MANUAL OF

NATO SAFETY PRINCIPLES

FOR THE

STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

Conditions of Release:

The NATO Manual of Safety Principles for the Storage of Military Ammunition and Explosives (AASTP-1) is a NATO Document involving NATO property rights.

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PART II

MAY 2006

CHAPTER 1 - INTRODUCTION

Section I - Preliminary

2.1.0.1. *Purpose and Scope of Part II*

This part of the Manual provides technical details to supplement the principles in Part I concerning aboveground storage in depots. This additional information includes design criteria, formulae and bibliography.

2.1.0.2. *Conditions of Release*

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2.1.0.3. *Inquiries*

Any questions or requirements for further information should be addressed to the Secretary of the AC/258 Group at NATO Headquarters, B-1110 Brussels, Belgium.

Section II – Notes on the Historical Background of the Manual

2.1.2.1.

The forerunner of this Manual was a document (AC/106-D5 dated 1st September 1963) drawn up by a Restricted Sub-Group AC/106 with members from France, Germany, the United Kingdom and the United States. These members met as specialists rather than as national representatives and made a study of the sustems in use in France, the United Kingdom and the United States. This included the national trials and recorded analuses of damage resulting from accidental explosions and war damage. It con be said that never before had such awide range of information on this subject been available to any single nation. In order to make the production of AC/106-D/5 at all practicable, it was essential that each of the members of the Restricted Sub-Group should agree to depart form some of the long established rules of his national system. This was sometimes found to be difficult but agreement was reached on the understanding that each country in authorizing the use of the system for NATO purposes within its territory would be free to exclude any practice on particular points where strong views were held. In reaching agreement on this basis the members hoped that in view of the wide range of information on which the document was based, new ideas would be accepted in te interests of NATO even if they were not in accordance with the normal national practice of the host country.

2.1.2.2.

The four specialists of the Restricted Sub-Group who drew up the original document were reconstituted in 1964 as the AC/74 Restricted Sub-Group of Experts on the Storage of Ammunition (STORAM) to supplement the document. This task included revision of the original document and completion of annexes on hazard calssification tests, storage on military airfields. Storage in ships and barges and underground storage. AC/106-D5(Revised) was issued in 1965.

2.1.2.3.

The work was in 1966 allocated to the „Group of Experts on Safety Aspects of Transportation and Storage of Military Ammunition and Explosives (AC/258)“. Under this Group a Strage Sub-Group with wider representation was set up which produced a further revision, published as document AC/258-D70 in December 1969. The principal changes were radical re-arrangement and clarification of the text and the addition of recommendations on storage near POL facilities and near radio-frequency transmitters.

2.1.2.4.

The quantity-distance tables were produced in a new format, using metric units only, in order to simplify the presentation. Certain corrections and rationalisations were intrduced in the tables and in the criteria for quantity-distances. Smaller intervals than hitherto were introduced in the values of explosives quantity to eliminate the need

for frequent interpolation and the consequent risk of mistakes. Values of quantity-distance were rounded off to give uniform precision of about 1 %. This eliminated cases of unduly large errors in the small distances in the original tables.

2.1.2.5.

The provisions for underground storage were completely re-written in the light of recent advances in this field of exploives technology. However, certain underground explisives starage criteria still remained to be formulated.

2.1.2.6.

The AC/258 Group had always hoped that the various national storage regulations would be harmonized on the basis of the principles in its own storage document (AC/258-D/70). Therefore in 1970 the Conference of National Armaments Directors (CNAD) on the recommendation of the Group formally invited nations to adopt the principles, in whole or in part, as the basis of their national regulations as a matter pf policy. Over the next few years member nations made declarations of intent or firm commitments. In many cases the timing of the change was linked to another innovation, the adoption of the International System of Classification of Explosives formulated by the United Nations Group of Experts on Explosives which dealt with the safety of both military and civil explosives during transport. The AC/258 Group adopted the UN system of compatibility groups as an amendment to the storage document in 1971. Evidently the ultimate degree of standardization could not be achieved until the Internation System of Classification as a whole was incorporated in the storage document. This involved replacing the NATO hazard classes by the divisions of the UN explosives class.

2.1.2.7.

Meanwhile interest in the storage document was growing as several nations outside NATO requested copies. The requests were usually granted by the appropriate authority. Member nations asked for additional topics related to storage to be included in the document or in supplements. Therefor an Editorial Sub-Group of AC/258 was set up in 1971 to promote consistent style and format in all the texts the Group adopted on these topics and to consider how best to publish the information.

2.1.2.8.

In 1974 the Group, nothing that the corrigenda which had been published (totally 14) had modified considerably the original text of AC/258-D/70, decided to publish a completely revised edition as a Manual in three parts: Part 1 dealing with general principles, Part II containing more detailed information on aboveground storage and on the historical background of the Manual, and Part III dealing with special types of storage.

2.1.2.9.

During the period of this major revision - where further two corrigenda were published to AC/258-D/70 – the Group participated in the design and assessment of field tests, both on scaled models and at full scale, to improve its criteria for quantity-distances. These tests resulted in more economical methods of storage in depots and more reliable assessment of the inherent risks of such storage. Members of the Group also participated in several international tests at a large scale to acquire better data on underground explosions. The conclusions and recommendations from all this experimental work were incorporated in the Manual.

2.1.2.10.

In 1981 during the work related to updating the chapter dealing with quantity-distance critaria for airfield, the Group found thad under certain circumstances it was not possible, without seriously prejudicing operational effectiveness, to apply the normal principles detailed in Part I of the Manual. As a consequence therefore, it was decided to publish a new part of the Manual – Part IV- where advice on safety principles under circumstances is ginven. At the same time it was decided that certain chapters (Field Storage, Missiles Installations and Basic Load Ammunition Holding Areas), which until then had been published in Parts II and III, rightly belonged to the contents of Part IV. Consequently they have been transferred to the new part of the Storage Manual. The safety principles which form the basis for the recommendatons are found in Part IV, Chapter 1.

2.1.2.11.

Almost the whole of Part I of the Manual was published in 1976 followed by certained chapters of Part II and Part III in 1977. In the period 1976 to 1982 new chapter and sections have been added and corrections have been made to Parts I to III. Part IV was in the main published in 1982. The „Group of Experts on Safety of Transportation and Storage of Military Ammunition and Explosives (AC/258)“ as custodian of theManual intends to maintain its value by publishing from time to time further chapters and requisite amendments to extend and update the guidance. It is even more important that the Group should maintain the reputation of its Storage Manual now that it is being used as the basis of national regulations as well as for its original purpose of giving guidance to NATO Infrastructure Staff.

CHAPTER 2 – RESERVED

CHAPTER 3 - ABOVEGROUND STORAGE

Section I - Special Storage Configurations

2.3.1.1. *Storage in Open Stacks/Buffered Storage*

a) Storage in Open stacks

The storage of shell in open stacks is described in paragraph 1.3.3.2. The special types of projectiles and the conditions for this type of storage are as follows:

1) The projectiles should be filled only with TNT or Amatol. RDX/TNT is unsuitable.

2) The projectiles should have walls generally similar to the 155 mm M107 and the 8 inch Howitzer projectiles as regards robustness and ability to withstand fragment attack. In particular, projectiles with thin noses (HESH or HEP) are unsuitable.

3) The projectiles should be unfuzed or should be fitted with nose plugs of a substantial design. The thickness of the plug must be at least 25 mm.

4) Each stack should be restricted to 6 800 kg NEQ and to 1 000 projectiles.

5) The projectiles in a stack should be arranged with axes parallel and noses in the same direction.

6) The separation of adjacent stacks of the maximum size should be 1.3 m between nearest parts (nose-plug rings or projectiles' bases). The separation of smaller stacks should be that indicated in Figure 3-I. Adjacent stacks may present the projectiles either nose-to-nose or base-to-base, but not nose-to-base nor vice versa.

7) At the ends of each stack the side-walls of projectiles will be exposed. These side-walls are relatively vulnerable to attack by fragments from another stack. Care must be taken to ensure that the arrangement of the stacks on a site (module) or in a building provides adequate protection against the risk of propagation by this means. One method is to ensure that all stacks are parallel and have the same dimensions, thus forming a rectangular arrangement. Another method is to use the walls of the storage building or the traverse to protect the ends of stacks. A third method is to observe the D9-distances in Part I, Annex A, Table 1 but such a large separation is rarely practical.

8) These stacks should be restricted to open sites (modules) with minimal weather protection or to aboveground buildings with walls and roofs of light construction. Exceptionally existing buildings with light roofs but solid walls may be used provided that these solidly constructed walls do not exceed 3 m in height. The stacking technique is based on US and UK tests in the open air and is not necessarily valid in an earth-covered building or an underground storage site which imposes a much greater confining effect.

9) An accidental explosion of one stack would scatter and disarrange the neighbouring stacks thus destroying the critical geometry upon which this stacking technique relies. To minimise any risk of subsequent fires which could cause the "cook-off" of one of these disarranged projectiles, and the resultant mass explosion of many other projectiles, softwood should be avoided in any pallets and dunnage. Combustible materials should be avoided as far as possible in the structure of a building used for such stacks.

10) The total NEQ on a storage site (module) or in a building should be restricted to 110 000 kg.

11) Each module or building should be surrounded by a barricade substantially of earth. This may be the double-slope type or the single-slope with one vertical wall type. The foot of the barricade should not be less than 2.4 m from the nearest stack. In establishing the height of the barricade the "2° rule" should be observed (see Section III).

12) Where adjoining modules or buildings are separated by a shared barricade, its thickness together with the distances from the stacks to that barricade are considered to provide adequate protection. Normal Inter-Magazine Distances do not apply.

13) The minimum Explosives Workshop Distance is 150 m in the case of barricaded workshops with protective roofs. Workshops without such protection should not be sited within the zone of severe debris risk, deemed to be the sectors lying within 30° on each side of those sides of the module or building which are parallel to the projectiles and extending to a distance of 600 m. Outside this zone, unprotected explosives workshops should be sited in accordance with Table 1 of Part I, Annex A.

14) A minimum Inhabited Building Distance and Public Traffic Route Distance of 600 m should be observed because of the severe risk from numerous whole projectiles likely to be projected from the upper tiers of stacks near an exploding stack. Such projectiles are not expected to explode

upon impact but present a serious debris hazard. This debris would be projected all at once and possibly without warning, unlike explosions involving ammunition of Hazard Division 1.2 where there usually is time for evacuation.

b) Buffered Storage

The storage of bombs using the buffered storage concept is briefly described in Part I, Paragraph 1.3.3.1. d). This concept can be used in all types of above-ground storage facilities. The special conditions for this type of storage are as follows:

1) The geometry of bomb and buffer stacks is critical and must be maintained at all times. (The buffer stack must preclude any direct line of sight between stacks of bombs.)

2) Vertical and horizontal offsets of rows and columns of containers in the buffer stacks are to be used to prevent alignments of the containers which would allow line of sight spaces through which fragments of a detonating bomb stack could pass unimpeded to the other stack of bombs in storage.

3) Bombs must be orientated nose to nose in those portions of the stacks which face each other. Metal nose and tail plugs must be used in all bombs.

4) In computing the maximum amount of explosives which could be involved in an accidental explosion in a bufferd storage arrangement, Hazard Division 1.4 munitions are not included in the total net explosives quantity.

5) The largest stocks of MK82/84 bombs authorized for buffered storage are

27 000 kg NEQ. Bomb stacks will be separated by a minimum of 11.6 metres.

6) When otherwise authorized, inert material or Division 1.4 munitions may be stored in the same structure or facility where buffered storage is in use.

Note: Use of buffered storage concept with MK82/84 bombs and the specific arrangement and types of buffer material is to be determined in the national area of responsibility. Inquiries regarding this concept and its implementation may be directed to the Secretary of AC/258.

Section II - Storage Buildings and their Construction

2.3.2.1. *Structural Materials*

a) Non-combustible materials must be used in the construction of buildings for storage of ammunition and explosives.

b) Buildings for the storage of bulk explosives relatively sensitive to spark or friction should not have any exposed iron, steel, aluminium or any aluminium alloy containing more than 1 % of magnesium where it may come into contact with explosive substances.

c) Buildings for the storage of ammunition with a toxic chemical hazard should be provided with a non-absorbing material on the floors and the walls to a height at least equal to the top of the stack. The building should have a barricade (see Section III). The building must be well ventilated.

2.3.2.2. *Protection of Igloos against Blast*

a) Performance Criteria

1) The primary objective is to prevent initiation of the contents. In order to qualify for the reduced Inter-Magazine Distances (see subparagraph 1.3.5.2.b)) an igloo at an ES must be designed to a 90 % confidence level that it does not collapse and its door(s)/door-freame does not fail although substantial plastic deformation of the arch or portal, the head-wall, the rear-wall, the side-wall, and the door(s) may occur. Deflection should be limited within the air gap around the contents so that the deformed structure and door(s) do not strike the contents. Major spalling into the igloo must be prevented. For spall with velocity exceeding 50 m/s the kinetic energy should not exceed 2 500 kg m^2/s^2; for spall with velocity not exceeding 50 m/s the momentum should not exceed 100 kg m/s. These values would not suffice for packaged primary explosive substances.

2) Ideally model or full-scale tests should be performed on a prototype structure or the design should be compared analytically with the strength of igloos which have been proof tested. In the case of model techniques, to assess structural response, it is important that models accurately scale the actual conditions with a linear scale of not less than 1 to 10. When reliance is completely placed on testing, then it is important that all structural elements (i.e. roof, front-wall, rear-wall and side-wall) are subjected to the anticipated blast loading. Igloos should be constructed in reinforced concrete or with corrugated steel arches.

b) Design Load for Head-Walls and Doors

Measurements on model and full-scale igloos indicate that design loads should be based upon the following values:

1) When igloos are constructed in parallel and subjected only to the risk from another igloo at the side-to-side Inter-Magazine Distance of 0.5 $Q^{1/3}$, the expected peak positive overpressure is 3 bar, the positive duration (ms) is 1.0 $Q^{1/3}$ and the positive impulse per unit area (bar ms) is 1.0 $Q^{1/3}$.

2) When the head-wall and door(s) of an igloo are exposed face-on to the blast from the rear-wall of another igloo at an Inter-Magazine Distance of 0.8 $Q^{1/3}$, the peak positive (reflected) overpressure is at least 7 bar, the positive duration (ms) is 1.0 $Q^{1/3}$ and the positive impulse per unit area (bar ms) is 2.0 $Q^{1/3}$. The value of 7 bar is suitable for the design of head-walls and doors at an ES when the donor is similar to one of the igloos described in Annex B, Section I and contains a NEQ not exceeding 75 000 kg. The actual value in a particular case is a complex function of the disposition and loading density of the explosives in relation to the magazine at the PES, the type and proportion of explosive substance in the ammunition, the mass and strength of the structure, and the mass and type of its earth-cover. It should be noted that close to the PES the blast wave is extremely complex and it is possible that a higher degree of loading on the head-wall or other structural elements may occur with a NEQ exceeding 75 000 kg. These factors may require consideration in the design.

3) Consideration of rebound conditions must be given in the design of the door(s). Attack on the steel-door(s) and the head-wall of an exposed igloo which is barri- caded or faces the earth-covered side of another igloo is not expected to be significant (hard rocks not exceeding 1 kg at 300 m/s).

c) Design Load for Roof and Earth-Covered Walls

1) The arch of a circular arch igloo should be statically designed to support the dead load pressure from the earth-cover by methods adapted from US highway design and should be compared with structures previously tested under blast loading. The rear-wall should be designed with reference to the dead load and, in addition, the anticipated dynamic loading in accordance with subparagraph 2) below.

2) An igloo which is not a true arch, such as a portal type or "flat arch" structure, should be designed for the likely blast loading on the earth-cover. Each structural element (roof, side-wall or rear-wall) may require consideration depending upon the type and orientation of the structure. Owing to the dearth of data on the loading beneath the earth-cover, it may be necessary to design for the anticipated worst case similar to the design loads for head-walls and doors, see subparagraph b) above. Design authorities should base their work upon applicable blast parameters from test references cited in Annexes A and B taking into account the maximum NEQ expected for the proposed facility and consulting at the earliest practicable date with national explosives safety authorities of the host and user nations.

d) Ventilation Openings

1) Igloo ventilation is commonly provided by an airtake opening below mid height in the front wall with an air outlet through the rear-wall above mid height into a vertical shaft to induce natural draught and take air out above the earth mound. These openings can be weak points in an igloo structure and consideration should be given to validating the design of openings by testing or other suitable means.

2) The design of openings should take account of potential ingress of direct blast, fireballs, primary and secondary fragments from a PES as well as the hazards from a slow burning fire. Some protection against physical entry or sabotage should also be incorporated.

2.3.2.3. *Protection against Projections*

a) Buildings should preferably be constructed in such a manner that they give protection against penetration by debris, comparatively low velocity fragments and lobbed ammunition. This may be obtained by a building with protective roof and 15 cm reinforced concrete walls without windows, or a building of equivalent construction. The windows of heavy-walled workshops must be effectively barricaded for the application of quantity-distances in the tables.

b) When earth-covered buildings with one relatively weak wall, designed to vent (see paragraph 2.3.2.4.) are exposed to the effects from an explosion or a fire in ammunition of Hazard Division 1.2 in neighbouring buildings or stacks, it is necessary that this relatively weak wall is constructed in accordance with the requirements of subparagraph a) to give protection against penetration by debris, comparatively low velocity fragments and lobbed ammunition. The door must also provide this equivalent protection for the application of the reduced Inter-Magazine Distances in Table 2 of Part I, Annex A.

2.3.2.4. *Pressure Release*

Buildings for ammunition or explosives involving a mass fire risk should be constructed with a relatively weak section to permit the release of internal pressure. In the case of an earth-covered building the roof or one end-wall or side-wall should be designed to permit this pressure release. An earth-covered building with a weak side-wall must not be sited with this wall facing a stack or a building unless the separation is large enough to prevent propagation of explosion by directional projection of burning propellants if the earth-covered building is used for ammunition of Hazard Division 1.3. This does not apply when the second building is also an earth-covered building whose weak side-wall is not exposed to this directional projection.

2.3.2.5. *Lightning Protection*

All permanent storage buildings and workshops for ammunition and explosives should be provided with lightning protection. The method of assessment of need for such protection and the details of suitable systems are given in Section IV.

2.3.2.6. *Rocket Storage Buildings*

Buildings utilised for the storage of rockets in a propulsive state (i.e. unpackaged rockets or missiles in the assembled condition) should be of sufficient strength to withstand their thrust. Alternatively the rockets should be provided with devices to secure them and thereby eliminate the additional hazard arising from the flight of the rocket (see paragraph 1.3.3.5.).

Section III - Barricades: Design Criteria

2.3.3.1. *Functions of Barricades*

a) General

The design criteria for a barricade depend on its location and the intended function.

b) Interception of High Velocity Projections

1) An effective barricade intercepts high velocity projections from a PES which otherwise may cause practically instantaneous propagation of explosion to ammunition and explosives at an ES; the barricade therefore has sufficient resistance to high velocity projections to reduce their speed to a tolerable level. The geometry of the barricade in relation to the PES and the ES is such that it intercepts the projections through a sufficient, solid angle. When the barricade is subject to destruction by blast from the PES, it is designed to remain substantially intact for a sufficient time to achieve its purpose.

2) An effective barricade reduces the number of high velocity projections which otherwise may endanger personnel and ES inside and outside the explosives area, but this is usually a secondary function.

c) Lobbed Ammunition and Fragments

An effective barricade also intercepts some lobbed items of ammunition and lobbed fragments but this is an incidental benefit. It is not usually practical to intercept items projected at a high elevation.

d) Modification of Blast and Flame

1) A barricade at a PES may induce directional effects of the blast and flame or it may merely perturb them. This is a secondary function of a barricade, unless it is especially designed to achieve one or more of these purposes.

2) A barricade between a PES and an ES may shield the ES from blast and flame. In order to have a marked shielding effect, the barricade is located close to the ES. The barricade may be part of the building-wall at the ES.

2.3.3.2. *Geometry of Earth Barricades*

a) General

Proper barricade geometry is necessary to reduce the risk that high velocity projections escape above or around the ends of the barricade and so produce an explosion in an adjacent site. Since such projections do not move along perfectly linear trajectories, reasonable margins in barricade height and length must be provided beyond the minimum dimensions which block lines of sight.

b) Height of Barricade

1) Line AB

(a) On level terrain point A is chosen as a reference on either of two stacks (see Figure 3-II). If the stacks have different heights, point A is on the lower stack. Point A is at the top of that face of the chosen stack which is remote from the other stack. If the stacks are covered by protective roofs, point A may be at the top of that face of the chosen stack which is nearer to the other stack (see Figure 3-II).

(b) On sloping terrain point A is on the stack whose top face is at the lower elevation (see Figure 3-III). Point A is at the top of that face of the chosen stack which is remote from the other stack. If the stacks are covered by protective roofs, point A may be at the top of that face of the chosen stack which is nearer to the other stack. Point B is on the top face of the other stack (see Figure 3-III).

(c) Line AB must pass through at least 2.4 m of barricade material or undisturbed natural earth between the two stacks, whether or not they are contiguous.

2) Line AC (2° Rule)

(a) Point A is chosen in accordance with subparagraph 1) above.

(b) On level or sloping terrain a second line (AC) is drawn at an angle of 2° above line AB.

(c) On level terrain, when stacks are separated by less than 5 $Q^{1/3}$ whether or not they are contiguous, line AC must pass through at least 1.0 m of barricade material or undisturbed natural earth.

(d) On sloping terrain when the stacks are contiguous line AC must pass through at least 1.0 m barricade material or undisturbed natural earth.

(e) On sloping terrain when two stacks are not contiguous but the quantity-distance between them is less than 5 $Q^{1/3}$, the 2° rule is not applicable.

3) Stacks separated by at least 5 $Q^{1/3}$

When stacks, contiguous or not, are separated by the quantity-distance 5 $Q^{1/3}$ or more, barricade requirements are assessed individually with respect to each stack.

c) Length of Barricade

The barricade length is determined by extending the barricade exclusive of the end slope to 1.0 m beyond lines between the extremes of the two stacks of ammunition under consideration. These lines must pass through at least 2.4 m of barricade material or undisturbed natural earth (see Figure 3-IV).

d) Distance from Stack to Barricade

1) The distance from a stack to the foot of a barricade is a compromise. Each case is considered individually to achieve the optimum solution taking account of the following factors.

2) A barricade close to a stack results in smaller dimensions for the barricade to intercept high velocity projections through a given solid angle. However, on sloping terrain the minimum separation may not result in the smallest barricade.

3) A barricade further away from the stack results in easier access for maintenance and for vehicles, and the possibility to site the barricade outside the predicted crater, when the PES contains ammunition and explosives of Hazard Division 1.1. Avoidance of the crater is an advantage in some circumstances, see subparagraph 2.3.3.3.c). The barricade must be sited so that the crater does not undermine it more than one third of its thickness at ground level.

2.3.3.3. *Material for Earth Barricades and for the Cover of Buildings*

a) Earth for barricades and for cover of buildings should be made of material as prescribed below. When concrete or brick is used in conjunction with earth, either of these materials may be taken as equivalent to 4 times its thickness of earth with regard to the ability to stop fragments. The concrete or brick may be used to support the earth or it may be those parts of the roof and walls of a building which intercept the high velocity projections.

b) There are two types of precaution which are necessary in the construction of earth barricades or the earth-cover for buildings used for storage of ammunition and explosives. One type relates to the potential hazards to other ammunition and to personnel in the event that the material is dispersed by an accidental explosion in the contained building. The other type relates to the precautions necessary to ensure structural integrity of the earth barricades or cover.

c) There is no need to consider the first type of precaution if it can be predicted that the material would not be dispersed by the postulated explosion. This will be the case if the barricade is sited beyond the crater radius. Scouring of the top surface by air blast can be neglected. The crater dimensions would be determined by the geometry of the stored explosives, their height above ground or depth of burial, and the nature of the ground. Unless the arrangement is particular asymmetrical, a good working estimate of the crater radius can be calculated from the formula:

$$\text{Crater radius (m)} = \tfrac{1}{2}\,(\text{NEQ (kg)})^{1/3}$$

This radius is measured from the centre of the explosives. In certain soil conditions (saturated soil or clay) the crater may be larger than calculated from the above formula (more complete information on cratering phenomenology is given in paragraphs 2.5.6.1. and 2.5.6.2.). In such conditions consideration should be given to increasing the Inter-Magazine Distances.

d) Where it is possible that the material would be dispersed by an explosion, precautions should be taken to reduce the hazard of large stones causing initiation by impact upon ammunition or explosives in adjacent storage sites. Where the storage site under consideration is near a densely occupied area, such as a group of explosives workshops, consideration should also be given to the hazard to personnel from flying stones etc. The selection of material and its use should be governed by the following prescriptions which represent a reasonable compromise between undue hazards and excessive costs of construction:

1. Do not deliberately use rubble from demolished buildings.

2. Ensure that stones larger than 0.3 m girth (about the size of a man's clenched fist) are removed during construction. Other deleterious matter should also be eliminated.

3. In climates where the ground becomes severely frozen, consideration should be given to the provision of an impermeable cover over the material or drainage to keep out excessive moisture.

e) The second type of precaution mentioned in subparagraph b) above, relating to structural integrity, applies in all cases. For this purpose the material should be reasonably cohesive and free from excessive amounts of trash and deleterious organic matter. Compaction and surface preparation should be provided as necessary to maintain structural integrity and avoid erosion. Where it is impossible to use a cohesive material, for example at a site in a sandy desert, the earth-works should be finished with either a layer of cohesive soil or an artificial skin. On the other hand one should avoid solid, wet clay during construction since this is too cohesive and would result in an excessive debris hazard.

2.3.3.4. *Walls as Barricades*

a) A building without windows and with walls with a thickness of 45 cm reinforced concrete (70 cm of brick) or its equivalent is acceptable as a barricaded building with regard to stopping fragments from an explosion in an adjacent building or stack. However, consideration must be given to the necessary blast resistance of such walls, see subparagraph 2.3.3.1.b)1). Furthermore account should be taken of the increased debris hazard from such walls at a PES. A 23 cm brick wall protected by a 45 cm brick wall is preferable to a single wall of about 70 cm brick. These buildings need not necessarily have a protective roof.

b) Walls can often be used to divide a building into individual rooms or compartments in accordance with subparagraph 1.3.2.2.b). The function of each dividing wall is to prevent, or at least delay substantially, transmission of explosion between explosives on opposite sides of the wall. the main advantage is that quantity-distances can then be based on the NEQ in one compartment instead of the aggregate amounts in the building. A second advantage is that an accidental explosion is less likely to render unserviceable all the stocks in the building. The specification of such a wall depends upon the quantity, proximity and type of ammunition or explosives on each side. The design must take into account the likely blast loading, including the effect of reflections, and the flame, ground shock, primary fragments and secondary missiles (spalling and scabbing from the remote face of the wall). In order to achieve an efficient and economical design for a particular situation, expert advice is essential. Information on the scope and state of the art of designing dividing walls is given in the technical manual "Structures to Resist the Effects of Accidental Explosions, US Army TM 5 -1300, June 1969" or a newer edition.

Section IV - Lightning Protection

2.3.4.1. *Definitions*

In addition to the definitions given in Part I, Chapter I, Section II the following definitions are used in connection with protection against lightning.

2.3.4.2. *Air Termination Network*

The part of a lightning protection system that is intended to intercept lightning discharges.

2.3.4.3. *Bond*

A conductor intended to provide electrical connection between the protective system and other metal work.

2.3.4.4. *Down Conductor*

A conductor which connects the air termination network with the earth termination network.

2.3.4.5. *Earth Termination Network*

The part of the lightning protection system which is intended to discharge lightning currents into the general mass of earth. All parts below the lowest test joint in a down conductor are included in this term.

2.3.4.6. *Joint*

The junction between portions of the lightning protection system.

2.3.4.7. *Ring Conductor*

The ring conductor is that part of the earth termination network which connects the earth electrodes to each other or to the down conductors.

2.3.4.8. *Test Joint*

A joint designed and situated to enable resistance or continuity measurements to be made.

2.3.4.9. *Zone of Protection*

The zone considered to be protected by a complete air termination network.

2.3.4.10. *General*

a) This chapter covers the particularities of lightning protection for ammunition handling installations and facilities. An effective lightning protection is part of the overall safety concept for the handling of ammunition and explosives.

b) Lightning protection systems are to be designed and constructed in a way which ensures an effective and long-term protection of the ammunition against lightning discharges. Lightning protection systems must be constructed by specialist personnel and according to the state-of-the-art of lightning protection technology.

c) As a matter of principle, installations and facilities used for handling ammunition must be equipped with lightning protection systems. Whether such systems can be omitted in individual cases is to be decided by the nations. The hazard of lightning discharges and possible consequences are to be assessed within the scope of a facility-related safety analysis.

d) A distinction must be made between "external" and "internal" lightning protection. External lightning protection forms the basis of an effective lightning protection consisting of

- air termination network,
- down conductors, and
- earth termination network.

For internal lightning protection a lightning protection equipotential bonding must be established between the lightning protection system of a building and the metallic installations and electrical systems of the building.

2.3.4.11. *Lightning Protection Systems for Buildings*

a) As a rule, buildings for the handling of ammunition and explosives (explosive workshops, magazines) are equipped with two external lightning protection systems, one lightning protection system which is insulated against the building and one lightning protection system for the building itself.
The insulated lightning protection system is designed to intercept high-current lightning discharges in order to keep them away from the lightning protection system of the building itself.

b) The lightning protection system for buildings designed for ammunition handling is to be arranged in such a way that an electroconductive cage is established. This cage must surround the building on all sides (ceiling, walls, ground). The design of the cage depends on the construction of the building.

2.3.4.12. *Insulated Lightning Protection System for Buildings*

a) As a rule, fixed air termination networks with a roof conductor in form of a mesh are applied in insulated lightning protection systems.

- The fixed air termination network is to be supported by supporting poles.
- The poles shall be positioned at least 3 m from the building.
- The mesh size must not exceed 10 m.
- Roof edges, projections, etc. shall be located at a maximum distance of 0.3 m from the network.
- Even if the network sags, the minimum distance from the roof of the building must be 1.5 m.

b) If vertical air termination networks are used, their height and zone of protection shall be such as to ensure that the entire surface of the building will be situated within this zone of protection (see Figure 3-V). The vertical air termination networks shall be positioned at least 3 m from the site. In case there should be a barricade, the vertical air termination networks may be mounted thereupon.
Instead of vertical air termination networks trees may be used and equipped with air termination networks if they are located in an appropriate position.

c) In buildings with a complete earth of at least 0.5 m, insulated lightning protection can be omitted; this applies also to earth covers with vent pipes.

2.3.4.13. *Lightning Protection Systems for Buildings*

a) Fixed air termination networks are to be arranged on the building with a mesh size not exceeding 10 m x 10 m. Parts of the building made of nonconductive material which protrude from the network are to be

equipped with suspended air termination networks and pointed conductors. Superstructures made of metal are to be bonded to the suspended air termination networks. The air termination networks of the lightning protection system of the building must be installed in the middle between the conductors of the insulated lightning protection system (top view). Each building must have one down conductor for 10 m each of the circumference of the building with four down conductors being the minimum number. Those down conductors should be positioned at least 0.5 m from windows, doors, and other openings. Aboveground pipelines leading up to the buildings are to be bonded to the down conductor next to them. In the case of reinforced concrete buildings which have connected reinforcing rods, these can be used as down conductors; these buildings only require air termination networks but not separate down conductors. Reinforced concrete buildings without connected reinforcing rods are to be equipped with air termination networks and down conductors. In any case the reinforcement is to be bonded to the internal ring conductor at intervals not exceeding 10 m.

b) For earth-covered buildings (e.g. igloo) with an earth-cover of at least 0.5 m a fixed air termination network having a mesh size not exceeding 10 m x 10 m and installed within or on the earth-cover is a sufficient lightning protection (see Figure 3-VI). For buildings with a lateral length of less than 10 m two conducturs in a diagonal arrangement are sufficient. Those conductors are to be bonded to a ring conductor. Metal venting systems which protrude from the earth-cover are to be equipped with down conductors which must be bonded to air termination networks or the ring conductor. Venting systems made of non-conductive material must be equipped with air termination networks and down conductors. In buildings made of reinforced concrete the connected reinforcement can be used as down conductor; it must be bonded to the ring conductor in at least two opposing locations. Suspended air termination networks are necessary here as well. Instead of a fixed air termination network, a space screen (e.g. as alternative upgrading measure) may be inserted into the building. The space screen consits of a network of band steel having a mesh size not exceeding 2 m x 4 m on which a fine grid (5 cm x 10 cm) is installed. The space screen must surround ceilings, walls, and columns; it is to be connected to the ring conductor.

2.3.4.14. *Earth Termination Networks*

Each lightning protection system must be grounded with an earth termination network. In most cases closed ring conductors or grounding circuits are used for that purpose.

- The total earth resistance of the earth termination network shall not exceed 10 Ω for buildings or groups of buildings.

- The earth termination network and the lightning protection system are to be appropriately connected.

- Earth termination networks of adjoining buildings within a radius of 20 m are to be connected underground.

- Ammunition and packagings containing ammunition are usually not grounded.

- Test joints are to be integrated into the lightning protection system between down conductor and earth termination network for test and measuring purposes. They are to be situated approximately 0.5 m above ground; below the test joint only parts of the earth termination network are permissible.

2.3.4.15. *Equipotential Bonding in Lightning Protection*

All essential conductive elements of a building such as machines, equipment, radiators, pipelines as well as large metal items (metal doors and windows, conductive floors) are to be bonded to the lightning protection system via lines.

2.3.4.16. *Lightning Protection Systems for Open-air Stacks of Ammunition*

a) Ammunition stacks endangered by lightning, especially those containing mass-detonating ammunition, are to be protected by a lightning protection system.
Ammunition stacks are particularly endangered by lightning discharge if they are situated.

- on mountain tops, hills,
- at the edges of woods, or
- under isolated trees.

b) In general, four horizontal aerial conductors of a rectangular shape (e.g. zinc-coated steel rope with a cross section of 50 mm2 mounted on insulated supports (e.g. made of wood) at least 0.5 m above the upper edges of the ammunition stack are sufficient to provide lightning protection. On each of the four corners one down conductor which is to be bonded to the ring conductor shall be installed at least 0.5 m from the stack. The ring conductor is to be buried at least 0.5 m below ground with a minimum lateral distance of 1 m round the perimeter of the stack (see Fig 3 - VII). If the stacks are positioned on floor plates the latter are to be connected with the ring conductor on the four corners of the stack.

c) For ammunition stacks established temporarily a makeshift lightning protection is sufficent which is arranged as follows:

A zinc-coated steel rope of at least 50 mm^2 in cross section or a copper rope of at least 35 mm^2 in cross section which is to be supported by 2 supports made of wood or metal is to be tensioned across the stack. Outside the supports the rope is to be secured in the ground with metal stays.

Additionally, each support has two stay wires with metal stays. The distance between the rope tensioned across the stack and the supports to the stack is to be 3 m; in case of deviations it must be ensured that the complete stack lies within the protected zone (see Fig 3 - V and 3 - VIII).

2.3.4.17. *Lightning Protection Systems for Ammunition Bins*

a) In ammunition bins made of concrete the reinforcement forms a conductive cage which is to be grounded using two earth electrodes (50 cm deep into the ground).

b) If ammunition bins made of wood are to be equipped with a lightning protection system, they must be provided with suitable suspended air termination networks and the conductive roof decks are to be included in the lightning protection system.

2.3.4.18. *Minimum Distances of Ammunition from Lightning Protection Systems*

Ammunition and packaging containing ammunition are to be stored so as to prevent flash over the lightning stroke from the lightning protection system to the ammunition or the packaging. Ammunition stacks in a magazin or an explosives workshop are to be positioned at a distance to walls, support, ceilings, beams, metal parts, and electrical installations which shall be:

- 10 cm at least if the lightning protection system is properly designed and meets the requirements of this chapter,

- 50 cm at least if the lightning protection system does not meet the requirements of this chapter.

2.3.4.19 *Testing of Lightning Protection Systems*

a) Each lightning protection system is to be tested upon completion. The result shall be recorded. The established values for the earth resistance are to be used as comparative values for future tests.

The proper condition of the lightning protection system is to be ensured by regular inspections and measurements.

Section V - Standard of Internal Lighting in Explosives Storage Buildings

2.3.5.1. *General*

In all explosives storage buildings there is a need to identify accurately stocks from markings and to carry out documentation. This requires a minimum standard of illumination.

2.3.5.2. *Minimum Standard*

Where fixed lighting is provided, the minimum acceptable standard for internal lighting in explosives storage buildings is 75 lux, measured at floor level.

Figure 3 - I Minimum Separation of Adjacent Stack of Certain Projectiles.

