Technical Note 10.20 / 01

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Estimation of Explosion Danger Areas

Warning

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Contents

Foreword

Management practices and operational procedures for humanitarian mine action are constantly evolving. Improvements are made, and changes are required, to enhance safety and productivity. Changes may come from the introduction of new technology, in response to a new mine or UXO threat, and from field experience and lessons learned in other mine action projects and programmes. This experience and lessons learned should be shared in a timely manner.

Technical Notes provide a forum to share experience and lessons learned by collecting, collating and publishing technical information on important, topical themes, particularly those relating to safety and productivity. Technical Notes complement the broader issues and principles addressed in International Mine Action Standards (IMAS).

Technical Notes are not formally staffed prior to publication. They draw on practical experience and publicly-available information. Over time, some Technical Notes may be 'promoted' to become full IMAS standards, while others may be withdrawn if no longer relevant or if superseded by more up-to-date information.

Technical Notes are neither legal documents nor IMAS. There is no legal requirement to accept the advice provided in a Technical Note. They are purely advisory and are designed solely to supplement technical knowledge or to provide further guidance on the application of IMAS.

Technical Notes are compiled by the Geneva International Centre for Humanitarian Demining (GICHD) at the request of the United Nations Mine Action Service (UNMAS) in support of the international mine action community. They are published on the IMAS website at www.mineactionstandards.org.

Introduction

The estimation of explosion danger areas for large UXO or during the multi-item disposal of ammunition and explosives is a technically complex issue. IMAS 10.20 Annex C provides general guidance on methodologies that can be applied; this Technical Note expands on these methodologies in more detail for the benefit of mine action programme managers and field staff.

The danger areas laid down for single mine or UXO disposal at IMAS 10.20 Annex C are based on the practical experience gained by military EOD technicians over many years. However, they are not fully comprehensive and are not intended to provide for every possible situation. They are intended purely as a general guide, and must be modified by the EOD technician, or other trained staff member, who must deal with each case on its merits based on experience, technical judgement and a detailed knowledge of ammunition and explosives.

This technical note contains two levels of information. At the first level, it contains simple tables, which should be sufficient for most demolition tasks in most mine-and munition-polluted countries. However, the field manager may well be faced with the need to conduct demolitions in confined spaces, or near to buildings and facilities. In these cases, some calculations will be necessary, and the second level of information will allow a more precise estimate of safety distances to be made.

The techniques proposed in this Technical Note should not be applied for the routine small single item mine and UXO clearance tasks most frequently encountered during demining operations. They are specifically designed for the more complicated UXO tasks and for multi-item demolitions. The calculations will estimate explosion danger areas, but make no allowance for the presence of tamping or protective works. When these are used, the EOD technician, or trained staff member, must again rely on experience, common-sense, sound technical judgement and a detailed knowledge of ammunition and explosives as is available. However, they will enable the EOD technician to be able to more accurately predict and estimate safe explosion danger areas.

Multi-item demolitions do result in increased fragmentation hazard[1] resulting from cooperative effects from adjacent munitions. Due to the complexity of these effects simple formulae to determine appropriate safety distances in these circumstances have yet to be derived. However, simple formulae based on experimentation and reference to accepted explosive effect equations have been postulated and trialled. The results have been encouraging to the degree where they are now in wider spread use. They are therefore used in this TN.

This Technical Note has been written as an advisory document to ensure that managers, field staff and EOD technicians are aware of both the rough “rule of thumb” distance calculations and the potential methodologies for more accurately estimating explosion danger areas by calculation. Microsoft EXCEL based spread sheets have been developed by the GICHD to assist in these calculations; requirement for the sheets should be sent to imas@gichd.org.

The estimation of explosion danger areas for large UXO and multi-item demolitions should only be undertaken by appropriately qualified EOD or academically trained personnel; it is not a task for basic deminers or other field staff. When in doubt, seek advice. If such advice is unobtainable, use the level one information as a minimum, and add 50% if the circumstances allow it.

[1] The detonation of the explosive generates a high enough pressure to rupture the explosive container (mine body) with sufficient force that relatively small “fragments” are propelled at high velocities. The size and shape of these fragments is determined by the metallurgical history of the container, its physical condition and the effectiveness of the explosive. The distance to which these fragments can fly, often at high velocity, is referred to as the fragmentation distance. This distance is the radius of the fragmentation hazard zone.

