation and debris. Whilst some militaries have the capability to model these hazards, this is far from common and carries limitations in terms of its ability to mimic reality accurately.

3.2 There are ways to mitigate the wide area effects of explosive weapons. Competent target analysis and approval procedure, positive target identification, evaluation of the vulnerabilities in the immediate physical environment, and selection of the most accurate and precise weapon available to the user are key factors in considering the wide area effects.

These factors guide the decisions over the method of employment[96], timing of the attack and weapon-target matching activities and assist in reducing collateral harm.

3.3 Weapon-target matching activities such as adjusting the time, angle and method of attack; fuze and munition selection and configuration; and delivery system optimisation, are critical in helping to reduce collateral harm. Weapon-target matching has limitations, however, pertinent to design-dependent characteristics of the explosive weapon that influence the accuracy, precision and the lethal effects of a given munition.

3.4 Conversely, weapon-target matching activities were found to be used in some cases to enhance the blast and fragmentation effects of an explosive weapon by fitting the munition with a proximity or time fuze set to deliver an airburst effect. Airburst employment of a conventional high explosive munition can increase its area effect by up to 100%. In a densely populated area this has the potential to significantly increase civilian harm.

3.5 Mortar and artillery systems continue to be 'walked on' to the target using the method of observing the impact location and thereafter correcting the aim. The first projectiles often impact areas outside the intended target. In order to maximise accuracy and precision during such procedures, extensive training, frequent weapon testing, access to modern technologies and detailed intelligence are paramount, supported by robust targeting policies and comprehensive and competent collateral damage estimates.

In conclusion, the use of explosive weapons in populated areas has resulted in numerous civilian deaths and injuries. In addition to the human cost, the case studies confirm substantial damage to essential infrastructure, homes and businesses. The effects of the detonation of high explosive munitions are intensified when this occurs in enclosed or semi-enclosed spaces such as buildings, tunnels, narrow streets or vehicles. This will result in a higher proportion of fatalities than would be likely in open spaces. In line with UNIDIR's recent findings[97], this report calls for research to better understand, quantify and prepare for the various effects of secondary fragmentation, debris and other potentially deadly sources of hazard in populated areas.

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96 i.e. direct, indirect or air-delivered fire.

97 Reverberating Effects of Explosive Force (Wille & Borrie, 2016).

The report also notes that a lack of standardised terms to describe arms and munitions and their effects in populated areas is an ongoing impediment to characterising explosive weapons accurately. More coherent use of terminology by news media, civil society organisations, policymakers and military would help in accomplishing a greater harmony in the collection and analysis of data, and consistency in reporting on explosive weapons events.

Finally, achieving a high degree of accuracy and precision with any of the studied explosive weapon systems does not negate their wide area effects. These are further amplified when firing them *en masse* – an indirect fire doctrine that continues to be practised in many armed forces today. Firing explosive weapon systems *en masse* follows century-old military tactics aimed at ensuring maximum coverage of the weapon effects over an area, while compensating for poor accuracy and precision. Such tactics, and explosive weapons, were developed in an era when precision of weapons and consistency of munitions were unattainable, and not a characteristic requirement. Whereas the use of indirect fire *en masse* is still a highly effective method for a quick delivery of lethal power to incapacitate an area target, considering the presence of civilians and civilian objects, this method is unsuitable for populated areas.