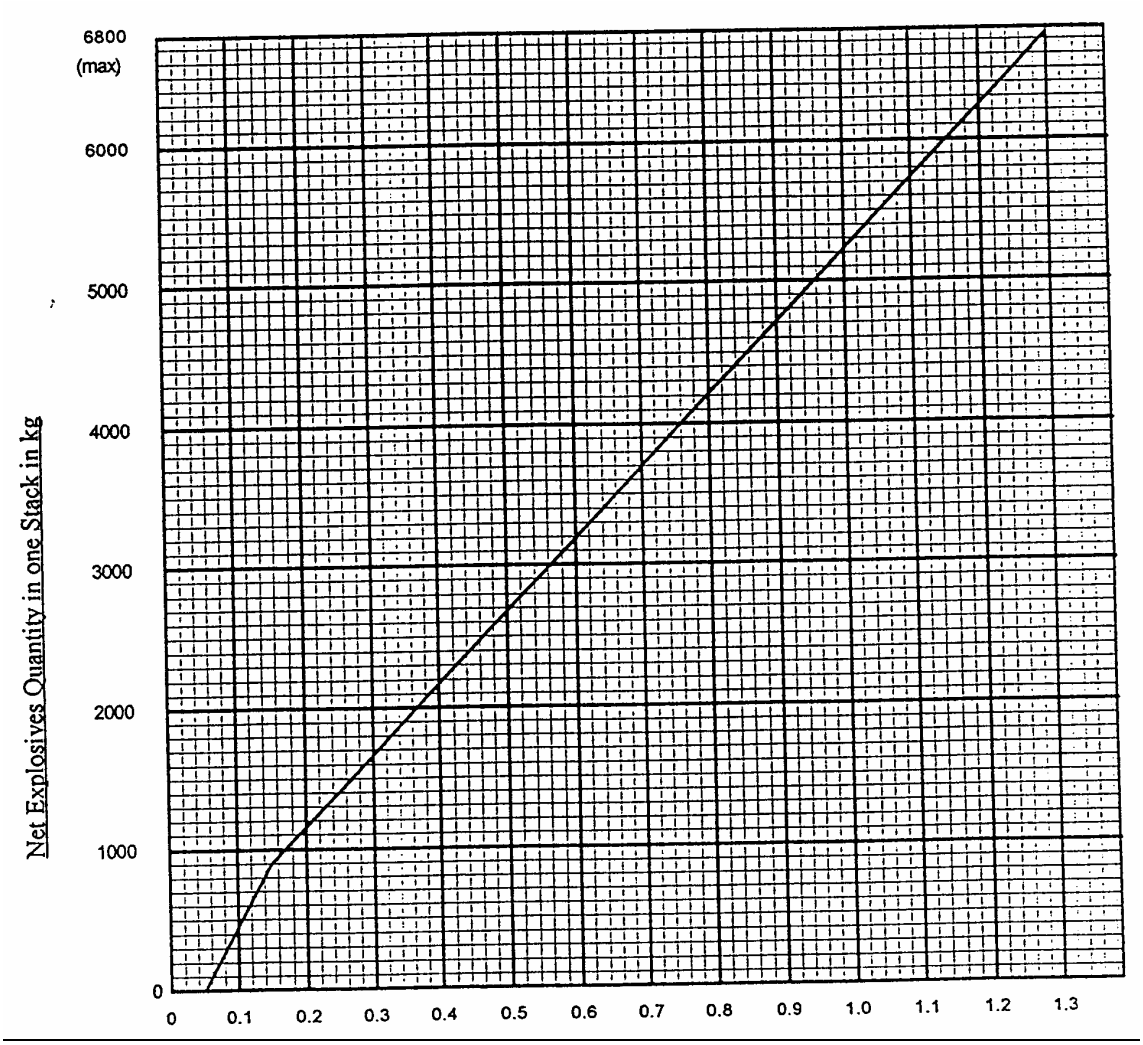


Figure 3 -II Determination of Barricade Height on Level Terrain

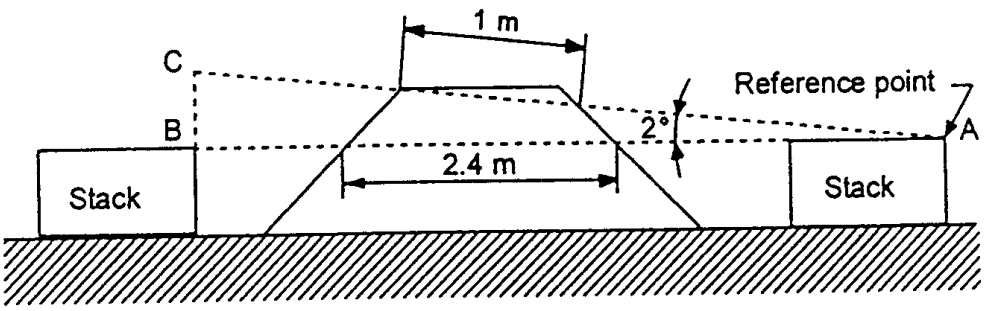


Figure 3 -III Determination of Barricade Height on Sloping Terrain

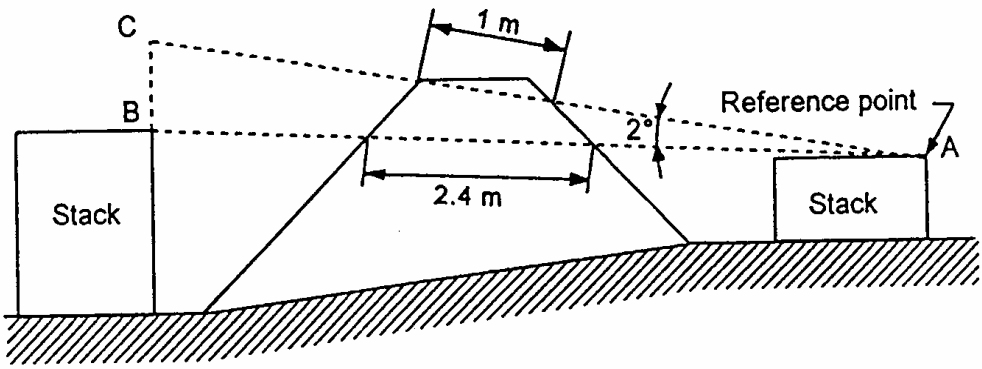


Figure 3 -IV Determination of Barricade Lenght

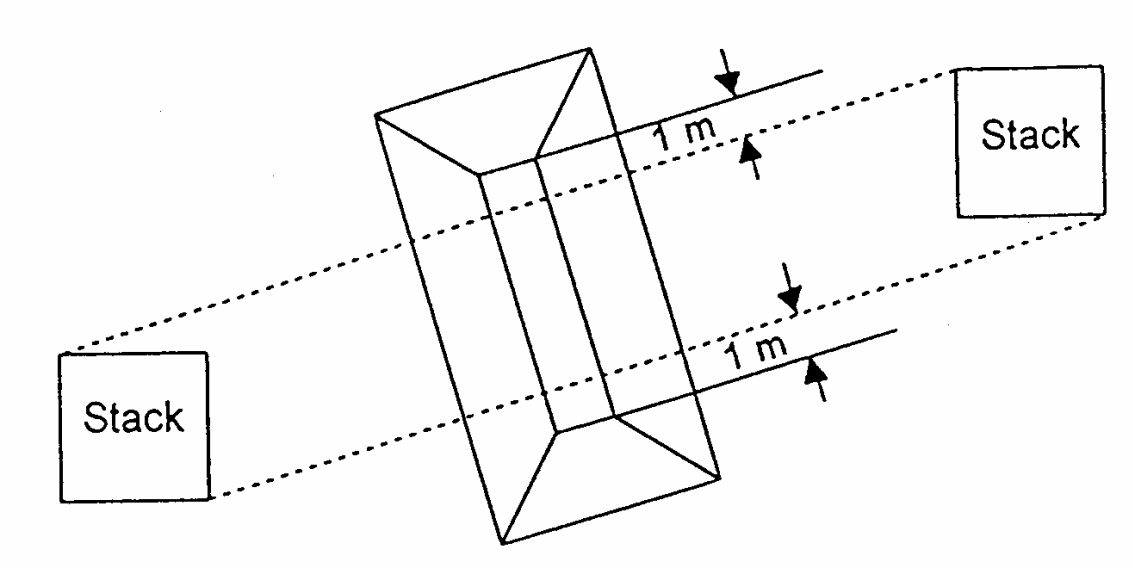


Figure 3 - V Zone of protection of a horizontal suspended air termination network (ridge network)

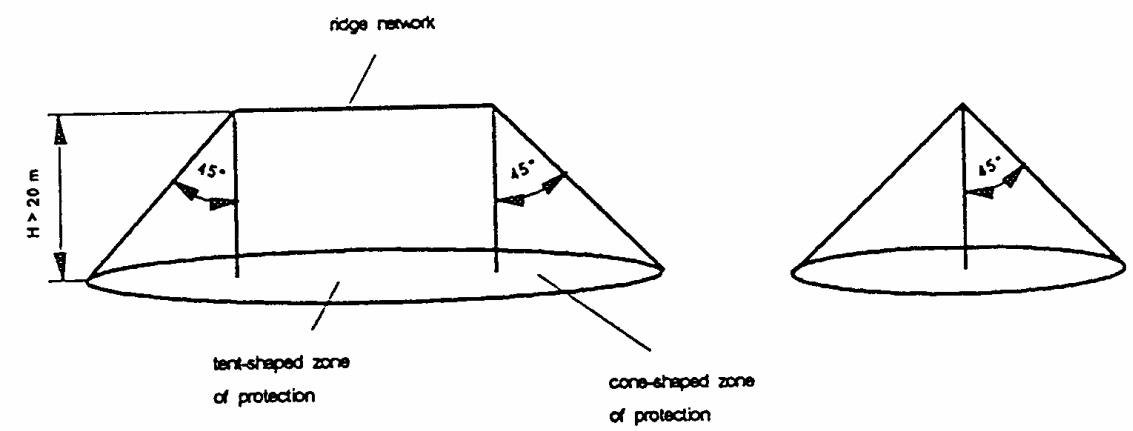


Figure 3 - VI

Schematic presentation of an earth-covered magazine with interconnecting reinforced steel

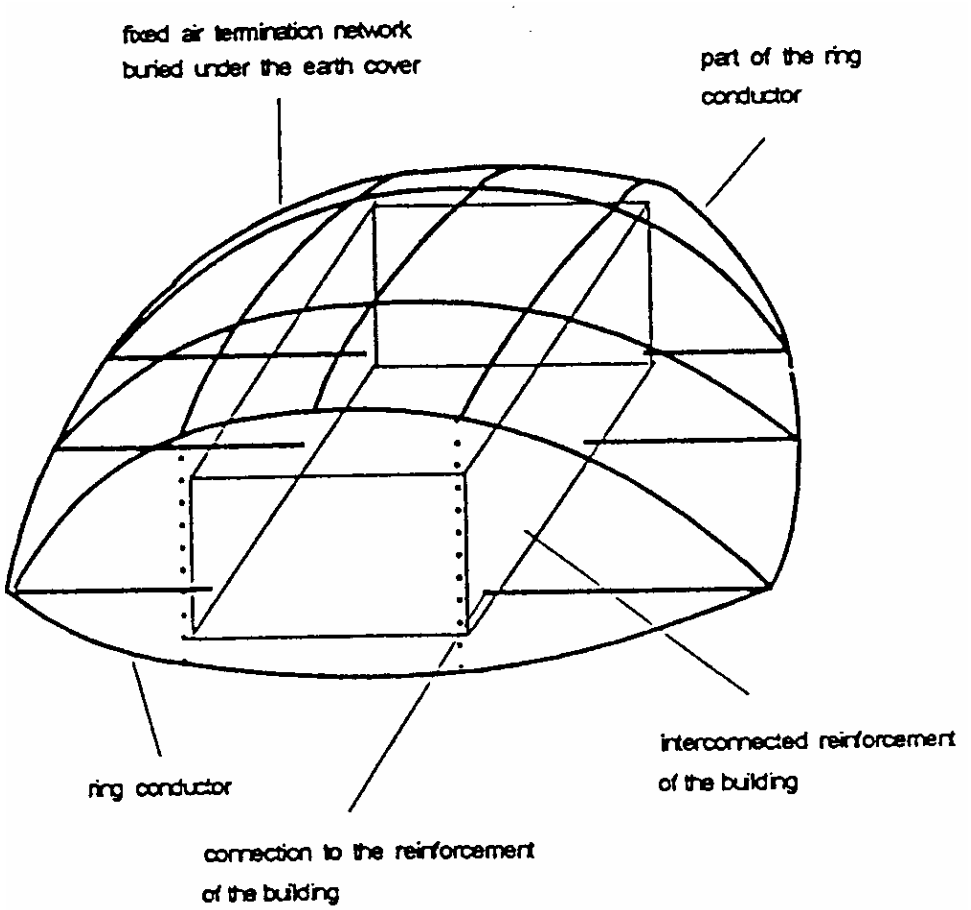


Figure 3 - VII

Lightning protection system for open stacks of ammunition

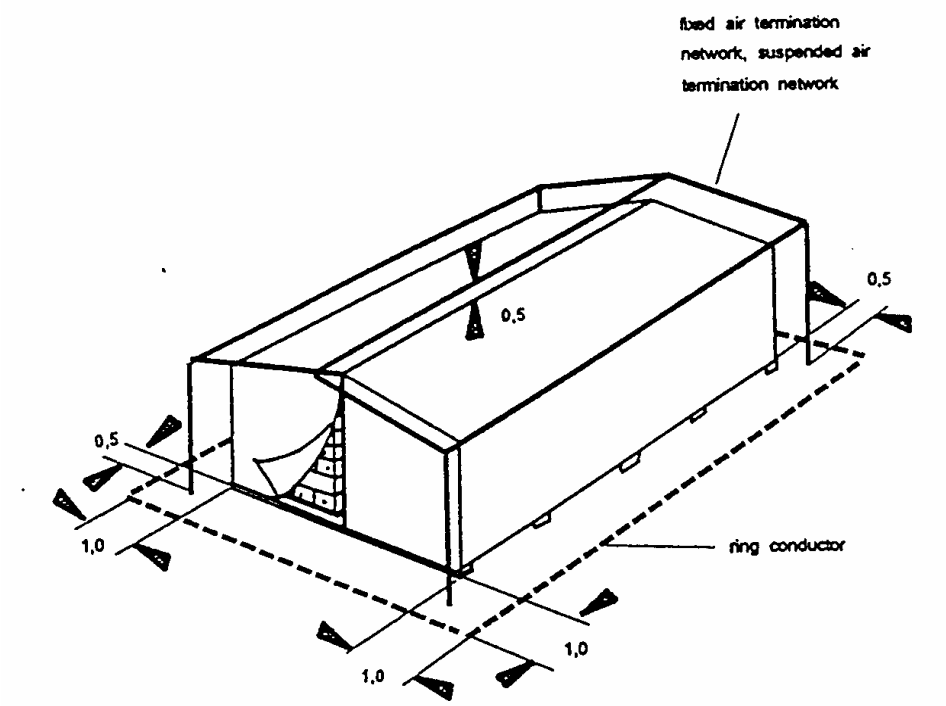
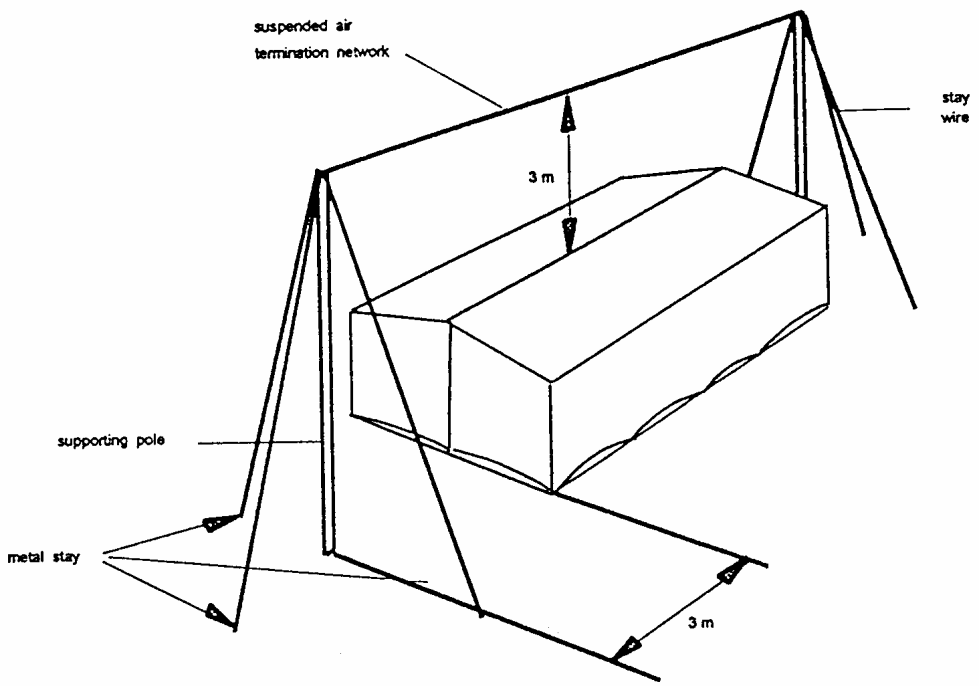


Figure 3 - VIII

Lightning protection system for open stacks of ammunition with an expected short-term deployment (up to one year)



CHAPTER 4 - FIRE-FIGHTING PROCEDURES

Section I - Symbols

2.4.1.1. Fire Division Symbols

a) Each of the four fire divisions is indicated by distinctive symbols (see Figure 4-I) in order to be recognized by fire-fighting personnel approaching a scene of fire. For the purpose of identifying these symbols from long range, the symbols differ in shape as follows:

Shape	Fire Division
Octagon	1
Cross	2
Inverted triangle	3
Diamond	4

b) The colour of all four symbols is orange in accordance with the colour on UN and IMO labels for Class 1 (Explosives).

c) The use of the specified fire division numbers is left to the discretion of National Authorities. When numbers are used they are painted in black.

d) The shape and size of the four division symbols are shown in Figure 4-I.

2.4.1.2. Supplementary Symbols

a) Toxic and pyrotechnic ammunition storage require supplementary symbols in addition to the fire division symbols. The supplementary symbols are used to indicate the precautions to be taken against the additional hazards proceeding from the chemical agents of that ammunition
(see Table 4-I). The supplementary symbols indicate the following precautions:

- wear full protective clothing,
- wear breathing apparatus,
- apply no water.

b) All three supplementary symbols are circular in shape. They correspond to the ISO Recommendations No. 408 (Safety Colours) and No. 457 (Safety Symbols) of the Technical Committee ISO/TC80. The supplementary symbols, their meanings and their sizes are shown in Figure 4-II.

c) The supplementary symbol prohibiting the use of water in fire-fighting (symbol No. 3 of Figure 4-II) may be placed together with one of the other supplementary symbols if required.

d) The supplementary symbol indicating the requirement to wear full protective clothing should also indicate the type of full protective clothing to be worn, as the different kinds of chemical agents demand different protective measures. The type of full protective clothing to be worn at a chemical ammunition storage site and the method by which this is indicated are the responsibility of the nation concerned.

e) The following sets of full protective clothing are recommended:

Set 1: Protective clothing against casualty agents, consisting of protective gas mask, impermeable suit, impermeable hood, impermeable boots, undergarments, coveralls, protective footwear and impermeable gloves.

Set 2: Protective clothing against harassing agents, consisting of protective mask, coveralls and protective gloves.

Set 3: Protective clothing against white phosphorus (WP) smoke, consisting of flameproof coveralls, flameproof gloves and chemical safety goggles.

The different sets of full protective clothing to be worn may be indicated by:

- a white number, corresponding to the set-no., on the blue background of the symbol, or
- a white rectangular plaque placed below the symbol listing in black letters the components of protective clothing to be worn.

f) The chemical agents mostly used in ammunition, the compatibility groups of that ammunition and the supplementary symbols required in storage are specified in Table 4-I.

Section II - Detailed Procedures

2.4.2.1. *General*

Fires of ammunition and explosives are fought according to their classification in fire divisions and the stage of fire.

2.4.2.2. *Fire Division 1*

a) A fire involving items of Fire Division 1 is fought during the developing stage with all available means and without awaiting specific instructions. If, in the developing stage, the fire cannot be controlled, the scene of fire is evacuated at once. In general, ammunition without its means of initiation and ignition can be exposed to a fire for several minutes before it explodes. Initiators, igniters, propelling charges, and rocket motors are extremely sensitive to fire.

b) A fully developed fire is not fought unless it is known:

- what types of ammunition or explosives are stored at the scene of fire;
- how long the ammunition or explosives may be exposed to a fire before they explode;
- how long the ammunition or explosives have been exposed to the fire.

c) If the fire-fighting forces cannot fight the fire, they must stay away from the scene of fire sufficiently to be protected from hazards. If possible, they should move to a protective site from behind which to fight the fires propagated in the vicinity of the original fire. If no adequate protective site is available, the fire-fighting forces should retreat from the scene of fire to a sufficiently remote site. A separation such as Explosives Workshop Distance is suitable.

d) After an explosion the fire-fighting forces may approach the scene of fire only if the ammunition or explosives have been completely destroyed by the explosion (mass explosion) so that only debris is left burning.

2.4.2.3. *Fire Division 2*

a) A fire involving items of Fire Division 2 is fought at once during the developing stage with all available means and without awaiting specific instructions. Fire Division 2 ammunition does not explode immediately after fire reaches it. Usually explosions from these fires can be expected only after the ammunition has been heated for an extended period of time (10 to 40 minutes).

b) If such a fire cannot be extinguished before the first explosions are to be expected, the scene of fire is abandoned and fire-fighting efforts are concentrated on preventing the spread of fire. The fire may be fought from a nearby protective site if protection from fragments and missiles is provided by that site.

c) A fully developed fire is not fought. The fire-fighting efforts are confined to protection of the vicinity. If no adequate protective site is available, the fire-fighting forces should retreat from the scene of fire to a sufficiently remote site. A separation such as the Explosives Workshop Distance is suitable. The fire-fighting equipment is kept operational at a protected location.

d) Such a scene, once evacuated, must not be entered again so long as the fire continues burning, not even for the purpose of defining the extent of fire.

2.4.2.4. *Fire Division 3*

a) A fire involving items of Fire Division 3 is fought at once during the developing stage with all available means and without awaiting specific instructions. If, in the developing stage, the fire cannot be controlled, the scene of fire is evacuated at once.

b) A fully developed fire is not fought from nearby because of the hazards of explosion and intense heat. If no adequate protective site is available, the fire-fighting forces should retreat from the scene of fire to a sufficiently remote site. A separation such as the Explosives Workshop Distance is suitable. Efforts are confined to fighting and containing propagated fires so as to prevent their spreading further. Whenever practicable, the fires should be fought from behind protective sites.

2.4.2.5. *Fire Division 4*

a) Fires involving items of Fire Division 4 are fought in all cases and with all available means.

b) After an extended period of time the ammunition may explode sporadically. For protection against fragments and missiles the fire-fighting forces should not approach the scene of fire any closer than 25 m. When possible the fire should be fought from a protected location.

2.4.2.6. *Ammunition requiring Supplementary Symbols*

Ammunition containing explosives and toxic or pyrotechnic agents (see Table 4-I) requires special attention and precautions in fire-fighting. Such ammunition belongs to different fire divisions depending on the kind and quantity of explosives contained in the ammunition. Such fires are fought in accordance with the fire division(s) involved taking into account the precautions indicated by the supplementary symbols. The issue of the corresponding special fire-fighting regulations is left to the discretion of the National Authorities.

2.4.2.7. *Fire-Fighting: Ammunition Containing Depleted Uranium*

Details are given in Chapter 8, Section VI.

TABLE 4-I

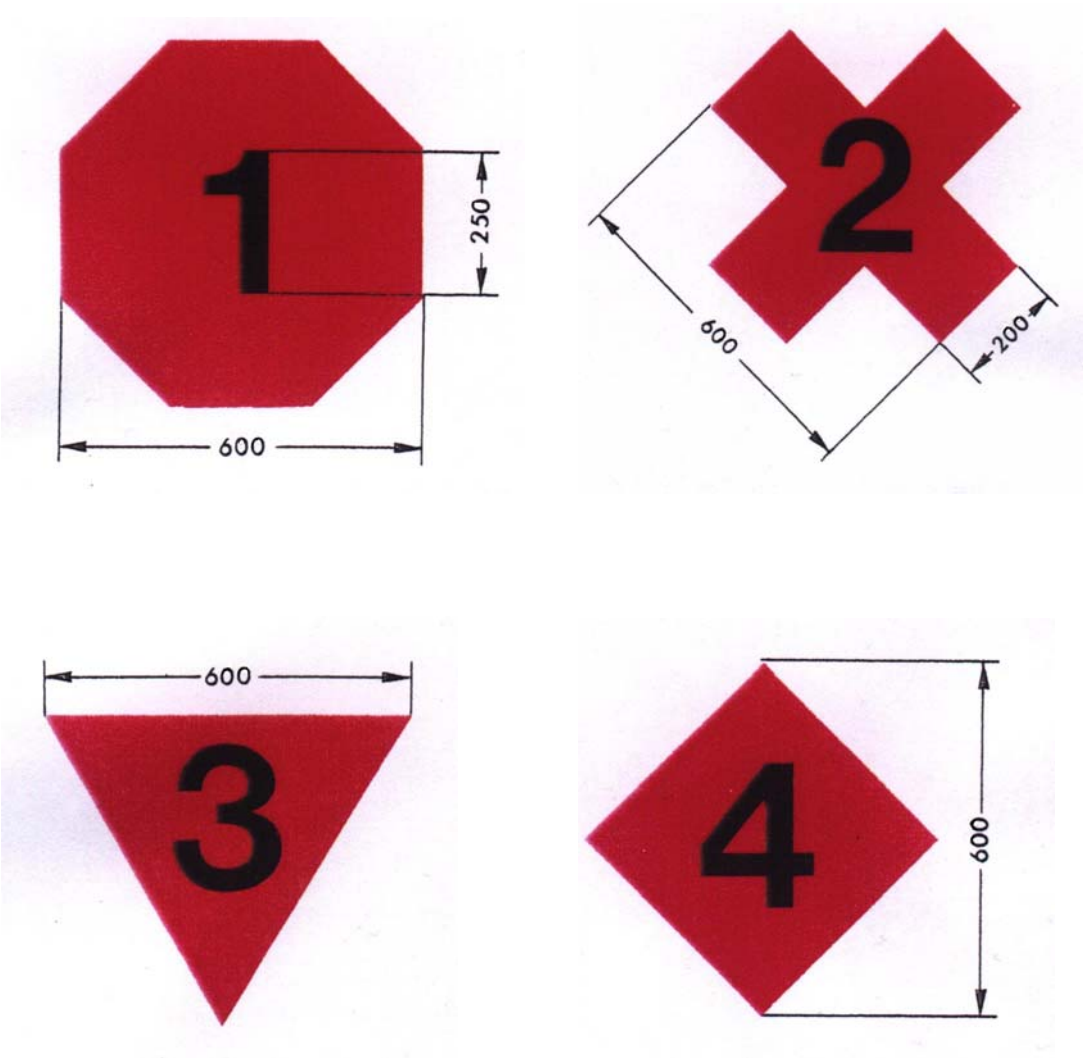
Chemical Agents contained in Ammunition and

the Supplementary Symbols required in Storage

Serial No.	Chemical Agents contained in Ammunition	Comp. Group	Supplementary Symbol				
			Wear Full Protective Clothing			Wear Breathing Apparatus	Apply no Water
			Set 1	Set 2	Set 3		
1	2	3	4	5	6	7	8
1	Casualty Agents (1)	K	X				
2	Tear Gas, O-Chlorobenzolmalononitrile (CS)	G		X			
3	Smoke, Titanium tetrachloride (FM)	G		X			
4	Smoke, Sulphur trioxide chlorosulphonic acid solution (FS)	G		X			
5	Smoke, Aluminium zinc oxide hexachloroethane (HC)	G		X			X
	White Phosphorus (WP)				X		
6	White Phosphorus plasticized (PWP)	H			X		
7	Thermite or Thermate (TH)	H				X	X
8	Pyrotechnic Material (PT)	G				X	X
9	Calcium Phosphide	G				X	X
10	Signalling smokes	L				X	
11	Isobutylmethacrylate with oil (IM)	G				X	
12	Napalm (NP)	J				X	
13		J					

(1) The storage of ammunition containing these agents is the responsibility of the authorized nations. Detailed statements of the agents concerned are beyond the scope of this table.

FIGURE 4-I FIRE DIVISION SYMBOLS
FIGURE 4-I SYMBOLES DE DIVISIONS D'INCENDIE

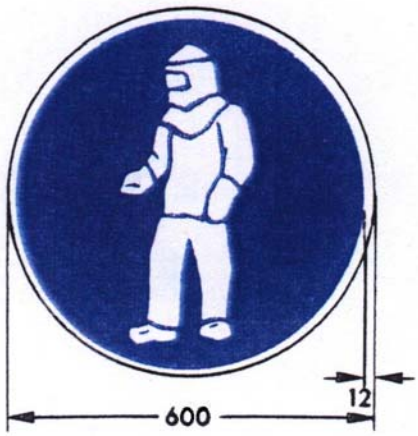


COLOUR OF SYMBOLS:
The background of all symbols is orange, the numbers are black.

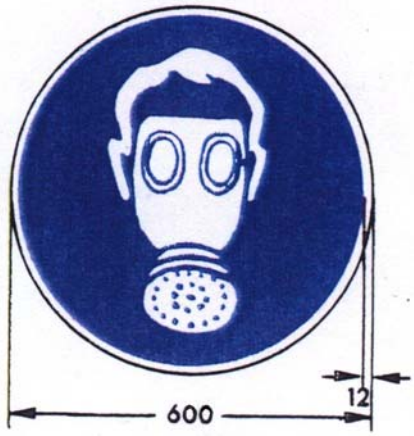
COULEUR DES SYMBOLES:
Le fond de tous ces symboles est de couleur orange, les numéros sont en noir.

FIGURE 4-II SUPPLEMENTARY SYMBOLS

FIGURE 4-II SYMBOLES SUPPLEMENTAIRES



1. Wear full protective clothing
   Port d'un éguipment complet
   de protection



2. Wear breathing apparatus
   Port dún masque respiratoire

COLOUR OF SYMBOLS:
The background of the symbols above is blue, the figures and the rim are white.

COULEUR DES SYMBOLES:
Le fond des symboles ci-dessus est bleu, les figures et la bordure sont blanches.

3. Apply no water – Défence dútiliser de léau

COLOUR OF SYMBOL:
The background of the symbol is white, the circle and the diagonal stripe are red, the figures are black.
(The colour specifications are those of ISO Recommendation No. 408 of the ISO Committee TC 80).

COLEUR DU SYMBOLE:
Le fond du symbole est blanc, le cercle et la bande diagonale sont rouges, les figures sont noires.
(Les spécifications de couleur sont celles de la recommandation ISO No. 408 du Comité ISO TC 80).

CHAPTER 5 - DESIGN ENVIRONMENT CRITERIA

Section I – List of Symbols

SYMBOL	DIMENSION	DESCRIPTION
A	(m^2)	Area
A_T	(m^2)	Area of target
$A_{(x)}$	(m^2)	Specifically defined area
A_f	(m^2)	Projected area of a projectile/fragment
A_D	(m^2)	Drag area
A_v	(g)	Maximum vertical acceleration (shock)
A_w	(m^2)	Area of wall
A_v , A_h	(m/s^2) . (g)	Maximum vertical/horizontal acceleration
a	(m/s^2)	Acceleration
a_o	(m/s)	Speed of sound
α	(^{o})	Angle
B, B_x	($\sqrt{kg/m^{7/6}}$)	Mott constant for explosives
b_f	(m)	Fragment width
β	(-)	Pressure drop constant in Friedländer function
C_D	(-)	Drag coefficient
C_E	(-)	Equivalent load factor
C_L	(-)	Confidence level
C_P	(m/s)	Seismic velocity in the ground
D	(m)	Distance
D	(m)	Blast wave position at maximum loading of structural element
D	(kg/m^3)	Density/caliber density
D	(N)	Attenuation force
DIF	(-)	Dynamic increase factor
DLF	(-)	Dynamic load factor
D_a, D_t	(m)	Depth of apparent/true crater
D_v, D_h	(m)	Maximum vertical/horizontal displacement
D/L	(-)	Blast wave position factor
DOB	(m)	Depth of burst
d	(s)	Duration
d_i	(m)	Mean inner diameter of ammunition case
E	(J)	Energy
E, E_c, E_m, E_s	(Pa)	Modula of elasticity for concrete, masonry, steel
E_{kin}	(J)	Kinetic energy
E_{cr}	(J)	Critical energy
ES	(-)	Exposed site
F	(N)	Force
F_D	(N)	Drag force
F	(Hz)	Frequency
f_r	(-)	Reflection factor
F1	(kg/m^3)	Ammunition storage building density factor
G	$\sqrt{(2 \cdot E)}$	Gurney constant
GOF		Terrain surface
g	(9.81 m/s^2)	Gravity acceleration

SYMBOL	DIMENSION	DESCRIPTION
H	(m)	Height
H_s	(m)	Height of building
H_w	(m)	(Height of wall
HOB		Height of burst
I	(Ns)	Shock impulse
I	(m^4)	Moment of inertia
I_s	(Pa-s)	Positive side-on impulse
I_r	(Pa-s)	Normally reflected positive impulse
I_q	(Pa-s)	Dynamic impulse
i_g	(Pa-s)	Gas impulse
i_s	(Pa-s/$kg^{1/3}$)	Scaled positive side-on impulse
i_r	(Pa-s/$kg^{1/3}$)	Scaled positive reflected impulse
k	(-)	Shape factor/ballistic density factor
L	(m)	Span of structural element under consideration
L	(m)	Length of flight path traveled after which the fragment trajectory velocity drops to the $(1/e)^{th}$ part of the fragment departure velocity
$L_\wedge$	(m/kg)	L related to the unity mass
L_H, L_L	(m)	Span in transverse/longitudinal direction
L_w	(m)	Blast wave length, positive phase
L_S	(m)	Width of structural element strip
L_w/L	(-)	Ratio between blast wave length and span of the structural element under consideration
l_d	(m)	Length of debris (average value of sphere and cube)
M	(kg)	Mass
M	(kg)	Static/dynamic system mass
M	(Nm)	Moment
M_A	(-)	Fragment distribution factor
M_e	(kg)	Effective mass
M_{ej}	(kg)	Crater ejecta mass
M_{ex}	(kg)	Explosive mass
M_c	(kg)	Total mass of ammunition case
M_d	(kg)	Design fragment mass
M_f	(kg)	Mass of the fragment under consideration
M_o	(kg)	Average fragment mass
M_p	(kg)	Projectile mass
M_{str}	(kg)	Mass of structure/structural component
M_t	(kg)	Total fragment mass
max	(-)	Maximum
min	(-)	Minimum
N	(-)	Geometrical constant
N_f	(-)	Number of fragments with masses higher than M_f
N_t	(-)	Total number of fragments
N_d	(-)	Number of fragments with masses higher than M_d
NEQ	(kg)	Net explosives quantity
NEQ_{TNT}	(kg)	Net explosives quantity; TNT equivalent
PES	(-)	Potential explosion site

SYMBOL	DIMENSION	DESCRIPTION
P_o	(Pa)	Peak overpressure
P_{so}	(Pa)	Peak side-on overpressure
P_s	(Pa)	Side-on overpressure
P_a	(Pa)	Atmospheric pressure; ambient pressure
$P_{a,s}$	(Pa)	Atmospheric pressure at standard sea level
P_r	(Pa)	Peak reflected overpressure
P	(Pa)	Pressure
$P_{(t)}$	(Pa)	Time-Dependent pressure
P_i	(Pa)	Pressure inside of building
P	(%)	Probability
Q, Q_{exp}	(kg)	Charge mass
Q_{TNT}	(kg)	Equivalent TNT charge mass
Q_o	(kg)	Reference charge, usually expressed at TNT equivalent
Q_o	(-)	Total number of fragments per unit solid angle emitted in target direction by ammunition item
Q_x	(kg)	Actual charge mass, usually expressed as TNT equivalent
q	(Pa)	Dynamic pressure
q_o	(Pa)	Peak dynamic overpressure
q	(kW/m^2)	Thermal radiation flux/radiation density
q_f	($1/m^2$)	Fragment density
R	(m)	Separation/radius/distance
R_a, R_t	(m)	Radius of apparent / true crater
R_e	(m)	Effective projection distance
R_f	(m)	Fragment distance
R_G	(m)	Ground distance
R_m	(N)	Maximum resistance of system
R_o	(m)	Reference distance from center of charge Q_o, for a defined overpressure or dynamic pressure
R_x	(m)	Distance from center of charge Q_x (kg) at which the explosion of the charge Q_x produces the same pressure as that caused by the reference explosion with the parameters R_o and Q_o
r	(Pa)	Unit resistance
rho	(kg/m^3)	Soil density
rho	(kg/m^3)	Air density
S	(-)	Position index/center of element strip
SGZ		Surface ground zero (point of burst)
T_{AG}	(s)	Arrival time of ground shock wave
T_o, t_o	(s)	Duration of positive air blast phase
t_{of}	(s)	Fictitious duration of positive airblast phase
T_a, ta	(s)	Arrival time of shock front
T_a	(^oC)	Ambient temperature
$T_{a,s}$	(^oC)	Ambient temperature at standard sea level
T_c, t_c	(s)	Clearing time of blast wave at target
T_o	(K)	Temperature
T_r, t_r	(s)	Time of load increase
t	(s)	Time

SYMBOL	DIMENSION	DESCRIPTION
t_w	(s)	Duration of loading
$t_{a,a}$	(s)	Arrival time of blast wave
$t_{a,s}$	(s)	Arrival time of direct ground shock wave
t_c	(m)	Mean thickness of ammunition case
t_c	(s)	Clearing time
t_s	(s)	Time at point of intersection between reflected pressure and combined side-on / drag pressure
t_r	(s)	Duration of reflected pressure
U	(m/s)	Shock front velocity
u	(m/s)	Particle velocity behind shock front
V_a, V_t	(m^3)	Volume of apparent/true crater
V	(m/s)	Velocity
V_{cr}	(m/s)	Critical velocity
V_f	(m/s)	Final velocity of projections
V_m	(m/s)	Mean impact velocity
V_o	(m/s)	Departure/initial velocity
V_r	(m/s)	Residual velocity
V_s, V_i	(m/s)	Impact velocity
V_v, V_h	(m/s)	Maximal vertical/horizontal velocity
W	(N)	Weight
W	(J)	Work
W_f	(N)	Fragment weight (mass)
W_s	(m)	Width of structure
X, x	(m)	Deformation
x	(-)	Position index
X_{el}, X_p	(m)	Elastic/plastic deformation
Y_{el}	(m)	Elastic deformation of system
Y_m, Y_p	(m)	Plastic deformation of system
Z	($m/kg^{1/3}$)	Scaled distance
Z_A	($m/kg^{1/3}$)	Scaled normal distance
Z_G	($m/kg^{1/3}$)	Scaled distance above ground

Section II - General

2.5.1.1 *Introduction*

This chapter deals with the effects of an accidental explosion or fire in an aboveground ammunition storage site on persons or surrounding buildings and other engineering works. The magnitude of the effects constitute the design environment criteria.

2.5.1.2 *General Principles*

a) Design Environment Criteria

The design environment criteria serve the purpose of …

- . . . preparing risk analyses;
- . . . designing and dimensioning ammunition storage facilities;
- . . . defining quantity distances;
- . . . determining hazard parameters in terms of quality and quantity;

Note:

The quantity distances are based on design environment criteria, threat spectrum as well as performance and safety requirements.

- . . . verifying design drawings and detail specifications for facilities of a particular site in order to assure compliance with the safety regulations;
- . . . modifying buildings originally constructed for other purposes to ammunition storage buildings and explosives workshops;
- . . . planning damage control, fire-fighting and rescue operations.

b) Basic Data

There is further basic research to be done in order to complete the technological basis required for exploiting all conceivable uses of explosives and ammunition storage buildings. The technological developments with respect to ammunition types, building materials as well as design and dimensioning make it necessary to constantly improve the relevant data and knowledge base. For the economical handling of the problem fields, special data banks with constant updating are required. Carefully prepared scaled model and full-scale tests will provide these data, constitute the basis for realistic risk analyses and help saving costs.

2.5.1.3 General Design Aspects

a) Design Principles

To ensure compliance with the safety requirements for exposed sites, the design methods applied must be selected according to the following basic conditions.

(1) No Design Environment Criteria Available (Standardized Construction)

When no design environment and performance criteria are given, the building shall conform to a standard construction which, in former explosion events, has proved to be satisfactory for a given **N**et **E**xplosives **Q**uantity (**NEQ**) at a specific distance or has been proof-tested, preferably in full-scale tests.

With this approach, additional design calculations are not required, and deviations from applicable construction specifications and quantity distance requirements are not permitted since the consequences are not predictable.

Note:
This method is inflexible and does no longer constitute a state-of-the-art approach.

(2) Limited Design Environment Criteria Available

In case only a few quantity distance values are available as design environment criteria, design and construction will be based on analytical calculations supported by model or full-scale tests. The construction may be safely used over the full range proved by the calculations. Appropriate consideration of design criteria (e.g. specified quantity distance) provided, modifications to the original construction are permissible since consequences of such modifications can be predicted to a large extent.

Note:
This method constitutes a compromise between empirical and analytical approaches.

(3) Complete Design Environment Criteria Available

When design environment criteria are available as continuous functions of net explosives quantity and distance from the **P**otential **E**xplosion **S**ite (**PES**), there is complete freedom to choose both the distance and the type of construction in order to obtain the most economical solution. Design and construction are based on analytical calculations supported by model or full-scale tests. The construction may be used over the full range proved by the calculations. Modifications may be made provided the design environment criteria are taken into account.

Note:
This is the ideal case giving complete freedom with respect to design and modifications.

When seeking the optimum combination of construction type, required quantity distance, and degree of protection, the following parameters shall be taken into account:

- Availability of land for building purposes;
- Costs of land;
- Construction costs;
- Value of ammunition and explosives stored in the **E**xposed **S**ite (**ES**) which would become unserviceable in case of an explosion in the potential explosion site.

For ammunition storage facilities exceeding the minimum strength and blast resistance requirements the quantity distances may be reduced provided qualified evidence has been furnished.

When designing a building for the storage of ammunition, in almost all cases the donor/acceptor conflict has to be solved.

- A building with donor function should be of lightweight in order to minimize the size and mass of projections.

- A building with acceptor function must have a relatively high strength in order to avoid sympathetic detonation due to airblast, projections, shock or collapse of buildings

b) Degrees of Protection

As it is uneconomical to use a building for only one hazard division, it is common practice to store ammunition of different hazard divisions in one storage facility.

The degrees of protection define the expected or required extent of protection against the effects of an accidental explosion for each hazard division.

The degrees of protection are distinguished as follows . . . .

Degrees of Protection	Hazard Division	Protection Criteria Remarks
Virtually Complete Protection	**1.1**	**- Against: Practically instantaneous propagation of explosion by ground shock, blast, flame and high velocity projections.** **- Result:** **- Immediate sympathetic detonation not to be expected.** **- Stored items largely remain serviceable.** **- Individual evaluation required for sensitive stored items.**
	1.2	**- Against: Immediate or subsequent fires and explosion caused by blast, flame, firebrands protections and lobbed ammunition.** **- Result:** **- Immediate or delayed sympathetic detonation not to be expected.** **- Stored items probably remain serviceable.**
	1.3	**- Against: Immediate or subsequent fires among the contents of an ES by flame, radiant heat, firebrands, projections and lobbed ammunition.** **- Result:** **- Immediate or delayed burning, deflagration or explosion of stored items not to be expected.** **- Inflammation of burnable external parts of the building.** **- No propagation of fire to stored items.**

Degrees of Protection	Hazard Division	Protection Criteria Remarks
High Degree of Protection	**1.1**	**- Against: Practically instantaneous propagation of explosion by ground shock, blast, flame and high velocity projections.** **- Result:** **- High protection against immediate sympathetic detonation.** **- Delayed fire and sympathetic detonation to be expected.** **- Bulk of stored items probably remains serviceable.**
	1.2	**- Against: Immediate propagation of explosion by blast, flame and projections.** **- Result:** **- High protection against immediate sympathetic detonation.** **- Delayed fire and sympathetic detonation to be expected.** **- Loss of stored items depends on effectiveness of fire fighting.**
	1.3	**- Against: Immediate propagation of fire to the contents of as ES by flame, radiant heat, firebrands, projections and lobbed ammunition.** **- Result:** **- Delayed burning, deflagration or explosion of stored items cannot be excluded.** **- Inflammation of burnable internal and external parts of the building.** **- Stored items may catch fire.**

Degrees of Protection	Hazard Division	Protection Criteria Remarks
Limited Degree of Protection	**1.1**	**- Against: Practically instantaneous propagation of explosion by ground shock, flame and high velocity projections.** **- Result: - Immediate sympathetic detonation to be expected.** **- Stored items severely damaged and unserviceable.**
	1.2	**- Against: Immediate or subsequent fires among the contents of an ES by flame, radiant heat, firebrands, projections and lobbed ammunition.** **- Result: - Limited protection against immediate sympathetic detonation.** **- Fire and sympathetic detonation to be expected.** **- Loss of stored items in case of ineffective fire fighting.**

Due to the high costs involved, virtually complete protection will only be reasonable, if the net explosives quantity is small or if the total quantity of the items stored inside the building is divided by walls into smaller portions thus avoiding immediate sympathetic detonation.

c) Protection Against Sympathetic Detonation

Ammunition storage buildings shall be designed in such a way as to reliably prevent sympathetic detonation of stored explosives.