The International Ammunition Technical Guidelines (IATG) 2011 contain a guideline on explosives related formulae (IATG 01.80 Formulae for ammunition management) and also guidance as to the development of an explosion consequence analysis (ECA) (IATG 02.10 Introduction to risk management principles). These particular IATG may be used by appropriately qualified staff to more accurately estimate explosion danger areas under particular conditions.

Estimation of explosion danger areas

1. Scope

This Technical Note establishes principles and provides guidance on the estimation of explosion danger areas by calculation, and the use of simple tables derived from experimental results based on the calculations.

2. References

A list of normative references is given in Annex A. Normative references are important documents to which reference is made in this Technical Note and which form part of the provisions of this Technical Note.

3. Terms and definitions

A complete glossary of all the terms, definitions and abbreviations used in the IMAS and Technical Notes series is given in IMAS 04.10.

In the Technical Notes series, the words 'should' and 'may' are used to indicate the intended degree of compliance. This use is consistent with the language used in International Mine Action Standards (IMAS), and guides.

a) 'should' is used to indicate the preferred requirements, methods or specifications; and

b) 'may' is used to indicate a possible method or course of action.

4. Hazard

The hazard to the general public from the demolition of UXO and multi-item demolitions arises from three main causes[2]: the shock front[3], the blast wave and the projection of high velocity fragments, (either primary or secondary).

The shock front hazard can be discounted for the purposes of danger area estimation as it decays at a much higher rate than the blast wave (usually within 2 charge diameters), which then takes over from it. If an individual is close enough to an explosion to be affected by the shock front, then the individual is too close anyway. The calculations used to estimate danger areas are based on the blast and fragmentation hazards, which extend much further out from the explosion source than the shock front hazard.

5. Blast hazard danger area

The safety distance for blast hazards should be calculated to reduce risk of temporary hearing loss. A simple estimated calculation of a blast hazard danger area can be taken from the attached tables at Annex B. Where more accurate calculations are required, the blast hazard area should be based on the methodology and calculations of “*Kingery and Bulmash*”[4].

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[2] The effects of radiated, conducted and converted heat are not considered as the blast effects apply to a greater range.

[3] The shock front is created by the detonation wave, which creates a shock-pressure of up to 3M psi. This is followed by the expanding gas cloud of much lower pressure. The detonation-shock pressure (the “shock front”) decays rapidly after leaving the explosive charge, whereas the expanding gas cloud (blast wave) can operate a significant distance from the charge centre.

[4] This can be found in "Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingery & Gerald Bulmash, US Technical Report ARBRL-TR-02555 dated April 1984.

This methodology calculates the blast over-pressure in kPa at varying ranges from the source explosive. It is accepted that eardrum rupture occurs at approximately 34.5 kPa, therefore the imposed danger area should be calculated to be that range at which the expected blast overpressure is significantly less than 34.5 kPa[5]. It is likely that the fragmentation danger area will be greater than the blast danger area in most cases, however for light cased munitions, where there is minimal fragmentation hazard, a blast danger area will usually suffice.

The GICHD has access to a computer model based on the "*Kingery and Bulmash*" methodology, which can be made available, on request, to demining organisations.

WARNING: **The computer model requires a certain level of explosive knowledge and expertise and should therefore only be used by an appropriately qualified EOD technician or academic. False results can be obtained if inaccurate or insufficient data is input.**

6. Fragmentation hazard zone

The fragmentation zone safety distance should be calculated to reduce the risk of harm from fragmentation thrown out from the explosion to those working on the worksite and to the local population. Where necessary, protective works, such as demolitions pits, earth bunds, sandbag walling or water suppression, should be used to reduce the extent of fragmentation hazard zones.

Theoretical methods can be used, but the calculation of fragmentation hazard zone areas is a more complex operation than that for blast hazard zone. Various methodologies can be used, but it is accepted that the use of the "*Gurney* Equation" to calculate the initial worst case fragment velocity, when combined with the "Fragment Slowdown Equation" and the effects of trajectory, gravity and air resistance can be used to estimate an acceptable danger area. This is complex and has not therefore been included in this TN.

An alternative is to use the USA Conventional Weapons Effects (CONWEP) computer model, if available.

A third approach to the calculation of fragmentation hazard zones is to use simplified equations based on experimental results combined with "*Gurney* Equation" predictions. These formulae utilise the all-up-weight of the munition to calculate an estimated hazard zone. It is stressed that only an appropriately qualified EOD technician should use these equations; various assumptions have to be made that are not applicable to all scenarios. These follow at Clause 7.