TERMINOLOGY

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE*
Abandoned explosive ordnance (AXO)	Explosive ordnance that has not been used during an armed conflict, a military exercise, or on a firing range, that has been left behind or dumped by a party to an armed conflict, or its owners, and which is no longer under control of the party that left it behind or dumped it. Abandoned explosive ordnance may or may not have been primed, fuzed, armed or otherwise prepared for use.	CCW V & IATG Mod.
Aircraft bomb	Explosive munition, not subject to centrifugal forces and with a nearly vertical angle of descent delivered from an aircraft.	IATG
Ammunition	A complete device (e.g. missile, shell, mine, demolition store etc.) charged with explosives, propellants, pyrotechnics, initiating composition or nuclear, biological or chemical material for use in connection with offence, or defence, or training, or non-operational purposes, including those parts of weapons systems containing explosives.	JSP 482
Area bombardment	An attack on an area rather than on one specific target by one or a number of weapons firing several projectiles into that area. Bombing of a group of targets constituting an area rather than a pinpoint target.	AAP-6 Mod.
Area effects	The magnitude sum of primary (i.e. blast, heat, fragmentation) and secondary (i.e. fragmentation, debris, burns, toxicity) explosive weapon effects on humans, including structural damage and collapse, radiating from the impact location(s) of one or more munitions.	CEW
Area target	A target consisting of an area rather than a single point.	AAP-6
Arm	To make a fuzing system ready for functioning by removal of all the safety constraints, thus permitting the munition to function on receipt of a specified firing stimulus.	JSP 482

* The key to source acronyms can be found at the end of the table.

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Artillery munitions	Medium and large-calibre munitions for artillery weapons, such as guns, howitzers, cannons, missile and rocket launchers, that are primarily designed to fire indirectly at targets.	CEW
Artillery gun	A gun of a calibre greater than 57 mm, which is not man-portable, is designed for indirect fire and capable of hitting targets at a considerable range. Characterised by a heavy barrel, generally several metres long and most commonly fitted to a self-propelled vehicle or a towed trailer. Modern artillery guns feature recoil mechanisms, and many are capable of being used in the direct fire role. Includes 'howitzers', which are generally understood to be comparatively short-range artillery guns firing a heavy projectile at a relatively low muzzle velocity.	ARES
Assembly area (civilian)	Any location where groups of people gather on a regular basis for various commercial, social, educational, religious, administrative or commuting purposes.	CEW
Assembly place	A place or building where it is customary for members of the public to assemble, e.g. church, school, sports stadium.	JSP 482
Barrage	For the purposes of CEW, barrage refers to an explosive weapon attack of a minimum of 8 projectiles of the same type impacting one (target) area. For example, 4 guns firing 2 rounds each. Fire, which is designed to fill a volume of space or area rather than aimed specifically at a given target.	CEW & AAP-6
Battle damage assessment (BDA)	The assessment of effects resulting from the application of military action, either lethal or non-lethal, against a military objective.	AAP-6
Bi-propellant	A liquid propellant in the form of two substances, a fuel and an oxidizer; they are stored separately and brought together when their mutual chemical reaction is required to produce thrust.	JSP 482

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Blast	A destructive wave of gases or air produced in the surrounding atmosphere by a detonation. The blast includes a shock front, high pressure behind the shock front and a rarefaction following the high pressure.	JSP 482 Mod.
Blind	A prepared explosive store, which though initiated, has failed to arm as intended or to explode after being armed; failing to function correctly after initiation, becoming *unexploded ordnance (UXO)*.	JSP 482 Mod.
Bomb	Explosive munition, not subject to centrifugal forces and with a nearly vertical angle of descent, usually delivered from an aircraft or mortar.	IATG
Brisance	The shattering effect of an explosive or explosion.	IATG
Calibre	The calibre designation of a munition reflects the nominal projectile diameter, which is most often determined based on the bore of a weapon, as measured across the features of the weapon's rifling. The calibre can be determined from the diameter of the lands (X), the diameter of the grooves (Y), or the average diameter of both (X+Y divided by 2); alternatively, it can correspond with an arbitrary figure, which is provided by the cartridge or weapon designer. Some calibres (typically those using imperial measurements) are commonly measured between the grooves, instead of being based on the diameter of the lands of the barrel's rifling, although this is not always the case. In smoothbore weapons, the calibre may be determined by measuring the diameter of the projectile, the barrel or may be an arbitrary measurement. The term 'calibre' is sometimes applied to measurements of munitions other than projectiles, such as rockets and missiles. In these cases, it is generally equivalent to the outer diameter of the body at its widest or average point.	ARES