Thus, the primary design objective must be to prevent destruction or collapse of the building.

Plastic deformation of structural parts shall be acceptable as long as the stability of the building is not impaired. Deformation, however, shall be less than the separation distance between the deformed part and the stored items so that no shock propagation is possible.

Proper design of the exposed site and adequate quantity distance from the potential explosion site are essential factors to prevent immediate sympathetic detonation which may be initiated by high-energy projections, spalling, torn-off structural parts (e.g. pillars, doors etc.), or by the collapse of the building.

Degree of hazard, type of stored items, design, and environment of the ammunition storage facility are critical parameters for the evaluation of the sympathetic detonation load case.

It is impossible to specify quantity distances which provide complete safety from sympathetic detonation, damage or injury. Economical and internal operational reasons may temporarily justify a calculated risk to personnel and material. It also may be necessary under certain circumstances to deviate from regulations due to tactical requirements. Design measures should be taken to prevent spalling inside the building. This applies primarily to buildings which are not earth-covered. Tests have demonstrated that spalling velocities are usually overestimated except when caused by contact detonations. Dangerous spalling effects are not to be expected with earth-covered buildings.

Lobbed ammunition may explode upon impact. The explosion of ammunition with a caliber of more than 155 mm impacting close to the wall or on the roof of an exposed storage building may cause a sympathetic detonation.

Ammunition storage buildings shall provide full protection against projections of any kind, such as fragments, structural debris, lobbed ammunition and spalling. The limits for spalling, below which no firing of packaged initiating devices will be caused, are specified in AASTP-1, 2.3.3.2.
According to this paragraph, for the different spalling velocities the following criteria shall apply
(-->> Table [5.27]) . . .

For velocities ≥ 50 m/s the kinetic energy shall be $E_{kin} \leq 2500$ Js	
For velocities ≤ 50 m/s the impulse	**shall be I ≤ 100 Ns**

Penetration by projections shall only be acceptable if the residual velocity (V_r) of the penetrating projectile is below the critical velocity (V_{cr}) at which sympathetic detonation is induced.

For $V_r \leq 50$ m/s	V_{cr}	=	$100 / M_p$	(m/s)
For $V_r \geq 50$ m/s	V_{cr}	=	$\sqrt{(5000/M_p)}$	(m/s)

d) Loads / Design Loads

As a rule, ammunition storage buildings should be individually designed according to local design environment criteria. Existing design formulations and data will allow the sufficiently safe determination of the various loads to be expected.

An accidental explosion or fire in an aboveground ammunition storage site constitutes a hazard to personnel, buildings, facilities, and other material due to airblast, fragments, structural debris, shock and thermal radiation. These effects, which occur almost simultaneously, define the design environment criteria for planning and designing ammunition storage buildings. The design loads for an exposed building or structural part of a building are functions of these effects as well as of geometrical and material conditions at the exposed site.

(1) Rebound of Closure Components

An airblast acting on closures, such as doors and gates, will produce extreme rebound loads on the latches and hinges. In order to ensure security of building closures, the ability of the construction to withstand these rebound loads must be mathematically proven.
The parameters of a blast wave due to an accidental explosion depend upon the complex conditions at the explosion site.
These include:

- Distribution of explosives at the storage site;
- Loading density;
- Types of explosives;
- Explosives content of the stored ammunition;
- Mass and type of earth cover and building;
- Constructional stability of the building.

e) Design Details

(1) Aboveground Ammunition Storage Buildings

For a storage site with earth-covered or detached uncovered aboveground ammunition storage facilities (e.g. igloos), the most straightforward and safe quantity distances will result if the storage area has a rectangular shape, the axes of the ammunition storage buildings are parallel to each other, and all doors face in the same direction.

An arrangement with the front walls of the buildings facing each other should be avoided for economical (area required) and safety reasons.

Due to its type of design, an earth-covered ammunition storage building (igloo type) will effectively withstand external effects such as airblast, fragments, and exploding lobbed ammunition, provide protection of the stored items and prevent sympathetic detonation.

(2) Ammunition Stacks

Exploding ammunition stacks in the open or inside storage buildings may produce highly effective projections, such as fragments, structural debris, and lobbed ammunition, which may penetrate into a storage facility and immediately ignite the stored explosives and ammunition. Ceilings, doors, and closures must be designed in such a way as to intercept projections of any kind or reduce their velocity to a safe residual value. As an additional safety measure, barricades may be retrofitted, which, however, will provide no protection against projections from above.
(-->> AASTP-1, 1.4.6.1. to 1.4.6.10.)

(3) Walls

The minimum thickness required for wall and ceiling slabs affording adequate protection against fragments, structural debris, detonating lobbed ammunition and firebrand, will depend upon the type of the stored ammunition.
Table [5-1] contains reference values for various construction materials related to selected ammunition types.
(-->> Ref [1], [2])

(4) Roofs and Ceilings

Roofs and ceilings may be designed such as to perform the following functions:

- Contain fragments and prevent emission of projections.
- Provide shielding against airblast, projections, and lobbed ammunition.

(5) Pressure Relief Walls

An explosion in an asymmetrical ammunition storage building with a weak wall or roof (frangible cover) will produce directed effects (airblast, flames, projections).

Pressure relief walls (frangible covers) as well as doors and other closures shall be designed fragment-proof and debris-proof. With standard earth covers, there will be no problems except in case of a contact hit.

In case of not earth-covered ammunition storage buildings, the conflict between pressure relief and fragment resistance requirements has to be solved. These requirements lead to contrary design solutions. An approach to this problem is the erection of barricades to shield the pressure relief component against fragments and debris.
(-->> AASTP-1, 2.3.2 and 2.3.3)

(6) External Walls

Experience has shown that for not earth-covered buildings two-leaf external walls provide a high degree of protection against airblast, fragments and debris. The outer leaf which is considerably thinner must be separated from the inner main leaf by an air gap of approximately **0.10 m**. The outer leaf, which serves to absorb the airblast, should consist of lightly reinforced concrete or masonry with a thickness of at least **0.10 m**.
(-->> AASTP-1, 2.3.3.)

(7) Internal Walls and Dividing Walls

Structures required to contain fragments, debris and lobbed ammunition necessitate a more sophisticated design than dividing walls to prevent sympathetic detonation. A double-leaf construction should always be taken into consideration.

(8) Doors and Gates

Doors and gates constitute weak points in terms of safety. As they have to be relatively large and must be movable in addition, their design tends to become very complex to ensure adequate resistance to explosion effects.

Doors and gates should be single-piece structures.

If a door is not part of a so-designed structural weak wall (frangible cover), it shall resist the airblast to be expected and be fragment-proof and debris-proof.

The following essential criteria shall be considered for the design of doors . . .

- Dynamic design with respect to airblast loading;
- Assessment of rebound loads and appropriate design of door hinges and latches;
- Proof of resistance to fragments;
- Proof of resistance to high impulse loads due to impact of debris;
- Ease of use.

(9) Barricades

Barricades are structures suitable to intercept directed projections and to a limited extent to constrain the effects of airblast and flames.

Above all, barricades reduce the effects of fragments and other projections ejected out of openings.

Note:
- Efficiency of protection and employment range of barricades are described in detail in AASTP-1, 1.4.6.
- Details on the design of effective barricades are given in AASTP-1, 2.3.3.

An earth-covered building may be considered equivalent to a building with barricades if, for example, the thickness and slope of the earth cover comply with the requirements of AASTP-1, 1.4.6, or meet the other criteria stated there.

Natural terrain features, such as wood, elevations, soil etc., may be regarded as "natural barricades" if they have proven to provide the required protection. It must be considered, however, that the natural environment and thus the protection it provides may change in the course of time.

(10) Ventilation

When designing the ventilation system, preference should be given to natural ventilation for economical reasons. The ventilation system must be designed such as to prevent ingression of airblast, primary and secondary projections as well as thermal radiation and flames or reduce their effects to a safe level.

f) Construction Materials for Ammunition Storage Buildings

Basically, fire-resistant or at least fire-retardant materials should be used.

Typical materials for the construction of aboveground ammunition storage buildings are concrete, reinforced concrete, masonry, corrugated steel liners or steel arches. In addition, soil material with a special consistency is normally used for the earth covers.

Exposed parts made of iron, steel, aluminum or aluminum alloys, which might come into contact with explosives, shall not contain more than 1 % of magnesium.

The walls and floors of rooms intended for the storage of chemical agents shall be lined with chemical agent-repellent material at least up to the height of the stacks. Adequate ventilation of the storage area shall be ensured.

2.5.1.4 *References*

Essential references -->> **Section VIII**

Ref [1], [2], [3], [4], [76], [77], [78], [79], [83], [89], [102]

Section III - Airblast

2.5.2.1 *Introduction*

g) General

Airblast parameters have been thoroughly investigated in the course of data collections carried out for weapons effects analyses. Open air and open surface detonations have been the subject of complex experiments and scientific research providing the data basis to determine the relevant airblast loads. Furthermore, a lot of experimental data and experiences from explosions are available covering the airblast loads occurring after accidental explosions in ammunition storage facilities. The scientific evaluation of these data as well will provide the necessary design basis.

Intensity, waveform and interaction of an airblast with persons, structures and equipment items are important factors in establishing the quantity distances for ammunition and explosives, especially such of hazard division 1.1.

In case standard quantity distance tables are not applied (or cannot be applied), potential explosion sites and exposed structures must be designed and calculated individually. Under certain circumstances, this procedure may lead to considerable cost savings in the design of ammunition storage facilities, e.g. in terms of material and land requirements.

h) Problem Description

The airblast load due to an explosion may be readily simplified for design purposes. It is characterized by a relatively flat blast wave, whose peak overpressure and variation with time essentially are functions of distance and charge, and the dynamic pressure variation with time. It must be noted that deviations from the model explosion environment will change the airblast parameters.

i) Assumptions and Definitions

Design and calculation methods for ammunition storage facilities are mainly based on modeling and practice-oriented assumptions.

In general, the following assumptions are introduced in order to simplify calculation of airblast loads and reduce input data.

(1) Charge Shape

The charge is assumed to be hemispherical and placed directly on the ground at sea level.

Note:

Other charge shapes and positions cause asymmetrical propagation of blast and, in part, considerable deviations of blast parameters.
(-->> Ref [3], [45], [52], [53], [62], [66])

(2) Reference Explosion

The reference explosion is taken to be the high order detonation of an exposed bare charge of TNT. In case of explosives other than TNT or different explosion environments, the TNT equivalent mass must be calculated using a conversion factor.

Note:

The TNT equivalent factor is not a constant value. Usually, a practicable value is used.
(-->> Table [5-2])

(-->> Ref [1], [3], [4], [55])

(3) Blast Attenuation by Donor Structure

The attenuation due to the external walls or the earth cover can be taken into account as follows:

- Proceeding from the basic assumption that a hemispherical charge explodes on the ground in the open, an empirical attenuation factor is introduced to extrapolate a fictitious explosives quantity inside the storage building.
- The maximum permissible explosives quantity for the storage building is determined using empirically developed and up dated regression equations for particular building types.
- The airblast loads are determined using empirically developed formulations.

Note:

All methods are based on empirical data.
(-->> Ref [65], [76], [87], [88], [101], [127], [133])

(4) Terrain and Vegetation

- All assumptions relate to flat terrain without obstacles and vegetation.
- Rising slops cause an increase of pressure.
- Falling slopes cause a decrease of pressure.
- A narrow valley with steep sides causes concentrated directional blast.
- Significant vegetation, such as wood with a tree top height of more than **3.5 m**, consumes blast energy.

j) Properties of an Airblast Wave

An airblast wave due to an explosion consists of an incident blast wave and a dynamic blast wave.
(-->> Figure [5-1])

The incident peak overpressure is significantly higher than the dynamic peak overpressure.

For design purposes, the duration of the incident blast wave and the dynamic blast wave may be taken to be equal although the pressure drops behind the respective shock fronts differ considerably and the dynamic pressure normally takes longer to decrease to the ambient pressure level. The pressure drop of the incident blast wave is much steeper.

The negative overpressure phase (suction phase) may be neglected for design purposes.

2.5.2.2 *Physical Relations Between Airblast Parameters*

The characteristic parameters of a blast wave with a sudden pressure discontinuity at the shock front are as follows:

- Overpressure;
- Dynamic pressure
- Reflected pressure;
- Density;
- Shock front velocity;
- Particle velocity.

These parameters are derived using the Rankine-Hugoniot equations. When one of the shock front parameters of the incident blast wave has been determined as a function of the scaled distance, the other parameters can be

calculated using the Rankine-Hugoniot equations and a simple integration procedure. The Rankine-Hugoniot equations are based on the principles of conservation of mass, energy and momentum.
(-->> Ref [3], [72])
Restrictions:

- The Rankine-Hugoniot equations are only applicable under the condition that the particle velocity ahead of the shock front is zero **($u_o = 0$)** and that the air behaves like an ideal gas with a specific heat ratio of τ = **1.4**.
- It is further assumed that there is one single shock front caused by a surface explosion of a hemispherical shaped charge.

k) Rankine-Hugoniot equations

(1) Shock front velocity U

$$U = a_o \cdot \left[1 + \frac{6 \cdot P_{so}}{7 \cdot P_a} \right]^{1/2} \qquad \textbf{eq [5-01]}$$

(2) Particle velocity u

$$u = \frac{5 \cdot P_{so}}{7 \cdot P_a} \cdot \frac{a_o}{(1 + 6 \cdot P_{so} / 7 \cdot P_a)^{1/2}} \qquad \textbf{eq [5-02]}$$

(3) Air density behind the shock front rho

$$Rho = \frac{7 + 6P_{so}/P_a}{7 + P_{so}/P_a} \cdot rho_{,a} \qquad \textbf{eq [5-03]}$$

(4) Dynamic pressure q_o

$$q_o = 0.5 \cdot rho \cdot u^2 \qquad \textbf{eq [5-04]}$$

$$q_o = \frac{5}{2} \left[\frac{P_{so}^{\,2}}{7 \cdot P_a + P_{so}} \right] \qquad \textbf{eq [5-05]}$$

(5) Normally reflected pressure P_r

$$P_r = 2 \cdot P_{so} \cdot \left[\frac{7 \cdot P_a + 4 \cdot P_{so}}{7 \cdot P_a + P_{so}} \right] \qquad \textbf{eq [5-06]}$$

Note:

For an ideal gas (τ = 1.4) and high shock front pressure P_{so}, P_r approaches the limit $8 \cdot P_{so}$. For air, this limit can be exceeded. For low shock front pressures, the reflection factor approaches the value of 2.
(Detailed formulations: -->> Ref [1], [3], [102])

(6) Pressure-Time Variations of Incident Airblast and Dynamic Pressure

The time-dependent variation of the incident (side-on) pressure $P_s(t)$, and the dynamic pressure $q(t)$ may be realistically represented using the modified Friedländer equation:
(-->> Ref [3])

$$P_s(t) = P_{so} \cdot \left(1 - \frac{t}{t_o}\right) \cdot e^{(-\beta \cdot t/t_o)} \qquad 0 \le t \le t_o \qquad \textbf{eq [5-07]}$$

$$q(t) = q_o \cdot (1 - \frac{t}{t_o}) \cdot e^{(-\beta \cdot t/t_o)} \qquad 0 \le t \le t_o \qquad \textbf{eq [5-08]}$$

(Empirical values for **β** are given in **Table [5-3]**)

(7) Positive Impulse

The decisive parameter for the damage caused by airblast is the positive overpressure impulse. It may be determined by integration of the positive overpressure phase, i.e. it is defined by the total area below the pressure-time curve.

General impulse equation: $i_s = \int_o^t P_s(t) \cdot dt$

$$\mathbf{I_s = \frac{P_{so} \cdot t_o}{\beta} \cdot (1 - \frac{1 - e^{-\beta}}{\beta})}$$

eq [5-09]

$$\mathbf{I_q = \frac{q_o \cdot t_o}{\beta} \left[1 - \frac{2}{\beta} \cdot (1 - \frac{1}{\beta}) - \frac{2}{\beta^2} \cdot e^{-\beta} \right]}$$

eq [5-10]

l) Scaling Laws

(1) General

The conversion of airblast parameters, distances and explosive charge masses from parameters of a known explosion environment may be accomplished using scaling laws.

(2) Cube-Root Law

Theoretically, the relation between distance, pressure, and explosive charge mass may be expressed by a cube-root law. Full scale tests have shown that this proportionality between distance and charge mass applies to quantities up to the megaton range.

(3) Scaling

- **Distance - Charge Mass**

$$\frac{R_x}{R_o} = \left[\frac{Q_x}{Q_o} \right]^{1/3} \qquad \textbf{eq [5-11]}$$

$$R_x = R_o \cdot \left[\frac{Q_x}{Q_o} \right]^{1/3} \qquad \textbf{eq [5-12]}$$

- **Dynamic impulse:**

Time - Charge Mass:

$$t_x = t_o \cdot \frac{R_x}{R_o} = t_o \cdot \left[\frac{Q_x}{Q_o} \right]^{1/3}$$

eq [5-13]

Impulse - Charge Mass:

$$I_x = I_o \cdot \frac{R_x}{R_o} = I_o \cdot \left[\frac{Q_x}{Q_o} \right]^{1/3}$$

eq [5-14]

Airblast parameters measure for different charge masses and at different atmospheric conditions may be converted to standard conditions applying the Hopkinson-Cranz cube-root law and the Sachs scaling laws. The latter is only applicable to ideal gases, i.e. it is not suited for air and high shock front pressures.

- **Scale Factors …**

… for Pressure P

$$S_P = \left[\frac{P_a}{P_{a,s}} \right]$$

eq [5-15]

… for distance R

$$S_d = Q_x^{1/3} \cdot \left[\frac{P_{a,s}}{P_a} \right]^{1/3}$$

eq [5-16]

… for time t

$$S_t = Q_x^{1/3} \cdot \left[\frac{P_a}{P_{a,s}} \right]^{1/3} \cdot \left[\frac{T_{a,s}}{T_a + 273} \right]^{1/2}$$

eq [5-17]

… for impulse I

$$S_t = Q_x^{1/3} \cdot \left[\frac{P_a}{P_{a,s}} \right]^{2/3} \cdot \left[\frac{T_{a,s}}{T_a + 273} \right]^{1/2}$$

eq [5-18]

--> Index $X_{a,s}$ …. standard conditions at sea level

(4) TNT equivalent

For determining the characteristic airblast parameters, it is advisable to convert the actual charge mass to the equivalent TNT charge mass in order to make use of the various existing design diagrams which are usually related to TNT. For design purposes, the values given in **Table [5-2]** may be used.

The majority of measurements of airblast parameters so far has been carried out using pure TNT charges. For calculations related to other explosives with or without confinement and different explosion environments, it is advisable to use the respective TNT equivalents for these conditions. These equivalents are individually determined with respect to pressure and impulse by means of tests or defined using the specific detonation energy of the explosive.

$$Q_{TNT,e} = \left[\frac{E^d_{exp}}{E^d_{TNT}} \right] \cdot Q_{exp} \qquad \textbf{eq [5-19]}$$

$Q_{TNT,e}$ (kg)	**equivalent TNT charge mass**
Q_{exp} (kg)	**actual explosive charge mass**
E^d_{TNT} (J/kg)	**specific detonation energy of TNT**
E^d_{exp} (J/kg)	**specific detonation energy of the actual explosive**

2.5.2.3 *Determination of Characteristic Airblast Parameters for Surface Detonations of Hemispherical Explosive Charges in the Open*

m) Characteristic Airblast Parameters

-	Peak side-on overpressure	P_{so}	MPa
-	Dynamic overpressure	q_o	MPa
-	reflected overpressure	P_r	MPa
-	Scaled positive side-on impulse	i_s	MPa-ms/(kg)$^{1/3}$
-	Scaled positive reflected impulse	i_r	MPa-ms/(kg)$^{1/3}$
-	Positive airblast duration	t_o	s
-	Arrival time	t_a	s
-	Shock front velocity	U	m/s
-	Particle velocity behind shock front	u	m/s

Note:
The scaled parameters must be multiplied by the cube root of the TNT equivalent mass.

n) Design Fundamentals

(1) Design Diagrams

For design and damage assessment purposes, the characteristic airblast parameters may be determined from **Figure [5-2a]** and **[5-2b]** taking into account the assumptions previously established. The diagrams are based on numerous tests and apply to charge masses from 1 kg up to **400 000 kg**.
(-->> Ref [5])

The curves shown in **Figure [5-2a]** and **[5-2b]** may be programmed as polynomial equations on a personal computer. The respective data are summarized in **Table [5-5]**.
(additional information: -->> Ref [3])

(2) Common Formulas

The formulations described in **Table [5-5]** are not suited to be used with pocket calculators. Therefore, the following formulas are recommended for quick calculations with acceptable accuracy.
(-->> Ref [133 revised]) …

Explosive	:	TNT, TNT - equivalent
Type of detonation	:	surface detonation
Place of detonation	:	in the open

Scaled distance	:	$z = R / (Q)^{1/3}$ $(m / (kg)^{1/3})$
Charge mass	:	Q (kg)
Distance	:	R (m)

- **Peak Side-On Overpressure P_{so} (MPa)**

Range	Function
$0.50 \le Z < 0.75$	$P_{so} = 1.313137 \cdot Z^{(-1.910441)}$
$0.75 \le Z < 3.50$	$P_{so} = 1.330026 \cdot Z^{(-2.218832)}$
$3.50 \le Z < 8.50$	$P_{so} = 0.724571 \cdot Z^{(-1.726565)}$
$8.50 \le Z < 30.00$	$P_{so} = 0.293592 \cdot Z^{(-1.295654)}$

- **Scaled Side-on Impulse i_s (MPa-ms/(kg$^{1/3}$))**

Range	Function
$0.50 \le Z < 1.0$	$i_s = -41.2564 \cdot Z^5 + 144.608 \cdot Z^4 - 198.8880 \cdot Z^3 + 134.238 \cdot Z^2 - 44.3554 \cdot Z + 5.8956$
$1.0 \le Z \le 30.0$	$i_s = -0.254674 \cdot Z^{(-0.918606)}$

- **Positive Pressure Duration T_o (ms)**

Linear pressure waveform:

$$T_o = \left[\frac{2 \cdot I_s}{P_{so}} \right] \qquad \text{eq [5-20]}$$

$$I_s = i_s \cdot NEQ^{(1/3)} \qquad \text{eq [5-21]}$$

Exponential Pressure Waveform:

-->> Figure [5-2a], [5-2b]

- **Pressure Drop Constant β**

The pressure drop constant β is determined by iteration of the following equation:

$$\frac{P_{so} \cdot t_o}{I_s} = \frac{\beta^2}{\beta - (1 - e^{(-\beta)})} \qquad \text{eq [5-22]}$$

2.5.2.4 *Determination of Characteristic Airblast Loads due to an Explosion Event in an Ammunition Storage Facility*

o) Earth-Covered Aboveground Storage Buildings

(1) General

Blast pressure and impulse are attenuated by the encasement of the potential explosion site. The degree of pressure and impulse reduction depends on the mass of the covering or shielding material (e.g. ammunition confinement, building encasement, earth cover) as well as the loading density. The attenuation effect may be observed mainly in the near field close to the explosion site, whereas in the far field the values approach and partly even exceed those for an open surface detonation of a hemispherical shaped charge. At these large distances, however, the pressure values are already on a comparatively low level. The attenuation effect is of particular importance for the prevention of sympathetic detonation between ammunition storage buildings.

(2) Attenuation Effect

- Attenuation by Donor Buildings

The degree of attenuation by donor buildings must be expected to differ for the main directions of blast (frontward, sideward and rearward) (Ref [133 (revised)], [65]). With standard earth-covered ammunition storage buildings, the highest pressure attenuation occurs in rearward direction. Since the front faces are usually uncovered, the near-field pressure acting in frontward direction is normally higher than that of an open surface detonation while it is considerably lower in the far field.

Test evaluation (Ref [65], [87], [88], [133]) have shown that for scaled distances in excess of **Z ≈ 10 to 15 m/kg^$^{1/3}$** the blast pressure in sideward direction is usually higher than that in frontward direction. In practice, this phenomenon has no considerable effect since the pressure level at these distances is already below **≈ 0.01 MPa**. The blast wave acting in rearward direction shows a different behavior from that acting in side-ward direction. Its pressure values approach those of the front wave; pressure equalization, however, happens at a considerably slower rate. The above observations may be transferred to the impulse behavior.

- Attenuation by Acceptor Buildings

The earth covers of ammunition storage buildings considerably reduce the airblast loads acting upon the external parts of the structures (soil berm shielding effect). The soil pressure loading at the soil-structure interface is significantly smaller than the loading due to a blast wave impacting directly. Peak overpressure and reflection factors are reduced whereas the loading duration increases. Thus, the probability of spalling at the inside surface of the walls is reduced, and the peaks of the dynamically relevant motion parameters are flattened.

Figure [5-2g] (-->> Ref [59]) shows a comparison of the airblast wave peak overpressure normally reflected at an external wall with the normally reflected peak pressures of various soil types at the soil-structure interface.

(3) Type of Construction

The individual construction of earth-covered ammunition storage buildings corresponding to an established standard type does not significantly influence the donor-specific attenuation effect. The decisive parameter with respect to blast attenuation in the near field is the mass to be moved which usually consists of approximately **80-90%** earth cover material.

The essential factors at to acceptor-specific attenuation are the geometry and the material of the earth cover. Earth covers of low-density materials, such as loose sand or a loose gravel-sand mixture, are most effective in reducing airblast loads.
(-->> Figure [5-2g])

(4) Formulations for Characteristic Airblast Parameters

Test evaluations provided the following formulas for calculating the characteristic airblast parameters taking into account the attenuation effect of a standard earth cover.
(-->> Ref [133] / Figure [5-2c] and [5-2e])

- **Side-On Peak Overpressure P_{so} (MPa)** **eq [5-23]**

Airblast Direction	Function
Front	$P_{so} = 0.435 \cdot z^{(1-541)}$
Side	$P_{so} = 0.301188 \cdot z^{(1.364270)}$
Rear	$P_{so} = 0.300052 \cdot z^{(1.513182)}$

- **Scaled Side-On Impulse i_s (MPa-ms/ (kg$^{1/3}$))** **eq [5-24]**

Airblast Direction	Function
Front	$i_s = 0.263627 \cdot z^{(-1-027171)}$
Side	$i_s = 0.191082 \cdot z^{(-0.922905)}$
Rear	$i_s = 0.120419 \cdot z^{(-0.888696)}$

- **Calculation of the Remaining Parameters -->> eq [7-13], [-714]**

p) Detached Uncovered Ammunition Storage Buildings

(1) General

After an explosion event in a detached uncovered ammunition storage building as well, airblast, peak overpressure and impulse will be considerably attenuated as compared with a free field detonation. The attenuation, however, is not as high as with earth-covered ammunition storage buildings since the masses to be moved are significantly smaller.

q) Ammunition Storage Structures Protected by Earth Mounds or Barricades - Magazines, Ammunition Stacks

(1) General

Tests have demonstrated that earth mounds or barricades have no significant blast attenuation effect. A load reducing effect due to interference with the airblast may only be observed in the near field (scaled distance $\mathbf{Z \approx 1\ m/kg^{1/3}}$). This effect, however, cannot exactly be quantified and thus should be disregarded in the calculations. There are graphical prediction methods for estimating the blast loads behind barricades. (-->> Ref [211])

(2) Characteristic Airblast Parameters

For the assessment of exposed buildings in the vicinity, airblast loads similar to those of a free field detonation should be assumed.

2.5.2.5 *Airblast Loading of Exposed Sites (ES)*

r) General / Load Model

The interaction between airblast loads and complex structures is a complicated process the treatment of which requires a high standard of knowledge and experience. Buildings for the storage and handling of ammunition usually are simple structures. Typical features are:

- Flat or arched roof;
- Closed Regular, clear contours, usually box-like shape;
- construction; openings, such as windows, hatches and doors, constitute less than **5%** of the total area;
- Approximately uniform strength, i.e. resistance, of all structural elements.

For practical purposes (explosions at a large distance from the structure), it may be assumed that the airblast strikes the structure as a planar wave front and that the time-dependent pressure level is thus evenly distributed over each surface of the structure.

In the case of a close-in detonation, this approach would be to conservative since the varying pressure levels of the blast wave strike the various regions of the structure at different times.

In principle, the structural elements exposed to an airblast should be individually designed with respect to the incident blast loading acting directly upon them.

Sometimes, it may be required to demonstrate the stability of a structure as a whole. In such cases, it must be taken into consideration that - similar as with a close-in detonation - the blast acts on the various structural elements at different times and with varying intensity.

The blast loading of a structure depends on the following characteristics:

- Load parameters: -
  - Pressure-time variation
    -->> Reflected pressure
    -->> Side-On pressure
    -->> Dynamic pressure
  - Positive impulse
- Structure parameters
  - Dimensions
  - Shape
  - Design
  - Material strength
- Orientation with respect to airblast

s) Determination of Relevant Load Waveforms
(Figure [5-4], [5-5] and [5-6])

(1) General

A fully developed and largely undisturbed airblast wave is most exactly expressed by an exponential function (Friedländer function).
(-->> Ref [3])

Triangular or bilinear blast waveforms used so far in order to simplify calculations usually provide results which are conservative.

For structural elements with span directions perpendicular to the shock front of a blast wave, a step-by-step analyses of the time-dependent blast loading would be required. This procedure is simplified by the use of an equivalent load model which represents the instantaneous element loading by a time-dependent evenly distributed loading producing the same stresses (inter-sectional forces) in the element. Details on this subject are given in **Ref [3]** for instance.

The above mentioned analyses will be applied to reinforced concrete structures provided upper and lower reinforcements extend across the entire span.

t) Basic equations

(1) Symbols
(-->> List of Symbols)

S Building height $\mathbf{H_s}$ or **0.5 · building width**, whichever is the smaller value
$\mathbf{L_{w,x}/L}$ Ratio between blast wave length and span of the structural element under consideration
X Position index
S Centre of element strip; relevant shock front position

(2) Airblast Duration and Blast Wave Length

$$t_{of,x} \quad \frac{2 \cdot I_{s,x}}{P_{so,x}} \qquad \textbf{eq [5-27]}$$

$$L_{w,x} = U_{,x} \cdot t_{o,x} \qquad \textbf{(approximate value)} \qquad \textbf{eq [5-28]}$$

(3) Equivalent Load Factors and Blast Wave Position Factor

The equivalent load factors and the blast wave position factor may be derived from **Figure [5-3]** or determined using the following polynomial functions ….

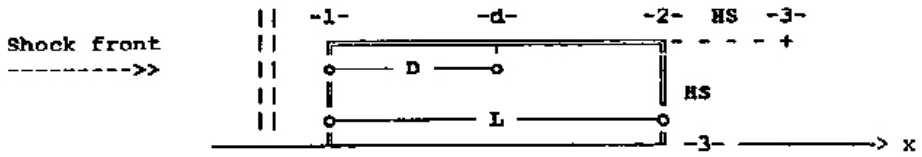
$$C = L_{w,x} / L$$

$$C_x = 0.0048 \cdot C^5 - 0.0584 \cdot C^4 + 0.2817 \cdot C^3 - 0.6963 \cdot C^2 + 0.9551 \cdot C + 0.2433 \qquad \textbf{eq [5-29]}$$

$$D/L = 0.0098 \cdot C^5 - 0.1203 \cdot C^4 + 0.5682 \cdot C^3 - 1.3207\ C^2 + 1.6217 \cdot C - 0.0774 \qquad \textbf{eq [5-30]}$$

$$D = L \cdot D/L \qquad \textbf{eq [5-31]}$$

(4) Determination of Characteristic Airblast Parameters



Pos	$P_{so,x}$	$I_{s,x}$	$P_{r\,x}$	$I_{r,x}$	$t_{a,x}$	$t_{o,x}$	$U_{,x}$	$L_{w,x}$

(x)	MPa	MPa-ms	MPa	MPa-ms	ms	ms	m/s	m
1	+	+	+	+	+	+	+	+
2	+	+	-	-	+	+	+	+
3	+	+	-	-	+	+	+	+

Determination of parameters: (+) yes / (-) no
using: -->> Figure [5-2a] through [5-2f]

Front Face

- **Bilinear Load Waveform:**
  (-->> Figure [5-4], [5-5], [5-6])

- **Pressure duration, side-on overpressure:**

$$t_{of} = \frac{2 \cdot I_s}{P_{so}} \quad \text{(ms)} \qquad \textbf{eq [5-32]}$$

- **Pressure duration, reflected overpressure:**

$$t_r = \frac{2 \cdot I_r}{P_r} \quad \text{(ms)} \qquad \textbf{eq [5-33]}$$

- **Dynamic impulse:**

$$I_q = 0.5 \cdot q_o \cdot t_{of} = I_s \cdot \left[\frac{q_o}{P_{so}}\right] \qquad \text{(Mpa-ms)}$$

$$I_d = C_D \cdot q_o \cdot \frac{t_{of}}{2} = C_D \cdot I_q \qquad \text{(Mpa-ms)}$$

- **Duration of peak reflected overpressure:**

$$t_s = \min\left[\begin{array}{l} \left(\dfrac{P_r \cdot t_r - (P_{so} + C_D \cdot q_o) \cdot t_o}{P_r - (P_{so} + C_D \cdot q_o)}\right) \\ t_c = 3 \cdot S/U \end{array}\right] \qquad \text{(ms)}$$

- **Total impulse:**

$$I = I_s + I_d + I_r^* \leq I_r \qquad \text{(Mpa-ms)}$$

$$I_r^* = 0.5 \cdot (P_r - P_{so} - C_D \cdot q_o) \cdot t_s \qquad \text{(Mpa-ms)}$$

- **Pressure waveforms: P(t) in (MPa)**

$$0 \le t \le t_a \qquad P(t) = P_r^* \cdot \left(1 - \frac{t}{t_a}\right) + (P_{so} + C_D \cdot q_o) \cdot \left(1 - \frac{t}{t_{of}}\right)$$

$$P_r^* = P_r - P_{so} - C_D \cdot q_o$$

$$t_a \le t \le t_{of} \qquad P(t) = (P_{so} + C_D \cdot q_o) \cdot \left(1 - \frac{t}{t_{of}}\right)$$

$$P_s(t) = (P_{so} - C_D \cdot q_o) \cdot \left(1 - \frac{t}{t_{of}}\right)$$

$$P_d(t) = C_D \cdot q_o \cdot \left(1 - \frac{t}{t_{of}}\right)$$

- **Exponential Load Waveform /Modified Friedländer equation:**
(-->> Figure [5-5])

The bilinear pressure-time waveform may be transformed into an equivalent exponential function which, from experience, has proved to correspond to the real airblast waveform.

- **Pressure waveform:**

$$P_s(t) = P_o \cdot (1 - t/t_o) \cdot e^{(-\beta \cdot (t/to))} \qquad \text{(Mpa)} \qquad \textbf{eq [5-34]}$$

- **Pressure drop constant:**

$$\beta \approx Po / Io \qquad \text{(---)} \qquad \textbf{eq [5-35]}$$

	Formula	Loaded Surface
Peak Overpressure	$P_o = \begin{cases} P_r \\ P_{so} + C_D \cdot q_o \end{cases}$	Front Side / Roof
Total Impulse	$I_r^* = \begin{cases} \min \begin{cases} I_r - I_a - I_d \le I_r \\ 0.5 \cdot (P_r - P_{so} - C_D \cdot p_o) \cdot t_a \end{cases} \\ 0.0 \end{cases}$	Front Side / Roof
	$I_q = I_a \cdot \left[\frac{q_o}{P_{so}}\right]$; $I_d = C_d \cdot I_q$	
	$I_o = \begin{cases} I_r^* + I_a + I_d \le I_r \\ I_a + I_d \end{cases}$	Front Side / Roof

Roof and Side Walls

Direction of Span of Relevant Element is Perpendicular to the Shock Front, i.e. in Blast Direction

$$t_d = D / U_{,2}$$

$$t_{2,eff} = (t_{a,2} - t_{a,1}) + t_{of,2}$$

- **Procedure:**

. . . Determination of required airblast parameters from **Figure [5-2a]** through **[5-2f]:**

$\mathbf{P_{so,2}}$ **;** $\mathbf{I_{s,2}}$ **;** $\mathbf{U_{,2}}$ **;** $\mathbf{t_{o,2}}$

. . . Determination of $L_{w,2}$ using **eq [5-28]**

. . . Determination of $\mathbf{C_E}$ and **D/L** or **D** as functions of $\mathbf{L_{w,2}}$ **/ L** using **Figure [5-3]** or **eq [5-29]** through **[5-31]**

. . . Determination of dynamic pressure $\mathbf{q_{o,2}}$ as a function of $C_E \cdot P_{so,2}$ using **Figure [5-2b]** or **eq [5-4]** and **[5-5]**

. . . Determination of drag coefficient $\mathbf{C_d}$ related to $\mathbf{q_{o,2}}$ using **Table [5-4]**

. . . Calculation of peak overpressure and total impulse:

$$\mathbf{P_o = C_E \cdot P_{so,2} + C_D \cdot q_{o,2}}$$

$$\mathbf{I_s = 0.5 \cdot P_o \cdot t_{2,eff}}$$

- Pressure waveform for t = 0 at front edge of structure:

$$\mathbf{0 \le t \le t_d \qquad P_s(t) = P_o \cdot \frac{t}{t_d}}$$

$$\mathbf{t_d \le t \le t_{2,eff} \qquad P_s(t) = P_o \cdot \left[1 - \frac{t \cdot t_d}{t_{2,eff} - t_d} \right]}$$

Direction of Span of Relevant Element is Parallel to the Shock Front;
Considering a Loaded Element Strip
(-->> Figure [5-5])

Assumption: Uniform time-dependent pressure loading of an element strip

$$\mathbf{t_{of,s} = \frac{2 \cdot I_s}{P_{so,s}}}$$

$$\mathbf{t_d = \frac{L_s}{U_{,s}}}$$

- Procedure:

. . . Determination of airblast parameters . . .

$\mathbf{P_{so,s}}$ **;** $\mathbf{I_{s,s}}$ **;** $\mathbf{U_{,s}}$ **;** $\mathbf{t_{o,s}}$

at position **s**, i.e. at the center of the element strip using **Figure [5-2a]** through **[5-2f]**

. . . Determination of dynamic pressure $\mathbf{q_{o,s}}$ using **Figure [5-2b]** or **eq [5-4]** and **[5-5]**

. . . Determination of drag coefficient $\mathbf{C_D}$ related to $\mathbf{q_{o,s}}$ using **Table [5-4]**

. . . Determination of peak overpressure $\mathbf{P_o}$**:**

$$P_o = (P_{so,s} + C_D \cdot q_{o,s}) \cdot \left[1 - \frac{0.5 \cdot t_d}{t_{of,s}} \right]$$

. . . Determination of total impulse $\mathbf{I_s}$**:**

$$I_s = 0.5 \cdot P_o \cdot (0.5 \cdot t_d + t_{of,s})$$

- **Pressure waveform for t = o at front edge of element strip**

$$0 \le t \le t_d = L_s/U_{,s} \qquad P_s(t) = P_o \frac{t}{t_d}$$

$$t_d \le t \le 0.5 \cdot t_d + t_{of,s} \qquad P_s(t) = (P_o \cdot \left[1 - \frac{t - t_d}{t_{of,s} - 0{,}5 \cdot t_d} \right]$$

Rear Wall

As soon as the shock front passes the rear edge of the roof or the side walls, the blast wave expands and produces secondary waves which propagate across the rear wall and will partly be reflected by the ground.

An equivalent uniform time-dependent pressure load is calculated for the rear wall as well.

$$t_{of,3} = \frac{2 \cdot I_{s,3}}{P_{so,3}}$$

$$t_d \quad \frac{D}{U_{,2}}$$

$$t_{3,eff} = [\, 2 \cdot H_s / (U_{,2} + U_{,3}) \,] + t_{of,3} \qquad \textbf{(rough)}$$

$$t_{3,eff} = (t_{a,3} - t_{a,2}) + t_{of,3} \qquad \textbf{(exact)}$$

$$L_{w,3} = U_{,3} \cdot t_{of,3} \qquad \textbf{(rough)}$$

- **Procedure:**

... Determination of required airblast parameters from **Figure [5-2a]** through **[5-2f]** ...

$$P_{so,3} \; ; \; I_{s,3} \; ; \; U_{,3} \; ; \; U_{,2} \; ; \; t_{o,3}$$

. . . Determination of factors $\mathbf{C_E}$ and **D/L** or **D** as functions of the ratio $\mathbf{L_{w,3}} / \mathbf{H_s}$ using **eq [5-28]** or **Figure [5-3]**

. . . Determination of $\mathbf{t_d}$

. . . Determination of dynamic pressure $\mathbf{q_{o,3}}$ as a function of $\mathbf{C_E \cdot P_{so,3}}$ using **Figure [5-26]** or **eq [5-4]**

. . . Determination of drag coefficient $\mathbf{C_D}$ as a function of $\mathbf{q_{o,3}}$ using **Table [5-4]**

. . . Determination of peak overpressure and total impulse at position **-3-** . . .