WARNING: **It must be understood by all involved in the estimation of explosion danger areas by calculation that these equations only predict the danger area "*outside which one would not normally expect more that one significant fragment to travel*".**

7. Multi-item demolition danger area estimation

7.1. General [6]

The multi-item demolition is the more likely contingency in the demining scenario. Where there are too many mines and munitions to destroy them individually *in situ*, and where the nature of the mines and munitions allow it, a centralised system of demolition will be used.

[5] The UK Health and Safety Executive generally accept that some form of ear damage can occur at 24.5 kPa; therefore it is recommended that this lower figure should be used. This will also give an additional margin of safety.

[6] These equations are based on work conducted by Mr Pilgrim, AWE Foulness, UK. Derivatives of these equations are used by the UK DERA in their trials work. This information was obtained from a UK MOD KGH/Safety Services Organisation paper on Danger Areas dated 31 July 1990.

The following equations have been derived from experimental results that have been compared with the "Gurney Equation" estimates as a means of validation. These ranges are those outside which only one fragment is expected to travel. A table of pre-calculated distances is at Annex C for ease of use. Remember that these ranges are to be used for those occasions when NO TAMPING or protective works are present.

7.2. Danger areas (public access)

It must be assumed that the local public will have access to most places outside sealed military camps. This means that the mine action management has a responsibility to ensure that the safety distances required to isolate the danger areas are strictly observed, and the rules for setting up demolitions contained in IMAS 10.30 are strictly adhered to, especially in the matters of warning the local villagers and of posting sentries to ensure no involuntary incursions my locals or their animals during demolitions. Where the ground makes observation by sentries difficult, the explosive weights of individual demolitions may have to be reduced to reflect the practical capabilities of the village authorities and sentries to keep locals, especially children, out of hazard range.

For danger areas where the public have access to the immediate area:

$$\mathbf{R = 634 \times (AUW)^{1/6}}$$

Where,

R = Range (m)

AUW [7] = All Up Weight of Demolition (kg)

7.2.1. Worked Example

This example is for 150 anti-vehicle mines with an All Up Weight of 10 Kg each. (This equates to an approximate explosive weight of 8 KG each):

$$R = 634 \times (AUW)^{1/6}$$

$$R = 634 \times 1500^{1/6}$$

$$R = 2145 \text{ m}$$

7.3. Danger areas (controlled access)

Controlled access can only be assumed if the mine action manager is convinced that there are no local people or animals in the area. If there is any doubt, the "public access" formula above should be used as a default solution.

For danger areas where it is certain that the public have NO access to the immediate area and only staff of the demining organisation are operating then:

$$\mathbf{R = 444 \times (AUW)^{1/6}}$$

Where,

R = Range (m)

AUW = All Up Weight of Demolition (kg)

7.3.1. Worked Example

This example is for 150 anti-vehicle mines with an All Up Weight of 10 Kg each. (This equates to an approximate explosive weight of 8 KG each):

[7] The All Up Weight (AUW) includes the Net Explosive Content (NEC) of the munitions, the weight of their casings and fuzing systems and the weight of the donor explosive charges.

$$R = 444 \times (AUW)^{1/6}$$

$$R = 444 \times 1500^{1/6}$$

$$R = 1502 \text{ m}$$

7.4. Condensed high explosive only

In practice, this kind of demolition will only be carried out if some stripping down of mines or munitions is undertaken, ie the removal of the explosive charge pellets from certain plastic or wood-cased anti-personnel mines, or the central charges from POMZ fragmentation mines. Some high-energy tank gun main armament separated charges should also be treated as high explosive.

For danger areas where no fragmentation hazard exists, the charge contains purely condensed high explosive, the distance at which no glass breakage can be expected can be estimated by:

$$\mathbf{R = 130 \times (NEC)^{1/3}}$$

Where,

R = Range (m)
NEC [8] = Net Explosive Content (kg)

This equation can be used as an alternative to the table at Annex B. It is based on experimentation rather than the *Kingary and Bulmash* methodology.

7.4.1. Worked Example

This example is for 150 plastic-bodied anti-vehicle mines (no major fragmentation hazard) with an All Up Weight of 10 Kg each. (This equates to an approximate explosive weight of 8 KG each):

$$R = 130 \times (NEC)^{1/3}$$

$$R = 130 \times 1200^{1/3}$$

$$R = 1381 \text{ m}$$

WARNING: **This is only a slightly smaller range than that for the metal-bodied anti-tank mines in a controlled access danger area. This illustrates one of the limitations of the equation, in that at 1000 metres and above, the two danger areas converge and the controlled access formula should be used.**

[8] The Net Explosive Content (NEC) of a munition or demolitions is the sum of the explosive contents of the munition (main charge, propellants, pyrotechnics etc).