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
City, Town, Village, Hamlet	A human settlement with a name, built-up area and an established community. The categorisation in terms depends on the size and density of the population as well as sum of housing and economic infrastructure, and varies from region to region. More specifically: • City is a large town; an inhabited place with greater size, population, administration or importance than a town. • Town has defined boundaries and local governance, and is larger than a village and generally smaller than a city, with its own business or shopping area. • Village is a group of houses and associated buildings, generally larger than a hamlet and smaller than a town, situated in a rural area. • Hamlet is a small settlement, generally smaller than a village and without a place of worship.	CEW
Cluster munitions	Containers designed to disperse or release multiple submunitions. *Note: generally only applied to weapons dispersing explosive submunitions.*	IATG
Collateral damage	Inadvertent casualties and destruction in civilian areas caused by military operations.	AAP-6
Concentration of civilians	Any concentration of civilians be it permanent or temporary, such as in inhabited parts of cities, or inhabited towns or villages, or as in camps or columns of refugees or evacuees, or groups of nomads.	CCW Protocol III
Conventional munitions	Munitions, which are neither nuclear, biological nor chemical.	AAP-6 Mod.
Conventional weapon	A weapon, which is neither nuclear, biological nor chemical.	AAP-6
Debris	Any portion of the natural ground or of a structure or material (not part of the functioning explosive weapon) that is propelled from the site of an explosion. Also known as projections.	JSP 482

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Deflagration	A rapid chemical reaction in which the output of heat is sufficient to enable the reaction to proceed and be accelerated without input of heat from another source. Deflagration is a surface phenomenon with the reaction products flowing away from the unreacted material to the surface at subsonic velocity. The effect of a deflagration under confinement is an explosion. Confinement of the reaction increases the pressure rate of reaction and temperature and may cause transition into a detonation.	JSP 482
Demilitarisation	The complete range of processes that render weapons, ammunition and explosives unfit for their originally intended purpose.	IATG
Detonation	An exothermic reaction wave, which follows and also maintains, a supersonic shock front in an explosive.	JSP 482
Detonator	A device containing a sensitive explosive intended to produce a detonation wave.	JSP 482
En masse	In a mass, all together, as a group: several weapons firing a number of munitions as a single group, near-simultaneously.	CEW
Explosion	A nuclear, chemical or physical process leading to the sudden release of energy (and usually gases and heat) giving rise to external pressure waves.	JSP 482
Explosive	Solid or liquid substance or mixture of substances, which by intrinsic chemical reaction is capable of producing an explosion. A substance or mixture of substances, which, under external influences, is capable of rapidly releasing energy in the form of gases and heat.	IATG
Explosive charge	A bagged, wrapped or cased quantity of explosives without its own integral means of ignition. Secondary means of ignition may or may not be incorporated.	IATG

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Explosive substance	A substance or mixture of substances, which are capable by a chemical reaction in itself of producing gas at such a temperature and pressure and at such speed as to cause damage to surroundings or which is designed to produce an effect by heat, light, sound, gas or smoke or a combination of these as a result of non-detonating, self-sustaining exothermic chemical reactions.	JSP 482
Explosive ordnance (EO)	All munitions containing explosives. This includes bombs and warheads; guided and ballistic missiles; artillery, mortar, rocket and small arms ammunition; all mines, torpedoes and depth charges; pyrotechnics; clusters and dispensers; cartridge and propellant actuated devices; electro-explosive devices; clandestine and improvised explosive devices; and all similar or related items or components explosive in nature.	AAP-6 Mod.
Explosive remnants of war (ERW)	Unexploded ordnance (UXO) and abandoned explosive ordnance (AXO) that remain after the end of an armed conflict, military operation, on a range etc., including all munitions, mines and cluster munitions.	IATG Mod.
Explosive weapons	Weapons and munitions that generally consist of a casing with a high explosive filling and whose destructive effects result mainly from the blast wave and fragmentation produced by detonation.	CEW
Explosive weapon primary effects	Destructive effects radiating from the point of initiation of detonating ordnance and include blast overpressure, fragmentation, heat and light.	CEW
Explosive weapon secondary effects	Destructive, immediate additional effects to the primary explosive weapon effects due to the interaction with structures and substances present in built and natural environments. Examples are secondary fragmentation generated by blast or primary fragmentation, fires caused by thermal output, the generation of toxic gases and hazardous chemicals, smoke, debris, etc.	CEW