Peak overpressure: $\mathbf{P_o = C_E \cdot P_{so,3} + C_D \cdot q_{o,3}}$

Total impulse : $\mathbf{I_s = 0.5 \cdot P_o \cdot (t_{3,eff})}$

- **Pressure variation for t = 0 at rear edge of structure:**

$\mathbf{0 \le t \le t_d}$ $$\mathbf{P_s(t) = P_o \cdot \frac{t}{t_d}}$$

$\mathbf{t_d \le t \le t_{3,eff}}$ $$\mathbf{P_s(t) = (P_o \cdot \left[1 - \frac{t - t_d}{t_{2,eff} - t_d} \right]}$$

2.5.2.6 References

Essential references -->> **Section VIII**

Ref [1], [3], [4], [5], [17], [45], [52], [53], [54], [62], [65], [72], [73], [76], [77], [78], [81], [82], [83], [84], [85], [86], [87], [88], [101], [102], [128], [133]

Section IV - Projections
- Fragments, Debris, Lobbed Ammunition -

2.5.3.1 *Introduction*

u) General

An explosion of an ammunition storage site produces the following four types of projections:

- **Ammunition fragments**
- **Debris from earth cover**
- **Structural debris**
- **Crater ejecta**

The following discussion attempts to set forth principles and guidelines which may be useful for the proper design of shelters and layout of safe ammunition and explosives storage areas when standard quantity distance tables cannot be applied. Effective administrative safety provisions and, in particular, structural measures against fragment and debris hazards may permit the reduction of quantity distances, thereby lowering the costs for the construction and maintenance of ammunition storage facilities to a considerable extent.

v) Problem Description

The assessment of fragment and debris hazard is for the most part based on probabilistic approaches. The reason for this is the fact that fragmentation and debris forming is a random process occurring under physical environmental conditions which are not exactly definable.

w) Proposed Solution

Ballistic and distribution parameters form the basis for the damage assessment of projections, i.e. for establishing their hazard characteristics and hazard potentials. Ballistic parameters are initial velocity, horizontal and vertical angles of departure as well as mass whereas distribution is determined with respect to number and mass of projections.

The vulnerability of the respective target is related to the damaging effect of the projections in order to determine the hazard level.

2.5.3.2 *Fragments*

x) General

An explosion event in an ammunition storage building involves a hazard from emitted fragments generated by detonating ammunition items in the **P**otential **E**xplosion **S**ite (**PES**).
Fragment generation essentially takes place in two phases:

- **During the explosion**
- **After the explosion event due to detonation of ammunition items being ejected from the potential explosion site or impacting on a hard surface**

With cylindrical ammunition items, most of the fragments are projected in radial direction while only a few heavy fragments are emitted from the nose and base at a low velocity. For worst case considerations, it is assumed that the ammunition item detonates with its longitudinal axis parallel to the respective structural component.

The emission of direct fragments from a potential explosion site depends on the properties of the respective structural components as well as on the time relation between fragment movement, airblast propagation, and build-up of chamber pressure.

The decisive parameters are …

- **Loading density;**
- **Arrangements of stored ammunition;**
- **Ammunition type.**

For aboveground storage of ammunition, the following hazard levels are distinguished depending on the type of storage.

- **Open storage**

  Full fragment hazard

- **Ammunition storage building without earth cover**

  Reduced fragment hazard.
  High fragment absorption by structural components.
  The velocity of impeded fragments is reduced by approx. 85% (energy absorption ≈ 95%).
  Locations of high fragment hazard are the front area and the doors of the ammunition storage building.

- **Earth-covered ammunition storage building**

  Little to no fragment hazard.
  Due to the inert behavior of the structure and earth cover mass, the high velocity fragments are almost completely absorbed.

y) Fragment Mass Distribution

(1) Constant

$$\mathbf{M_A = B_x \cdot t_c^{5/6} \cdot d_i^{1/3} \cdot (1 + t_c/d_i)} \qquad \mathbf{(kg)^{1/2}} \qquad \textbf{eq [5-36]}$$

$\mathbf{B_x\ (kg^{1/2}) / (m^{7/6})}$	explosive constant in accordance with **Table [5-6]**
$\mathbf{t_c\ (m)}$	casing thickness
$\mathbf{d_i\ (m)}$	inner casing diameter

(2) Number of Fragments

Fragment mass distribution is represented in the form of the cumulative distribution of the number of fragments $\mathbf{N_f}$, individually heavier than a defined mass $\mathbf{M_f}$, as a function of $\mathbf{M_f}$. Such a function may be derived directly from the results obtained by testing or determined analytically using the Mott distribution:

$$\mathbf{N_f = (M_t / M_o) \cdot e^{(-(2 \cdot Mf/Mo)^{1/2})}} \qquad \textbf{eq [5-37]}$$

Formulation according to Ref [2], [3], [4]

$$\mathbf{N_f = (M_t / (2 \cdot M_A^2)) \cdot e^{(-\sqrt{M_f}/M_A)}} \qquad \textbf{eq [5-38]}$$

Total number of fragments:

$$\mathbf{N_t = M_c / (2 \,.\, M_A^2)} \qquad \textbf{eq [5-39]}$$

Mass of nominal fragment for design purpose:

$$M_d = M_A^2 \cdot I_n^2(1 - C_L) \qquad \text{for} \ldots 0.9500 \le C_L \le 0.9999$$

$$M_d = M_A^2 \cdot \ln^2\left[1 - C_L\left(1 - e^{(\sqrt{M_C}/M_A)}\right)\right] \qquad \text{for} \ldots 0.9999 \le C_L \le 1.0000$$

Number of fragments individually heavier than M_f :

$$N_f = N_t \cdot (1 - C_L) = (M_C/(2 \cdot M_A^2)) \cdot e^{(-\sqrt{M_C}/M_A)}$$

Detonating stacks of ammunition tend to produce mass distributions with a relatively higher percentage of heavy fragments than single items detonating individually.

For practical purposes, the number of heavy fragments is the most important parameter, since they are the most effective fragments with regard to ballistics and energy content.

A distribution of the form given above (Mott distribution), but with its main emphasis on the heavier portion of the fragment spectrum, is useful for representing test results and defining hazard levels.

z) Fragment Ballistics

If the mass distribution, angles of departure and initial velocities of fragments at the point of origin are known, trajectories, impact parameters and distribution density of the fragments can be determined. Gravity and atmospheric drag are essential parameters affecting the trajectory, which should be taken into account, at any rate, in order to find a safe and economical solution.

(1) Ballistic Properties

Preformed and irregular fragments may be assumed to be geometrically similar.
Fragment mass M_f and presented area A_f are proportional and related by the shape factor **k . . .**

$$M_f = k \cdot A_f^{3/2} \qquad \textbf{eq [5-40]}$$

This shape factor or **ballistic density** is determined empirically from ballistic tests and depends on the type of ammunition.
(-->> Table [5-7])

(2) Initial Velocity

Besides field measurements during fragmentation trials, the initial velocity of a fragment may be estimated from the . . .

. . . Gurney formula :

$$V_o = G / ((M_c/M_{ex}) + (n/(n+2)))^{1/2} \qquad \textbf{eq [5-41]}$$

$G = \sqrt{(2 \cdot E)}$	Gurney velocity, a constant for a given explosive Values: -->> Table [5-6]
n	Geometrical constant: -->> Table [5-8]

The basis for the equation above is an analysis of the behavior of a cylindrical or spherical casing subjected to an internal gas pressure. For projectiles, the formula may only be applied to fragments emitted radial from the casing.

Note:
The Gurney formula is not mass-dependent and applies primarily to fragments of up to 150 g, approximately. For heavier fragments, the formula gives a conservative result, since lower initial velocities are to be expected. The Gurney formula is adapted to different types of ammunition. Thus, there are different Gurney constants and geometrical constants. The literature referenced below contains details and additional formulations for the determination of initial velocities.

Ref [164 et al] -->> additional formulations:

. . Modified Gurney formula
. . Lukanow-Molitz formula
. . Swedish formula
. . Allison-Schriempf formula
. . Gabeaud formula

(3) Angle of Departure

Fragments from individual items of ammunition normally depart radial from the casing. Depending upon the type of ammunition, the area fragment distribution varies along the projectile axis.

For details and modeling procedures refer to the literature reference in Section VIII.
- e.g. Ref [171], [173], [174]

(4) Trajectory

For design purposes in the far-field range (with regard to the explosion site) the influence of gravity is essential. When designing shelters, or if the near field is concerned, the effect of gravity is negligible and straight trajectories may be assumed.
Non-linear fragment trajectories are very important for safety-related analyses of ammunition.

(5) Trajectory Calculation

Fragment trajectories are usually calculated with computers using numerical formulations since closed solutions are impossible due to the complex parameters such as wind, atmospheric drag etc. influencing the trajectory.

For this purpose, efficient programs considering the essential parameters affecting the trajectory are available.
(-->> ref [201], [203])

Trajectory Calculation Procedures and References :

Subject Matter	References
(1) Exterior Ballistics of Fragments	[164]
C_D Values for Irregular Fragments	
(2) Mass and Shape Distribution	[163]
Laws for Irregular Fragments	[4]
(3) SIACCI Method	[165]
(4) Primary and Secondary Fragments	[211], [4]
(5) Fragmentation	[211], [1]
(6) Fragment Protection	[3]

(6) Trajectory Velocity

For the practically relevant range, the fragment velocity as a function of distance can be estimated from the exponential function below, assuming a constant drag coefficient and disregarding gravity.

The C_D-value can be obtained from **Figure [5-7]** or **Table [5-9] :**

$$V_{(R)} = V_o \cdot e^{(-R/L)} \qquad \textbf{eq [5-42]}$$

$$L = \frac{2 \cdot (k^2 \cdot M_f)^{(1/3)}}{(C_D \cdot rho)} \qquad \textbf{eq [5-43]}$$

(7) Impact Velocity

The impact velocity varies between the near-field limits (low-angles of departure) according to **eq [5-44]** and the far-field limits (long fragment distance) according to **eq [5-45]**, with the latter physically representing the terminal velocity in free fall.

- Conservative formulas for the estimation:

. . . near field: $V_i = V_o \cdot e^{(-(Re/L))}$ **(m/s)** **eq [5-44]**

. . . far field: $V_i = \sqrt{(g \cdot L)}$ **(m/s)** **eq [5-45]**

- According to Ref [1], [3] . . .

$$V_i = V_o \cdot e^{(-(0.004 \cdot R_e \cdot / M_f^{(1/3)})} \qquad \textbf{(m/s)} \qquad \textbf{eq [5-46]}$$

(8) Impact Angle

The fragment impact angle depends upon the departure parameters and other external conditions (wind, air density, fragment parameters etc.).

For design purposes, normal impact, i.e. $\boldsymbol{a_i = 90^o}$, is to be assumed.

(9) Impact Energy/Impact Impulse

Impact energy and impact impulse, respectively, are decisive parameters for the assessment of fragment hazard levels.

The fragment mass $\mathbf{M_f}$ and the impact velocity $\mathbf{V_i}$ are essential parameters.

Impact energy: $E_{kin} = E_i = \dfrac{M_f \cdot V_i^2}{2}$ **(J)** **eq [5-47]**

Impact impulse: $I_i = M_f \cdot V_i$ **(Ns)** **eq [5-48]**

(10) Fragment Number Density

The probability of fragments striking a target **(ES)** at a given position is determined by the area density of flux of fragments, through the target area projected on a plane normal to the fragment trajectory at impact. When gravity effects are considered, numerical calculation techniques must be utilized even if simplifying assumptions have to be made regarding atmospheric drag and the mass distribution of the fragments. If gravity is ignored, however, the fragment flux with respect to distance follows an inverse-square law.

Assuming:

- The Mott fragment mass distribution;
- Fragment masses greater than the defined mass $\mathbf{M_f}$ **;**
- A target area normal to the fragment trajectory at a distance **R**.

The area density q_f of fragments is given by:

$$q_f = \frac{Q_o}{R^2} e^{(-(2M_f/M_o)^{1/2})} \qquad \text{(Number / m}^2\text{)} \qquad \textbf{eq [5-49]}$$

Determination of $\mathbf{Q_o}$ on the basis of the individual fragment distribution curves for ammunition or according to
-->> Ref [1], [3], [4]

In this approximation, consideration of the influence of gravity refers to its effect on impact velocity but not to the terminal phase of the trajectory.

The effective value of $\mathbf{Q_o}$, $\mathbf{Q_{o,eff}}$ depends upon the prevailing storage conditions. The effective value for fragments from a stack of ammunition is estimated by multiplying the value for a single ammunition item by the effective number of items $\mathbf{N_E}$**.**

$$Q_{o,eff} = Q_o \cdot N_E \qquad \textbf{eq [5-50]}$$

- **For a stack in the open, N_E is derived from:**

$$N_E = 0.9 \cdot N_s + 0.1 \cdot N_T \qquad \textbf{eq [5-51]}$$

- **For a stack in an earth-covered magazine N_E is:**

$$N_E = 0.7 \cdot N_s + 0.1 \cdot N_T \qquad \textbf{eq [5-52]}$$

Where

$\mathbf{N_E}$	Effective number of items of ammunition
$\mathbf{N_s}$	Number of items of ammunition on the side of the stack facing the potential target
$\mathbf{N_T}$	Number of items of ammunition in the top layer of the stack.

aa) Hazard Potential

(1) Probability of Impact

The probability of impact $\mathbf{P_f}$ of an individual fragment or a fragment flux is calculated using the area density $\mathbf{q_f}$.

The impact process is assumed to be uniformly random in the vicinity of the target point, so that fragment impact is equally probable on all equal area elements in the vicinity of the point. The probability of impact $\mathbf{P_f}$ of one or more fragments of a mass $\mathbf{M_f}$ or greater on a given target area is thus given by:

$$P_f = 1 - e^{(-q_f \cdot A_T)} \qquad \textbf{eq [5-53]}$$

$\mathbf{q_f}$ (Number/m^2) . . . with **eq [5-49]**
$\mathbf{A_T}$ (m^2) . . . target area

For a standing man, e.g., facing the explosion:

. . . $A_T \approx 0.56\ m^2$

(2) Hazard Criteria / Hazard Levels

Fragment hazard levels for a given target are determined using the essential parameters below:

- Fragment density at the target or hit probability of the individual fragment or the fragment flux;

- Impact energy - kinetic energy - of the individual fragment:

$$E_{kin} = E_i = (M_f \cdot V_i^2) / 2 \qquad \text{(Nm)} \qquad \text{eq [5-54]}$$

- Impact impulse of the individual fragment:

$$I_i = M_f \cdot V_i \qquad \text{(Ns)} \qquad \text{eq [5-55]}$$

- Vulnerability / destructibility criteria of the target in question.

(3) Injury Criteria / Casualty Criteria

A variety of functions of impact velocity and fragment mass have been proposed as injury criteria. NATO-wide, a lethal fragment is defined as a fragment with a kinetic energy exceeding the critical value of **79** Joules. This limit applies to fragment masses ranging from a few grams to several kilograms. In most cases, severe injuries will be caused.

Further details -->> Section VII

bb) Fragment Calculation Procedure

(1) Calculation of the initial fragment velocity

using the . . .

- GURNEY-Constant **Table [5-6]**
- GURNEY-Formula **eq [5-41]**
- with **n = 2** for cylindrical projectiles

(2) Calculation of the number of fragments

. . . per unit solid angle based on the number of fragments $\mathbf{Q_o}$ or $\mathbf{Q_{o,eff}}$ emitted from an item of ammunition or ammunition stack in the direction of interest. This is usually the direction perpendicular to the ammunition axes.

(3) Determination of the average fragment mass M_o

using . . .

- Available data bases;
- The average mass $\mathbf{M_o}$ of an individual item of ammunition, obtained by fitting a Mott distribution to data from a single item, emphasizing the heavier fragments within the mass spectrum.

In order to account for the greater ballistic and energetic effectiveness of fragments from stacks of ammunition, a shape factor **k = 4.74 g/cm^3** will be assumed.

(4) Determination of the mass M_f of the lightest hazardous fragment

Reaching a specified distance **R** using a parameter for the critical kinetic energy of a hazardous fragment.

Formulation 1: The terminal energy of a fragment of mass $\mathbf{M_f}$ in free fall is less than the critical energy.

$$\mathbf{M_f = 2 \cdot \frac{E_{cr}}{V_i^2}} \qquad \textbf{(kg)} \qquad \textbf{eq [5-56]}$$

$$\mathbf{V_i = V_o \cdot e^{(-R\,/\,L)}} \qquad \textbf{(m/s)}$$

$$\mathbf{L = \frac{2 \cdot k^{(2/3)}}{C_D \cdot rho} \cdot M_f^{(1/3)}} \qquad \textbf{(m)}$$

Formulation 2: The terminal energy of a fragment of mass $\mathbf{M_f}$ in free fall is greater than the critical energy.

$$\mathbf{M_f \left[\frac{2 \cdot E_{cr}}{g \cdot L_1} \right]^{3/4}} \qquad \textbf{(kg)} \qquad \textbf{eq [5-57]}$$

Notes:

- Whichever gives the smaller value of $\mathbf{M_f}$ will be used.
- For $\mathbf{E_{cr}}$ **= 79 Joules** and **k = 4.74 g/cm^3** the transition occurs at **Mf = 0.1 kg,** approximately.

(5) Calculation of the area fragment density

For fragments heavier than $\mathbf{M_f}$ and distance **R** in accordance with **eq [5-49].**

Alternatively, the distance **R** at which the critical density $\mathbf{q_{cr}}$ **(1/56 m^2)** for hazardous fragments is exceeded will be determined iterative using **eq [5-49], [5-56]** and **[5-57]**.

Note:
The result is the larger of the two values of **R** so obtained.

(6) Determination of the injury probability

The determination of the injury probability p at distance R from **eq [5-53].**

For small values of $\mathbf{q_f}$, the following approximation applies:

$$\mathbf{p \approx q \cdot A_T} \qquad \textbf{eq [5-58]}$$

Notes:
- The procedure above can be adapted for use with an injury criterion other than impact energy.
- Ballistic terminal parameters from other calculations may of course be introduced.

(7) Stacks Effects

There are strong indications that the fragmentation characteristics of stacks of ammunition differ significantly from those of a single detonating item.

- Detonating stacks emit a higher number of larger or heavier fragments.

This effect is influenced by the charge-to-metal (casing) ratio. Ammunition with small values of this ratio (e.g. artillery projectiles) generally produce fragments of greater individual mass.

- The initial fragment velocities for stacks of ammunition have been observed to be almost twice as high as for fragments from single items of ammunition.

- In the case of mass detonations, only the items of ammunition on the sides and top of a rectangular stack appear to contribute to the far-field area density of hazardous fragments.

2.5.3.3 *Debris and Crater Ejecta*

cc) Structural Debris

(1) General

An accidental explosion in an ammunition storage facility produces an impulsive peak overpressure leading to the shattering of or heavy damage to the structure. The resulting structural debris generally come from walls, foundation, bottom slab, ceiling, piers, screens, and fixtures.

The subsequent **'quasi-static'** internal pressure ruptures the building and vents through newly created or existing openings. Shattered structural components and other objects located on or within the building are accelerated by the releasing overpressure and projected from the explosion site. Main debris distribution is approximately normal to or at an acute angle to the original building walls or main axes.

These debris constitute a substantial hazard to objects and personnel in the vicinity.

The size of the structural debris depends upon the . . .

- **. . . Construction of the building,**
- **. . . Material of the building and the strength of the material,**
- **. . . Type of ammunition,**
- **. . . Loading density.**

Small structural debris are to be expected in the case of . . .

- **. . . Increasing loading density,**
- **. . . Brittle material,**
- **. . . Low-strength material,**
- **. . . Thin-walled structural component,**
- **. . . A small percentage of reinforcement,**
- **. . . Pre-damaging due to fragment impact.**

Larger structural debris are to be expected in case of . . .

- **. . . A solid, heavy construction,**
- **. . . Strong reinforcement,**
- **. . . Tough material,**
- **. . . Low loading density,**
- **. . . A blast effect alone.**

(2) Debris Mass Density

Detached Ammunition Storage Building

The debris/fragment departure from a detached ammunition storage building depends on several parameters, i.e . . .

- **. . . Loading density,**
- **. . . Type of ammunition/casing factor,**
- **. . . Geometry and strength of the building,**
- **. . . Direction of debris departure with regard to the building.**

In **Ref [76]** the debris mass density is given by the following equation . . .

$$\mathbf{rho_{,deb} = 0.36 \cdot M_a \cdot {}^{(0.58)} \cdot e^{(-0..047 \cdot R \cdot Q)^{(-0.29)}}} \quad \mathbf{(kg / m^2)} \qquad \mathbf{eq\ [5\text{-}59]}$$

all masses are in tons (to) = 1,000 kg
R (m) distance from the building center
f_1 -->> Figure [5-8]
V_i (m^3) internal volume of building
Q (to) = NEQ_{TNT} (to)

- **M_a . . . Total mass of ejecta**

  $$\mathbf{M_a = M_o + M_g + M_m} \quad \mathbf{(to)}$$

- **M_g . . . Mass of building**

  $$\mathbf{M_g = f_1 \,.\, V_i} \quad \mathbf{(to)}$$

- **M_o . . . Ejected earth mass of apparent crater**

  $$\mathbf{M_o \approx 100 \cdot NEQ_{TNT}} \quad \mathbf{(to)}$$

- **M_m … mass of ejected ammunition components in (to)**

  Estimates: $\mathbf{M_m \approx 0.0}$ **mines and high explosive**
  $\mathbf{M_m \approx 0.25 \cdot V_i}$ **cased ammunition**

Earth-Covered Ammunition Storage Building

In addition to the parameters decisive for the debris projection from detached ammunition storage buildings, in this case also the type, geometry and mass of the earth cover are of importance
(-->> Ref [75]) …

$$\mathbf{rho_{,deb} = 0.036 \cdot M_a \cdot e^{(-0.015 \cdot R)}} \quad \mathbf{(kg / m^2)} \qquad \mathbf{eq\ [5\text{-}60]}$$

all masses are in tons (to) = 1,000 kg
R (m) distance from the building center
f_1 -->> fig/[5-8]

V_i (m^3) internal volume of building

- **M_a . . . Total mass of ejecta**

  $M_a = M_o + M_g + M_m$ (to)

- **M_g . . . Mass of building**

  $M_g = f_1 \cdot V_i$ (to)

- **M_o . . . Ejected earth mass of apparent crater and earth cover (standard) empirical hypothesis:**
  mass of standard earth cover ≈ 4 to $5 \cdot M_g$

  $M_o \approx 100 \cdot NEQ_{TNT} + 4 \cdot M_g$ (to)

- **M_m . . . mass of ejected ammunition components (to)**

  Estimates: $M_m \approx 0.00$ mines and high explosive
  $M_m \approx 0.25 \cdot V_i$ cased ammunition

(3) Ballistics

Because of the high complexity of the event, it is very difficult to reliably determine the ballistic parameters of structural debris or crater ejecta resulting from an accidental explosion. There are not as many fundamental and other basic data available as is the case for fragments.

The departure parameters - velocity, angle, and mass - may vary substantially with the explosion environment. The engineer de-signing potentially exposed sites must, under these conditions, normally rely on threshold functions.

Velocity of Departure

The velocity of departure is dependent upon the loading density, the type of explosive, the structural strength, and the point of departure of the debris.

The full scale tests described, e.g., in **Ref [86], [106],** where fragments and debris have been thoroughly recorded and evaluated, confirm the above statements. Normally, fragments are accelerated more effectively than building debris or crater ejecta because of the higher loading density.

Depending upon the structure of the building and the loading density, more or less massive structural debris nevertheless can achieve velocities of departure of up to **V_o = 1,000 m/s**.

Since their mass is generally greater than that of fragments, they must be considered to have a higher energetic effectiveness in the far field.

Angle of Departure

Generally, structural debris will depart at an angle normal to the structure surface. Vertical and horizontal angles of departure vary from approximately **±10°** to **±20°**. Depending upon the loading density and the structural design of the building at intersections and junctions of components, angles of departure of up to approximately **30°** from the normal may occur due to angular moments at the time of departure.
(-->> Ref [155], [157], [200], [211])

(4) Hazard / Damage Predictions

The hazard level with respect to personnel or material depends upon the local situation and the predominant type of load. Debris impact density and impact energy constitute essential hazard parameters.

Detailed Hazard Data -->> Section VII

Inside inhabited buildings situated at the required quantity distance to the explosion site, the hazard to persons is mainly due to secondary debris formed in the close vicinity by the air-blast. The limit pressure currently specified for inhabited buildings is approximately **5 kPa**.
(-->> Section VII).
This overpressure causes minor structural damage such as glass breakage, cracks in plaster, and damage to the exterior wall lining.

dd) Debris from Earth Covers and Crater Ejecta

(1) General

Soil and rock material being ejected from the explosion crater is defined as **"crater ejecta"**. In the case of accidental explosions involving only individual ammunition components or small quantities of explosives, the load case "crater ejecta" generally constitutes a minor potential hazard as compared to the other effects such as airblast, fragments, structural debris and shock.

In the case of surface bursts of larger quantities of explosives, however, a substantial debris hazard has to be assumed, and the load case "crater ejecta" has to be taken into account in the safety-related assessment of ammunition facilities and their surroundings.

The cover material of earth-covered ammunition storage facilities produces additional ejecta. With standard installations, this covering material should consist of fine-grain particles with a relatively small mass. Projection distance and impact energy of this material are generally less than that of structural debris.

(2) Mass Density

In **Ref [31]**, the mass density of the crater ejecta for an open surface burst is given by the following mean relationship. .

$$\mathbf{rho_{,ej} = 27 \cdot NEQ_{TNT}^{1.4} \cdot R^{(-3.6)}} \qquad \mathbf{(kg / m^2)} \qquad \mathbf{eq\ [5\text{-}61]}$$

NEQ (kg) ; R (m)

(3) Ballistics

The ballistic performance of crater ejecta is similar to that of structural debris.

Formulations for ballistic parameters of crater ejecta have been examined and developed.
-->> Ref [31], [32], [33], [76], [77].

Ejecta Range

In the case of explosions on the surface of or inside cohesive soil, the total mass of ejecta is to be found within the following range . . .

$$\mathbf{R_{ej} \approx 30 \cdot R_a} \qquad \mathbf{eq\ [5\text{-}62]}$$

The maximum projection distances of crater ejecta are determined by an **NEQ$^{0.4}$** - law and depend upon the type of soil . . .

. . . for rock : $R_{ej,max}$ = 30 m/kg $^{0.4}$

. . . for soil : $R_{ej,max}$ = 12 m/kg $^{0.4}$

(4) Hazard Area (estimated)

Explosions on the surface of or inside cohesive soil or rock lead to longer ejecta distances. The data from **Table [5-10]** may be used as estimates for these cases.

(5) Hazard Criteria

The hazard from ejecta (crater, earth cover) is due to their kinetic energy (impact force) upon impact and due to their penetration or punching capability. This primarily affects weaker structural components such as roofs, ceilings and large walls of relatively low thickness.

Whereas less solid ejecta material (gravel, sand, clayey sand, clay, etc.) crumbles upon impact or is subjected to heavy deformations, solid, practically undeformable material (e.g. rock, broken stone, gravel) has a hazardous penetration and punching capability.

Penetration by "Undeformable" Ejecta

"Quasi-undeformable" ejecta transfer high, short shock impulses to the target material exposing it to risk of punching or perforation.

The penetration capability of high-strength rock (basalt, granite) as compared to soft rock (friable standstone, slate) may be assumed to be **7 to 1 .**

Figure [5-9] shows the penetration of mild steel plate by hard rock ejecta.

Figure [5-10] shows estimates of the perforation threshold of non reinforced concrete slabs for the impact of hard rock ejecta.

The diagrams are based on the conservative assumption of an impact of "undeformable" ejecta in a realistic velocity range.

Hazard thresholds for persons and material -->> Section VII

(6) Load Assumptions for Structural Component Design

Undeformable Crater Ejecta

The design of structural components assuming dynamic loads can be facilitated in the case of solid ejecta using the **"impulse formulation"**.
(-->> Ref [7 (2.3 and 5.5)], [3])

Shock Impulse: $$I = M_{ej} \cdot V_i \quad \text{(Ns)} \qquad \text{eq [5-63]}$$

Maximum Deformation: $$y_m = \frac{I^2}{2 \cdot M_{str} \cdot R_m} + \frac{y_{el}}{2} \quad \text{(m)} \qquad \text{eq [5-64]}$$

Deformable Crater Ejecta

Moist, cohesive ejecta is deformed upon impact and acts as solid ejecta with a lower peak impulse, but a longer effective duration.

Building damages are caused less due to punching than to local bending failures.

A simplified structural component design assuming a dynamic load can be carried out with the following formulations . . .

$$V_f = 0$$

$$1_d \approx 1.12 \cdot (M_{ej} / rho)^{1/3} \quad (m)$$

$$V_m = (V_i + V_f) / 2 \quad (m/s)$$

Mean shock impulse: $I_m = M_{ej} \cdot V_m$ **(Ns)**

Deformation assumption (empirical) : $x_{pl} = 2/3 \cdot 1_d$ **(m)**

Shock period:

$$t_d = \frac{x_{pl}}{V_m} + \frac{2 \cdot l_d}{2 \cdot v_m}$$

Load:

. . . Peak load for triangular load history:

$$F_{max} = \frac{2 \cdot I_{dm}}{t_d} \quad (N)$$

. . . Peak load for constant load history:

$$F_d = \frac{I_m}{t_d} \quad (N)$$

Figure [5-10] shows estimates for the maximum shock loads of long distance ejecta.
(-->> Ref [1])

Dynamic Strength Increase

The short-time loading of protective structures - ammunition storage magazines, aircraft shelters, etc. - involves an increase in strength of the loaded material as a function of loading rate.

For the load cases described, the **"Dynamic Increase Factor" (DIF)** should be selected from the values given in **Table [5-11]** and **Ref [1], [4]** respectively.

2.5.3.4 *References*

Essential references **-->> Section VIII**

Ref [1], [3], [4], [7], [31], [32], [33], [41], [76], [77], [78], [83], [84], [86], [96] [128], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165, [166], [167], [168], [171], [173], [174], [181], [182], [183], [189], [192], [199], [200], [201], [202], [203], [204]. [211]

Section V - Ground Shock

2.5.4.1 *General*

Ground shock constitutes a grave danger to structures and their contents. In general, however, ground shock is no critical parameter in the design of airblast and fragment resistant buildings.

Ground shock effects are very dependent on various charge configurations (e.g. sphere tangent to and above ground surface, half-buried or hemispherical charges).

This paragraph describes the ground shock effects of surface and near-surface bursts.

Test detonations in the order of . . .

$$\mathbf{0.5\ kg \leq NEQ_{TNT} \leq 500\ 000\ kg}$$

. . . have been evaluated and have supplied data for scaled distances.

$$\mathbf{0.2 \leq z\ (m/kg^{1/3}) \leq 24}$$

2.5.4.2 *Phenomenology*

ee) General

Ground shock is a result of energy imparted to and propagating within the ground. Sources of energy may be shocks due to explosions or mechanically produced shocks. In the event of an explosion, the shock loads generated in the vicinity of the point of burst are transmitted directly through the ground as well as in-directly by means of the airblast wave.

According to the manner of induction, two types of ground shocks are distinguished:

- **DI-Ground Shock / Direct-Induced Ground Shock**

- **AI-Ground Shock / Airblast-Induced Ground Shock**

ff) Direct-Induced (DI) Ground Shock

The DI ground shock comprises the original, directly induced ground motions as well as those induced by cratering. The latter are generally of longer duration and are the result of cratering explosion events. In general, both phenomena are of longer duration than the **AI** ground shock. The shock waveform is usually sinusoidal. Although the dominant motions are vertical, a DI ground shock may have strong horizontal components, especially at close-in distances.

gg) Airblast-Induced (AI) Ground Shock

The airbast wave compresses the ground surface and transfers the shock impulse to the adjacent medium. Magnitude and duration of the shock impulse depend upon the progression of the blast wave and the characteristics of the ground medium. In general, the induced ground motions are directed downwards. Starting with maximum intensity at the ground surface the motions attenuate with depth. Discontinuities of the ground material and stratifications, e.g. groundwater, rock layers, may change the attenuation process. In general, however, the surface soil layer is the decisive factor.

Both types of shock act independently of each other. The decisive shock (motion) parameters - displacement, velocity and acceleration of the soil particles - depend upon the super-position and the time of arrival of the different shock waves. Primarily, this time is determined by the shock front velocity or the peak overpressure of the airblast wave, respectively, by the seismic velocity, and the distance between the point of burst and the exposed site.

In the vicinity of the point of burst, the airblast shock front velocity is substantially higher than the seismic velocity within the ground. Within this **"superseismic region"**, the air-blast reaches the exposed site before the **DI** ground shock wave. With increasing distance from the point of burst the velocity of the airblast wave decreases and the **DI** ground shock wave finally catches up with and outruns the blast wave within the "out-running region", resulting in the superposition of both shock waves. At greater distances, the two waves may separate again, with the DI wave leading the AI wave.

2.5.4.3 *Physical Fundamentals for Ground Shock Computation*

hh) General

Literature analyses show that, in fact, on the **AI** ground shock correlates quantitatively with the test results. The acoustic impedance **'cp · rho'** and the pore volume of the soil seem to be the important material parameters in this context.

Formulations for the computation of **DI** ground shock parameters for three essential types of soil - dry soil, saturated soil, and rock - are given in **Table [5-14]**. Generally, further subdivisioning does not result in substantially greater accuracy.

ii) AI Ground Shock

The **AI** ground shock can be determined by means of a one-dimensional wave propagation theory.

For surface structures with a response behavior unaffected by seismic wave reflected from soil layers, simple empirical conditional equations will result.

The equations given in **Table [5-12]** provide reasonable estimates of the **AI** ground shock at the soil surface, assuming a homogeneous soil structure for a distance corresponding to the wavelength of the blast wave.
For design purposes, the overall motions of structures with shallow foundations may be considered to be similar to the motions described.

jj) DI Ground Shock

For the determination of **DI** ground shock, empirical equations have been developed **(-->> Table [5-14])**, which may be applied to TNT surface or near-surface bursts.

The equations are given for 3 selected types of soil . . .

. . . dry soil,
. . . saturated soil,
. . . rock.

2.5.4.4 *Design Implications*

kk) General

The effects of ground shocks have to be considered in connection with safety and design requirements. There are safety problems for or hazards to personnel, traffic routes, inhabited buildings, installations of ammunition storage facilities and equipment. Therefore, the consideration of shock processes in the design is imperative. The designing engineer certainly requires suitable basic design data, e.g. in the form of permissible limits of motion parameters in the vicinity of the exposed site.

ll) Personnel

Personnel is subjected to shock effects via the ground itself or the structure in which they are staying at the time of an explosion. The human body will be exposed to accelerations and vibrating loads. The

hazards to personnel are: impact on hard surfaces or edges, distortion of limbs or possibility of being hit by objects which have been accelerated as a result of the shock.

mm) Inhabited Buildings

Referenced sources derive the vulnerability levels of inhabited buildings and other unhardened inhabited facilities from the motion parameters of the ground medium exposed to the ground shock load.

nn) Magazines

When determining the permissible minimum distances between ammunition storage buildings such as magazines and explosives workshops, the ground effect is an important factor. In general, the buildings concerned are massive and solid structures with shallow foundations which must be capable of withstanding a relatively high airblast as well as the impact of debris and fragments. The destruction of aboveground ammunition storage facilities by a **DI** ground shock is thus quite improbable. The deeper a building extends into the ground, though, the stronger is the effect of the DI ground shock.

Although at common inter-magazine distances small explosives quantities cause high accelerations of the soil particles, there are practically no damages because of the slight soil displacements and the small quantity of energy imparted.

In the case of large explosives quantities, the accelerations are relatively low, but high ground motion velocities and large displacement may however constitute a substantial hazard to external connections and joints of the building, which may be torn off. Usually, suitable design is an easy way to counteract that hazard. For closely situated magazines, the **AI** ground shock is negligible.
(-->> Ref [4])

oo) Equipment

In general, equipment and explosives located in ammunition storage facilities are highly vulnerable to shock effects. Electric and electronic installations, in particular, have to be shock-hardened.

The shock is imparted either directly through the structure itself or indirectly by way of displacement (falling down, impact etc.) of equipment.

The hazards described can be avoided by the following design measures:

- Determination of the shock response spectrum (SRS) for the soil-structure interaction at a specified shock loading.
- Determination of the shock tolerance spectrum (STS) for essential pieces of equipment;
- Performance of a shock analysis;
- Installation of dynamically loadable mounting elements;
- Installation of dampers and isolators with mathematically proven performance characteristics;
- Purposive shock tests for the determination of the specific shock effects.

Hazard limits: -->> Section VII

2.5.4.5 *Design Procedure*

For the protection of personnel and equipment against ground shock effects the design procedure described below is recommended:

- Determination of the relevant soil characteristics and detonation parameters;

- Computation of the motion parameters of the ground using specified formulas;

(-->> Table [5-12], [5-14]; -->> Ref [1], [3])

- Comparison of the maximum motion parameters to be encountered with the limits specified in Section VII;

- Application of shock-hardening measures, if the limits are exceeded;

- Assessment of the potential damage to sensitive equipment by means of a **S**hock **R**esponse **S**pectrum (**SRS**) and an equipment-specific **S**hock **T**olerance **S**pectrum (**STS**);
  Detailed information on simple methods for preparing **SRS** or **STS** are given in Ref [1], [3], [4];

- Superposition of the two shock spectra; if the values of the **SRS** exceed those of the STS, the equipment concerned must be shock-hardened; specific analyses/tests may be required in order to determine the tolerance of specific equipment.

2.5.4.6 *References*

Essential references **-->> Section VIII**

Ref [1], [3], [4], [76], [77], [78], [150], [151], [153]

Section VI - Cratering

2.5.5.1 *General*

This section describes the cratering process and the essential relevant parameters, depicts the spectrum of effects and the hazard potential and specifies formulations for the determination of the decisive crater dimensions - diameter, depth and volume.

In comparison with the other hazards resulting from an accidental explosion, cratering effects are usually of minor importance. In certain situations, however, cratering may cause severe damage because of excavation, subsurface disturbances or surface heaves. Under certain conditions, the propagation of detonation to an adjacent magazine is also possible.

Hazards from crater ejecta and structural debris have to be taken into consideration, particularly for larger quantities of stored ammunition and explosives.

These hazards are detailed in Section VII.

2.5.5.2 *Phenomenology*

A Crater is a hole in the ground resulting from mechanical displacement of the adjacent ground material in the course of an explosion of demolition charges.

Primarily, a crater is defined by the following parameters:
(-->> Figure [5-12])

- The "apparent crater" is the visible cavity left after an explosion and is defined by the "apparent radius" and the "apparent depth".

- The "true crater" is the entire cavity formed by an explosion part of which is being filled up again by the fallback (fallen back ground material). The "true crater" is defined by the "true radius" and the "true depth".

- The "rupture zone" is that region at the crater flanks, where the ground material remains in place, but its inner structure is substantially disturbed by the forces of the explosion.

- The "plastic zone" is the area adjacent to the "rupture zone" and is less disturbed than the latter.

- The "upthrust zone" is the original ground above the rupture and plastic zones that has been permanently elevated. The "upthrust zone" is usually covered by the crater ejecta.

- The "Crater lips" is the material around the crater that lies above the original surface elevation and is formed by upthrust and ejecta. The "Crater lips" may extend to widths of several crater radii.

2.5.5.3 *Crater Computation*

pp) Decisive Parameters

The crater size depends mainly upon the following parameters:

- **Type of explosive;**
- **Net Explosives Quantity (NEQ;**
- **Depth of Burst (DOB) / Height of Burst (HOB)**
- **Stratification and type of soil.**

qq) Depth of Burst (DOB)

Figure 5-13 illustrates the variation in crater size and formation as a function of the **DOB**. Cratering is described here from a classical context and no direct account is taken of the inefficiency associated with accident explosions in most storage situations when compared with the standard, buried charge situation.

Accidental explosions which are large enough to form craters originate from concentrations of explosives in a number of different configurations, typically:

- On or just above the ground surface, e.g. in transport vehicles **(-->> Figure 5-13a)**.

- In deep-buried magazines where the explosions are less efficient in producing craters ad ejecta than the standard buried charge from which most cratering data has been obtained **(-->> Figure 5-13b)**. The difference is mainly one of degree related to the free volume inside the magazine and the mechanics of the crater formation and throw-out of ejecta / debris is essentially the same.

- Underground magazines where the depth of cover is such that no external crater is formed as a result of an explosion **(-->> Figure 5-13e)**.

For constant explosive quantity and type of explosive, crater size increases with depth of burst until the maximum crater size is reached at the optimum **DOB**.

When the **DOB** is further increased, soil resistance exceeds the explosion energy; cratering is suppressed and fallback of the crater ejecta increases, thus constantly reducing the visible crater size. Beyond a certain **DOB**, there is no cratering at the surface any more.

Finally, complete confinement of the ground burst occurs. This results in surface heaves and soil disturbances as well as in the forming of subsurface craters or camouflage craters.

rr) Stratification and Type of Soil

Cratering is mainly determined by the type of soil, the stratification near the ground surface and the water content of the soil.

Important relevant findings are:

- Craters in sandy soil are smaller than those in clay soil. Other types of soil, such as clayey sand, silt or loam, fall in between these two extremes.

- Craters in moist or saturated soil are larger than in dry soil. This applies, in particular, to clay soil.