WARNING: **High Explosive Anti-Tank (HEAT) Munitions. Typical examples area shoulder-launched anti-tank rockets, anti-tank missile warheads and even some sub-munitions and anti-tank mines. The shaped charge contained within HEAT munitions will produce a high velocity jet of molten material that can be expected to travel up to 1800 metres in free air. During demolition consideration MUST be given to jet formation and the direction of travel. The munitions should be pointed downwards, or otherwise appropriately positioned to negate the risk of jet formation in free air. If this is not possible, then a danger area of 1800 metres should be imposed at an arc of 45^0 around the direction in which the jet could be expected to form.**

7.5. Alternative methodology

The Australian Defence Science and Technology Organisation (DSTO) conducted research in March 1997[9] into multi-item demolition of ammunition and explosives. They concluded that fragmentation explosion danger areas for multi-item demolitions can be reduced to that of the largest NEQ single munition in the demolition provided:

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

b) the ordnance is detonated simultaneously; and

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

In this case the formula to be applied would be:

$$\mathbf{R = 370 \times (AUW)^{1/5}}$$

Where,

R = Range (m)

AUW = All Up Weight (kg)

For the above anti-tank mine examples (Paragraphs 7.2.1, 7.3.1 and 7.4.1) the danger area using this methodology and formula would be 1597m. This compares well with the controlled access danger area result.

8. Ground shock

Demolitions are normally carried out far from buildings, power lines or pipelines, or from installations containing delicate electronic gear. If circumstances dictate the demolitions of mines or munitions must be carried out near such facilities, ground shock needs to be taken into account.

The estimation of ground shock is a complex area, which requires extensive experimentation and modelling. It would clearly inappropriate to expect a demining organisation to do this work. However, purely as a guide, the equation used by the UK Defence Evaluation and Research Agency during demilitarization operations to predict the distance at which significant ground shock can be felt, and damage may be expected to structures, is:

$$\mathbf{R = 32 \times \sqrt{NEC}}$$

Where,

R = Range (m)

NEC = Net Explosive Content (kg)

[9] DSTO-TR-0505, Safety Distance Calculations for Multi-Item Fragmenting Munitions, *D A Jones and G Kemister*, March 1997.

8.1.1. Worked Example

Again, this example is for 150 anti-vehicle mines with an All Up Weight of 10 Kg each. (This equates to an approximate explosive weight of 8 KG each):

R = **32 x √NEC**

R = **32 x √1200**

R = 1109 m

9. Recommendations

9.1. National mine action authorities

It is the responsibility of the National Mine Action Authority to ensure that the managers of all local demining teams, NGOs or commercial companies are aware of the existence of this Technical Note, and make copies available of them.

9.2. Demining organisations

It is the responsibility of the management of local demining teams, NGOs or commercial companies to pay attention to this Technical Note, and incorporate the working table, formula and recommendations into SOPs where appropriate. It is also the responsibility of the manager of the demining organisation to make available the skills of a trained EOD staff member, either by recruitment or re-training.

In areas or programmes where no National Mine Action Authority exists, or the authority has not yet taken over full responsibility, it is their responsibility of demining managers to ensure that all demining teams, in their own and other organisations, are aware of the recommendations in this Technical Note.

9.3. Demining personnel

It is the responsibility of all field staff, whether deminers or EOD, to carry out any SOPs based on the recommendations in this Technical Note to the best of their ability, and to inform their management if compliance with the recommendations cannot be achieved.

Annex A
(Normative)
References

The following documents, when referred to in the text of this Technical Note, form part of the provisions of this guide.

a) IATG 01.80. Formulae for ammunition management;

b) IATG 02.10. Introduction to risk management processes and principles;

c) IMAS 04.10. Glossary of mine action terms;

d) IMAS 10.20. Demining worksite safety.

The latest version/edition of these references should be used. GICHD hold copies of all references used in this Technical Note. A register of the latest version/edition of the IMAS standards, guides and references is maintained by GICHD, and can be found on the IMAS website (www.mineactionstandards.org/). National mine action authorities, employers and other interested bodies and organisations should obtain copies before commencing mine action programmes.