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Explosive weapon tertiary effects	Indirect increase in the pattern of harm from the primary and secondary effects, manifesting in reduced safety and security, lack of health services, lost livelihoods, poor nutrition and hygiene, weakened governance and social services and rise of socio-economic problems. Examples are lack of food and water supply, dysfunction of sewage system and telephone lines, inability to access medical care and schooling, loss of livelihoods and unemployment, lack of basic security and other detrimental consequences on everyday activity. Interchangeable with *Reverberating* effects.	CEW
Explosive weapons in populated areas (EWIPA)	Refers to the use of an explosive weapon (primarily ones capable of wide area effects) in a hamlet, village, town or city where there are civilians and civilian infrastructure within the range of its primary and/or secondary effects.	CEW
Fragment	Any solid material in contact with an explosive or surrounding it closely that is propelled from the site of an explosion and often splintered. It is mainly applied to the ordnance metal casing and other non-explosive components. *Note: secondary fragments may be glass, concrete, metal, wood, etc. from the environment affected by blast and primary fragmentation.*	JSP 482 Mod.
Fuse	In munitions and explosive terms: a simple burning fuse, e.g. safety fuse, fuse instantaneous.	JSP 482 Mod.
Fuze	A device designed to control the initiation of a main (explosive) charge.	JSP 482 Mod.
Grenade	Munition that is designed to be thrown by hand or to be launched from a rifle. Excludes rocket-propelled grenades (c.f. Rocket).	IATG
Guided missile (GM)	Guided missiles consist of propellant-type motors fitted with warheads containing high explosive or other active agent and equipped with electronic guidance devices.	IATG

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Harm	Physical injury, death or damaging effects to the health of people, or damage to property or the environment.	IATG
Hazard	Potential source of harm.	IATG
Heavy explosive weapon	Artillery weapon system (field gun, howitzer, cannon, mortar, rocket launcher), air-delivered bomb, a missile or a tank gun, which has a calibre of 100 mm and above and munition with explosive payload.	CEW
High explosive (HE)	A substance or mixture of substances, which in their application as primary, booster or main charge in ammunition is required to detonate.	JSP 482
High velocity projections	Debris or fragments at high velocity as the result of an explosion and that may have sufficient remaining energy to propagate the explosion of another source capable of explosion or deflagration.	CEW
Hospitals, schools etc.	Vulnerable buildings, facilities or groups of these where people are normally present in large numbers.	CEW
Hypergolic	Capable of spontaneous ignition on contact with another specific substance.	JSP 482
Hypergolic propellant	A self-igniting bi-propellant in which fuel and oxidizer ignite on contact with each other.	JSP 482
Hypergolic reaction	The spontaneous ignition of two components, particularly relevant in the case of liquid bi-propellants.	IATG
Incendiary munition	A munition containing an incendiary substance, which may be a solid, liquid or gel; this includes white and red phosphorus, thermite, jellied fuel mixture, etc.	IATG Mod.
Inert	A munition that contains no explosive, pyrotechnic, lachrymatory, radioactive, chemical, biological or other toxic components or substances. This term is also used for the empty body of an item before being filled, or a rendered safe item.	IATG Mod.

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Inert filling	A non-explosive filling used to replace explosives and enable operational items to be simulated for training and testing, and increasingly for operational purposes.	JSP 482 Mod.
Inhabited area	An area where people live, visit or work.	CEW
Inhabited building	A building or structure occupied in whole or in part by people. Used synonymously with occupied building.	JSP 482
Inhabited place	Any place (area) where people are present.	CEW
Lachrymatory ammunition	Ammunition containing chemical compounds that are designed to temporarily incapacitate by causing tears or inflammation of the eyes.	IATG
Light explosive weapon	Any man-portable weapon designed for use by two or three persons serving as a crew (although some may be carried and used by a single person) that is designed to expel or launch a projectile by the action of an explosive charge and uses high explosive munitions. Includes hand-held under-barrel and mounted grenade launchers, portable anti-aircraft guns and missile systems, portable anti-tank guns and rocket and missile systems, recoilless rifles and mortars of a calibre of less than 100 mm, as well as their parts, components and high explosive munitions.	IATG Mod.
Liquid propellant	Any liquid that can be used for the chemical generation of gas at controlled rates and used for propulsion purposes.	JSP 482
Low order detonation	An incomplete and relatively slow detonation, being more nearly combustion than an explosion.	IATG
Market place	A dedicated area, normally in or near a settlement, where stalls or shops are erected on at least one day per week and people can exchange or buy goods or services.	CEW