- Subsurface layers such as groundwater-saturated soil or rock may strongly influence the crater size. This applies when the distance in depth to the layer concerned is less than 1.5 Ra (Ra for layer free soil), and results in more shallow but wider craters. If the layer is intersected by crater, the variation in size may be up to 50 % below or above the corresponding undisturbed crater parameter (depth, radius). In cases where the groundwater level lies approximately 2 m below the surface, a large explosion may form a crater with twice the diameter of a crater in soil without groundwater.

- In the case of saturated soil of relatively low density, there may be soil liquefaction effects causing a slump of the crater walls. The resulting crater is very wide and shallow, with a radius several times that of a normal crater. The liquefaction effects may endanger the stability of structures at distances of 20 to 30 times the crater radius.

ss) Crater Dimensions

The results of many tests have been evaluated and prepared for practical use in the form of compensation functions or design diagrams.

Figure [5-14] shows the **"apparent crater"** dimensions for three types of soil.

For the determination of the **"true crater"** sizes for all **DOB** less than the **optimum DOB**, the following rule of thumb applies:

$$R_t \approx 1.10 \text{ to } 1.15 \cdot R_a \quad \text{(m)} \qquad \text{eq [5-65]}$$

$$D_t \approx 0.16 \cdot NEQ^{1/3} + DOB \quad \text{(m)} \qquad \text{eq [5-66]}$$

On the case of a surface or air burst, the crater is **"blown clear"** so that the "true crater" is approximately the same as the "apparent crater".

For DOB greater than the optimum, the diameter of the "true crater" corresponds largely to that for optimum DOB, whereas the depth of the "true crater" increases with DOB.

The rupture zone extends to approximately **1.5** to **2** times the radius of the "true crater" and **1.3** to **2** times the depth of the "true crater".
Generally, the plastic zone is twice as large as the rupture zone.

tt) Ammunition Storage Facilities

For determining the decisive crater parameters for a major accidental explosion inside an aboveground storage facility, the diagrams in **Figure [5-14]** to **[5-19]** or regression equations may be used.
It must be taken into account, though, that in the case of explosions inside structures the foundation or bottom slab-depending upon the loading density - either prevents the forming of a typical crater (loading densities in the order of **10 to 20 kg/m^3 (-->> Ref [77])** or, at higher loading densities, more shallow craters with greater diameters are formed.

The coupling factor **"f_o"** is used for converting the data of an underground storage facility completely filled with explosives to that of a partially filled one. For the specified loading densities, the coupling factor is . . .

$$\ldots \tau \approx 1600 \text{ kg / m}^3 \quad \text{--->>} \quad f_o = 100\% = 1.0$$

$$\ldots \tau \approx 10 \text{ kg / m}^3 \quad \text{--->>} \quad f_o = 10\% = 0.1$$

Coupling factor **'f_o'** :
-->> Figure [5-20]

Depending upon the loading density, the coupling factor reduces the ground shock, cratering and ejecta/debris effects. The effective or calculated explosives quantity results from the following product:

$$NEQ_{eff} = f_o \cdot NEQ_{TNT}$$

uu) Crater Parameter Formulas

(1) Symbols

R_a, R_t	**(m)**	radius of apparent/true crater
D_a, D_t	**(m)**	depth of apparent/true crater
V_a, V_t	**(m^3)**	volume of apparent/true crater
R_{sl}	**(m)**	fictitious crater radius for completely symmetrical explosive charge

L_{sl}	**(m)**	crater length for oblong explosive charge *)
B_{sl}	**(m)**	crater width for oblong explosive charge *)
D_{sl}	**(m)**	crater depth
V_{sl}	**(m)**	volume of apparent crater
sl		with bottom slab
a,f		apparent parameters; open surface burst without bottom slab

*) Here, " oblong explosive charge " means the usual distribution of explosives in an oblong ammunition storage building.

(2) Open Surface Burst Without Bottom Slab

According **Ref [32]** for sandy, gravely soil . . .

$$R_{a,f} = 0.400 \cdot NEQ^{0.333} \text{ (m)}$$

$$D_{a,f} = 0.200 \cdot NEQ^{0.300} \text{ (m)} \qquad \textbf{eq [5-67]}$$

$$V_{a,f} = 0.042 \cdot NEQ\ 0.960 \text{ (m}^3\text{)}$$

According to Ref [1], [2], [3] . . .

$$R_{a,f} = A \cdot NEQ^{B} \text{ (m)}$$

$$D_{a,f} = A \cdot NEQ^{B} \text{ (m)} \qquad \textbf{eq [5-68]}$$

	Basalt high-strength		Granite high-strength		Sandstone medium-strength	
	A	B	A	B	A	B
$R_{a,f}$	0.330	0.330	0.510	0.330	0.360	0.313
$D_{a,f}$	0.120	0.330	0.170	0.330	0.200	0.315
	Sandstone slate		Gravelly Sand dry		Coarse Sand dry	
$R_{a,f}$	0.760	0.294	0.590	0.294	0.570	0.294
$D_{a,f}$	0.320	0.294	0.200	0.294	0.220	0.294
	Sand-Clay coarse, dry		Fine-Grained Wet Clay		Silt, Clay saturated	
$R_{a,f}$	0.400	0.333	0.510	0.333	0.830	0.333
$D_{a,f}$	0.190	0.333	0.260	0.333	0.500	0.333

According to Ref [1], [2] . . .

- **Crater radius:**

$$x = DOB / NEQ_{TNT}^{1/3} \qquad \text{(m/kg)}^{1/3}$$

$$C = c_6 \cdot x^6 + c_5 \cdot x^5 + c_4 \cdot x^4 + c_3 \cdot x^3 + c_2 \cdot x^2 + c_1 \cdot x + c_0$$

	Clay		Clayey Sand		Sand	
	wet	dry	wet	dry	wet	dry
c_6	- 0.9138	3.4296	1.5254	6.6138	5.3895	3.9615
c_5	4.5971	-14.1268	- 7.5848	-21.6824	-19.9765	-13.9722
c_4	- 9.6611	20.7724	13.5517	25.5991	25.9610	17.1007
c_3	10.6273	12.7799	-10.4240	-13.2913	-13.6946	- 8.7749
c_2	- 7.0956	1.1501	1.4237	1.5053	0.7827	0.3314
c_1	3.1878	2.2545	2.2503	1.7332	2.1788	1.7526
c_0	1.7470	1.1539	1.2592	0.9416	1.0426	0.8610

$$R_{a,f} = \frac{C}{2} \cdot NEQ_{TNT}^{1/3} \quad (m) \qquad \text{eq [5-69]}$$

- **Crater depth:**

$$x = DOB / NEQ_{TNT}^{1/3} \quad (m/kg)^{1/3}$$

$$C = c_6 \cdot x^6 + c_5 \cdot x^5 + c_4 \cdot x^4 + c_3 \cdot x^3 + c_2 \cdot x^2 + c_1 \cdot x + c_0$$

	Clay		Clayey Sand		Sand	
	wet	dry	wet	dry	wet	dry
c_6	0.0000	0.0000	0.0000	3.9156	0.0000	0.0000
c_5	- 0.5074	- 0.5634	0.1109	-10.6347	- 1.7342	- 2.1635
c_4	1.8409	1.4661	- 0.5177	9.7514	4.6696	4.0866
c_3	- 2.0285	- 1.5432	0.7502	- 3.9218	4.6469	- 3.1802
c_2	- 0.3971	- 0.2424	- 1.4739	- 0.0049	0.8813	0.3980
c_1	1.4481	1.0880	1.3841	0.8711	0.9596	0.6974
c_0	0.5446	0.4125	0.4561	0.3016	0.3414	0.2616

$$R_{a,f} = C \cdot NEQ_{TNT}^{1/3} \quad (m) \qquad \text{eq [5-70]}$$

(3) Burst Inside a Detached Aboveground Magazine

According Ref [77], [32] . . .

$$R_{s1} \approx 1.5 \cdot R_{a,f} \quad (m)$$
$$D_{s1} \approx 0.8 \cdot D_{a,f} \quad (m) \qquad \text{eq [5-71]}$$
$$V_{s1} \approx 1.5 \cdot V_{a,f} \quad (m)^3$$

with eq [5-67] . . .

$$R_{s1} \approx 0.600 \cdot NEQ_{TNT}^{0.333} \quad (m)$$
$$D_{s1} \approx 0.160 \cdot NEQ_{TNT}^{0.300} \quad (m) \qquad \text{eq [5-72]}$$
$$V_{s1} \approx 0.063 \cdot NEQ_{TNT}^{0.960} \quad (m)^3$$

(4) **Burst Inside an Earth-Covered Aboveground Magazine**

For the derivation of universal crater parameters for earth-covered magazines only very few basic data are available.

The evaluation of a full-scale test with $\mathbf{NEQ_{TNT} = 75\ (to)}$ according to **Ref [86]** results in the formulations below, which are in reasonable relation to the above-mentioned explosion conditions and can therefore be recommended for estimation purposes . . .

$$\begin{aligned} R_{s1} &\approx 0.40 \cdot NEQ_{TNT}^{\,0.333} \quad (m) \\ L_{s1} &\approx 0.43 \cdot NEQ_{TNT}^{\,0.333} \quad (m) \\ B_{s1} &\approx 0.33 \cdot NEQ_{TNT}^{\,0.333} \quad (m) \\ D_{s1} &\approx 0.06 \cdot NEQ_{TNT}^{\,0.300} \quad (m) \\ V_{s1} &\approx 0.05 \cdot NEQ_{TNT}^{\,0.960} \quad (m)^3 \end{aligned} \qquad \textbf{eq [5-73]}$$

2.5.5.4 *References*

Essential references **-->> Section VIII**

Ref [1], [2], [3], [4], [17], [18], [19], [27], [163], [164], [165], [166], [167], [169], [170], [171], [172], [173], [174], [175]

Section VII - Thermal Radiation

2.5.6.1 *General*

Detonation of an explosive typically results in the production of a relatively short flash accompanied by high thermal radiation.

Normally, the radiation from this short-lived flame constitutes a negligible hazard in comparison with blast and projection effects. Propellants and pyrotechnic substances of Hazard Division 1.3 differ from detonating explosives of Hazard Division 1.1 in that, unless heavily confined, their reaction does not result in the generation of high blast pressures.

Although the energy per unit mass of these explosives is comparable, they differ in the duration of energy release. The energy of detonating explosives is released within a time scale of a few milliseconds, whereas energy from an unconfined propellant or a pyrotechnic substance is released over a period measured in seconds or longer. The energy is released in the form of an intense, very hot flame. The potential hazard is due to thermal radiation and the direct impingement of the flame.

As compared to blast and fragment/debris effects, there are only few studies on the effects of thermal radiation available which offer quantifiable formulations.

Thus, the statements below are coarse, conservative guidelines for determining the decisive hazard parameters of ammunition and explosives of Hazard Division 1.3 in the case of fire during storage and transport.

2.5.6.2 *Fireball Computation*

The development and the behavior of a fireball as well as the decisive parameters - dimensions, temperature, and duration - are generally varying and strongly affected by the environment (e.g. wind, buildings, vegetation etc).

Therefore, the formulations below may only be used as rough estimates:

vv) Burning of Propellant Powder in the Open
(-->> Ref [30])

(1) Radius of Fireball

. . . Maximum radius of fireball few meters above the ground

$$\mathbf{R_{max,\,a} = 2.8 \cdot NEQ^{0.28}\,(m)} \qquad \textbf{eq [5-74]}$$

. . . Maximum radius at ground level

$$\mathbf{R_{max,\,s} = 0.45 \cdot NEQ^{0.44}\,(m)} \qquad \textbf{eq [5-75]}$$

(2) Duration of Fireball

$$\mathbf{t_{eff,50} = 0.93 \cdot NEQ^{0.21}\,(s)} \qquad \textbf{eq [5-76]}$$

Note:
After ignition, the fireball expands and reaches a maximum within a period of about 2 seconds. After several seconds of intense radiation, depending upon the quantity of propellant involved, the fireball collapses. In general, the actual extinction of the visible flame occurs not until after thermal radiation has decreased to comparative insignificance. The effective duration of thermal radiation $\mathbf{t_{eff,50}}$, thus is de-fined by the time required for the fireball to shrink to **≈ 50%** of its maximum radius.

ww) Explosion of Explosives Inside an Earth-Covered Magazine
(-->> Ref [78]; -->> Figure [5-21])

(1) Radius of Fireball

$$R_{max} \approx 1.9 \cdot NEQ^{1/3} (m) \qquad \text{eq [5-77]}$$

(2) Temperature Inside Fireball

$$T \approx 5000 \quad (°C)$$

(3) Maximum Duration

$$d_{max} \approx 0.17 \cdot NEQ^{1/3} \qquad \text{eq [5-78]}$$

xx) Thermal Radiation Energy

The thermal radiant power of burning or exploding high explosives, propellants or liquids is difficult to measure or determine otherwise. Thermal radiant power, fireball geometry and duration are strongly affected by the type of packaging used, the direction and speed of the wind and the storage conditions.

Tests with bulk (unpacked) propellant powder (worst case) for an energy flux of . . .

$$q = 4\ cal/cm^2 = 40\ kcal/m^2 = 167\ kWs/m^2$$

. . . resulted in a formulation for the following limiting radius, at which the above value is reached . . .

$$R_{max} \approx 1.0 \cdot NEQ^{0.44} (m) \qquad \text{eq [5-79]}$$

This value will generally not be exceeded.

yy) Thermal Radiation Flux of Burning Propellant Powder

Thermal radiation flux of burning propellant powder is represented by the relationship below.
(-->> Ref [23])

$$q \approx 19 \cdot NEQ^{0.82} / R^2 (kW/m^2) \qquad \text{eq [5-80]}$$

where
NEQ (kg) = quantity of propellant powder
R (m) = distance from the radiation source

2.5.6.3 *Barriers to Resist Thermal Radiation and Flame from Ammunition and Explosives of Hazard Division 1.3*

Normal construction materials such as steel, concrete or brick as well as earth-covered structures can be used for the protection against thermal radiation and direct flame impingement.

Wooden or light metal doors and windows are structural weak points. Unless these doors/windows face away from the external source of thermal radiation, they must be considered non-resistant or vulnerable. Windows are diathermy and not resistant to direct flame impingement.

Heavy metal covers and closures resist thermal radiation and flame impingement.

Closures must be sealed as to prevent the entry of flames.

2.5.6.4 *Design and Construction of Storage Buildings for Ammunition and Explosives of Hazard Division 1.3*

Storage buildings shall be constructed of non-combustible materials such as steel, concrete, brick or natural stone. A standard earth cover may be considered as fireproof.

Buildings containing ammunition and explosives of Hazard Division 1.1 situated in the vicinity of storage buildings containing Hazard Division 1.3 ammunition and explosives must be built of non-combustible materials.

Buildings for the storage of ammunition and explosives of Hazard Division 1.3 must not contain any exposed components made of steel, iron, aluminum or aluminum alloy with magnesium content exceeding **1%**.

The ceiling or roof should be made of concrete, reinforced concrete or steel plate and be designed as light as possible (frangible cover).

Unless these requirements are met, flame jets ejected from openings (doors, windows) of the building have to be expected that might ignite e.g. opposite buildings.

In the case of opposite building entrances, these should be offset by a minimum distance of **one (1)** fireball diameter **(eq [5-77])** or a barricade capable of stopping or deflecting a flame jet should be erected across the line of sight to the adjacent building entrance.

Windows and/or wooden doors and other openings in unbarricaded storage buildings should be covered using heavy steel plate backed up with thermal insulation material. The cover must be large enough to cover all combustible structural components such as wooden frames.

Air vents and air shafts must be designed in such a way as to prevent the fireball, flame jet or burning debris from entering the interior of the building.

If buildings for the storage of ammunition and explosives of Hazard Division 1.3 are equipped with a blow-out wall (frangible cover), this weak wall must not face any stack or storage building, unless the distance is great enough to prevent sympathetic detonation due to directed burning debris.

2.5.6.5 *Hazards form Fire Involving Ammunition and Explosives of Hazard Division 1.3*

Thermal radiation from the fireball produced by burning ammunition and explosives of Hazard Division 1.3 is capable of causing injury to personnel and of communicating the fire to other buildings and explosives storage facilities. This hazard may be substantially increased by even normal winds, which will deflect the upper parts of the fireball away from the seat of fire. This may cause the thermal radiation source to be moved closer to the exposed site in the order of one radius of the fireball.

Ammunition and explosives of Hazard Division 1.3 are normally packaged before storage or transport. A typical storage arrangement would place the ammunition or explosives in buildings of different construction. The confinement produced by even a weak building is sufficient to significantly affect the mode of burning of stacks of propellant powder. The range of a directed high-energy jet of flame which may emerge through openings or frangible covers will be much longer than the comparable flame radius of the unconfined explosive. Furthermore, direct impingement of such a jet of flame will impart a greater heat dose to an exposed object than radiation from a fireball, and may also eject burning stored items and other burning material.

In strong storage buildings a fire can lead to the buildup of high pressure generating effects comparable, after all, with those of a detonating explosive, i.e. cratering, airblast and debris projection.
(-->> Ref [23])

Confined explosions constitute the hazard of a cone of flame being ejected through destroyed openings (doors, etc.) which may extend beyond the permissible quantity distance for Hazard Division 1.1.
(--->> Ref [23])

2.5.6.6 *References*

Essential references **--->> Section VIII**

Ref [1], [4], [20], [21], [22], [23], [78]

Section VIII - Damage Criteria / Hazard Limits
- Risk Assessment Guidelines -

2.5.7.1 *Personnel*

zz) Airblast

Airblast caused by an explosion endangers personnel in different ways through:

- **The shock wave and the time-depending overpressure;**
- **The debris from destroyed structures or accelerated objects;**
- **The impact of the accelerated human body on obstacles or on the ground.**

The body regions most endangered by airblast are:

- **The respiratory system with lungs and trachea;**
- **Head;**
- **Ears and ear-drums;**
- **Spleen, liver, heart.**

The extent of the injuries caused directly by airblast is strongly affected by:

- **The rate of pressure increase within the shock front;**
- **The peak overpressure within the shock front;**
- **The duration of the positive pressure phase.**

Damage thresholds according to literature analyses:

(1) Direct Airblast Effect

Type of Injury / Position	P %	T_o ms	P_s Mpa	I_s MPa-ms	Ref
LETHALITY	1	3	2.00		[18]
	1	5	0.90		[207]
	1	100	0.25		
	1	> 1000	0.28		[207]
	50	3	3.00		[18]
	50	5	1.20		
	50	100	0.35		
	50	> 1000	0.35		[207]
	99	3	4.00		[18]
	99	5	1.70		
	99	100	0.50		
	99	> 1000	0.50		[207]

(-->> Figure [5-27])

Type of Injury / Position	P %	T_o ms	P_s Mpa	I_s MPa-ms	Ref
HEAD REGION	1 50 99			0.382 0.527 0.676	[149]

(-->> Figure [5-22] and [5-23]

LUNGS	1 50 99 1 99	 3-5 3-5	0.13 0.144 0.28 0.21-0.28 0.58-0.63		[149] [18] [74] [4]

LUNGS -Lethality - Standing Person	1 1 1 50 50 50 99 99 99	2 20 100 2 20 100 2 20 100	0.56 0.22 0.21 0.88 0.32 0.28 1.05 0.42 0.38		[207]

LUNGS -Lethality - Prone Person	1 1 1 50 50 50 99 99 99	2 20 100 2 20 100 2 20 100	1.13 0.35 0.28 1.76 0.56 0.44 2.81 0.81 0.70		[207]

UPPER RESPIRATORY SYSTEM	1 1 99	4 10 10	0.070 0.035 0.127		[47]

(-->> Figure [5-24])

EARDRUM **-Temporary loss of hearing** **-Threshold inside a shelter**	**1** **50** **99**		**0.035** **0.044** **0.086** **< 0.035** **> 0.017**		**[74]** **[4]**
GASTROINTESTINAL TRACT	**1** **1** **99** **99**	**4** **10** **4** **10**	**0.1200** **0.135** **0.250** **0.250**		**[74]**

(2) Indirect Airblast Effect

(-->> Figure [5-25] and [5-26])

Type of Injury / Position	P %	V_{cr} m/s	Ref
LETHALITY FOR IMPACT OF WHOLE BODY ON HARD SURFACE (CONCRETE)	**0** **1** **50** **99**	**3.0** **6.5** **16.5** **42.0**	**[144]**
STANDING PERSON, STIFF-LEGGED **No Effect** **Injury** **Fracture**		 **2.4** **3.0-3.6** **3.6-4.8**	**[19]**
SITTING PERSON **No Effect** **Injury**		 **2.4** **4.5-7.8**	**[19]**
PUNCH against entire ABDOMINAL WALL **Injury**	**1** **50** **99**	**3.0** **7.8** **9.0**	**[19]**

(-->> Figure [5-27]

SKULL INJURY; FRACTURED SKULL BASE **Blunt Impact** **Edgewise Impact**	**1** **50** **99**	**3.0** **5.5** **9.0** **< 3.0**	**[4]**

aaa) Projections
- Fragments, Debris and Ejecta -

Because of the complexity of the process, the reliable determination of the ballistic parameters of projections from accidental explosions is difficult. Basic data and information on structural debris and crater ejecta are limited as compared to fragment data.

The hazards to the different regions of the human body - depending upon their respective sensitivity - are listed below in descending order:

- **Head region : fractured skull**
- **Chest region : fractured rip, pneumorrhagia, cardiac damage**
- **Abdominal region : damage to liver, spleen**
- **Limbs : bone fracture and secondary damage**

The unprotected area of a standing person is defined to be . . .

$$A_T = 0.56 \text{ m}^2$$

The currently accepted limit values for hazards to persons due to projections are as follows:-

- **Mass density : 1 projection / 56 m ^{2} (1/600 ft ^{2})**
- **Impact energy ($E_{kin} = M \cdot V^2 / 2$) : 80 Joule (58 ft/lb$_f$)**

With projections as described above, severe to lethal injuries have to be expected as a rule.

Table [5-15] lists discriminating limits for blunt impact injuries based on empirical tests with animals and corps.
(-->> Ref [4], [19], [31], [206])

Table [5-15]

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

Note:
Figure [5-29] and [5-30] show lethality as a function of impact energy

Using the Walker-Duncan-method, formulas to calculate the probability of penetration of human and animal skins by projectiles have been developed.
(-->> Ref [136], [137], [139], [144])

Probability of penetration of human skin:

$$P_i = \frac{1}{1 + e^{(-(A + B \cdot \ln C))}}$$

eq [5-81]

TARGET	A	B	Ref
Bare Skin	- 28.42	2.94	[144]
Bare Skin	- 27.35	2.81	[136]
Uniform, 2 Layers	-48.47	4.62	[159]
Uniform, 6 Layers	- 50.63	4.51	

Constant C :

$$C = \frac{M_p \cdot V_i^2}{10 \cdot A_f}$$

M_p (kg) mass of projectile
V_i (m/s) impact velocity
A_f (m^2) projection area of projectile

bbb) Shock

The following shock loading threshold values for personnel are commonly accepted.
(-->> Ref [4], [144])

Table [5-16]

THRESHOLD FOR SHOCK LOADING ON PERSONNEL	
DAMAGE	CRITICAL IMPACT VELOCITY $V_{i.cr}$ (m/s)
Minor	3.0
Threshold	4.0
50% Skull Injury	5.5
100% Skull Injury	7.0

THREAT	ACCELERATION a (g)
Loss of Balance	
- nuclear, horizontal	0.5
- nuclear, vertical	1.0

CRITICAL OSCILLATION TOLERANCES FOR PERSONNEL	
Acceleration (g)	Frequency (Hz)
2	< 10
5	10 - 20
7	20 - 40
10	> 40

ccc) Thermal Radiation

Burns may be classified in ascending order of severity as:

- First degree burn : reddening and swelling of the affected skin region, pain, healing without scarring;

- Second degree burn: (a) reddening, swelling, pain, blistering, healing without scarring;

(b) anemic skin / no coetaneous circulation/leatherlike white necrosis, pain, blistering, scarring (necrosis = devitalized tissue) ;

- Third degree burn : total necrosis, destruction of skin to the point of charring, open flesh, no pain.

The degree of burn is a function of the total dose of radiation energy received and of the radiant power, i.e. the radiation energy received per unit of time.
(-->> Figure [5-31])

Table [5-17] ; Ref [89]

RADIANT ENERGY REQUIRED TO CAUSE FLASH BURNS			
PERIOD	**RADIATION ENERGY**		**DEGREE OF BURN**
t_w (s)	**(kWs/m ^{2})**	**(cal/cm ^{2})**	
$t_w < 1$	**62.8**	**1.0**	**1**
	125.6	**3.0**	**2**
	188.4	**4.5**	**3**
$t_w \approx 5$	**125.6**	**3.0**	**1**
	251.2	**6.0**	**2**
	376.7	**9.0**	**3**
Source: AASTP - 1 Corr No 7			

Ref [140] specifies the radiant power or radiation energy of burning fuel - as an equivalent of burning propellants or pyrotechnic substances - required for causing the different degrees of burn on human bodies as follows . . .

Table [5-18]

RADIATION INTENSITY q / t_w (kW · s / m ^{2}			
DEGREE OF BURN	**PROBABILITY OF INCIDENT**		
t_w (s)	**1%**	**50%**	**99%**
1st degree	**38.5**	**68.8**	**122.7**
2nd degree	**87.8**	**156.4**	**278.6**
3rd degree	**92.8**	**184.5**	**364.1**
t_w = active duration of the radiation			

2.5.7.2 *Damage Criteria for Structures and Materials*

ddd) Airblast

Damage to structures caused by conventional ammunition and explosives:

Table [5-19]

Symbols:	**X occasional**	**C heavy damage**
	A minor damage	**D destruction**
	B medium damage	**Pressure: Pso [kPa]**

DAMAGE CRITERIA FOR STRUCTURES / COMPONENTS DUE TO PRESSURE						
OBJECT	**X**	**A**	**B**	**C**	**D**	
glass, large window	**0.2**	**-**	**-**	**-**	**-**	
glass, typical	**-**	**1.1**	**-**	**-**	**3.5-7.0**	
window frame	**0.5**	**-**	**-**	**-**	**-**	
window frame	**-**	**10.6**	**-**	**-**	**-**	
door frame	**-**	**10.6**	**-**	**-**	**-**	
door, window	**-**	**-**	**-**	**-**	**6.0-9.0**	
plaster	**-**	**3.5-7.0**	**-**	**-**	**-**	
tiles (roof)	**-**	**3.0**	**-**	**5.3**	**-**	**0%-50%**
dwelling house	**-**	**3.0*)**	**8.1**)**	**36.6**)**	**80.9**)**	
wall, ceiling	**-**	**-**	**-**	**14.1**	**-**	**partial**
concrete wall, 0.3 m	**-**	**-**	**-**	**14-21**	**-**	**plain**
unreinforced build.	**-**	**-**	**-**	**-**	**70.3**	**cd**
brick wall	**-**	**-**	**-**	**56.3**	**70.3**	
brick wall, 20-30 cm	**-**	**-**	**-**	**-**	**56.3**	**flexure**
brick wall, 45 cm	**-**	**-**	**-**	**-**	**91.4**	**cd**
steel building	**-**	**9.1**	**14.0**	**17.6**	**21.1**	
wooden building	**-**	**-**	**12.0**	**17.0**	**28.0**	
building, block	**-**	**-**	**70.0**	**-**	**-**	
factory chimney	**-**	**14.0**	**-**	**-**	**-**	
industrial building	**-**	**-**	**28.0**	**-**	**-**	
administr. building	**-**	**-**	**38.0**	**-**	**-**	
brick building	**-**	**-**	**28.0**	**-**	**-**	
RC-structures	**-**	**-**	**38.0**	**53.0**	**-**	
steel girder build.	**-**	**-**	**-**	**31.6**	**63.3**	
cladding of build.	**-**	**7.0**	**-**	**-**	**14.1**	
heavy bridge	**-**	**-**	**-**	**-**	**492.3**	
steel truss bridge	**-**	**-**	**-**	**-**	**63.3**	**coll.**
motor vehicle	**-**	**28.2**	**35.2**	**70.3**	**-**	**crushed**
rail car	**-**	**18.3**	**39.4**	**60.5**	**77.4**	
wooden utility pole	**-**	**28.0**	**-**	**-**	**-**	**snapped**
power mast	**-**	**28.0**	**-**	**-**	**-**	**snapped**
radio mast	**-**	**14.0**	**-**	**-**	**-**	**snapped**
oil storage tank	**-**	**6.3**	**21.0**	**24.6**	**28.1**	
tree	**-**	**-**	**-**	**21.1**	**175.8**	**90%**

*) **inhabitable** **cd** **completely demolished**
) **uninhabitable **coll.** **collapsed**

Damage limits for brick buildings:
-->> Figure [5-32]

eee) Projections

The impact of hard projections at relatively high velocities results in extremely high local load peaks at the target (ES) with relatively short impulse duration. In general, hazards are presented due to the perforation or punching of the affected structural component. Spalling involving high secondary projection velocities may occur at the backside of the target. The hard projections often ricochet off the target and cause damage in the vicinity. The extent of the damage depends upon the geometry and material properties of the target and has to be analyzed in detail.

Figure [5-10] and **[5-11]** show approximate data for the thickness of unreinforced concrete slabs required in the case of hard projection impact.

Normally, deformable projections transfer their entire kinetic energy to the target or break upon impact. The longer shock pulse duration resulting from the deformation leads to a reduced peak load. As compared to the impact of hard projections, the punching and perforation hazard to the target is

substantially reduced. The structural component affected is, however, subjected to a higher bending load.

Figure [5-10] shows approximate data for load peaks due to the impact of deformable projections (ejecta).

fff) Shock

(1) Inhabited Buildings

The damage threshold values below are recommended for inhabited buildings . . . .

Table [5-20]

DAMAGE THRESHOLD FOR DIRECT-INDUCED GROUND SHOCK / Ref[89]		
DAMAGE	**max. VELOCITY vertical/horizontal V_{max} (m/s)**	**SCALED DISTANCE Z (m/kg $^{1/3}$)**
No	≤ 0.05	6.6
minor/medium	0.05 - 0.14	3.6
heavy	0.14 - 0.19	2.9

Note:
All the scaled distances above are shorter than the inhabited building quantity distance. They are also within the airblast and projection hazard zones.

Table [5-21]

DAMAGE THRESHOLD for AIRBLAST-INDUCED GROUND SHOCK (for -3- selected soils) Ref [89]				
DAMAGE	**$V_{v/h,max}$**	**SCALED DISTANCE Z (m/kg$^{\wedge 1/3}$)**		
	(m/s)	**soil -1-**	**soil -2-**	**soil -3-**
No	**≤ 0.05**	**5.7**	**3.4**	**2.9**
Minor/medium	**0.05 - 0.14**	**2.7**	**1.7**	**1.5**
heavy	**0.14 - 0.19**	**1.5**	**1.0**	**0.8**

No	TYPE OF SOIL	DENSITY Rho	SEISMIC VEOLOCITY C_p
		(kg/m ^{3})	(m/s)
1	**Soil**	**1520**	**460**
2	**Saturated soil**	**2000**	**1520**
3	**Rock**	**2560**	**4000**

For similar damage levels, the scaled distances for AI ground shock are shorter than those for DI ground shock. Therefore, it is not likely for the AI ground shock to be used as a measure for the determination of critical inhabited building quantity distances.

Other threshold values for comparison:

- For buildings required to retain their useable condition, German Standard DIN 4150, Part 3, specifies the following max. oscillating velocities resulting from a short shock load.

Table [5-22]

CRITICAL OSCILLATING VELOCITY	
- dwelling and business building	0.008 m/s
- braced buildings with heavy components; braced skeleton buildings	0.030 m/s
- historical buildings/monuments	0.004 m/s

- **Ref [10]** specifies the threshold values below for normal buildings in good condition:

Table [5-23]

CRITICAL OSCILLATING VELOCITY ON BASE Ref [10]	
- individual, minor damage	0.070 m/s
- damage threshold	≈ 0.140 m/s
- 50% structural damage	≈ 0.180 m/s

(2) Magazines

Ref [78] specifies the limiting criteria below for damage to or destruction of earth-covered magazines:

Table [5-24]

CRITICAL SOIL PARTICLE VELOCITIES FOR AMMUNITION STORAGE BUILDINGS Ref [78]	
QUANTITY OF STRUCTURE	max. VELOCITY of soil particles V (m/s)
- no damage	< 0.2
- rigid frame prefabricated concrete buildings	0.2 - 1.5
- heavy reinforced concrete magazines	3.0

(3) Equipment

Shock tolerance limits -->> Ref [1], [3], [4] et al.

Some selected examples . . . . . .

Table [5-25]

SHOCK TOLERANCES FOR SELECTED EQUIPMENT			
EQUIPMENT	DAMAGE a (g)		FREQUENCY f_{min}
	no	heavy	(Hz)
- Heavy weight machinery . engines, generators, . transformers M > 2000 kg	10	80	5
- Medium weight machinery . pumps, condensers,	15	120	10

SHOCK TOLERANCES FOR SELECTED EQUIPMENT			
EQUIPMENT	DAMAGE a (g)		FREQUENCY f_{min}
	no	heavy	(Hz)
. air conditioners M ≈ 500 - 2000 kg			
- Light Weight machinery	30	200	15
. small engines > 500 kg			
- Duct work, piping, storage batteries	20	280	5
- Electronic equipment, relays, magnetic drum units, racks of communication equipment	2	20	10

a (g) acceleration ; $f_{min.}$ (Hz) minimum natural frequency

ggg) **Thermal Radiation**

Thermal radiation can damage or destroy buildings. The damages range from scorching to complete burning of structures. Heating of non-combustible materials may result in reduced strength and stiffness and thus in the collapse of the building.

On principle, there are two **(2)** different damage classes resulting from thermal radiation.
(-->> Ref [140])

Class -1- : - burning of a building or of essential structural components
- collapse of a building or of essential structural components

Class -2- : - heavy scorching of the building surface and deformation of non-combustible structural components without collapse

For different materials, critical radiation flux values are specified. This critical intensity is defined as that value which causes no ignition even after prolonged exposure.

Table [5-26]

CRITICAL RADIATION INTENSITY kW / m ^{2}		
MATERIAL	CLASS -1-	CLASS -2-
Wood	15	2
Plastics	15	2
Glass	4	-
Steel	100	25

Hazardous radiation flux limits: -->> ref [21]

The estimated limits below may be used for determining the maximum acting thermal radiation flux **q . . .**

5 kW/m ^{2} breaking of windowpanes sensation of pain due to thermal radiation burn
10 kW/m^2 occurrence of scorching possible ignition of combustible material
15 kW/m^2 spontaneous ignition of material, e.g. wood

hhh) Sympathetic Detonation

(1) General

As for the sympathetic detonation as a function of different detonation effects, only insufficient quantitative limits are available. Several studies have attempted the formulation of such limits.

Airblast involving high peak overpressure, shock and the impact of projections may result in the sympathetic detonation of high explosives. The individual tolerance thresholds of the high explosives, however, are varying.

(2) Airblast

Except for extremely high pressures, the majority of high explosives are insensitive to airblast effects. In most cases, the sympathetic detonation is caused by secondary effects, such as the projection of the high explosive against a hard impact surface.

(3) Shock

The shock-induced motion of the storage building or the displacement of the explosive and the resulting impact on a hard surface may lead to a sympathetic detonation.

Ref [78] specifies critical soil particle velocities. According to this reference, the propagation of detonation will be **1.5 m/s** for prefabricated, solid concrete structures and **3 m/s** for heavy reinforced concrete storage buildings.

(4) Fragments

Because of their high kinetic energy, fragments can cause the sympathetic detonation of adjacent ammunition components. Therefore, buildings or structural components should be designed fragment-proof and open-storage stacks should be separated by the required quantity distances.
(-->> Ref [4])

Protective roofs and barricades are important means for preventing sympathetic detonation due to fragment impact.

The limits below may be used as estimates for the impact energy and the critical impact impulse.
(-->> Ref [89])

Table [5-27]

CRITICAL PROPAGATION IMPACT PARAMETERS		
IMPACT VELOCITY V_i (m/s)	**ENERGY E_{kin} (J)**	**IMPULSE I (Ns)**
≤ 50 m/s	**----**	**100**
≥ 50 m/s	**2500**	**----**

(5) Craters

The radius of the crater to be expected should be used as the relevant assessment parameter. If the acceptor magazine (ES) is located within the area defined by the radius of the crater, sympathetic detonation has to be expected.

(6) Thermal Radiation

Adjacent ammunition storage buildings are normally located within the fireball area. The burning gas or the extreme heat may cause a fire inside the storage facility and thus a subsequent sympathetic detonation if the openings and entrances are destroyed. This can and should be prevented by an appropriate design.

2.5.7.3 *References*

Essential references **-->> Section VIII**

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2.5.8.3. *Figures*

FIGURES

2.5.8.4 *Tables*

TABLE [5-1]

FRAGMENT PERFORATION THROUGH WALL AND ROOF (calculation with Ref [1])					
AMMUNITION	R(m)	REQUIRED MEMBER THICKNESS (m)			
		concrete/brick	steel	sand	wood
GP-Bomb 500 kg	5	0.29	0.070	0.78	1.31
	20	0.23	0.058	0.77	1.23
GP-Bomb 250 kg	5	0.20	0.052	0.55	0.73
	20	0.15	0.040	0.51	0.66
Art Round 155 mm	5	0.12	0.030	0.59	1.08
	20	0.10	0.025	0.55	1.02

TABLE [5-2]

-TNT- EQUIVALENT WEIGHT FACTORS FOR FREE AIR EFFECTS

Ref [1], [3], [89]

MATERIAL	PEAK PRESSURE Equivalent Mass	IMPULS Equivalent Mass	PRESSURE RANGE [MPa]
ANFO (9416 Am/Ni/ Fuel Oil	0.82	0.82	0.007 - 0.700
Composition A-3	1.09	1.07	0.035 - 0.350
Composition B	1.11	0.98	0.035 - 0.350
Composition C-4	1.37	1.19	0.070 - 0.700
Cyclotol 70/30 [1]	1.14	1.09	0.035 - 0.350
Comp B / TiH2 70/30	1.13	1.13	-
Explosive D	0.85	0.81	-
HBX-1	1.17	1.16	0.035 - 0.140
HBX-3	1.14	0.97	0.035 - 0.176
H-6	1.38	1.15	0.035 - 0.700
Minol II	1.20	1.11	0.021 - 0.140
Octol 70/30 [2]	1.06	1.06	e)
Octol 75/25	1.06	1.06	e)
Pentolite	1.42	1.00	0.035 - 0.700
Pentolite	1.38	1.14	0.035 - 4.219
PETN	1.27	-	0.035 - 0.700
Picratol	0.90	0.93	-
RDX	1.14	1.09	-
RDX/5 Wax	1.19	1.16	-
RDX/Wax 98/2	1.19	1.16	-
Tetryl	1.07	-	0.021 - 0.140
Tetrytol 75/25 [3]	1.06	-	e)
Tetrytol 70/30	1.06	-	e)
Tetrytol 65/35	1.06	-	e)
TNETB	1.36	1.10	0.035 - 0.700
TNT	1.00	1.00	Standard
Torpex II	1.23	1.28	-
TRITONAL 80/20	1.07	0.96	0.035 - 0.700

[1] RDX / TNT
[2] HMX / TNT
[3] TETRYL / TNT
e) estimated

TABLE [5-3]

BLAST WAVE ATTENUATION CONSTANT VS. NORMALISED SIDE-ON PRESSURE

(P_{so}/P_a) [1)]	ß	(P_{so}/P_a) [1)]	ß	(P_{so}/P_a) [1)]	ß
67.90	8.90	3.46	3.49	0.161	0.382
37.20	8.75	2.05	2.06	0.062	0.098
20.40	9.31	1.38	1.58	0.037	0.117
11.90	10.58	0.77	0.32	0.026	0.111
7.28	7.47	0.51	1.05	0.020	0.149

Ref [3]

1) **P_a = Ambient Pressure**

TABLE [5-4]

RECOMMENDED VALUES FOR 'SIDE-ON' DRAG COEFFICIENTS

Ref [1], [3]

PEAK DYNAMIC PRESSURE		DRAG COEFFICIENT
[MPa]	[psi]	[--]
0 - 0.18	0 - 25	- 0.4
0.18 - 0.35	25 - 50	-0.3
0.35 - 0.70	50 - 100	-0.2

TABLE [5-5]

POLYNOMINAL EQUATIONS FOR COMPUTING AIRBLAST PARAMETERS

Ref [3]

HEMISPHERICAL SURFACE BURST

Functions to represent the airblast parameters versus distance in meters for a 1-kilogram TNT hemispherical surface burst are presented in the following equations. The values in parentheses convert the equations to English units. Substituting the parenthesized values for the constants K_o and C_o, convert the equations to provide the surface burst parameters for a one pound TNT hemispherical charge versus distance in feet.