The latest version/edition of the Technical Notes can be accessed via the GICHD website at www.gichd.org.

Annex B
(Informative)
Multi-item demolition danger area tables (blast)

The Danger Areas shown in this table have been pre-calculated for ease of use from *Kingerey and Bulmash* methodology. These distances should only be used for demolitions with NO fragmentation hazard. They estimate the distance at which hearing damage, from a blast overpressure (reflected pressure) of 24.5 KPa,[10] can be expected, and assume a hemispherical charge at ground level:

NEC[11] (KG)	RANGE (M)
(a)	(b)
10	15
100	33
500	56
1000	71
5000	121
10000	153
15000	174
20000	192

These figures show, that in terms of damage to human hearing, the blast effects of an explosive are not a significant factor. Common sense and prudence dictates that protection must also be gained from secondary fragmentation, (stones, rocks etc.), and therefore some form of direct line of sight cover must be used.

This formula ONLY calculates the effect of blast on hearing at range, and has been included for illustrative purposes. Common sense dictates that it is NOT a particularly sensible idea to detonate 20 tonnes of HE from 192 metres! This formula is only ONE of the three or four that must be used in all circumstances. The formula at Clause 7.4 indicates the safe distance for glass breakage; in the case of 20 tonnes of HE this is over 2 km!

Clearly explosions of this magnitude at these ranges will result in some form of damage to property. Therefore, it is **highly recommended**, that an Explosion Consequence Analysis is conducted by the EOD technician, or other trained field staff, before the danger areas in the above table are even considered for application to an EOD task. Their inclusion in this Technical Note is to inform EOD technicians, or other qualified field staff, of the consequences of blast damage to personnel.

[10] UK HSE recommendation for onset of hearing damage.

[11] NEC = Net Explosive Content.

Annex C
(Informative)
Multi-item demolition danger area tables (fragmentation)

The Danger Areas shown in this table have been pre-calculated for ease of use:

AUW Footnote 12 (KG)	$R = 634 \times (AUW)^{1/6}$ (Metres) Public Access	$R = 444 \times (AUW)^{1/6}$ (Metres) Controlled Access	$R = 130 \times (NEC)^{1/3}$ (Metres) No Fragmentation Hazard	REMARKS
(a)	(b)	(c)	(d)	(e)
1	634	444	130	
2	712	498	164	
3	761	533	187	
4	799	559	206	
5	829	581	222	
10	931	652	280	
20	1045	732	353	
30	1118	783	404	
40	1172	821	445	
50	1217	852	479	
60	1254	879	509	
70	1287	901	536	
80	1316	922	560	
90	1342	940	583	
100	1366	957	603	
150	1461	1023	691	
200	1533	1074	760	
250	1591	1114	819	
300	1640	1149	870	
350	1683	1179	916	
400	1721	1205	958	
450	1755	1229	996	
500	1786	1251	1032	
1000	2005	1404	1300	
2000	2250	1576		**Controlled Range and Bare Explosive Range converge at this point.**
3000	2408	1686		
4000	2526	1769		
5000	2622	1836		
10000	2943	2061		
20000	3303	2313		

[12] AUW = All Up Weight. The NEC (Net Explosive Content) has been used for the $R = 130 \times (NEC)^{1/3}$ column calculations, as this formula should be used for bare explosive or munitions with no fragmentation hazard.

Amendment record

Management of Technical Notes amendments

Technical Notes (TN) are subject to review on an 'as required' basis. As amendments are made to this Technical Note they will be given a number, and the date and general details of the amendment shown in the table below. The amendment will also be shown on the cover page of the Technical Note by the inclusion under the version date of the phrase *'incorporating amendment number(s) 1 etc.'*

As reviews of TN are made new versions may be issued. Amendments up to the date of the new version will be incorporated into the new version and the amendment record table cleared. Recording of amendments will then start again until a further version is produced.

The most recently amended TN will be the versions that are posted on the IMAS website at www.mineactionstandards.org.

Number	Date	Amendment Details
1	03 Jan 2013	1. Updated links and email addresses. 2. Inclusion of an IATG paragraph in introduction. 3. Removal of Annex B. 4. Reference to IMAS 04.10 for definition in clause 3. 5. Inclusion of reference to IATG 01.80 and 02.10 in Annex A. 6. Inclusion of amendment record. 7. Minor typographical amendments.
2	01 July 2013	1. Inclusion of amendment No, date in the title and header. 2. Updated links and email addresses.