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Medical/first aid centre	A place where people can go for assistance if they are wounded or ill. Can be anything from a marked out area with no structure, to a large hospital.	CEW
Meeting place	A geographically defined place where groups of people regularly meet, often for a common purpose or to assemble prior to travelling to another place.	CEW
Mine	In land mine warfare, an explosive munition designed to be placed under, on or near the ground or other surface area and to be actuated by the presence, proximity or contact of a person, land vehicle, aircraft or boat, including landing craft.	AAP-6
Missile	An armament store designed to be released from an aircraft or discharged from a gun or launcher towards a selected point usually to cause damage at that point. *Note: the term is often used synonymously with guided missile.*	IATG
Mortar	Generally a smoothbore, muzzle-loading, indirect fire gun firing relatively low velocity munitions. Conventional mortars do not have recoil mechanisms, with the main recoil force being transmitted directly to the ground via the baseplate. Most mortars are restricted in elevation, and are only capable of firing at high-angle trajectories (above 45°), preventing use in the direct fire support role.	ARES
Multi barrel rocket launcher (MBRL)	A rocket launching system with more than one barrel, arranged so as to be able to fire in relatively quick succession, without the need to reload. Most commonly fitted to a self-propelled vehicle or a towed trailer. Sometimes referred to as a 'multiple launch rocket system' (MLRS), however this is the name of a specific U.S.-made weapon system.	ARES

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Munition	A complete device, (e.g. missile, shell, mine, demolition store etc.) charged with explosives, propellants, pyrotechnics, initiating compositions or nuclear, biological or chemical material, for use in connection with offence, or defence, or training, or non-operational purposes, including those parts of weapon systems containing explosives. Synonymous with Ammunition. *Note: term 'ammunition' includes; shells, bullets, fuses and powder; whereas 'munition' carries a broader reference to, artillery guns, missiles, and bombs. 'Munitions' (plural) can be 'weapons used in combat'.*	JSP 482 Mod.
Nature (when related to ammunition)	The specific types of ammunition. A means of categorising ammunition or munitions by their function (e.g. anti-tank ammunition or riot control ammunition).	IATG
Neutralize	To alter the state of a piece of ammunition or munition so that it cannot explode, e.g. by replacing safety devices such as pins or rods into an explosive item to prevent the fuze or igniter from functioning, or by disrupting the explosive train.	IATG
Net explosive quantity (NEQ)	The total explosives content present in a container, ammunition, building etc., unless it has been determined that the effective quantity is significantly different from the actual quantity. It does not include such substances as white phosphorus, war gas or smoke and incendiary compositions unless these substances contribute significantly to the dominant hazard of the Hazard Division concerned. Also known as Net Explosive Content (NEC), Net Explosive Mass (NEM) or Net Explosive Weight (NEW). Can also be referred to as Equivalent Net Explosive Quantity (ENEQ), where TNT equivalence is used.	JSP 482 Mod.
Overpressure	The pressure *above atmospheric pressure* resulting from the blast wave of an explosion. It is referred to as 'positive' when it exceeds atmospheric pressure and 'negative' when during the passage of the wave the resulting pressures are less than the atmospheric pressure.	JSP 482 Mod.