In general,

T = common logarithm of the distance in meters
$$U = K_o + K_1 T$$

Y = common logarithm of the airblast parameter in metric units
$$Y = C_o + C_1 U + \ldots C_N U^N$$

1. <u>Incident Pressure (kPa, psi)</u>

Range of applicability: **(0.170 - 100.0 feet)**
0.0674 - 40.0 meters

$$U = \overset{(-0756579301809)}{-0.214362789151} + \overset{(1.9422502013)}{1.35034249993}T$$

$$\begin{aligned} Y = {} & 2.78076916577 - 1.6958988741U - 0.154159376846U^2 \\ & + 0.514060730593U^3 + 0.0988534365274U^4 \\ & - 0.293912623038U^5 - 0.0268112345019U^6 \\ & + 0.109097496421U^7 + 0.00162846756311U^8 \\ & - 0.0214631030242U^9 + 0.0001456723382U^{10} \\ & + 0.00167847752266U^{11} \end{aligned}$$

2. <u>Incident Impulse (kPa - msec, psi - msec)</u>

Two funktions are required:

Function I

Range of applicability: **(0.170 - 2.41 feet)**
0.0674 - 0.955 meters

$$U = 2.06761908721 + 3.0760329666T^{(0.832468843425)}$$

$$Y = 2.52455620925 - 0.502992763686U + 0.171335645235U^2 + 0.0450176963051U^3 - 0.0118964626402U^4$$

Function II

Range of applicability: (2.41 - 100.0 feet) 0.955 - 40.0 meters

$$U = 1.94708846747 + 2.40697745406T^{(-2.91358616806)}$$

$$Y = 1.67281645863 - 0.384519026965U - 0.0260816706301U^2 + 0.00595798753822U^3 + 0.014544526107U^4 - 0.00663289334734U^5 - 0.00284189327204U^6 + 0.0013644816227U^7$$

3. Reflected Pressure (kPa, psi)

Range of applicability: (0.170 - 100.0 feet) 0.0674 - 40.0 meters

$$U = 0.24657322658 + 1.36637719229T^{(-0.789312405513)}$$

$$Y = 3.40283217581 - 2.21030870597U - 0.218536586295U^2 + 0.895319589372U^3 + 0.24989009775U^4 - 0.569249436807U^5 - 0.11791682383U^6 + 0.224131161411U^7 + 0.0245620259375U^8 - 0.0455116002694U^9 - 0.00190930738887U^{10} + 0.00361471193389U^{11}$$

4. Reflected Impulse (kPa - msec, psi - msec)

Range of applicability: (0.170 - 100.0 feet) 0.0674 - 40.0 meters

$$U = -0.246208804814 + 1.33422049854T^{(-0.781951689212}$$

$$Y = 2.70588058103 - 0.949516092853U + 0.112136118689U^2$$

$- 0.0250659183287U^{3}$

5. Shock Front Velocity (m/msec, ft/msec)

Range of applicability: **(0.170 - 100.0 feet)**
0.0674 - 40.0 meters

$$U = -0.202425716178 + 1.37784223635T^{(-0.755684472698)}$$

$$Y = -0.06621072854 - 0.698029762594U + 0.158916781906U^{2} + 0.443812098136U^{3} - 0.113402023921U^{4} - 0.369887075049U^{5} + 0.129230567449U^{6} + 0.19857981197U^{7} - 0.0867636217397U^{8} - 0.0620391900135U^{9} + 0.0307482926566U^{10} + 0.0102657234407U^{11} - 0.00546533250772U^{12} - 0.000693180974U^{13} + 0.0003847494916U^{14}$$

$$(0.449774310005)$$

6. Arrival Time (msec)

Range of applicability: **(0.170 - 100.0 feet)**
0.0674 - 40.0 meters

$$U = -0.202425716178 + 1.37784223635T^{(-0.755684472698)}$$

$$Y = -0.0591634288046 + 1.35706496258U + 0.052492798645U^{2} - 0.196563954086U^{3} - 0.0601770052288U^{4} + 0.0696360270981U^{5} + 0.0215297490092U^{6} - 0.0161658930785U^{7} - 0.00232531970294U^{8} + 0.00147752067524U^{9}$$

$$(-0.173607601251)$$

7. Positive Phase Duration (msec)

Three functions are required:

Function I

Range of applicability: **(0.450 - 2.54 feet)**
0.178 - 1.01 meters

$$U = 1.92946154068 + 5.25099193925T^{(-0.1790217052)}$$

$$(-0.728671776005)$$

$$Y = -0.614227603559 + 0.130143717675U + 0.134872511954U^2 + 0.0391574276906U^3 - 0.00475933664702U^4 - 0.00428144598008U^5$$

Function II

Range of applicability: **(2.54 - 7.00 feet)** **1.01 - 2.78 meters**

$$U = (-5.85909812338) - 2.12492525216 + 9.2996288611T$$

$$Y = (0.20096507334) \; 0.315409245784 - 0.0297944268976U + 0.030632954288U^2 + 0.0183405574086U^3 - 0.0173964666211U^4 - 0.00106321963633U^5 + 0.00562060030977U^6 + 0.0001618217499U^7 - 0.0006860188944U^8$$

Function III

Range of applicability: **(7.00 - 100.0 feet)** **2.78 - 40.0 meters**

$$U = (-4.92699491141) - 3.53626218091 + 3.46349745571T$$

$$Y = (0.572462469964) \; 0.686906642409 + 0.0933035304009U - 0.0005849420883U^2 - 0.00226884995013U^3 - 0.00295908591505U^4 + 0.00148029868929U^5$$

TABLE: [5-6]

FRAGMENTATION RELATED EXPLOSIVE CONSTANTS

EXPLOSIVE		DENSITY		Bx MOTT-Constant		G GURNEY-Constant	
		$1b/ft^3$	k/m^3	$\sqrt{1b/ft^{7/6}}$	$\sqrt{kg/m^{7/6}}$	ft/s	m/s
AMATOL		106.74	1710	1.589	4.279	6190	1886
BARATOL		164.17	2630	2.324	6.260	5200	1585
COMPOSITION A-3	(RDX/WAX)	99.88	1600	0.998	2.688	8629	2630
COMPOSITION B	(RDX/TNT/WAX)	106.74	1710	1.007	2.712	9100	2774
COMPOSITION C-3		99.88	1600	-	-	8800	2682
COMPOSITION C-4		106.74	1710	-	-	8300	2530
CYCLONITE	(RDX)	106.74	1710	-	-	9300	2835
CYCLOTOL (75/25)	(RDX/TNT)	109.49	1754	0.895	2.410	8900	2713
CYCLOTOL (20/80)	(RDX/TNT)	106.74	1710	-	-	8380	2554
CYCLOTOL (60/40)	(RDX/TNT)	106.74	1710	1.226	3.301	7880	2402
H-6	(RDX/TNT/AL/WAX)	106.74	1710	1.253	3.375	8600	2621
HBX-1	(RDX/TNT/AL/WAX)	106.12	1700	1.161	3.127	8100	2469
HBX-3	(RDX/TNT/AL/WAX)	112.98	1810	1.466	3.949	6509	1984
HMX		106.74	1710	-	-	9750	2972
HTA-3		106.74	1710	-	-	8500	2591
MINOL II	(AN/TNT/AL)	104.86	1680	-	-	8300	2530
NITROMETHANE		106.74	1710	-	-	7900	2408
OCTOL (75/25)		113.67	1821	-	-	9500	2896
PBX-9404	(Plast.Bonded HMX)	106.74	1710	-	-	9500	2895
PENTOLITE (50/50)	(TNT/PETN)	104.24	1670	1.126	3.032	8400	2560
PETN		106.74	1710	1.126	3.033	9600	2926
PICRATOL		106.74	1710	-	-	7600	2316
PTX-1	(RDX/TETRYL/TNT)	106.74	1710	1.007	2.712	-	-
PTX-2	(RDX/PETN/TNT)	106.74	1710	1.031	2.778	-	-
RDX		106.74	1710	0.963	2.594	9600	2926
TACOT		106.74	1710	-	-	7000	2134
TETRYL		106.74	1710	1.236	3.329	8200	2499
TETRYTOL		106.74	1710	-	-	-	-
TNT		106.74	1710	1.416	3.815	8000	2438
TORPEX-2	(RDX/TNT/AL)	106.74	1710	1.415	3.811	8800	2682
TRIMONITE No 1		106.74	1710	-	-	3400	1036
TRITONAL		106.74	1710	-	-	7600	2316

TABLE [5-7]

BALLISTIC DENSITY FACTOR -k- / Ref[89]	
k ($g/cm^{\wedge 3}$)	Type of Ammunition
2.61	forged steel projektiles fragmentation bombs
2.33	demolition bomb
4.27	steel cube
5.89	steel sphere

TABLE [5-8]

GEOMETRICAL CONSTANT -n- / Ref [3]			
1	for	planar	geometry
2		cylindrical	geometry
3		spherical	geometry

TABLE [5-9]

BALLISTIC DRAG COEFFICIENT C_D

Ref [164]

DRAG COEFFICIENTS for SPHERE		DRAG COEFFICIENTS for ROTATING CYLINDER (h=D)	
v [m/s]	C_D	M	C_D
0	0,46	0,1 - 0,6	0,80
100	0,48	0,6 - 0,8	0,82
170	0,50	0,8 - 0,9	0,86
255	0,62	0,9 - 1,0	0,915
340	0,80	1,0 - 1,1	1,035
425	0,96	1,1 - 1,2	1,18
510	1,00	1,2 - 1,3	1,265
680	1,02	1,3 - 1,4	1,315
1020	0,98	1,4 - 2,8	1,195
1430	0,92	2,8 - 5,6	1,065
3060	0,92	5,6 - 11,2	1,04

DRAG COEFFICIENTS for ROTATING CUBE		DRAG COEFFICIENTS for CUBE	
M	C_D	v [m/s]	C_D
0,1 - 0,2	0,80	0	0,78
0,2 - 0,4	0,82	170	0,80
0,4 - 0,6	0,845	272	0,92
0,6 - 0,8	0,88	340	1,14
0,8 - 0,9	0,975	408	1,26
0,9 - 1,0	1,075	476	1,28
1,0 - 1,1	1,16	613	1,22
1,1 -1,2	1,225	680	1,16
1,2 - 1,3	1,245	783	1,12
1,3 - 1,4	1,245	1500	1,08
1,4 - 2,8	1,175	3060	1,08
2,8 - 5,6	1,12		
5,6 - 11,2	1,11		

DRAG COEFFICIENTS for IRREGULAR FRAGMENTS		DRAG COEFFICIENTS for IRREGULAR FRAGMENTS	
M	C_D	v [m/s]	C_D
0,1 - 0,2	0,85	0	1,08
0,2 - 0,4	0,86	204	1,08
0,4 - 0,6	0,90	272	1,12
0,6 - 0,8	1,10	340	1,24
0,8 - 0,9	1,25	408	1,36
0,9 - 1,0	1,33	476	1,40
1,0 - 1,1	1,385	544	1,40
1,1 -1,2	1,415	680	1,36
1,2 - 1,3	1,42	1020	1,28
1,3 - 1,4	1,40	1700	1,20
1,4 - 2,8	1,29	3060	1,12
2,8 - 5,6	1,15		
5,6 - 11,2	1,115		

TABLE [5-10]

DOB	EJECTA WITHIN CRATER LIP AREA Ref [89]	
	mass distribution	distance from SGZ
GOF	40%	2 to 4 · R_a
Optimal	90%	2 to 4 · R_a

SGZ surface ground zero
R_a apparent crater radius
GOF ground surface

TABLE [5-11]

DYNAMIC INCREASE FACTOR DIF	
Material	DIF
RC - slabs	2.5
steel plate	2.5
wood	1.75

TABLE [5-12]

PREDICTION EQUATIONS FOR AIR-BLAST-INDUCED GROUND SHOCK			
direction	displacement max. D (m)	velocity max. U (m/s)	acceleration max. A (g)
vertical	$D_v = \frac{I_s}{c_p \cdot rho}$	$V_V = \frac{P_{so}}{c_p \cdot rho}$	1) $A_V = \frac{122 \cdot P_{so}}{c_p \cdot rho}$
horizontal	$D_h = D_v \cdot F1$	$V_h = V_v \cdot F1$	$A_h = A_v \cdot F1$
$F1 = \tan \cdot [\sin^{-1} \cdot (c_p / U)]$			

Notes:

1) - The equation for maximum vertical acceleration is valid for dry soil. For saturated soils and rock doubling of the acceleration values is recommended.

2) - For all cases > $F1 = \tan \cdot [\sin^{-1} \cdot (c_p / U)] \geq 1$ the horizontal quantities of motion will be equated with the vertical quantities.

- Seismic velocities and soil densities are presented in TABLE [7-13]. For conservative estimation of the quantities of motion the minor values of the velocity should be taken.

TABLE [5-13]

SOIL AND ROCK PROPERTIES FROM EXPLOSIONS TESTS

Ref [1], [3], [30]

SOIL DESCRIPTION	DRY UNIT MASS	TOTAL UNIT MASS	AIR FILLED VOIDS	SEISMIC VELOCITY	ACCOUSTIC IMPEDANCE	Attenuation Coefficient
Dry desert alluvium and playa	1394	1490	>25	640 a)	954	3 - 3.25
Partially cemented	1394	1602	>25	1280	2051	3 - 3.25
Loose, dry, poorly graded sand	1282	1442	>30	183	264	3 - 3.5
Loose, dry sands and gravels with low relative density	--	1490	-	183	273	3.1
Loose, wet, poorly graded sand	1554	1858	10	152	283	3
with free standing water	1554	1858	10	183	340	3
Dense dry sand, poorly graded	1586	1666	32	274	457	2.5 - 2.75
"	1586	1666	32	396	660	2.5 - 2.75
Dense wet sand, poorly graded, with free-standing water	1730	1986	9	305	605	2.75
Very dense dry sand, relative density = 100%	1682	1746	30	488	852	2.5
Dense sand (high relative density)	--	2030	-	488	991	2.5
Sandy loam, loess, dry sands, and back fill	--	1630	-	305	498	2.75
Silty clay, wet	1522	1922	9	213	410	2.75 - 3
"	1602	2003	9	274	549	2.75 - 3
Moist loess, clayey sand	1602	1954	5-10	305	596	2.75 - 3
Wet sandy clay with >4% air voids	--	1990	>4%	549	1093	2.5
Wet sandy clay, above water table	1522	1922	4	549	1055	2.5
"	2003	--	4	-	-	2.5
Saturated sand-below water table (b.w.t.) in marsh	--	--	1-4 b)	1494	-	2.25 - 2.5
Saturated sandy clay - b.w.t c)	1250	1762	1-2	1524	2686	2 -2.5
"	1602	1986	1-2	829	3633	2 -2.5
Saturated sandy clays and sands with 1% air voids	--	1920	<1%	1524	2926	2.4
Saturated sandy clay - b.w.t. c)	1602	2003	<1	1524	3052	1.5
"	1602	-	<1	2017	-	1.5
Saturated stiff clay, saturated clay-shale	--	1922	0	1524	2930	1.5
"	--	2083	0	1524	3174	1.5
Heavy saturated clays and clay shales	--	2030	-	1829	3712	1.5
Shale and marl	--	2320	-	1800-5300	4175-12296	
Basalt	--	2740	-	5400	14796	
Granite	--	2640	-	5100	13464	
Cointed Granite	--	2640	-	2400-4600	6336-12144	
Limestone	--	2400	-	5200	12480	
Limestone-chalk	--	2100	-	2100-6400	4410-13440	
Sandstone	--	2400	-	5760	13824	
Volcanic rock	--	2400	-	3000-6700	7200-16080	
Sound plutonic rocks	--	2700	-	4000-7600	10800-20520	
Weathered rocks	--	2300	-	600-3100	1380-7130	
Concrete	--	2400	-	≈3500	8400	
Water	--	1000	-	1460	1460	

a) High because of cementation b) Estimated c) b.w.t. - below water table

$$rho_{,deb} = 0.36 \cdot M_a \cdot {}^{(0.58)} \cdot e^{(-0..047 \cdot R \cdot Q)} \quad (kg / m^2) \qquad \text{eq [5-59]}$$

TABLE [5-14]

PREDICTION EQUATIONS for DIRECT-INDUCED GROUND SHOCK			
medium	**displacement max. D (m)**	**Velocity max. V (m/s)**	**Acceleration max. A (g)**
vertical parameters of motion: D_v (m), V_V (m/s), A_V (g)			
ROCK	$\frac{(R_G \cdot Q)^{1/3}}{37000 \cdot Z_G^{1/3}}$	-	-
SOIL	$\frac{(R_G \cdot Q)^{1/3}}{1000 \cdot Z_G^{2.3}}$	-	-
ALL	-	$\frac{0.95}{Z_G^{1.5}}$	$\frac{1200}{Z_G \cdot R_G}$
horizontal parameters of motion: D_h (m), V_h (m/s), A_h (g)			
ROCK	$0.5 \cdot D_V$	V_V	A_V
SOIL	D_V	V_V	-
DRY SOIL	-	V_V	$0.5 \cdot A_V$
WET SOIL	-	V_V	A_V
& ROCK	-	V_V	A_V

R_G = ground range Z_G = scaled distance above ground

TABLE [5-15]

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

TABLE [5-16]

THRESHOLD FOR SHOCK LOADING ON PERSONNEL	
DAMAGE	**CRITICAL IMPACT VELOCITY $V_{i,cr}$ (m/s)**
Minor	≤ 3.0
Threshold	4.0
50% Skull Injury	5.5
100% Skull Injury	7.0

THREAT	ACCELERATION a (g)
Loss of Balance	
- nuclear, horizontal	0.5
- nuclear, vertical	1.0

CRITICAL OSCILLATION TOLERANCES for PERSONNEL	
Acceleration (g)	Frequency (Hz)
2	< 10
5	10 - 20
7	20 - 40
10	> 40

TABLE [5-17] ; Ref [89]

RADIANT ENERGY REQUIRED TO CAUSE FLASH BURNS			
PERIOD t_w (s)	RADIATION ENERGY (kWs/m^2)	(cal/cm^2)	DEGREE OF BURN
t_w< 1 s	62.8	1.5	1
	125.6	3.0	2
	188.4	4.5	3
$t_w \approx 5$ s	125.6	3.0	1
	251.2	6.0	2
	376.7	9.0	3
Source: AC/258 Corr No 7			

TABLE [5-18]

RADIATION INTENSITY $\frac{q}{t_w}$ (kW·s / m^2)			
DEGREE OF BURN	PROBABILITY OF INCIDENT 1%	50%	99%
1st degree	38.5	68.8	122.7
2nd degree	87.8	156.4	278.6
3rd degree	92.8	184.5	364.1
t_w = active duration of the radiation			

TABLE [5-19]

Symbols: **X occasional** **C heavy damage**
A minor damage **D destruction**
B medium damage

DAMAGE CRITERIA FOR STRUCTURES AND COMPONENTS DUE TO OVERPRESSURE [kPa]						
OBJECT	**X**	**A**	**B**	**C**	**D**	
glass	0.2	-	-	-	-	large window
glass, typical		1.1	-	-	3.5-7.0	
window frame	0.5	-	-	-	-	
window frame	-	10.6	-	-	-	
door frame	-	10.6	-	-	-	
door, window	-	-	-	-	6.0-9.0	distorted
plaster	-	3.5-7.0	-	-	-	
tiles (roof)	-	3.0	-	5.3	-	0%-50% tiles displaced
dwelling house	-	3.0*)	8.1**)	36.6**)	80.9**)	
wall, ceiling	-	-	-	14.1	-	partial
concrete wall	-	-	-	14-21	-	Plain concrete, s=0.2-0.3 m
unreinforced build.	-	-	-	-	70.3	completely demolished
brick wall	-	-	-	56.3	70.3	completely demolished
brick wall, 20-30 cm	-	-	-	-	56.3	fail by flexure
brick wall, 45 cm	-	-	-	-	91.42	completely demolished
steel building	-	9.1	14.0	17.6	21.1	
wooden building	-	-	12.0	17.0	28.0	
building	-	-	70.0	-	-	block building
factory chimney	-	14.0	-	-	-	
industrial building	-	-	28.0	-	-	
administr. building	-	-	38.0	-	-	
brick building	-	-	28.0	-	-	
RC-structures	-	-	38.0	53.0	-	
steel girder build.	-	-	-	31.6	63.3	
cladding of build.	-	7.0	-	-	14.1	
heavy bridge	-	-	-	-	492.3	masonry or concrete
steel truss bridge	-	-	-	-	63.3	collapse
motor vehicle	-	28.2	35.2	70.3	-	severe displacement, crushed
rail car	-	18.3	39.4	60.5	77.4	
wooden utility pole	-	28.0	-	-		snapped
power mast	-	28.0	-	-		snapped
radio mast	-	14.0	-	-	-	snapped
oil storage tank	-	6.3	21.0	24.6	28.1	
tree	-	-	-	21.1	175.8	90% blown down

*) inhabitable **) uninhabitable

TABLE [5-20]

DAMAGE THRESHOLD for DIRECT-INDUCED GROUND SHOCK / Ref [89]		
DAMAGE	max. VELOCITY vertical/horizontal V_{max} (m/s)	SCALED DISTANCE Z (m/kg^$^{1/3}$)
no	≤ 0.05	6.9
minor/medium	0.05 - 0.14	3.6
heavy	0.14 - 0.19	2.9

TABLE [5-21]

DAMAGE THRESHOLD for AIR-BLAST-INDUCED GROUND SHOCK (for -3- selected soils) Ref [89]				
DAMAGE	$V_{V/h,max}$ (m/s)	SCALED DISTANCE Z (m/kg^$^{1/3}$) soil -1-	soil -2-	soil -3-
no	≤ 0.05	5.7	2.7	1.5
minor/medium	0.05-0.14	3.4	1.7	1.0
heavy	0.14-0.19	2.9	1.5	0.8

No	TYPE OF SOIL	DENSITY rho (kg/m^$^{1/3}$)	SEISMIC VELOCITY c_p (m/s)
1	soil	1520	460
2	saturated soil	2000	1520
3	rock	2560	4000

TABLE [5-22]

CRITICAL OSCILLATING VELOCITY	
- dwelling and business building	0.008 m/s
- braced buildings with heavy components	
braced skeleton buildings	0.030 m/s
- historical buildings/monuments	0.004 m/s

TABLE [5-23]

CRITICAL OSCILLATING VELOCITY ON BASE Ref [10]	
- individual, minor damage	0.070 m/s
- damage threshold	= 0.140 m/s
- 50% structural damage	= 0.180 m/s

TABLE [5-24]

CRITICAL SOIL PARTICLE VELOCITIES FOR AMMUNITION STORAGE BUILDINGS Ref [78]	
QUALITY OF STRUCTURE	**max. VELOCITY of soil particles V (m/s)**
- no damage	< 0.2
- rigid frame prefabricated concrete buildings	0.2 - 1.5
- heavy reinforced concrete magazines	3.0

TABLE [5-25]

SHOCK TOLERANCES FOR SELECTED EQUIPMENT			
EQUIPMENT	**DAMAGE a (g)**		**FREQUENCY f_{min} (Hz)**
	no	**heavy**	
- heavy weight machinery · engines, generators, · transformers M > 2000 kg	10	80	5
- medium weight machinery · pumps, condensers, · air conditioners M ≈ 500 - 2000 kg	15	120	10
- light weight machinery · small engines M > 500 kg	30	200	15
- duct work, piping, storage batteries	20	280	5
- electronic equipment, relays, magnetic drum units, racks of communication equipment	2	20	10

a (g) acceleration ; f_{min} (Hz) minimum natural frequency

TABLE [5-26]

CRITICAL RADIATION INTENSITY q (kW / m^2)		
MATERIAL	**CLASS -1-**	**CLASS -2-**
wood	15	2
plastics	15	2
glass	4	-
steel	100	25

TABLE [5-27]

CRITICAL PROPAGATION IMPACT PARAMETERS		
IMPACT VELOCITY V_i (m/s)	**ENERGY E_{kin} (J)**	**IMPULS I (Ns)**
≤ 50 m/s	----	100
≥ 50 m/s	2500	---

CHAPTER 6 - OPERATIONS IN AN EXPLOSIVES AREA

Section I - Introduction

2.6.1.1. *General*

The purpose of this chapter is to provide management and administration considerations for the guidance of National Authorities in the promotion of safe and efficient operations in explosives areas. This chapter contains a list of considerations which may serve as an aid to users in the preparation of national regulations on the subject.

Section II - General Safety Precautions

2.6.2.1. *Responsibilities of Commanding Officers/Superintendents*

The Commanding Officer/Superintendent of an ammunition facility has primary responsibility for safe working and storage conditions within the facility. The following actions should normally be taken:

1. Establish and enforce personnel limits for explosives facilities.

2. Establish and enforce explosives limits for all magazines, transit sheds/areas, outside stacks or hardstands, workshops, laboratories and proof areas.

3. Ensure that Standard Operating Procedures (SOP) are prepared, displayed in buildings and enforced for all examination, repair, renovation, modification, disassembly, assembly, proof and disposal (by breakdown, burning, or demolition) of ammunition and explosives.

4. Review periodically working conditions within the explosives area.

5. Maintain blueprints, maps, or drawings showing the locations of all buildings in the explosives area, and the distances to public traffic routes, inhabited and uninhabited buildings on and off defence property.

6. Maintain Standing Orders to take account of local conditions and supplement national or other orders pertaining to the operation of the facility.

7. Implement an ammunition safety programme with a system of accident, incident, defect and malfunction reports and investigations.

2.6.2.2. *Safety Responsibilities*

a) All personnel in the course of their duty who are required to handle ammunition or explosives should have a detailed knowledge of orders or directives issued to reduce the inherent hazards associated with the work.

b) A high degree of care must be demanded of personnel who are in charge of, or are handling ammunition, where even a slight degree of negligence involves danger to life or damage to property.

c) It is the responsibility of all personnel to maintain vigilance to improve and develop safe practices, methods and attitudes.

2.6.2.3. *Admission to Explosives Areas*

a) No person shall enter an explosives area except by authorized entrances and only then under authority of a pass issued by the Commanding Officer, Superintendent or Officer in charge.

b) Any person showing the least signs of intoxication or impairment from drugs shall not be admitted to explosives areas.

2.6.2.4. *Personnel Employed in Explosives Areas*

A person should not be employed in the explosives area unless the Commanding Officer/Superintendent is satisfied that the person is suitable for such employment.

2.6.2.5. *Prohibited and Restricted Articles*

a) No stores, other than explosives, which have been properly classified and authorized for storage therein, and such tools, appliances and materials as are authorized from time to time, are to be permitted into an explosives area.

b) In particular admission of the following is to be prohibited or strictly controlled:

1. Oil or gas filled lighting, heating or burning appliances and all flame, spark or fire producing appliances.
2. Matches, cigarettes and other portable means of producing spark or flame.
3. Radio transmitters and receivers.
4. Tobacco in any form and any article used for the purpose of smoking or carrying tobacco.
5. Beers, wines and alcoholic liquor.
6. Motor spirit, flammable oils and solvents not contained in the fuel tank of a vehicle or in a sealed container.
7. Fire arms.
8. Cameras.
9. Drugs and medicines.

10. Food and drink unless for sale or consumption in official canteens or refreshment areas.

11. Battery operated equipment e.g. hearing aids, calculators.

2.6.2.6. *Food and Drink*

When approved by national regulations canteens or lunch rooms may be located within the explosives area. These may, under stringent controls, be authorized as smoking areas.

2.6.2.7. *Smoking*

a) Smoking inside explosives areas is strictly forbidden except in authorized smoking areas.

b) Prominent signs should be displayed at each exit from the smoking area with the wording "NO SMOKING BEYOND THIS POINT". A sign with the wording "WARNING NO LIVE AMMUNITION OR EXPLOSIVES ARE PERMITTED IN THIS AREA" should be placed on or near the doors leading into the smoking area.

2.6.2.8. *Employee Working Alone*

No one person should be permitted to work alone (where another person cannot provide immediate assistance in case of an accident) in explosives workshop or laboratory operations which involve the assembly or breakdown of ammunition or the exposure of explosive fillings, or in any other operation which involves the opening of packages and the exposure of loose ammunition.

2.6.2.9. *Photography*

Photographs taken within the explosives area should be restricted to those required for official purposes. Where explosives are exposed, electro-explosive devices (EED) are involved or explosive or flammable gases may be present, the use of cameras with electrically operated equipment should be avoided unless specially approved for the purpose.

2.6.2.10. *Portable Hand Lights*

Portable hand lights may be used within the explosives area if they are of a design that meets the national electrical requirements for the particular building/area in which they are to be used.

2.6.2.11. *Wearing of Rings and Other Jewellery*

It is general good industrial safety practice to discourage the wearing of rings and other jewellery by personnel employed in explosives workshops.

2.6.2.12. *Battery Operated Devices*

Battery operated devices may be used in locations within the explosives area at the discretion of the Commanding Officer/Superintendent. Only "intrinsically safe" devices should be approved for use in those areas where EED, explosive dust or other conditions which might give rise to an explosion are present. To be "intrinsically safe" the device should be incapable of producing sufficient energy to initiate an explosion.

2.6.2.13. *Thunderstorms*

a) At the discretion of National Authorities, work involving explosives and in buildings containing explosives should cease during thunderstorms and personnel evacuated to a suitable location at the appropriate distance from PES.

b) Truck loads of ammunition should be moved under cover. Loads which must be left in the open should be covered with tarpaulins.

2.6.2.14. *Private Motor Vehicles*

Standing Orders should include regulations to cover local conditions for the certification, control and use of private vehicles in the explosives area.

Section III - Arrangement of Ammunition and Explosives in a Building or Stack

2.6.3.1. *Ammunition and Explosives Storage - General*

Ammunition and explosives should be stored only in locations designated for that purpose. The types and quantities of materiel which may be stored in these locations must be in accordance with the quantity-distance requirements prescribed in this Manual or appropriate national publications.

2.6.3.2. *Use of Magazines*

a) Magazines are intended for the storage of ammunition and explosives including explosive components and should not be used for the storage of non-explosive stores unless no other suitable accomodation is available. Explosive items and their related non-explosive components may be stored together in the same magazine, for example, aircraft bombs and their tail units. To preclude errors when issuing, dummy, display and other inert ammunition should not be stored in the same building with their live counterpart. Inert ammunition should normally be stored in non-explosive storehouses.

b) Ammunition and explosives, packages and containers should be properly marked, in good repair and free from loose dirt, grit or other contamination before being stored in magazines. Any broken or damaged packages or containers should be repacked, before being accepted into a magazine, unless the damage is slight and does not adversely affect the protective qualities of the package. Repacking should not be carried out in the magazine.

2.6.3.3. *Ammunition Stacking*

a) Ammunition and explosives should be stored in stable stacks in magazines in an approved manner which precludes toppling or collapse of the stacks, or the crushing or deforming of the containers in the lower tiers. Dunnage should be used to secure the stacks. When a specified method of stacking a particular item is not prescribed, explosives and ammunition should be stacked in accordance with the following guidelines:

1. Ammunition and explosives should be stored in their approved ontainers and should be separated in stacks by nature, type, and lot number. All containers should be closed and sealed by suitable means.

2. Sufficient space should be left between ammunition stacks and the floor, ceiling and walls of the magazine to permit air circulation. Additional space may be provided for inspection etc., as required by national regulations.

3. Ammunition stacks should be placed at least 1 m from doorways to provide protection from direct sunlight, rain etc. when doors are open.

4. Light cased phosphorus filled ammunition should be in double rows to permit rapid identification and removal of leaking packages. Stack heights should not exceed 2 m or one pallet. Pallets should be arranged in single lines with sufficient room between each line to permit the removal of any container showing signs of leakage. Suitable tools to cut the strapping should be readily available in the building.

5. Partly filled boxes should have a fraction tag attached, or be otherwise marked, and the box placed conspicuously on the stack. There should be only one fraction box per lot.

6. Ammunition stacks should be placed at an appropriate distance from heating devices.

b) Records of storage arrangements should be maintained to aid in space control and to ensure the authorized explosives limits are not exceeded.

2.6.3.4. *Ventilation of Magazines*

Magazines should be kept as dry and temperate as possible. To assist in the reduction of condensation, magazines should be fitted with a ventilator; where the climate warrants, power ventilators or dehumidification equipment may be necessary. The ventilators should be designed to prevent the insertion into the magazine of any extraneous object, and to close automatically in the event of a fire either inside or on the outside of the magazine. Older magazines, or magazines with ineffective ventilating systems should be ventilated by opening the doors and ventilators when atmospheric conditions and temperatures are favourable.

2.6.3.5. *Temperature*

a) Temperature control is important in magazines used for the storage of those types of ammunition which are adversely affected by extremes of temperature.

b) Magazine temperature records should be maintained when:

1. Such records are useful for the selection of lots for proof or test.

2. Ammunition in the magazine has published temperature limitations which are liable to be exceeded under prevailing climatic conditions.

2.6.3.6. *Authorized Stores and Equipment*

Only stores, tools and equipment authorized and required for use should be permitted in magazines. A list of stores, tools and equipment approved for use should be displayed in the building. In particular, empty pallets and dunnage should not be allowed to accumulate in magazines containing ammunition.

2.6.3.7. *Aisles and Safety Exits*

Aisles and safety exits in magazines containing ammunition should not be blocked or obstructed. When work is being conducted doors should not be fastened with other than approved quick-release devices which shall be maintained in good working order. Where quick-release devices are not fitted the doors shall be unlatched or open. All doors should be outward opening.

2.6.3.8. *Isolation Magazines*

a) Condemned or unserviceable ammunition presenting more than a normal storage hazard should be removed to an isolation magazine pending destruction. In the absence of an isolation magazine, outside storage may be used if national regulations permit.

b) Condemned or unserviceable ammunition not presenting more than normal storage hazards may be stored in magazines with serviceable stores but should be clearly marked as condemned or unserviceable to prevent inadvertent use or issue.

c) Ammunition and explosives of different compatibility groups may be mixed in isolation magazines. Such mixing in isolation magazines should only be permitted when it is unavoidable and does not significantly increase either the probability or severity of an accident. An effective control when storing condemned or unserviceable ammunition is required.

2.6.3.9. *Transit Magazines*

A transit magazine is defined as a magazine used for:

1. The receipt of small consignments which may be mixed prior to being placed in permanent storage.

2. The assembly of small issues which may be mixed prior to dispatch.

In buildings authorized as transit magazines, ammunition and explosives of different compatibility groups may be mixed in the same way as is permitted for the appropriate mode of transport. If it is necessary to open packages, for acceptance, receipt or issue inspections or for identification, verification of quantity, repack or other process, this should be done in an adjacent building or separate compartment of the same building; only one nature should be present in this building or compartment at any time. Remarking of the outer packages and sorting of packages may be carried out in the main transit magazine. Irrespective of the quantities of each hazard division present at any time the overall explosive limit applied to the building should be that for the hazard division which permits the least NEQ for the available quantity-distances.

Section IV - Handling of Ammunition and Explosives

2.6.4.1. *Cleanliness of Buildings*

The cleanliness of all magazines and other buildings containing explosives should be maintained at a high standard. The following precautions shall be taken:

1. Dangerously combustible materiels, such as paper, oily rags, cotton waste, paints, solvents, volatile liquids, and painting cloths required for use in an explosives storehouse or explosives workshop should be removed to a safe storage place when not actually in use.

2. Particular care should be exercised to avoid the presence of steel wool, sand, gravel, or any other abrasive substance upon the floors, tables, or other working places where explosives are being handled.

3. Explosive dusts or vapours should not be allowed to accumulate inside or outside a building.

4. Electrical fixtures and motors should be kept free from dust.

5. Special precautions (see paragraph 2.6.5.4.) should be observed when packages containing explosives liable to initiation by spark or friction are stored and are not in dust tight containers.

2.6.4.2. *Electrical Extensions*

When not specifically prohibited and when it is necessary to use extension lights during the handling, loading, or unloading of explosives or ammunition in magazines or other buildings or on board vessels, lighters, railroad cars, trucks, or other vehicles, portable electric extension lights may be used provided they are in accordance with the national electrical code for use in such locations. In the case of visiting forces the electrical code of the host nation should be the minimum standard.

2.6.4.3. *Handling Equipment*

Handling equipment should be in accordance with approved specifications, used in accordance with the manufacturer's instructions, and maintained and inspected in accordance with the manufacturer's recommended maintenance schedules.

2.6.4.4. *Parking of Vehicles, Railcars and Barges*

Vehicles, railcars and barges should be parked in the vicinity of magazines and workshops only for the period of time required for loading or unloading; at all other times designated holding or marshalling areas should be used for parking purposes. When such vehicles/vessels are moving through explosives areas appropriate routes should be used to minimize the risk of an explosion and propagation between PES.

2.6.4.5. *Ammunition Returned from Bases or Units*

a) All ammunition received from user units should be given an inspection to ensure that it is suitable for storage and subsequent re-issue. The inspection sample size will depend upon national practices.

b) All empty ammunition containers, packaging materials, empty cartridge cases, empty ammunition components etc., received from user units should be given a 100 % inspection and certified free from explosives before being declared as scrap, government provided material as aids to production, or otherwise disposed of.

Section V - Repair, Modification, Inspection and Proof of Ammunition

2.6.5.1. *Introduction*

This section contains special requirements for the repair, modification, inspection and proof of ammunition and explosives in explosives workshops. These activities should only be conducted in the locations designated. The NEQ of ammunition permitted in an explosives workshop should be governed by the quantity-distances in Part I, Chapter 4 of the Manual.

2.6.5.2. *Workshop and Laboratory Working Conditions*

a) Clean conditions should pertain to explosives workshops only when explosive contents are exposed. See subparagraph 2.6.5.5.a) for the definition of clean conditions.

b) Each work area should be thoroughly cleaned daily and each time work is changed from one nature of explosives to another.

c) Before any article is taken into an explosives workshop operating under clean conditions, it should be examined externally and any grit or objectionable substance removed.

d) Work benches on which explosives are likely to be exposed should be so situated that nothing can accidentally fall on the explosives; this is particularly important when dealing with detonators or other sensitive materiel.

e) Work should be arranged so that explosives are never exposed to direct sunlight.

f) Explosives not being worked upon should be kept covered.

g) In explosives workshops, oils, spirits, paint, etc. should be in sound containers, which in turn should be kept in a metal tray the size of, which should be adequate to contain spilling. The quantity should be kept to a minimum and during non-working hours should be kept in a metal locker outside the building or special fireproof room approved for this purpose. These lockers should be included in the daily security check.

h) All doors in explosives workshops not equipped with quick release hardware shall be unlocked when work is in progress.

i) Appropriate protective shieldings should be erected around assembly or disassembly apparatus, as required, to protect operators against flash and splinters in case of accident. Protective shields should be proof-tested prior to initial use and only used for the purpose for which they have been proof-tested.

j) When movement of unpacked ammunition is necessary care must be taken to ensure that it is securely held and is protected against damage and dislodgement.

k) Ammunition containing exposed percussion caps or primers should have the caps protected from accidental striking by means of the appropriate cartridge clips, or other means.

l) Ammunition containing EED should not be removed from its package for longer than is essential, so as to minimize the time during which it may be susceptible to electromagnetic pick-up. Whenever it is necessary to remove ammunition of this kind from its package the safe distances from RF-sources specified, in national regulations, should be fully observed.

m) Grenades, and other similar small stores, which are potentially dangerous when fitted with initiators, should be dealt with in a room provided with a disposal chute or equivalent facility.

n) Workshops or parts of workshops used for paint or rust removal should not be considered as clean areas while being so employed. They should be thoroughly scrubbed and cleaned before being included in the clean area.

o) Paint or rust removal and painting operations should not be conducted in the same workshop room.

p) Ovens for drying non-explosive components should not be located in clean areas or explosives workshops.

q) Non-ferrous metal receptacles should be appropriately located at workplaces when there is a possibility of loose explosives or propellants being scattered on floors or work benches.

2.6.5.3. *Standing Operating Procedures (SOP)*

a) A SOP should prescribe step-by-step procedures to control operations and the precautions to be taken in the course of workshop and laboratory operations. They should be available in the building for the operation in progress.

b) A SOP should be approved by the Commanding Officer/Superintendent and include as applicable:

1. Drawings, specifications, gauge schedules, tools, apparatus, and restriction lists.
2. Static electricity grounding (earthing) requirements.
3. Maximum and/or minimum humidities.
4. Clothing and foot-wear requirements.
5. The maximum number of personnel to be in the workshop or laboratory at any one time.
6. The maximum quantity of explosive items permitted in the building and/or to be worked on at any one time.
7. Any additional safety precautions necessary for the ammunition being worked on.

c) Operations may proceed while the SOP are being printed provided a draft has been approved by the Commanding Officer/Superintendent and is posted in the working area.

2.6.5.4. *Personnel and Explosive Limits*

To reduce the risk of injury of personnel and damage to property the number of personnel employed, and the quantity of ammunition within an explosives workshop should be kept to the minimum required to maintain the operation. Dividing the overall quantity into separate bays or rooms, with substantial internal walls or barricades, will reduce the risk of explosive propagation and probably reduce the effects of an explosives accident. The personnel and explosive limits vary with each operation and should be included in the SOP.

b) A personnel limit is to be assessed for each building, room or area in accordance with the following principles:

1. The number of persons employed should be the minimum compatible with the highest standards of safety, quantity and an even flow of work.

2. The personnel limit should include all persons employed including those employed on the movement of the ammunition or other tasks in the immediate vicinity.

3. The limit may include up to two supervisors or inspectors even though their presence is not continuous.

4. The limit should be related to the size of the building and number of exits. Irrespective of other considerations, each person is to have ample working space and suitable evacuation routes.

c) A working explosive limit for each building, room or area should be assessed in accordance with the following principles:

1. It should not exceed the quantity permitted by available quantity-distances.

2. The limit should represent the minimum number of containers or rounds required to maintain an even and continuous flow of work.