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Performance failure	The failure of ammunition or any of its constituent parts, including the explosives, to function as designed.	IATG
Phosphorus	A flare/smoke-producing incendiary composition, or smoke-screening agent, made from a common allotrope of the chemical element phosphorus.	IATG
Place of worship	A specially designed structure or consecrated space where individuals or groups of people perform religious acts.	CEW
Populated area	Area likely to contain concentrations of civilians. The term 'concentrations of civilians' is defined in Protocol III to the Convention on Certain Conventional Weapons as any concentration of civilians, be it permanent or temporary, such as in inhabited parts of cities, or inhabited towns or villages, or as in camps or columns of refugees or evacuees, or groups of nomads. *Note: populated areas are **not** synonymous with 'urban'.*	CCW
Population density	The number of human inhabitants of an area per square kilometre (km^2).	CEW
Precautionary measures	Precautions in attack (art 57): verify that targets are military objectives and not subject to special protection; choose means and methods of warfare to avoid and minimise loss of civilian life and injury and damage to civilian objects; refrain from launching a disproportionate attack; cancel or suspend an attack if the target is not a military objective or subject to special protection; provide effective advance warnings whenever possible; and choose the military objective expected to cause least danger to civilians and civilian objects. Precautions against the effects of attack (Art 58): seek to remove the civilians and civilian objects from the vicinity of military objectives; avoid locating weapons, troops or other military objectives within or near densely populated areas; and take other precautions to protect the civilians and civilian objects against dangers resulting from military operations.	ICRC API Art. 57-58 Mod.

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Preventive measures	Measures taken in advance to prevent the occurrence of collateral damage or to mitigate their effects.	CEW
Primary explosive	An explosive substance, which is sensitive to spark, friction, impact or flame, and is capable of promoting initiation in an unconfined state. Generally, primary explosives are synonymous with initiating explosives.	JSP 482
Proliferation	The increase or spread of weapons and ammunition to users.	IATG
Proof	The functional testing and assessment of an explosive to ascertain its performance.	JSP 482
Propellant	A substance on its own or in a mixture with other substances that can be used for the chemical generation of gases at the controlled rates required for propulsive purposes.	JSP 482
Propellant stabiliser	A substance added to single or double base propellants to retard decomposition.	IATG
Protective measures	Means used to reduce risk.	IATG
Pyrophoric	A substance capable of spontaneous ignition when exposed to air, such as white phosphorous.	IATG
Pyrotechnic	A substance or mixture of substances which, when ignited, undergo an energetic chemical reaction at a controlled rate intended to produce effects such as light, smoke, sound or flame.	JSP 482
Recreation area	A designated area for recreational use.	CEW

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Reverberating effects	Reverberating Effects of Explosive Force (REEF) is interchangeable with Tertiary Explosive Weapon Effects.	CEW
Risk	Combination of the probability of occurrence of harm and the severity of that harm.	IATG
Risk analysis	Systematic use of available information to identify hazards and to estimate the risk.	IATG
Rocket	A missile whose motion is due to reaction propulsion and whose flight path cannot be controlled during flight.	JSP 482
Rocket motor	Article consisting of a solid or liquid fuel contained in a cylinder fitted with one or more nozzles. They are designed to propel a rocket or a guided missile.	IATG
Round	A complete assembly of a projectile (with or without fuze), the propelling charge in a cartridge case and the means of igniting the propelling charge.	JSP 482 Mod.
Salvo	For the purposes of CEW, salvo refers to an explosive weapon attack of between 2 and 9 projectiles of the same type in one (target) area by at least two weapons (one round each).	CEW
Safe	The absence of risk. Normally the term 'tolerable risk' is more appropriate and accurate.	IATG
Safety	The reduction of risk to a tolerable level. The degree of freedom from unacceptable risk.	IATG
Secondary fragmentation	Fragmentation, which in an explosive event, did not originate from the munition.	IATG Mod.

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Small arms ammunition (SAA)	Ammunition fired from weapons not above 14.5 mm in calibre.	CEW
Smoke ammunition	Ammunition containing a smoke-producing substance.	IATG
Spalling	Spalling occurs by the transmission of a shock wave through material that creates high-speed particles from the opposite face of that material without breaching it.	JSP 482
Standing operating procedures (SOPs)	Instructions that define the preferred or currently established method of conducting an operational task or activity. Their purpose is to promote recognisable and measurable degrees of discipline, uniformity, consistency and commonality within an organisation, with the aim of improving operational effectiveness and safety. SOPs should reflect local requirements and circumstances.	IATG
Submunition	Any munition that, to perform its tasks, separates from a parent munition (e.g. cluster munitions).	IATG
Supply centre	A location where natural resources, raw materials, components and finished products are gathered prior to being distributed to customer outlets or customers.	CEW
Supply chain	A system of organisations, people, activities, information and resources involved in moving a product or service from producer to customer.	CEW
Tank gun	A gun fitted to a battle tank as its primary armament. In modern usage, typically of 75 mm to 155 mm in calibre, featuring an advanced stabilisation system and capable of firing a variety of different munitions. Often, but not always, fitted with an autoloader.	ARES

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Target	The object of a particular action, for example a geographic area, a complex, an installation, a force, equipment, an individual, a group or system planned for capture, exploitation, neutralization or destruction by military forces.	AAP-6
Target area	The target plus the surrounding area within range of a weapon's primary and secondary explosive effects.	CEW
Targeting	The process of selecting and prioritising targets and matching the appropriate response to them, taking into account operational requirements and capabilities.	AAP-6
Tolerable risk	Risk, which is accepted in a given context based on the current values of society.	IATG
Town	A town is a human settlement generally larger than a village but smaller than a city. What constitutes a town varies considerably in parts of the world and is mainly dictated by the population density, occupied geographical area and economical functions within, as well as administrative importance to the host state. A town has defined boundaries and local governance, with its own business or shopping area. Refer to *City, Town, Village, Hamlet*.	CEW
Transport hub	A transport hub (also interchange) is a place where passengers and cargo are exchanged between vehicles or between transport modes. Public transport hubs include train stations, rapid transit stations, bus and tram stops, airports and ferry terminals.	CEW
Type	A division of ammunition in accordance with its general design, e.g. AP, SAP, Nose Ejection.	JSP 482

TERM	DESCRIPTION (FOR THE PURPOSE OF CHARACTERISATION)	SOURCE
Unexploded ordnance (UXO)	EO that has been primed, fuzed, armed or otherwise prepared for use or used. It may have been fired, dropped, launched or projected yet remains unexploded either through malfunction or design or for any other reason.	IMAS
Village	Human settlement. Usually small and consisting of a few dwellings and only the most basic of infrastructures. In a more populated region can refer to a settlement of up to 5000 people and have basic necessities i.e. shops, church, meeting place etc. Refer to *City, Town, Village, Hamlet*.	CEW
Vulnerable building	Building deemed to be vulnerable by nature of its construction or function.	JSP 482
Warhead	That portion of a missile intended to be lethal or incapacitating.	JSP 482
Weapon	Anything used, designed or intended for use in causing death or injury, or for the purposes of threatening or intimidating any person.	IATG
Weapon with wide area effects	An explosive weapon capable of producing primary and secondary effects well beyond the point of initiation, including by means of the large destructive radius of the individual munition(s) used, inaccuracy of the delivery system or munition, the use of multiple munitions, or a combination of these factors.	CEW

Key to term sources

ARES	Terms established by Armament Research Services.
AAP-6	NATO Glossary of terms and definitions: Allied Administrative Publication No. 6.
CCW	Terms recorded in the text of the Convention for Certain Conventional Weapons and appearing in the Protocols I, II and IV and Amended Protocols III and V.
CEW	Terms established by GICHD wherein no suitable description for the EWIPA context could be found in recognised publications on explosive weapons and munitions.
IATG	International Ammunition Technical Guidelines; UN publication controlled by UN Office for Disarmament Affairs.
ICRC	Terms recorded in the text of Geneva Conventions and appearing in the Protocols, maintained by the International Committee of the Red Cross.
IMAS	International Mine Action Standards. UN publication controlled by UN Mine Action Service and maintained by GICHD.
JSP 482	Joint Service Publication No. 482: British Forces Joint Service ammunition authority.
Mod.	Modified description based on an existing definition, altered from the original to a small extent (i.e. condensed), or combined from several similar definitions, for the purposes of characterisation activity.

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