3. The working limit should include all ammunition held within the building and the immediate vicinity. It should also include ammunition that has been processed or waiting to be processed, whether on vehicles or on the ground.

4. The possibility of reducing the hazard presented both inside and outside the building by the use of adequate internal traverses should be considered.

d) Signs should be conspicuously posted to provide the following information:

1. The nature and type of ammunition being processed.

2. Details of the operation i.e. re-boostering.

3. The compatibility group, hazard division and fire class of ammunition.

4. Personnel and explosive limits.

This information should be repeated as necessary for rooms or confined areas where special working conditions are prescribed. The explosive limits may be stated in terms of NEQ and/or number of rounds or containers.

2.6.5.5. *Clean Working Areas*

a) Clean conditions may be described as a set of precautions that are taken in explosives laboratories, workshops, proof areas, and certain magazines, to prevent the introduction of, or the contact of explosives

with, extraneous matter such as ferrous metals, aluminium or aluminium alloys or grit which might cause an explosion through friction or spark.

b) Working areas that are required to be maintained under clean conditions should be provided with a changing lobby. The lobby should be divided by a barrier to indicate the clean area.

2.6.5.6. *Clothing for Clean Conditions*

Clothing used for wear in explosives workshops or laboratories maintained under clean conditions should be specified by the appropriate National Authority, and will normally include items such as spark-proof conductive footwear, flameproofed smocks or coveralls and suitable hair covering.

2.6.5.7. *Static Electricity Precautions*

a) Ammunition workshops should be provided with conductive or anti-static flooring. Conductive flooring is designed to provide a path of conductivity for the free movement of electrostatic charges, thereby preventing a charge accumulation.

b) Anti-static flooring differs from conductive flooring in that it offers greater resistance to the passage of electrical current.

c) Grounding (earthing) points should be available for equipment, tools and ammunition in explosives workshops, to prevent a difference of electrical potential between operators and the material that they must handle.

d) Conductive flooring and grounding (earthing) systems should be tested for continuity in accordance with national specifications.

e) Personnel working in explosives workshops should wear conductive footwear or copper chain, when conductive flooring is present. Such safety devices should be tested frequently.

2.6.5.8. *Painting Operations*

a) Painting and stencilling operations should only be conducted in well ventilated rooms or outdoors.

b) Spray painting operations, when conducted indoors, should be done in spray painting booths, except for minor touch-up or stencilling using low pressure spray markers or aerosol containers.

c) Operators and helpers should wear protective masks while spray painting is in progress, unless the spray booths are properly exhausted so as to preclude exposure of personnel to toxic atmosphere.

2.6.5.9. *Heat Sealing Equipment*

a) The use of heat sealing equipment for packaging of ammunition in polyethylene is permitted under the following conditions:

1. The ammunition is suited to heat sealing.

2. The heat sealing apparatus is approved.

3. It is used in accordance with the manufacturer's instructions.

4. It is properly maintained and inspected for serviceability and cleanliness before initial use and at the beginning of each shift, and should be checked for cleanliness (absence of any spillings) before each operation.

b) The sealing equipment should be restricted for use as permitted by the host country within a transit magazine or explosives workshop in a room or segregated area apart from other activities. However, heat sealing equipment must not be permitted in a room maintained under clean conditions.

c) Items to be heat sealed should be in serviceable condition and free of defects.

d) Detonators and heat sensitive items such as propellants or explosive samples should be suitably packaged before heat sealing.

2.6.5.10. *Tools*

a) Only non-sparking tools should be used in direct contact with exposed explosives or in rooms maintained under clean conditions.

b) Special or locally designed tools and equipment should not be used in ammunition operations nor should modifications or alterations to approved tools or equipment be made without prior approval.

c) Tools and appliances designed and provide for particular explosives operations should not be used for other purposes without approval.

d) Only those tools authorized for use by the applicable SOP for the operation being performed should be permitted in the room or area.

2.6.5.11. *Closedown of Explosives Workshops*

a) When an explosives workshop is vacated all electrical installations and powered equipment other than essential services should be switched off or disconnected. At the end of each working day the building should be secured.

b) Ammunition remaining in the building should be subject to the following:

1. During temporary breaks within the course of a working day, the ammunition may be left in position provided it is safely stowed, and the explosive is not exposed.

2. At the end of each working day ammunition may be left in the work area providing it is packaged, (except for ammunition which is not normally stored in packages) and placed on the floor. Items should be grounded (earthed) as applicable.

2.6.5.12. *Supervision*

Constant supervision should be maintained by supervisory staff and all personnel should be safety conscious. Each operator should be fully acquainted with any hazards associated with the ammunition on which he is required to work. Before commencing an operation each operator should be familiarized with the particular task that he will perform.

2.6.5.13. *Accident Involving Ammunition*

a) In the event of an accident or incident involving ammunition, all operations shall cease immediately and the situation shall be reported to the Commanding Officer/Superintendent. Nothing shall be disturbed, except in

the interest of safety or as may be necessary to give assistance to injured persons. Precautions should be taken to prevent unauthorized personnel from entering the area.

b) Accidents involving ammunition shall be reported in accordance with national regulations.

Section 6 – Destruction of Ammunition and Explosives

2.6.6.1 *Introduction*

a) This section contains advice pertaining to the destruction (by open burning/open detonation) of ammunition and explosives which has deteriorated or which has been declared surplus or obsolete. These recommendations establish measures and procedures for minimizing the risk in destroying unwanted ammunition and explosives. All destruction operations must be carried out in accordance with rules and regulations established by the competent National Authority.

b) This section does not deal with matters pertaining to Explosive Ordnance Disposal (EOD) emergency actions.

2.6.6.2 *Selection Of Destruction Areas For Open Burning/ Open Detonation*

The ideal destruction area is one with deep soil, free from loose rocks, where trenches and pits can be dug easily and in which the risk of fire is negligible. In the selection of a permanent destruction area, the land should be above rather than below the surrounding area, naturally drained. The destruction area must be as far as possible from:

a) magazines and other buildings in the explosives area;

b) administration buildings and depot offices;

c) public or inhabited buildings;

d) overhead and underground cables;

e) land drainage systems, water mains, sewers and underground pipelines;

f) railway and highway cuttings, tunnels and embankments where earth shocks might undermine or cause debris to fall on the tracks or roads;

g) airfields and

h) environmentally sensitive areas; such as areas containing wetlands, endangered species, or threatened plants.

2.6.6.3 *Explosive Limits For Destruction Areas*

a) Explosives limits for destruction areas will vary because of local conditions. In establishing limits for items of Hazard Division 1.1, 1.2, 1.3 and 1.4 involved in individual destruction operations, the maximum quantity to be destroyed at any time must be determined carefully by the competent National Authority.

b) When determining these limits, consideration must be given to:

1. the maximum radius of fragment and debris hazards;

2. the maximum radius of blast effects;

3. shock transmission through the particular ground strata (e.g. high water tables or rock formations);

4. the effects of overcast weather conditions; and

5. the effects of wind.

2.6.6.4 *Destruction Area Maintenance*

a) Fire breaks must be maintained around and within destruction areas as required.

b) All trees, dry grass and underground within a radius of 60 m from the destruction point must be removed.

c) The area should be restricted and marked as required by the competent National Authority.

2.6.6.5 *Splinter-proof Shelters*

Where Ammunition is being destroyed by detonation, a splinter-proof shelter should be provided as a

control point and to provide protection for personnel. Where provided, it must be located not less than 90 m from the actual destruction point. Where a splinter-proof shelter is not provided, the Control Point should be located at a sufficient distance from the destruction point in order to provide adequate safety to personnel.

2.6.6.6 *Record Keeping*

A record keeping system should be maintained that includes location of destruction, summary of items destroyed, date of operation and other data required by the competent National Authority.

CHAPTER 7 - DETAILED INFORMATION RELATING TO HAZARDS FROM ELECTRO MAGNETIC RADIATION TO AMMUNITION CONTAINING ELECTRO-EXPLOSIVE DEVICES

Section I - Characteristics of Electro-Explosive Devices

2.7.1.1. *General*

Electro-Explosive Devices (EED) are used to produce an explosive response by conversion of chemical energy into heat following their electrical initiation.

EED are designed to be initiated by the application of suitable electrical stimuli, but unintentional initiation may occur if the EED or its associated circuitry is exposed to electromagnetic radiation. Unintentional initiation can also occur if any electrically charged body is allowed to discharge trough the EED

2.7.1.2. *Types of Electro-Explosive Devices*

At present and in the envisaged future four types of EED are employed:

Bridge-wire and Film bridge EED

These devises are activated by passing a current through a resistive bridge (wire, film or tape) which is in close thermal contact with an explosive charge. Power dissipation in the bridge produces a temperature rise at the explosive, which if high enough will lead to a self-sustaining thermal reaction, causing initiation. Functioning time for these devices varies from a few microseconds for the faster film bridge (FB) devices to a few milliseconds for typical bridge-wire (BW) EED.

2. Conducting Composition EED

The priming layer of a conducting composition (CC) EED consists of a primary explosive mixed with a small proportion of finely divided graphite which forms a number of conducting chains. Application of a voltage across the chains leads to power concentrations at one more critical graphite-graphite junctions and the sputtering of graphite on the neighbouring explosive crystals causes then to ignite the concentration of electrical energy into a few low mass graphite-graphite

junctions resulting in CC devices being sensitive to low energy levels and functioning time can be in the microsecond region.

3. Exploding Bridge-wire EED

Exploding bridge-wire (EBW) detonators require a dissipation of 0.25 J or more in a low resistance BW in a period of less than a microsecond to cause initiation. The high instantaneous power results in the explosion of the BW, inducing detonation in a relatively insensitive low density secondary explosive which in turn initiates a high density output pellet. The main safety characteristics inherent in the EBW concept is that it requires the high and rapid energy input from a specialised power source in order to function. EBW EED can be initiated by the application of other energy inputs eg, AC mains electricity, but the main charge in unlikely to detonate.

4. Slapper Detonator

Slapper detonators (SD) (sometime called an exploding foil initiator (EFI) operate by applying a high energy impulse to a foil or film bridge causing it to explode. This explosion punches a flyer from a plastic disc and propels it analog a barrel section to impact a secondary explosive charge thereby causing detonation. Slapper detonators are similar to EBW in terms of sensitivity and functioning times but are less prone to dudding by low currents than EBW since the bridge is separated from the explosive charge. These devices provide an alternative to EBW particularly in high temperature and high shock applications.

2.7.1.3. *EED Sensitivity Thresholds*

In general EED in Service use fall into two broad categories:
Those with long thermal time constants (typically 10ms – 50 ms) such as BW which are known commonly as “slow responding power sensitive “ EED.

Those with a short thermal time constant (typically 1us – 100 us) such as FB and CC which are known commonly as “fast responding energy sensitive” EED.

As consequence BW EED tend to integrate transient energy and, in the case of repetitively pulsed radars will respond as though to continous wave (CW) (mean or average) power levels. Whereas energy sensitive devices tend to respond to the peak power level and this must be taken into account when determining the susceptibility of such devices.

Whilst the above groups describe the salient characteristics of each type of EED it should not be inferred that they react exclusively to either power or energy impuls

It is impractical to attempt to define uniquely the stimulus level at which none of a paricular batch of EED will fire. The threshold sensitivity of the EED is usually derived from statistical measurements, an assumption being made that the probability distribution of sensitivity obeys a normal law, when the logarithm of applied stimulus is taken as the independent variable.

In determining hazard tresholds (known as No-Fire Tresholds (FT)) both the power and the energy are considered and defined in terms of the 0.1% probability of firing at a single sided lower 95% confidence level.

To illustrate the results of such sampling on the worst cast BW EED (Igniter Type F 120) the NFT figures are indicated in the following example:

Resistance Range Ω	No-Fire Tresholds Values			Time Constant ms
	Energy mJ	Current A	Power mW	
(a)	(b)	(c)	(d)	(e)
10-16	0.2	0.045	26	8

Section II - Nature of the Radiated Field and Transmitter Antennas

2.7.2.1. *Nature of the Radiated Field*

a) In the far-field the electromagnetic field radiating from a transmitting antenna consists of an electric (E) and a magnetic (H) component, which are in phase and mutually perpendicular to each other and to the direction of propagation. The strength of the field is measured in volts per m for the electric component and in amps per m for the magnetic component. The power density (S) is the power present in a unit area perpendicular to the direction of propagation and is an expression of the strength of the radiated far-field. It is measured in watts per m^2 and is related to the electric and magnetic components by:

$$S = \frac{E^2}{377} = 377\, H^2 \qquad \text{(eq 7-1)}$$

where 377 Ω is the impedance of free space.

b) Within the near-field or Fresnel Region, the magnitudes of the H and E components vary and one or the other can exceed the values they assume at the perimeter. Starting at the perimeter of the Fresnel Region the power density falls off inversely with the square of the distance.

2.7.2.2. *Transmitter Antennas*

a) Unipole and dipole antennas are commonly used for communications in the frequency range below 300 MHz. The radiation from this type of antenna falls into two basic regions:

1. The near-field region which extends out to a distance of 2-3 wavelengths from the antenna. In this region the E and H components of the radiated field have not established their correct phase relationship.

2. The far-field region extends beyond the near-field and as for directional antenna, the power density is given by:

$$S = \frac{G\,P}{4\,\pi\,d^2} \qquad \text{(eq 7-2)}$$

where

G	=	Power ratio gain of the transmitter antenna
P	=	The mean power in watts fed to the transmitting antenna (peakpower x pulses per second x pulse width)
d	=	The distance in m from the antenna to where the field is under consideration.

b) The radiation pattern from a highly directional radar antenna falls into two main regions as follows:

1. A Fresnel Region which extends from the aperture of the antenna to a distance in front of the antenna dependent on the physical area of the dish.

2. The Frauenhofer Region or far-field. This extends beyond the Fresnel Region.

c) The end of the Fresnel Region and the start of the Frauenhofer Region is not well defined but is arbitrarily taken to be at a distance of 2 L^2/λ , where L is the largest dimension of the antenna. Within the Fresnel Region the maximum power density is given by:

$$S = \frac{16\,\pi\,P}{G\,\lambda^2} \qquad \text{(eq 7-3)}$$

This is the worst case; if an unacceptable hazard is indicated then a more detailed calculation should be carried out by the competent National Authority. Beyond the Fresnel Region in the far-field or Frauenhofer Region, the maximum mean power density is given by:

$$S = \frac{G\,P}{4\,\pi\,d^2} \qquad \text{(eq 7-4)}$$

Section III - Conditions for Maximum Pick-Up in an EED

2.7.3.1. *General*

a) Relatively little power is required to fire most EED which are normally operated by a direct or alternating current firing pulse. Whether fitted to ammunition, connected to firing leads or held as separate components, EED respond and may fire when subjected to EM energy propagated from antennas of radio and radar transmitters.

b) Energy from the EM environment can enter an ammunition item through any discontinuity in its skin, e.g. joints, inspection windows, etc. The energy may be conducted into the EED via its firing leads or other electrical conductors such as wires, tools and fingers.

c) The protective switch in a circuit which prevents the initiation of an EED by direct current until the desired time, is not an effective barrier to EM energy.

d) In general, ammunition containing EED are more susceptible to EM energy pick-up during assembly, disassembling, testing, handling, loading and unloading into weapons. The attachment of external cables and test sets to such ammunition usually increases its susceptibility to EM energy pick-up.

e) The ability of a firing circuit to pick up sufficient energy to cause an EED to operate depends on many factors. These include the electrical characteristics of the EED installed, the nature of the firing line, its length and geometry, ambient EM field strength and frequency. The EM field strength is dependent on the power output of the transmitter, the characteristics of the system and the distance between the antenna and the firing circuit. It is not the position of the EED that is important but the position of the whole firing circuit in relation to the EM field.

2.7.3.2. *Maximum Energy Pick-Up*

The maximum energy pick-up in an EED is dependent on:

1. the physical and electrical parameters of the firing circuit;
2. the frequency of the transmitter;
3. the power density of the EM field in the vicinity of the receiving antenna, i.e. the firing circuit.

2.7.3.3. *Types of Antennas*

a) To evaluate the maximum gain, the EED firing circuit can be considered to be one of several types of antennas, namely:

1. Dipole
2. Loop
3. Long Wire
4. Rhombic

b) Depending on the actual firing circuit design one or more of the above configurations can be considered a reasonable approximation as the receiving antenna. For example, placing a short circuit across the firing lines would make it equivalent in performance to either a loop or rhombic antenna.

c) In practice, for weapon systems less than 5 m in length, the dipole antenna is a good approximation. Long wire and rhombic antenna configurations can be applicable, but not generally while the weapon is in the transport and storage mode. For missiles in excess of 5 m in length and when missiles are attached to test facilities with long leads, long wire or rhombic configurations may have to be considered. The technical basis for the assumption that in the general case the receiving antenna will act as a dipole is given in Section IV.

2.7.3.4. *Conditions for Maximum Pick-Up*

a) Assuming that the receiving antenna (EED circuitry) approximates a dipole maximum pick-up will be attained under the following conditions:

1. - The lead wires to the EED opened out straight, their combined length equal to half the transmitted EM wavelength or an odd multiple thereof and the EED at the centre of the leads

   or

   - one lead wire (or case) of the EED grounded and the other lead wirestraight and its length equal to one-quarter of the transmitted EM havelength or an odd multiple thereof.

2. The lead wires parallel to the electrical field vector.

3. The antenna configuration and the EED in the zone of maximum radiation.

b) It should be noted that any electrically conductive component forming the structure of a system may present a halfwave antenna or a loop or a rhombic antenna and the resultant circulating currents can induce EM energy into EED circuits in the vicinity of such structures. In practice it can be considered worst case when a long wire or rhombic antenna is formed. In those cases, the amount of EM pick-up could increase approximately 10 dB relative to the pick-up in a dipole antenna.

2.7.3.5. *Effect of a Metal Container*

a) An EED assembly incorporating a firing connector which is mounted through a metal container, such as a cartridge case, is less sensitive to EM energy when it is not connected to the firing lines due to the inefficient antenna the assembly presents. During handling, however, if contact is made between the connector and an external body such as the system structure, a length of wire, screwdriver, or the finger of an operator then a more efficient antenna may be formed.

b) A receiving antenna is most effective when situated in free space and unobscured from the source of radiation. In general, the presence of obstructions in the vicinity of the receiving antenna (EED circuitry) will reduce the power picked up by the antenna. However, under certain conditions the EM field reflected from such obstructions could increase the incident field at the receiving antenna. In ammunition where the EED and firing lines are mounted within the metal skin or situated within a metal container, then the EM pick-up may be reduced by a factor up to 20 dB relative to that from a matched antenna in free space.

2.7.3.6. *Impedance of the Antenna*

a) Although it is unlikely that the impedance of the antenna configuration formed will match that of the EED, the possibility remains that this may occur at some frequencythroughout the spectrum.

b) Firing lines disconnected from the firing supply and short circuited will form a loop antenna and as such are more likely to pick up EM energy at lower frequencies. In addition, the impedance of a loop antenna is more likely to match the impedance of a bridgewire EED than that of a halfwave dipole; consequently more RF power will be fed to the EED.

2.7.3.7. *Rhombic or Long Wire Configurations*

The EM energy pick-up with rhombic or long wire configurations can in practice be up to 10 dB greater than that picked up by a dipole configuration. If the firing lines to an EED are open-circuited as close to the EED as possible the susceptibility of the EED to EM fields will be reduced where the wavelengths are large compared to the EED lead dimensions. For example, if the EED lead(s) are less than 100 mm in length, EED susceptibility will be reduced significantly at frequencies less than 750 MHz. Placing broadband RF filter(s) in the firing line(s) as close to the EED as possible will also reduce the susceptibility of the system.

Section IV - Consideration of the Pick-Up in Different Types of Antenna

2.7.4.1. *Efficiency of the Circuit*

The maximum efficiency of the circuit connected to the EED, a part of which acts as an antenna, is dependent on four electrical properties:

1. R_a (radiation resistance of antenna) (Ω)
2. R_o (ohmic resistance of the lines) (Ω)
3. X_a (reactive impedance of antenna) (Ω)
4. G (gain of antenna relative to an isotropic (a dimensionless ratio) antenna)

These properties are dependent upon geometry, dimensions, and materials of the antenna, the frequency, and the proximity to ground and other nearby objects.

2.7.4.2. *Maximum Power*

a) The maximum power that is induced in the antenna at a given frequency is dependent upon R_a and G and is attained at optimum orientation.

When the circuit which plays the part of the antenna has been determined, the classical theory can be used to find the energy distribution. The electrical representation is as follows:

c) V_a is the voltage induced in the antenna. Maximum voltage is dependent upon the external field intensity and effective height of the antenna.

The impedance of the EED and the antenna are given by:

$$Z_L = R_L + j X_L \qquad \text{(eq 7-5)}$$

$$Z_a = R_a + j X_a \qquad \text{(eq 7-6)}$$

d) It can be easily shown that the maximum power is dissipated in the EED when

$R_L = R_a + R_o$ and $X_a = -X_L$

then

$$A_{max} = \frac{\lambda^2 R_L G}{4\pi (R_L + R_o)} \qquad \text{(eq 7-7)}$$

where A_{max} is the maximum aperture of the antenna.

Generally R_o is negligible and the maximum aperture obtained is

$$A_{max} = \frac{G \lambda^2}{4\pi} \qquad \text{(eq 7-8)}$$

thus the maximum power is then only dependent on the gain and the wavelength.

e) The value of G that should be used and which gives A_{max} is dependent on the length of the lead wire L:

1) When L ≤ ¼ λ the dipole antenna should be considered and the maximum value of gain can be taken as G = 1.64.

2) When ¼ λ < L ≤ λ the long wire antenna configuration should be considered and the maximum value of the gain will be given by:

$$G = 1.4 + \frac{L}{\lambda} \qquad \text{(eq 7-9)}$$

3) When L > λ the rhombic configuration should be considered and the maximum value of the gain will be given by:

$$G = \frac{10\,L}{4\lambda} \; when \; \frac{L}{\lambda} \leq 20 \qquad \text{(eq 7-10)}$$

f) The formulae given in subparagraph e) above show that the rhombic and long wire configurations have a gain larger than a dipole. However, for the frequency range in which the circuit is very large in respect to λ, the radiation resistance, R_a does not present the most favourable value and when R_a becomes very large, it can be assumed that $R_a >> R_o + R_L$

$$Ae = \frac{R_L\, G\, \lambda^2}{\pi\, R_a} = \frac{K\, G\, \lambda^2}{4\,\pi} \qquad \text{(eq 7-11)}$$

where Ae is the effective aperture and

$$K = \frac{4\, R_L}{R_a} \qquad \text{(eq 7-12)}$$

g) When L >> λ, R_a is normally high. However, there is a small possibility that wiring between the antenna configuration and the EED may act as an impedance matching transformer. Therefore, the most conservative assumption is made when $R_L = R_a$ and

$$G = \frac{10\,L}{4\,\lambda} \qquad \text{(eq 7-13)}$$

2.7.4.3. *Conclusions*

a) In practice, however, for weapon systems the length of which are less than 5 m, a matched half wave dipole is a good approximation of the worst case configuration.

b) Long wire and rhombic configuration should however be used for EED on launchers and attached to test facilities and for very long missiles.

CHAPTER 8 - DEPLETED URANIUM AMMUNITION

2.8.1. *General*

Depleted Uranium (DU) is mildly radioactive at a level that is low enough to permit handling and transportation with simple precautionary measures. DU has a chemical toxicity at the same level as other heavy metals such as Lead, allowing handling and transportation in authorized packaging without abnormal risk. The mechanisms whereby radioactivity and toxicity might lead to harmful effects are if:

(1) Personnel are in close contact with DU over extended periods, or

(2) If DU is involved in a fire or explosion in which Uranium Oxides from the ammunition could be dispersed and inhaled by personnel sited downwind from the event.

For detailed information on DU, refer to the United Nations Website:

http://www.who.int/ionizing_radiation/env/du/en.

Also refer to World Health Organisation (WHO) Guidance on Exposure to Depleted Uranium: (WHO/SDE/OEH/01.12.2001):

http://www.who.int/ionizing_radiation/en/Recommend_Med_Officers_final.pdf.

2.8.2. *Storage Facilities*

Storage facilities for DU ammunition will usually be located in military controlled sites, at distances from the nearest point of public access beyond which the predictable explosive, inhalation and surface contamination effects would be acceptable. Thus, any accidental contamination requiring remedial action should be confined to areas under military control and therefore restriction of access necessary during such action should not interfere significantly with normal public life.

2.8.3. *Principles of Segregation*

The separate storage of the DU and explosive components of the ammunition, or, at least, the separate storage of DU ammunition from other types must be regarded as offering positive safety advantages and should be adopted whenever practicable.

2.8.4. *Fire-fighting*

2.8.4.1. *Combustion of DU*

The combustion properties of DU metal should be taken into account when dealing with a fire involving DU ammunition. It is prudent to assume from the outset that DU is burning and that DU oxide smoke is being produced and to apply the appropriate precautions, as follows:

2.8.4.2. *Precautions*

Once uranium metal has ignited and a vigorous self-sustaining oxidation reaction has commenced, the application of small quantities of conventional extinguishants is likely to be ineffective and may even add to the spread of the fire by dispersing the burning uranium. For example, insufficient water to cool the fire would react with hot uranium metal to form hydrogen gas. For a small fire involving uranium and no explosives, the most effective extinguishant is an inert powdered smothering agents, but when explosives are present the closeness of approach necessary to deliver such an extinguishant to the seat of the fire would be hazardous to the fire fighters. In particular, propellants, the most likely energetic material to be closely associated with the DU, may produce intense radiant heat, firebrands and some ejected fragments. The firebrands may be only small pieces of packaging materials but it is possible that they could be fiery fragments of burning propellant.

2.8.4.3. *Fire-Fighting Methods*

a) The most practicable method is to drench the fire with copious quantities of water delivered from a safe distance with the aim of rapidly cooling the combustibles. Normal precautions in dealing with an explosives fire such as the fire crew sheltering behind protective barriers should be observed. Self-contained breathing apparatus should be worn and, where practicable, the fire should be tackled from the windward side. Care should be taken to ensure that the fire is completely extinguished and that the remaining ashes and debris are cold and thoroughly saturated with water.

b) Disposition of water contaminated with DU particulates should be based on the advice of the local National Authority.

QUANTITY-DISTANCE CRITERIA FOR ABOVEGROUND STORAGE

(See also Part I, Annex I-A)

SECTION I GENERAL
SECTION II CRITERIA FOR Q-D TABLE 1
SECTION III CRITERIA FOR Q-D TABLE 2
SECTION IV CRITERIA FOR Q-D TABLE 3A
SECTION V CRITERIA FOR Q-D TABLE 3B

Section I - General

1. *Purpose and Content of the Annex*

This annex gives the criteria and the formulae used to generate values in the Q-D Tables in Part I, Annex I-A. For each distance function, constant distance and minimum value in the tables there is a paragraph or subparagraph in the appropriate section of this annex. Each one records the basis of the Group's decision (specific experimental observation or value judgement) and indicates by a number the appropriate reference in the bibliography (e.g. "Ref.1" means reference number 1 in Annex II-C).

2. *Conversion Factors*

Length	:	1 m	=	003.2808 ft
Area	:	1 m^2	=	010.7639 sqft
Mass	:	1 kg	=	002.2046 lb
Energy	:	1 kgm	=	007.2330 ftlb
			=	009.8066 Joule
Pressure	:	1 kg/cm^2	=	014.2233 psi
			=	980.665 mb

Length	:	1 ft	=	000.3048 m
Area	:	1 sqft	=	000.0929 m^2
Mass	:	1 lb	=	000.4536 kg
Energy	:	1 ftlb	=	000.1383 kgm
			=	001.3558 Joule
Pressure	:	1 psi	=	000.0703 kg/cm^2
			=	068.948 mb

3. Conversion of American and British Formulae

American and British Units	Metric Units
$d = k\,W^{\frac{1}{3}}$	$d = 0.3967\,k\,Q^{\frac{1}{3}}$
$d = k\,W^{\frac{1}{2}}$	$d = 0.4526\,k\,Q^{\frac{1}{2}}$
$d = k\,W^{\frac{2}{3}}$	$d = 0.5136\,k\,Q^{\frac{2}{3}}$
$RB = \dfrac{14\,W^{\frac{1}{3}}}{\sqrt[6]{\left(1 + \left(\frac{7000}{W}\right)^2\right)}}$	$RB = \dfrac{5.6\,Q^{\frac{1}{3}}}{\sqrt[6]{\left(1 + \left(\frac{3175}{Q}\right)^2\right)}}$

American and British Units

d = quantity-distance in feet (ft)

W = Net Explosives Quantity (NEQ) in pounds (lb)

RB = radius of B damage in feet (ft)

Metric Units

d = quantity-distance in metres (m)

Q = Net Explosives Quantity (NEQ) in kilogrammes (kg)

RB = radius of B damage in metres (m)

B damage is such severe damage to domestic constructions of 9 inch (23 cm) brickwork as to necessitate demolition.

4. *Mathematical Signs and Symbols Used to Determine Mechanical Magnitudes*

Designation	Formula Symbol	Unit Name	Unit Symbol	Conversion
Force	F	Newton	N	$N = \frac{M_T}{m_o} \cdot e^{-\sqrt{2\frac{m}{m_o}}}$
Mass	m	Kilogram	kg	$1\ kg = 10^3\ g$
Velocity	v	Metre per second Kilometre per Hour	$\frac{m}{s}$ $\frac{km}{h}$	$1\ \frac{m}{s} = 3.6\ \frac{km}{h}$
Acceleration	a	Metre per square second	$\frac{m}{s^2}$	
Pressure	p	Pascal	Pa	$1\ Pa = 1\ \frac{N}{m^2} = 1\ \frac{kg}{ms^2}$
		Bar	bar	$1\ bar = \frac{10\ N}{cm^2} = 10^5\ Pa$
Energy/Work	E	Joule	J	$1\ J = 1\ Nm = 1\ Ws = 1\ \frac{kgm}{s^2}$
Power	P	Watt	W	$1\ W = 1\ \frac{J}{s} = 1\ \frac{Nm}{s} = 1\ \frac{kgm^2}{s^3}$

Section II - Criteria for Q-D Table 1

In this section the different types of distances are covered as follows:

- Inter-Magazine Distances	:	paragraphs	5 - 12
- Explosives Workshop Distances	:	paragraph	13
- Inhabited Building Distances	:	paragraphs	14 - 16
- Special Distances	:	paragraphs	17 - 18

1. *D1-Distances and D2-Distances*

a) Distance Functions

1) $D1 = 0.35\ Q^{1/3}$ Valid for $Q \leq 30\ 000$ kg

2) $D2 = 0.44\ Q^{1/3}$ Valid for $30\ 001 \leq Q \leq 120\ 000$ kg

b) Explanation

The D1- and D2-distance functions are based on UK trials (Ref. 1) with barricaded open stacks of aircraft bombs, subsequently reviewed (Ref. 2) in the light of US trials on modular storage. The distances prevent simultaneous propagation of detonation to adjacent stacks beyond the earth barricades (see paragraph 1.3.3.1.) though some damage to bombs and occasional fires or delayed explosions may occur.
The use of D2-distances is limited to situations not involving combustible materials and with only lightweight weather protection (i.e. metal shed roof or tarpaulin). Delayed propagation by fire should not occur.

2. *D3-Distances*

a) Distance Function

$D3 = 0.5\ Q^{1/3}$

This formula gives the normal minimum separation between the walls of adjacent igloos when the relevant roof and wall of the igloo at the PES and that at the ES are both protected by the prescribed amount of earth (Ref. 3-14, 17).

b) Explanation

The D3-distances apply to any combination of rear-walls and side-walls. Thus the head-wall and door(s) of the acceptor igloo, at the ES, would not be exposed face-on to the blast from an explosion at the PES. This minimum separation should not be used in wet sand or wet clay which is associated with unusually large crater size and ground shock effects.

3. *D4-Distances*

a) Distance Function

$$D4 = 0.8\ Q^{1/3}$$

This formula is based upon French (Burlot) (Ref. 15) and US trials (Ref. 8, 13, 16). D4-distances prevent propagation of an explosion by flame through the crater and by blast. Barricades give protection against propagation by projections.

b) Explanation

The D4-distances give normal minimum separation between the walls of adjacent igloos when either the relevant wall of the igloo at the PES or that at the ES is protected by the prescribed amount of earth, but not both. The D4-distances apply when the front of the one igloo faces the rear-wall of another provided the construction of the head-wall and door(s) are of sufficient quality. Thus the head-wall and door(s) of the acceptor igloo would be exposed face-on to the blast from an explosion at the PES. This is why the peak overpressure specified in subparagraph 2.3.2.2.b)2) is greater than that in subparagraph 2.3.2.2.b)1) despite the greater distance. The use of igloos with their axes perpendicular presents special problems which require individual assessment. The D4-distances are not sufficient when the front of one igloo faces the side-wall of another (see paragraph below).

4. *D5-Distances*

a) Distance Function

$$D5 = 1.1\ Q^{1/3}$$

This formula is used when the front of one igloo faces the side-wall of another.

b) Explanation

The D5-distances give the normal minimum separation between the side of a donor igloo (PES) and an acceptor head-wall (ES) without significant risk of explosion communication (by impact of ejecta and structure debris) (Ref. 8).

5. *D6-Distances*

a) Distance Function

$D6 = 1.8\ Q^{1/3}$

This formula is based upon US trials (Ref.). D6-distances prevent propagation of an explosion by flame and blast when the walls of the ES are of reinforced concrete at least 25 cm thick.

b) Explanation

The D6-distances give the normal minimum separation between the walls of adjacent igloos when the layout would qualify for the use of D4-distances but the design of head-wall, door frame or door(s) does not meet the stringent requirements specified in paragraph 2.3.2.2. In some cases it may be economic to improve the design of these features in order to qualify for the smaller Inter-Magazine Distances.

6. *D7-Distances*

a) Distance Function

$D7 = 2.4\ Q^{1/3}$

This formula is based upon French (Burlot) (Ref. 15) and UK trials (Ref.). The D7-distances prevent propagation of an explosion by flame, heat and blast.

b) Explanation

7. *D8-Distances*

a) Distance Function

$D8 = 3.6\ Q^{1/3}$

This formula is based upon UK trials (Ref.). The D8-distances prevent propagation by fragments where the radius of fragments is greater than the flame radius.

b) Explanation

8. *D9-Distances*

a) Distance Function

$D9 = 4.8\ Q^{1/3}$

b) Explanation

9. *D10-Distances*

a) Distance Function

$D10 = 8.0\ Q^{1/3}$

This formula is based upon UK trials (Ref.) and US trials (Ref.). The D10-distances protect personnel against severe injuries by blast.

b) Explanation

The D10-distances give the minimum distance from any aspect of an igloo to ensure that the blast effects are tolerable for an explosives workshop which is barricaded and has a protective roof. The normal design load for an explosives workshop is free field overpressure of 0.2 bar, the positive duration (ms) is $4.0\ Q^{1/3}$ and the positive impulse per unit area is $0.4\ Q^{1/3}$ (bar ms).

c) Minimum Distance

D = 270 m

The distance is the minimum distance from an igloo at which the hazard from rocks and structural debris is tolerable for an explosives workshop which is unbarricaded or has no protective roof. This minimum distance is used in conjunction with the formula for blast protection given by D10-distances.

10. *D11-Distances*

a) Distance Functions

1) $D = 3.6\ Q^{1/2}$

This formula is valid for $Q \leq 4\ 500$ kg. The distances are two thirds of the Inhabited Building Distances given by $D = 5.5\ Q^{1/2}$, suitably rounded (Ref.).

2) $D = 14.8\ Q^{1/3}$

This formula is valid for $Q > 4\ 500$ kg. The distances are exactly two thirds of the Inhabited Building Distances given by $22.2\ Q^{1/3}$ (Ref.).

b) Explanation

c) Minimum Distance

$D = 180$ m

The distance is exactly two thirds of the minimum Inhabited Building Distance D = 270 m (Ref.).

11. *D12-Distances*

a) Distance Function

$D12 = 22.2\ Q^{1/3}$

b) Explanation

12. *D13-Distances*

a) Distance Functions

1) $D13 = 5.5\ Q^{1/2}$

This formula is valid for $Q \leq 4\ 500$ kg. The distances were based originally on a UK analysis (Ref.) of bomb damage to traditional British brick dwellings including a survey of accidental explosions and trials. Subsequently the US independently re-appraised the expected damage from small explosions (Ref.). The

Group (Ref.) abolished the former reduction of distances by 20 % for Q ≤ 3 600 kg in the light of UK trials (Ref.) and US trials (Ref.) and statistical analysis of damage from accidental explosions (Ref.). The distances do not correspond to a fixed value of peak overpressure, the positive impulse per unit area approximates to ?? bar ms (Ref.).

The expected degree of damage to dwellings is tolerable since the extent of buildings affected by an explosion not exceeding 4 500 kg would not be great (Ref.).

2) $D13 = 22.2\ Q^{1/3}$

This formula is valid for Q > 4 500 kg. The distances were based originally on the same analysis (Ref.) as 1) above. The US had contemporaneously adopted values tending to $20\ Q^{1/3}$ based on a review of a comprehensive study of damage to dwellings of North American construction from a very large accidental explosion (Ref.). The Group subsequently adopted the criterion 50 mb peak overpressure for all normal types of construction (excluding curtain wall) and for caravans (Ref.) in the context of the tolerable degree of damage to a limited number of dwellings (individual risk). Discussion continues on the tolerable extent of such damage (group risk) (Ref.).

b) Explanation

c) Minimum Distances

1) D = 270 m

This distance is the minimum distance at which the risk of injury from projections for an individual in a dwelling is considered to be tolerable in sparsely populated areas (i.e. individual risk). It is not tolerable in a built-up area (group risk), nor in a vicinity of an igloo which produces many pieces of structural debris (Ref.).

2) D = 400 m

This distance is the minimum distance for tolerable group risk in a built-up area (Ref). It is also the minimum distance for tolerable individual risk in a sparsely populated area near an igloo owing to the many pieces of structural debris produced.

13. *D14- and D15-Distances*

a) Distance Functions

1) $D14 = 14.0\ Q^{1/3}$

2) $D15 = 18.0\ Q^{1/3}$

b) Explanations

1) The D14- and D15-distances are based on US full scale and model trials (Ref. 18-20).

2) D14-distances are used for Inhabited Building Distances from the rear of and D15-distances from the side of earth-covered buildings acting as a PES. The buildings must meet the requirements of subparagraph 1.3.6.7.a), have an internal volume exceeding 500 m^3 and have a NEQ of Hazard Division 1.1 ammunition not exceeding 45 000 kg. In no case may the Q-D be less than 400 m.

14. *D16- and D17-Distances*

a) Distance Functions

$D16 = 9.3\ Q^{1/3}$

$D17 = 12.0\ Q^{1/3}$

b) Explanations

1) The D16- and D17-distances are based on US full scale and model trials (Ref. 18-20).

2) The D16- and D17-distances are the Public Traffic Route Distances corresponding (i.e. 2/3) to D14- and D15-Inhabited Building Distances. The D16-distances therefore apply tothe rear of and the D17-distances to the side of an earth-covered building acting as a PES. The buildings must meet the requirements of subparagraph 1.3.6.7.a), have an internal volume exceeding 500 m^3 and have a NEQ of Hazard Division 1.1 ammunition not exceeding 45 000 kg. In no case may the Q-D be less than 270 m. However, the full Inhabited Building Distances (D14- and D15-distances) with a minimum of 400 m should be used, when necessary, in accordance with subparagraph 1.3.1.14.b).

Section III - Criteria for Q-D Table 2

In this section the different types of distances are covered as follows:

- Inter-Magazine Distances	:	paragraphs	19 - 20
- Explosives Workshop Distances	:	paragraph	21
- Public Traffic Route Distances	:	paragraphs	22 - 23

1. *Fixed Distance*

a) D = 2 m

This distance is used whenever the ES offers protection against fragments and/or debris from the PES.

b) Explanation

2. *Fixed Distances*

a) D = 10 m - 25 m - 90 m

These distances are dependent on:

1) The fragments and debris likely to arise from the PES in the event of an accidental explosion in the PES.

2) The susceptibility of the ES i.e. door facing PES, weak roof etc. to attack by such debris and/or fragments.

3) The desired level of protection.

b) Explanation

3. *Fixed Distances*

a) D = 25 m - 90 m - 135 m

The fixed distance 25 m is used for the barricaded workshop with a protective roof i.e. it offers good protection against fragments. The fixed distances 90 m and 135 m are used for barricaded workshops with light roofs and unbarricaded workshops with or without protective roof. 90 m or 135 m are used depending on the PES contains ammunition up to 60 mm calibre only or ammunition above 60 mm calibre.

b) Explanations

1) (for D = 25 m)

2) D = 90 m. Based upon US trials (Ref.). Acceptable risk from fragments and lobbed ammunition. Workshops can be evacuated and traffic can be stopped before the final fragment saturation has been reached. In the first minutes of an accidental explosion only a few items and fragments can be expected to be propelled at that distance. The possibility that protected buildings may be breached by an explosion within them and that subsequent explosions may cause ammunition to be lobbed out through these breaches is accepted.

3) (for D = 135 m)

4. *Fixed Distances*

a) D = 90 m - 135 m

A fixed distance of 90 m or 135 m depending on the calibre of the ammunition in the PES is used when traffic can be stopped promptly to avoid the worst attack.

b) Explanation

D = 90m and 135 m. Based upon US trials. Acceptable risk from fragments and lobbed ammunition. Workshops can be evacuated and traffic can be stopped before the final fragment saturation has been reached. In the first minutes of an accidental explosion only a few items and fragments can be expected to be propelled at that distance. The possibility that protected buildings may be breached by an explosion within them and that subsequent explosions may cause ammunition to be lobbed out through these breaches is accepted.

5. *Distance Functions*

a) 1) $D1 = 53\ Q^{0.18}$

2) $D2 = 68\ Q^{0.18}$

b) Explanation

The D1- or D2-distances depending on the calibre of the ammunition in the PES are used when it is impossible to stop traffic promptly in the event of an explosion.

Section IV - Criteria for Q-D Table 3A

In this section the different types of distances are covered as follows:

- Fixed Distances	:	paragraphs	24 - 28
- Distance Functions Distances	:	paragraphs	29 - 32

1. *Fixed Distance*

a) D = 2 m

This distance is used, providing virtually complete protection, whenever the PES is an earth-covered building or heavy-walled building with or without protective roof, which is side - or rear - on to the side, rear or face (when doors and head-wall are resistent to fire) of an ES which is an earth-covered building or building of non-combustible construction with walls of 70 cm concrete, brick or equivalent with protective roof.

b) Explanation

2. *Fixed Distance*

a) D = 10 m

This distance is used, providing high/limited degree of protection, whenever the PES is an open stack or light structure, barricaded or unbarricaded, or earth-covered building with door facing the ES and where the ES is a side-on earth-covered building not complying with paragraph 2.3.2.2. or a barricaded open stack or light structure.

b) Explanation

3. *Fixed Distance*

a) D = 25 m

This distance is used as alternative to 2 m or 10 m to provide a better degree of protection or in cases where resistance of head-wall and doors is inadequate.

b) Explanation

Known as Fire-Fighting Distance this distance prevents ignition of buildings and stacks by radiant heat, whilst UK and US trials with propellants in buildings designed to vent through the door end show that the contents of the buildings are thrown through the front only.

4. *Fixed Distance*

a) D = 160 m

This distance is used as minimum distance for Public Traffic Routes when the PES is an unspecified earth-covered building with door facing the route and likely reaction of drivers on busy roads is considered to be acceptable.

b) Explanation
2/3 minimum Inhabited Building Distance used for PES detailed in subparagraph 27.a) above.

5. *Fixed Distance*

a) D = 240 m
This distance is the minimum Inhabited Building Distance when the PES is an unspecified earth-covered building with door facing the inhabited building.

b) Explanation

Based upon US trials with propellants. Minimum distance for protection against burning items projected by mortar effect (i.e. directional projection).

6. *D1-Distances*

a) $D1 = 0.22\ Q^{1/2}$

D1-distances are used, with a minimum of 25 m, in those cases when because of orientation or construction of either PES or ES, 25 m fixed distance is inadequate.

b) Explanation

Based upon UK trials with propellants. Derived from UK formula $D = 1.05\ W^{0.44}$. Distances protect against communication by flame and heat.

7. *D2-Distances*

a) $D2 = 3.2\ Q^{1/3}$

D2-distances are used, with a minimum of 60 m, as distance to workshops from all types of PES except when the PES is an unspecified earth-covered building with unbarricaded door facing the workshop.

b) Explanation

Based upon UK and US trials with propellants. Derived from UK formula $D = 8\ W^{1/3}$; corresponding US formula $D = 7\ W^{1/3}$ (approx.). Distances protect against effect of radiant heat. Heavy-walled buildings are considered to give no appreciable protection against the hazard.

8. *D3-Distances*

a) $D3 = 4.3\ Q^{1/3}$

D3-distances are used as Public Traffic Route Distance, with a minimum distance of 60 m (but see paragraph 27 above), when reaction of drivers on busy roads is considered to be acceptable.

b) Explanation

These distances are 2/3 of the Inhabited Building Distance. The distances are reduced in conformity with UK wartime and US current practices. Distances give a reasonable degree of protection against flame, heat and lobbed ammunition.

9. *D4-Distances*

a) $D4 = 6.4\ Q^{1/3}$

D4-distances are used, as Inhabited Building Distance with a minimum of 60 m (but see paragraph 28 above).

b) Explanation

Based upon UK trials with propellants. Derived from UK formula $D = 16\ W^{1/3}$. Distances protect against flame and heat.

Section V - Criteria for Q-D Table 3B

In this section the different types of distances are covered as follows:

- Fixed Distances	:	paragraphs	33 - 36
- Distance Function Distance	:	paragraph	37

1. *Fixed Distance*

a) D = 2 m

This distance is used, providing virtually complete protection, for all side- or rear-on earth-covered ES regardless of PES and when the PES is a side- or rear-on earth-covered building and the ES is a face-on earth-covered building with protective door and head-wall or a heavy-walled building with protective roof.

b) Explanation

2. *Fixed Distance*

a) D = 10 m

This distance is used, providing either virtually complete or high/limited degree of protection, where the PES is a heavy-walled building with or without protective roof or an open stack or light structure with or without barricade and the ES is a face-on earth-covered building or barricaded open stack or light structure.

b) Explanation

3. *Fixed Distance*

a) D = 25 m

This distance is used as alternative to or in place of 10 m when resistance of headwall and door of an earth-covered building or other form of ES is inadequate. It is also used as Workshop Distance where the workshop is a barricaded heavy-walled building with protective roof.

b) Explanation

Known as Fire-Fighting Distance this distance prevents ignition of buildings and stacks by radiant heat, whilst UK and US trials with propellants in buildings designed to vent through the door end show that the contents of the buildings are thrown through the front only.

4. *Fixed Distance*

a) D = 60 m

This distance is used as alternative to or in place of 25 m when construction or orientation of the PES/ES is considered to be inadequate. It is also used as Workshop Distance where the workshop does not have a protective roof and/or a barricade and as fixed Public Traffic Route Distance when traffic can be stopped promptly.

b) Explanation

Based upon French (Burlot's) trials. Minimum distance from a PES containing Hazard Division 1.3 items, other than propellants.

5. *D4-Distances*

a) $D4 = 6.4\ Q^{1/3}$

D4-distances are used as Inhabited Building Distances with a minimum of 60 m.

b) Explanation

Based upon UK trials with propellants. Derived from UK formula $D = 16\ W^{1/3}$. Distances protect against flame and heat.

DETAILED INFORMATION RELATED TO EARTH-COVERED MAGAZINES (IGLOOS)

SECTION I TYPES OF IGLOOS

SECTION II BLAST DATA FOR DESIGN OF IGLOOS

Section I - Types of Igloos

1. *General*

a) On the basis of data from structural analyses, modeltests and full-scale trials of the response of structures to explosion blast loads, the following designs are considered by the nations concerned to be suitable for Inter-Magazine Distances prescribed in Part I, Annex A.

b) The information contained in this section reflects the designs and features applicable to national requirements of NATO nations for the storage of ammunition and explosives. The types described do not necessarily equate to each other and should not be considered as freely interchangeable or alternative types.

c) Note should be taken of revisions among the specified drawings which include strengthening of head-walls, doorframes and doors, compared with earlier designs.

d) Less onerous requirements obtain for earth-covered magazines if they are sited at Inter-Magazine Distances greater than those prescribed in Part I, Annex A. Conversely, stronger types of construction may warrant smaller Inter-Magazine Distances. It is for the National Authority to balance the cost of real estate and to determine the optimum in any particular situation other than the norm.

e) When it is not possible for NATO authorities to obtain safety requirements from a host nation, they may contact the AC/258 Group for general guidance or for amplification of the principles in this Manual.

2. *French Igloo-Magazine Types*

a) The magazines below are approved by the French Ministry of Defence (Décision ministérielle N° 4986/DEF/DCG/T2 dated 9th September, 1975). There are three types of magazines:

1. Steel-arch type, 7 mm thick (ARMCO)
2. Steel-arch type, 5 mm thick (ARVAL)
3. Reinforced concrete arch type, 200 mm thick.

b) All magazines have a circular arch and all have earth-cover of 0.6 m. The usable interior dimensions are 12 m by 20 m giving a gross floor area of 240 m^2. The capacity is a NEQ of 60 000 kg. Two other models with dimensions of 12 m by 10 m and 12 m by 30 m are used, their gross floor areas and their NEQ vary in the same proportions.

c) The head-walls and the doors (single sliding doortype) are designed to resist an external blast loading of 7 bar and an impulse of 140 bar ms. The door consists of two steel sheets each 10 mm thick, reinforced by U-shaped girders. The dimensions of the door are 3.25 m by 3.25 m giving an opening of 3 m by 3 m.

3. *German Reinforced Concrete, Portal Type*

Reinforced concrete, portal type, earth-covered magazines, designed to vent through the head-wall, the construction of which is at least equivalent in strength to that specified in German Ministry of Defence drawings 75743 or 75740 for 50 m^2 storage area magazines and in drawings 75744 or 75741 for 25 m^2 storage area magazines (Munitionslagerhaus 611). The original doors and doorframes shown in the drawing no. 75929/4 are not satisfactory and must be redesigned for exposure as specified in subparagraph 2.3.2.2.b)2). The NEQ is limited to 125 000 kg explosives of Hazard Division 1.1 and to 250 000 kg of Hazard Divisions 1.2 and 1.3 based only on the limitation of quantity-distances.

4. *German Reinforced Concrete, Stradley*

Reinforced concrete, Stradley (Yurt) magazines, earth-covered, designed to vent through the head-wall, the construction of which is at least equivalent in strength to that specified in the German Ministry of Defence drawing 75737 (Munitionslagerhaus 602) for 93 m^2 and 186 m^2 storage area magazines. The original door and doorframes shown in the drawings nos. 75737/8 and 9 are satisfactory. The NEQ is limited to 125 000 kg explosives of Hazard Division 1.1 and 250 000 kg explosives of Hazard Divisions 1.2 and 1.3 based only on the limitation of quantity-distances.

5. *German Reinforced Concrete, Portal Type 180B and 90B*

Reinforced concrete, portal type, earth-covered magazines with a floor space of 180 m^2 and 90 m^2 respectively, designed in accordance with AC/258-D/211(Revised) dated 4th September, 1975 (Project No. 71517). Head-wall and door are satisfactory for exposure to a blast loading of 7 bar and an impulse of 84 bar ms. The earth-covered side-walls and rear-wall are satisfactory for exposure to a blast loading of 3 bar and an impulse of 42 bar ms. The NEQ is limited to 75 000 kg.

6. *German Corrugated Steel, Oval Arch Type 180S and 90S*

Corrugated steel, oval arch type, earth-covered magazines with a floor space of 180 m^2 and 90 m^2 respectively, designed in accordance with AC/258-D/211(Revised) dated 4th September, 1975 (Project 71922). Head-wall and door are satisfactory for exposure to a blast loading of 7 bar and an impulse of 84 bar ms. The earth-

covered side-walls and rear-wall are satisfactory for exposure to a blast loading of 3 bar and an impulse of 42 bar ms. The NEQ is limited to 75 000 kg.

7. *Norwegian Reinforced Concrete, Arch Type*

The following reinforced concrete, arch type, earth-covered magazines whose construction is at least equivalent in strength to Norwegian Defence Construction Service drawings as stated below:

1. Drawings A-6631, sheet 20-26 (arch radius 3.5 m)
2. Drawings A-7324, sheet 1-9 (arch radius 4.0 m)

Both types have double winged steel doors according to drawings A-7126, sheet 1-12. The front-wall and door of both types have been structurally calculated to withstand a long duration blast load of 8 bar overpressure. The door has been proof tested for a 12 bar and 150 bar ms blast load and classified as a 14 bar and 120 bar ms door. The arch and the rear-wall are statically designed to support the dead load pressure from the earth-cover and have been compared with model and full-scale tested US-designs. It has been concluded that the arch and the rear-wall will not collapse at scaled distances of $0.5^{1/3}$ and $0.8^{1/3}$ respectively. Only type 2 is now applied for new sites. According to the Norwegian Service Regulations for Storage dated 1st July, 1974, the maximum permitted NEQ in a single magazine is 80 000 kg for any magazine type. Any request for further information should be forwarded through the appropriate channels to the Norwegian Defence Construction Service.

8. *United Kingdom Reinforced Concrete, Portal Type*

a) The following reinforced concrete, portal type, earth-covered magazines the construction of which is at least equivalent in strength to the United Kingdom Department of the Environment Drawings shown below:

1. Single Bay. Drawing No. XB1/1, 1/2, 1/6, 1/9A and 1/10.
   Gross Floor Area: 149 m^2

   (1) Type 1. Storage capacity 80 NATO standard pallets.
   Stacked 2 high.

   (2) Type 2. Storage capacity 120 NATO standard pallets.
   Stacked 3 high.

2. Double Bay. Drawing No. XB1/3A, 1/5B, 1/6, 1/9A and 1/10.
   Gross Floor Area: 288 m^2

   (1) Type 1. Storage capacity 160 NATO standard pallets.

Stacked 2 high.

(2) Type 2. Storage capacity 240 NATO standard pallets.
Stacked 3 high.

b) The magazines have been dynamically designed in accordance with the load parameters given in Part II, paragraph 2.3.2.2. for a maximum NEQ of 75 000 kg of Hazard Division 1.1 and up to 250 000 kg of Hazard Divisions 1.2 and 1.3 depending on quantity-distances available. The magazines are designed to vent through the head-walls which have also been designed to resist an external blast loading of 7 bar and an impulse of 84 bar ms. The design parameters permit the magazines to be sited with Inter-Magazine Distances of 0.5 $Q^{1/3}$ side-to-side and 0.8 $Q^{1/3}$ rear-to-front for storage of Hazard Division 1.1.

9. *United States Earth-Covered Magazines*

a) US earth-covered magazines are of approved designs based upon satisfactory survival of a full-scale proof test, or by analytical and model test comparison with proven types. Except as noted, all are approved for the exposures as in subparagraphs 2.3.2.2.b)1) and 2.3.2.2.b)2) for any quantity of explosives allowed by applicable tables.

b) Reinforced Concrete, Arch Type

Reinforced concrete, arch type, earth-covered magazines whose construction is at least equivalent in strength to those in United States Army Corps of Engineers drawing 33-15-06 dated 1st August, 1951, revised 31st May, 1956. The arch door(s), doorframe(s), and head-wall(s) of these magazines are satisfactory for any quantity of explosives allowed by applicable tables. These magazines are approved based upon full-scale and model tests in the Arco-DDESB series of 1944-1946, and comparison with the Fre-Loc non-circular concrete arch tested full-scale in ESKIMO-V 1977.
(DDESB = Department of Defense Explosives Safety Board).

c) Reinforced Concrete, Arch Type
Reinforced concrete, arch type, earth-covered magazines whose construction is at least equivalent to US Navy drawings 357428 through 357430 dated 9th August, 1944 and modified in accordance with Naval Facilities Engineering Command (NAVFAC) drawing 626739 dated 19th March, 1954, or NAVFAC drawings 627954 through 627957, 764957, 793747, 658384 through 658388, 724368,764596, and 793746. The arch, door(s), doorframe(s), and head-wall(s) of these magazines are satisfactory for any quantity of explosives allowed by applicable tables.
These magazines are approved based upon full-scale and model tests in the Arco-DDESB series of 1944-1946 and comparison with the Fre-Loc non-circular concrete arch tested full-scale in ESKIMO V.

d) Corrugated Steel, Arch Type

Corrugated steel, arch type, earth-covered magazines whose construction is at least equivalent in strength to those in United States Army Corps of Engineers drawings AW 33-15-63 (5th March, 1963), AW 33-15-64 (10th May, 1963) and AW 33-15-65 (10th January, 1963); NAVFAC drawings 1059128-30, 1059132, 1069906, 1355460-61, and specifications cited therein. The arch and rear-wall of these magazines are satisfactory for any quantity of explosives allowed by applicable tables. The original doors and doorframes shown in these drawings are satisfactory for exposure in subparagraph 2.3.2.2.b)1) but marginal for exposure as in subparagraph 2.3.2.2.b)2) for the larger quantities currently allowed. If maximum utilization is desired for Hazard Division 1.1 a door and head-wall such as that for OCE 33-15-73 below should be used. The se magazines were proof tested at full-scale in the Naval Weapons Center-DDESB Steel Arch Igloo test series of 1963-1965 and in ESKIMO I. Various door and head-wall modifications were further evaluated in ESKIMO II and IV.

e) Corrugated Steel, Oval Arch Type

Corrugated steel, oval arch type, earth-covered magazines whose construction is at least equivalent in strength to those in United States Army Corps of Engineers drawing 33-15-73 dated 21st February, 1975. The arch, door, head-wall and rear-wall of this magazine are satisfactory for any quantity of explosives allowed by applicable tables. It has been fully evaluated by full-scale proof test in ESKIMO III, IV and V including a door and head-wall combination suitable for 14 bar pressure and 80 bar ms impulse with a donor of 160 000 kg NEQ and with the originally required concrete thrust beams omitted.

f) Reinforced Concrete, Stradley

Reinforced concrete, Stradley (Yurt) magazines, earth-covered, whose construction is at least equivalent in strength to those in United States Army Corps of Engineers drawing 33-15-61 (sheets 1 to 12). The original door(s) and doorframe(s) shown in these drawings are satisfactory for any quantity of explosives allowed by applicable tables. These magazines are approved based upon analytical comparison with other types tested in US DDESB test programme and specific testing of doors and head-walls at full-scale in ESKIMO II and IV.

g) Reinforced Concrete, Fre-Loc

Reinforced concrete, earth-covered magazines whose construction is at least equivalent in strength to those in US Army Engineer Command Europe drawing 33-15-13. The arches, head- walls and rear-walls of these magazines are suitable for any quantity of explosives permitted by applicable tables. The magazine was exposed in the ESKIMO V test to an impulse load of 33 bar ms with a peak pressure of about 7 bar on the surface of the earth-cover over the arch. The originally designed doors

may be marginal for exposures listed in subparagraph 2.3.2.2.b)2) and loadings greater than 7 bar. Thus in some cases, it may be desirable to specify stronger doors, such as those for OCE 15-33-73 above.

h) Reinforced Concrete, Strengthened Fre-Loc

Reinforced concrete, earth-covered magazines whose construction is at least equivalent in strength to that in US Army Office, Chief of Engineers drawing 33-15-74 dated 11th April, 1979. The arch, head-wall and rear-wall of these magazines are suitable for any quantity of explosives permitted by applicable tables. The drawing cited depicts a magazine whose arch and rear-wall are identical to those of the Fre-Loc (subparagraph g) above), and whose head-wall and door are identical to those of the oval steel arch magazine (subparagraph e) above). In the ESKIMO V test, the Fre-Loc magazine was exposed to an impulse load of 33 bar ms, with a peak pressure of about 7 bar in the surface of the earth-cover over the arch. The door and head-wall combination had been subjected in ESKIMO IV to an impulse load of 80 bar ms with a peak pressure of 14 bar.

10. *Tabulated Information*

Available information on Igloos has been given in Table 1.

TABLE 1 - INFORMATION ON IGLOOS - CHART OF CODE NUMBERS

Criteria	Designation	GE 90/180B	GE 90/180S	USA RC Arch	UK Single Box Portal	UK Double Box Portal	FR RC Arch
Protec-tion	Headwall Bars(Pr)		7	*	7	7	7
	Strength Bar.ms (Ir)	84	84	*	84	84	140
	HV/LV (Prt)						
	NEQ (HD1.1) (kgs)	75.000	75.000	125.000	75.000	75.000	60.000
Mate-rial	Reinforced Concrete	X		X	X	X	X
	Corrugated Steel Sheet		X				
	Other (Brick etc)						
Shape	Circular/Oval Arch		X	X			X
	Portal (1,2,3 Bays)	X (1)			X (1)	X (2)	
Floor Area (m^2)		90/180	90/180		149	288	240
Remarks			RC Head-wall	*		2 Head-wall doors	H/Wall door 3 x 3 m
Drg.No / Project No		71517	71922	33-15-06	XB1/1	XB1/3A	
Annex "B" Ref Para		5	6	9 (b)	8 (a) 1	8 (a) 2	2 (a) 3
Code Number		GE01	GE02	US01	UK01	UK02	FR03

Pr	reflected pressure in bars	Ir	reflected impulse in bars/ms
HV/LV	high/low velocity proterction	*	AS Eskimo V Fre-Loc

Section II - Blast Data for Design of Igloos

1. *Origins of Data*

This section sets out, in a format that facilitates comparisons, all the blast data measured during the United States ESKIMO III Trial in 1974 and the five United Kingdom model tests 1971-1972. It also gives some of the data from earlier United States full-scale trials on igloos 1962-1963.

2. *Tabulation of Data*

The data has been arranged in a number of tables based on the nominal scaled separation of the Explosion Site and the ES. Table 1 presents the data for a separation of 0.5 $Q^{1/3}$, Table 2 for 0.6 $Q^{1/3}$, Table 3 for 0.8 $Q^{1/3}$, Table 5 for 8 $Q^{1/3}$ while Table 4 relates to sundry observations between 1 and 2 $Q^{1/3}$.

3. *Arrangement of Data in each Table*

In each table the values have been arranged in ascending order of the scaled distance from the centre of the explosion to the gauge, rounded to two decimal places. The locations of the Explosion Site and the gauge are shown in column (2). These diagrams are not to scale; they show a plan view and ignore differences in elevation, for simplicity. The important variable is the orientation of the Explosion Site relative to the ES and the gauge. As a convention, the Explosion Site is always shown on the left of the diagram.

4. *Blast Parameters*

The values of side-on and face-on blast parameters are shown in separate columns. The latter include the reflected shocks sometimes observed in the vicinity of the head-walls of the igloo at the ES, except for certain values of scaled distances in Table 4 (no. 4-11), where the reflected values are given in a separate column. Values of positive duration and positive impulse per unit area have been scaled by dividing by the cube root of the NEQ.

5. *Validity of Model Testing*

The validity of comparisons between model and full-scale igloos was established by the Arco trials of the United States 1946 and is corroborated by the recent United States and United Kingdom tests.

6. *Rounding of Values*

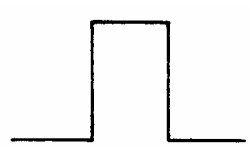
All values have been rounded for simplicity in making comparisons. The experimental variations among replicate tests are such that an implied precision better than about 10 % would not be justified. Certain unreliable

observations, such as those from gauges underneath sand cover in the United Kingdom models, have been excluded from the tables.

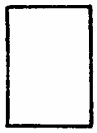
7. *Symbols*

The symbols used are as follows:

1) Igloo plan view with head-wall/door downwards



2) Foundation slab for UK Test 5 (no Explosion Site)



3) Sand barricade (UK model tests)

4) In the tables igloo A is the left igloo and igloo B is the right igloo.

TABLE 1 - BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 0.5 $Q^{1/3}$

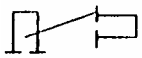
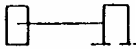
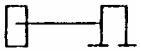
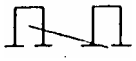
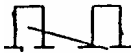
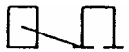
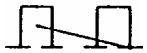
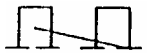
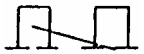
No.	Location of gauge (scaled distance)	IDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
1.	0.57 	10.3	-	-	17.2	-	-	Gauge shows initial shock and reflection from headwall. Contents of acceptor igloo detonated after 60 ms.	90 700 kg TNT in 155 mm projectiles (15% net charge).	AS/DDESB 1971 Eskimo 1, East igloo, gauge flush with ground, left of door.	1.
2.	0.60 				18.0	0.6	4.5	Gauge on sidewall of igloo underneath the sandcover.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 1/A.	2.
3.	0.62 				22.0	0.4	16.0	Gauge on sidewall of igloo relatively exposed to the air, by partial removal of sand cover over the gauge zone (re-sidual cover 0.1-6m).	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 1/H.	3.
4.	0.62	5.2	0.7	0.8				Gauge 3 m toward donor from igloo A centerline, on headwall 1.2 m from ground	159 000 kg tritonal in 750 lbs bombs.	US/DDESB Eskimo III	4.
5.	0.62	3.8	-	0.8				Gauge 3 m toward donor from igloo B centerline, on headwall 1.2 m from ground.	159 000 kg tritonal in 750 lbs bombs.	US/DDESB Eskimo III	5.
6.	0.68 	3.4	0.8	0.4				Gauge on igloo A centerline, in ground 0.6 m in front of door.	159 000 kg tritonal in 750 lbs bombs.	US/DDESB Eskimo III	6.
7.	0.68 	4.5	0.8	0.5				Gauge on igloo B centerline, in ground 0.6 m in front of door.	159 000 tritonal in 750 lbs bombs.	US/DDESB Eskimo III	7.

TABLE 1 (page 2) – BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPERATION OF 0.5 $Q^{1/3}$

No.	Location of gauge (scaled distance)	IDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
8.	0.70	1.7	1.2	0.4				Gauge flush with headwall, beside door.	64 kg tetryl/TNT in steel case, 20% net.	UK/ESTC 1971 Test 2, gauge 1/C	8.
9.		2.7	1.3	1.3				idem	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 3, gauge 1/C	9.
10.		2.7	0.8	0.9				idem	idem	UK/ESTC 1972 Test 4, gauge 1/C	10.
11.	0.72 	5.5	0.2	0.5				Gauge flush with headwall, beside door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 1/C	11.
12.	0.73	33.2	0.4	1.7				Gauge flush with roof, devoid of any sand cover.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 1/D	12.
13.		35.3	0.4	1.3				idem	idem	UK/ESTC 1972 Test 5, gauge 1/E	13.
14.	0.73 	4.1	-	1.0				Gauge 3 m farther from donor than igloo A centerline, on headwall 1.2 m from ground.	159 000 kg tritonal in 750 lbs bombs.	US/DDESB Eskimo III	14.
15.	0.73 	2.8	1.0	0.8				Gauge 3 m farther from donor than igloo B centerline, on headwall 1.2 m from ground.	159 000 kg tritonal in 750 lbs bombs.	US/DDESB Eskimo III	15.
16								Gauge on outside of door, in middle.	45 400 RDX/TNT bulk explosive in cane.	US/ASESB 1963 Test 6, West igloo	16
17.	0.75	3.4	0.8	1.0				Gauge flush with headwall, above door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1971 Test 1, gauge 1/B	17.
18.		2.2	0.6	0.5				idem	64 kg tetryl/TNT in steel cans, 20% net.	UK/ESTC 1971 Test 2, gauge 1/B	18.
19.		2.2	1.0	1.2				idem	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 3, gauge 1/B	19.
20.		2.0	1.1	0.8				idem	idem	UK/ESTC 1972 Test 4, gauge 1/B	20.

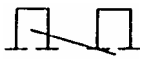
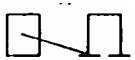
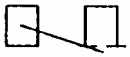
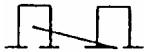
No.	Location of gauge (scaled distance)	IDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
21.	0.77 	2.6	1.0	1.0				Gauge flush with ground.	64 kg tetryl/TNT uncased charge	UK/ESTC 1972 Test 4, gauge G1	21.
22.	0.77 	7.6	1.0	1.3				Gauge flush with headwall, above door.	64 kg tetryl/TNT uncased charge	UK/ESTC 1972 Test 5, gauge 1/B	22.
23.	0.80 	10.8	0.7	1.2				Gauge flush with ground.	64 kg tetryl/TNT uncased charge	UK/ESTC 1972 Test 5, gauge G1	23.
24.	0.93 	2.4						Gauge allegedly "normal to door" but is assumed to record side-on overpressure only.	580 kg TNT equivalent (HE plus propellant in 3 missiles.	UK/ASESB 1963 Test 5, igloo C	24.

TABLE 1 (PAGE 3) – BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPERATION OF 0.5 $Q^{1/3}$

TABLE 2 - BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 0.6 $Q^{1/3}$

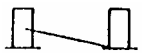
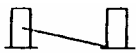
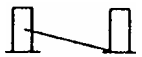
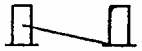
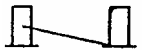
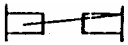
No.	Location of gauge (scaled distance)	SIDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms .$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
1.	0.77 	2.2	1.1	0.9				Gauge flush with headwall, beside door.	64 kg tetryl/TNT uncased charge	UK/ESTC 1971 Test 1, gauge 2/C	1.
2.	0.83 	3.7	-	-				Gauge on outside face of door, in middle.	45 400 kg RDX/TNT bulk explosive in case.	US/ASESB 1963 Test 6, East igloo	2.
3. 4.	0.85 	2.3 1.7	1.3 0.8	1.0 0.6				Gauge flush with headwall, above door. idem	64 kg tetryl/TNT uncased charge. 64 kg tetryl/TNT in steel case, 20% net.	UK/ESTC 1971 Test 1, gauge 2/B UK/ESTC 1971, Test 2, gauge 2/B	3. 4.
5.	1.02 	2.5	-	-				Gauge allagedly "normal to door" but is assumed to record side-on overpressure only.	580 kg TNT equivalent (HE plus pro-pellant en 3 missiles).	US/ASESB 1963 Test 5, igloo B	5.
6.	1.03 	1.7	2.3	-				Gauge allegedly "normal to igloo face" but is assumed to record side-on overpressure only.	910 kg TNT equivalent in lightly cased charges.	US/ASESB 1962 Test 7, nearer door of acceptor igloo.	6.
7.	1.60 	0.3	-	-				Gauge allegedly "normal to the door" but is assumed to record side-on overpressure only.	580 kg TNT equivalent (HE plus pro-pellant in 3 missiles).	US/ASESB 1963 Test 5, igloo D	7.

TABLE 3 (page 1) - BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 0.8 $Q^{1/3}$

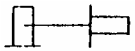
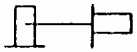
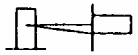
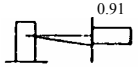
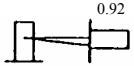
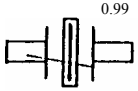
No.	Location of gauge (scaled distance)	SIDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$ (5)	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)		(6)	(7)	(8)	(9)	(10)	(11)	(1)
1.	0.86 	54.8	0.7	7.2				Gauge flush with ground. Headwall failed under blast load and was projected into igloo, damaging rear wall.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge G2	1.
2.	0.86 	5.6	0.9	1.8				Gauge flush with ground. Gauge shows initials shock & reflection from headwall.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 4, gauge G2	2.
3.	0.90 				6.6	0.8	1.8	Gauge flush with headwall, above door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 3, gauge 2/B	3.
4.					6.2	0.8	2.0	Gauge flush with headwall, beside door.	idem	UK/ESTC 1972 Test 3, gauge 2/C	4.
5.	0.91 				168	0.8	10.7	Gauge flush with headwall, above door, wall failed.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 2/B	5.
6.					162	0.7	11.2	Gauge flush with headwall, beside door.	idem	UK/ESTC 1972 Test 5, gauge 2/C	6.
7.	0.92 				5.6	0.7	1.6	Gauge flush with headwall, above door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 TEST 4, gauge 2/B	7.
8.					6.9	1.1	2.4	Gauge flush with headwall, beside door.	idem	UK/ESTC 1972 Test 4, gauge 2/C	8.
9.	0.99 	5.2	-	-	16.4	0.3	-	Gauge shows initial shock & reflection from headwall.	90 7000 kg TNT in 155 mm projectiles (15% net charge).	US/DDESB 1971 Eskimo I, North igloo, right ground gauge	9.

TABLE 3 (PAGE 2) – BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 0.8 $Q^{1/3}$

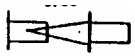
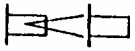
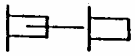
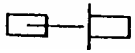
No.	Location of gauge (scaled distance)	SIDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
10.	1.00 				5.0	0.6	1.0		90 7000 kg TNT in 155 mm projectiles (15% net charge).	US/DDESB 1971 Eskimo I. Sauth igloo, gauge flush with headwall, left door	10.
11.					5.2	0.7	1.1		idem	Idem but gauge right of door	11.
12.	1.00 	1.9	-	-	4.2	0.6	-	Gauge shows initial shock & reflection from headwall.	90 700 kg TNT in 155 mm projectiles (15% net charge).	US/DDESB 1971 Eskimo I. South igloo, left ground gauge	12.
13.		2.3	-	-	4.2	0.6	-	idem	idem	US/DDESB 1971 Eskimo I. South igloo, right ground igloo	13.
14.	1.00 	3.1	0.7	1.0				Gauge shows initial shock & reflection from headwall.	64 kg tetryl/TNT uncased charge	UK/ESTC 1972 Test 4, gauge G3	14.
15.	1.01 	20.6	0.9	3.7				Headwall cracked by blast load but remained in place.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge G3	15.

TABLE 3 (PAGE 3) – BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 0.8 $Q^{1/3}$

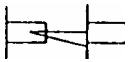
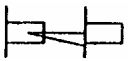
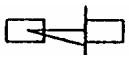
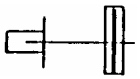
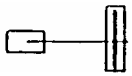
No.	Location of gauge (scaled distance)	SIDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$ (5)	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)		(6)	(7)	(8)	(9)	(10)	(11)	(1)
16.	1.05 				5.6	0.6	1.5	Flus gauge above door.	64 kg tetry/TNT uncased charge.	UK/ESTC 1972 Test 3, gauge 3/B	16.
17.					6.9	0.8	1.2	Flush gauge beside door.	idem	UK/ESTC 1972 Test 3, gauge 3/C	17.
18.					2.7(3.0)	0.7(2.9)	1.0(5.3)	Flush gauge above door. Two distinct pulses recorded.	idem	UK/ESTC 1972 Test 3, gauge 3/B	18.
19.					4.8	0.6	1.1	Flush gauge beside door.	idem	UK/ESTC 1972 Test 3, gauge 3/C	19.
20.	1.07 				4.5	1.0	1.5	Flush gauge above door.	64 kg tetryl/TNT uncased charge	UK/ESTC 1971 Test 1, gauge 3/B	20.
21.					5.6	0.7	1.2	Flush gauge beside door.	idem	UK/ESTC 1971 Test 1, gauge 3/C	21.
22.					2.8	-	-	Flush gauge above door.	64 kg tetryl/TNT in steel cases, 20% net.	UK/ESTC 1971 Test 2, gauge 3/B	22.
23.	1.07 				54.1	0.6	4.9	Gauge flush with headwall, above door. Headwall cracked by blast, remained in place.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 3/B	23.
24.					41.2	0.6	3.3	Gauge flush with headwall beside door.	idem	UK/ESTC 1972 Test 5, gauge 3/C	24.
25.	1.08 	6.7	0.8	1.2				Gauge flush with ground beyond sand barricade.	64 kg tetryl/TNT uncased charge.	UK/estc 1972 Test 4, gauge C5	25.
26.	1.08 	11.0	0.8	1.5				Gauge fluh with ground beyond sand barricade.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge G4	26.

TABLE 4 - BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 1 - 2 $Q^{1/3}$

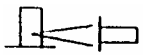
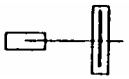
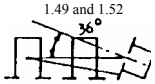
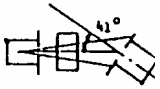
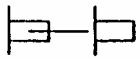
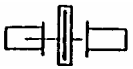
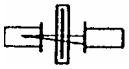
No.	Location of gauge (scaled distance)	SIDE-ON			REFLECTED		FACE-ON			Remarks	Q	Reference	No.
		Peak over-pressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar mskg$^{-1/3}$ (5)	Peak overpressure bar	Scaled impulse bar ms- $kg^{-1/3}$ (5a)	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)		(3a)		(6)	(7)	(8)	(9)	(10)	(11)	(1)
1.	1.17 	1.7	-	-			4.4	0.9	-	Seperation of igloos -1.1 $Q^{1/3}$. Gauge shown initial shock & reflection from headwall.	90 700 kg TNT in 155 mm projectiles (15% net charge).	US/DDESB 1971, Eskimo I, West igloo, left ground gauge	1.
2.		2.6	-	-			4.7	0.9	-	idem	idem	US/DDESB 1971, Eskimo I, West igloo, right ground gauge	2.
3.	1.20 	8.5	0.7	1.1						Beyond sand barricade. Gauge flush with ground.	64 kg te-tryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge G5	3.
4.	1.49 and 1.52 	-	-	-	6.6	-				Gauge 3 m from igloo C centerline on headwall 1.2 m from ground.	159 000 kg tritonal in 750 lbs bombs.	US/DDESB, Eskimo III	4.
5.		3.1	-	-	7.9	-				Gauge on igloo C centerline, in ground 0.6 m in front of door.	idem	US/DDESB, Eskimo III	5.
6.	1.45, 1.50 and 1.58	-	-	-	5.2	1.1				Gauge 3 m from igloo D centerline on headwall 1.2 m from ground.	idem	US/DDESB, Eskimo III	6.
7.		1.7	-	-	4.8	-				Gauge on igloo D centerline, in ground 0.6 m in front of door.	idem	US/DDESB, Eskimo III	7.
8.		-	-	-	5.2	0.7				Same as above off-centre gauge.	idem	US/DDESB, Eskimo III	8.
9.	1.63, 1.68 and 1.75 	-	-	-	11.4	2.0				Gauge 3 m from igloo E centerline on headwall 1.2 m from ground.	idem	US/DDESB, Eskimo III	9.
10.		5.2	-	-	12.4	-				Gauge in igloo E centerline, in ground 0.6 m in front of door.	idem	US/DDESB, Eskimo III	10.
11.		-	-	-	10.3	1.6				Same as above off-centre gauge.	idem	US/DDESB, Eskimo III	11.
12.	2.18 						0.3	2.5	0.2	Seperation of igloos -1.8 $Q^{1/3}$. Gauge flush with ground. Assumed to be the reflected shock from headwall.	1 000 kg TNT equivalent, teking account of explosive type (Comp B) & GP bomb case.	US/ASESB 1962 Test 1, North-east igloo, gauge NE-1	12.

TABLE 5 - BLAST DATA FOR IGLOOS AT NOMINAL SCALED SEPARATION OF 8 $Q^{1/3}$

No.	Location of gauge (scaled distance)	SIDE-ON			FACE-ON			Remarks	Q	Reference	No.
		Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$	Peak overpressure bar	Scaled duration ms $kg^{-1/3}$	Scaled impulse bar.ms.$kg^{-1/3}$				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(1)
1.	8.13	0.3	3.6	0.3				Gauge beyond sand barricade flush with ground. Gauge shows initial shock & reflection from headwall.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 4, gauge G9	1.
2.	8.15 	0.6	3.4	0.4				Gauge beyond sand barricade flush with ground. Gauge shows initial shock & reflection from headwall.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge G9	2.
3.	8.25				0.2	2.3	0.2	Gauge fluh with headwall, above door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 4, gauge 4/B	3.
4.					0.2	2.7	0.3	Gauge flus with haedwall, beside door.	idem	UK/ESTC 1972 Test 4, gauge 4/C	4.
5.	8.27				0.5	3.0	0.4	Gauge fluh with headwall, above door.	64 kg tetryl/TNT uncased charge.	UK/ESTC 1972 Test 5, gauge 4/B	5.
6.					0.6	2.8	0.4	Gauge flus with haedwall, beside door.	idem	UK/ESTC 1972 Test 5, gauge 4/C	6.

BIBLIOGRAPHY

BIBLIOGRAPHY

No.	Paper ref.	Date	Contents
1	ESTC SOLTAU TRIALS	AUG 1947	
2	AFWL-TR-67-132	MAY 1968	High Explosive Storage Test BIG PAPA
3	AC/258(ST)WP/1	OCT 1970	Original basis for discussion
4	AC/258-D/152	JUL 1971	Summary of London meeting, February 1971
5	AC/258-D/176	FEB 1972	Summary of Brussels meeting, January 1972
6	AC/258(ST)WP/31	NOV 1972	Blast Data from ESKIMO I
7	Informal Working Papers United Kingdom	JAN-AUG 1972 and SEP-DEC 1972	Blast and response data from UK model tests
8	NWC TP 5430	APR 1973	Final technical report on ESKIMO I
9	AC/258-R/14	JAN 1974	AC/258-D/211 principles approved as part of AC/258-D/70
10	NWC TP 5557	SEP 1974	Final technical report on ESKIMO II
11	US(ST)IWP/11	SEP 1974	US data on earth-covered igloos
12	US(ST)IWP/16	NOV 1974	ESKIMO III test results
13	US(ST)IWP/49	JAN 1976	ESKIMO IV test results
14	AC/258-D/211(2nd Revise)	MAY 1977	Quantity-Distances for earth-covered magazines (igloos)

No.	Paper ref.	Date	Contents
15		OCT 1985	Burlot See FR(ST)IWP/2-85
16	NWC TR 5873	MAR 1977	ESKIMO IV magazine separation test
17	NOTS TR 3843	JUL 1965	Summary report of earth-covered Steel Arch Magazine Test
18	US(ST)IWP/13-82	8th OCT 1982	Reduced Q-D from the side and rear of igloos
19	US(ST)IWP/8-83	3rd AUG 1983	Reduced Q-D from the side and rear of igloos
20	AC/258-UK(ST)IWP/137	21st MAR 1984	Reduced Q-D from the side and rear of igloos