ALLIED AMMUNITION STORAGE AND TRANSPORT PUBLICATION

AASTP-1
Edition 1
Corrected version
English only

NATO INTERNATIONAL STAFF – DEFENCE INVESTMENT DIVISION

MANUAL OF NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

AASTP-1

May 2010

Declassified for release to the public
in accordance with C-M(2002)60.
Reference of decision for release:
AC/326-N(2007)0001-AS1 05-09-2007

Change 3

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(AASTP-1)

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FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

May 2010

NORTH ATLANTIC TREATY ORGANIZATION

MILITARY AGENCY FOR STANDARDIZATION (MAS)

NATO LETTER OF PROMULGATION

August 1997

1. AASTP-1 – MANUAL OF NATO SAFETY PRINCIPLES FOR STORAGE OF MILITARY AMMUNITION AND EXPLOSIVES is a NATO UNCLASSIFIED publication. The agreement of interested nations to use this publication is recorded in STANAG 4440 (Edition 1).

2. AASTP-1 is effective upon receipt.

3. AASTP-1 contains only factual information. Changes to these are not subject to the ratification procedures; they will be promulgated on receipt from the nations concerned.

A. GRØNHEIM
Major General, NOAF
Chairman, MAS

RECORD OF CHANGES

CHANGE	DATE OF CHANGE	SIGNATURE	REMARKS
1	18 February 1998	-	AC/258-D/455
2	May 2006		
3	May 2010		

AASTP-1 CHANGE PROPOSAL/COMMENT FORM

To: MSIAC
Custodian

Information:
National Representative(s)

Serial Number [1] . . . .

Date Received [1] . . . .

AASTP-1 Part(s) [1] . . . .

PART 1: (to be completed by the originator)

Originator Details:

Name: . . . .   Job Title: . . . .

Nation: . . . .   Organisation: . . . .

Telephone: . . . .   Email: . . . .

AASTP-1 Details:

Part:	Chapter/Annex:	Section:	Paragraph(s):

Observation:

Proposed Text:

Other Comments/Recommendations/Associated Changes Required:

Supporting Evidence (Reports, Trials, etc):

PART 2: (for completion by the appropriate AASTP-1 Custodian)

Approved?   Yes/No   For inclusion as an amendment to: . . . .

Reason for Non–approval: . . . .

Signature: . . . .   Name: . . . .

Custodian of Part:. . . . .   Date: . . . .

CONTENTS

[1] To be entered by MSIAC

LIST OF ABBREVIATIONS

In this Manual the following abbreviations have been used, but not necessarily in all places where the word combinations appear.

Depleted Uranium	=	DU
Electro-Explosive Device	=	EED
Exposed site	=	ES
Exterior Quantity Distance	=	EQD
Hazard Division	=	HD
Inhabited Building Distances	=	IBD
Interior Quantity Distance	=	IQD
Inter-Magazine Distance	=	IMD
Maximum Credible Event	=	MCE
Net Explosive Quantity	=	NEQ
Potential Explosion Site	=	PES
Public Traffic Route Distance	=	PTRD
Quantity Distance	=	QD
Petroleum, Oils and Lubricants	=	POL

PREFACE

Section I - General

1. *Purpose and Scope of the Manual*

The primary object of this Manual is to establish safety principles to be used as a guide between host countries and NATO forces in the development of mutually agreeable regulations for the layout of ammunition storage depots and for the storage of conventional ammunition and explosives therein. These principles are intended also to form the basis of national regulations as far as possible.

This Manual is in four parts: Part I sets out general ammunition safety principles for all explosives storage and QD for aboveground storage; Part II provides technical details for design of explosives storage magazines and operational guidelines for explosives facilities; Part III deals with underground storage; and Part IV deals with ammunition handling in special situations such as on military airfields and during the transfer of ammunition and explosives in naval ports.

A Manual of this type cannot provide the answers to all problems which arise. In circumstances where the answer is not provided the problem should be submitted to the Secretary of the Conference of National Armaments Directors (CNAD) Ammunition Safety Group (CASG), AC/326.

Since this Manual is a guide rather than a set of mandatory regulations the words "must", "should" "may/can" and "is/are" are used in the following sense:

MUST	-	Indicates a technical requirement which is vital for safety and the avoidance of a catastrophe.
SHOULD	-	Indicates a safety requirement which is important but not essential.
MAY/CAN	-	Indicates optional courses of action and possibilities.
IS	-	Indicates a fact or a valid technique.

2. *Basis of the Manual*

The Manual is based upon, and supersedes NATO DOCUMENT AC/258-D/258 (1976) and it’s numerous corrigenda. It is one of a series of publications that have been promulgated by the CASG as Allied Ammunition Storage and Transportation Publications (AASTP’s), as follows:

AASTP-2 – Manual of NATO Safety Principles for the Transport of Military Ammunition and Explosives

AASTP-3 – Manual of NATO Safety Principles for the Hazard Classification of Military Ammunition and Explosives

AASTP-4 – Explosives Safety Risk Analysis

AASTP-5 – NATO Guidelines for the Storage, Maintenance and Transport of Ammunition on Deployed Operations or Missions

3. *Updating*

The Logistic Storage and Disposal Sub-group (SG5), as custodian of this Manual, will keep this manual current. Proposals for change should be submitted to the Secretary of AC/326 using the form “AASTP-1 Change Proposal/Comment Form”.

4. *Conditions of Release*

The NATO Manual on Safety Principles for the Storage of Ammunition and explosives (AASTP-1) is a NATO Document involving NATO property rights. The understanding and conditions agreed for the release of the Manual are that it is released for technical defence purposes and for the use by the defence services only of the country concerned. This understanding requires that the release of the whole, or any part, of the Manual must not be undertaken without reference to, and the written approval of, NATO.

5. *Inquiries*

Any questions or requirements for further information should be addressed to the Secretary of the AC/326 Sub-Group 5 at NATO Headquarters, B-1110 Brussels, Belgium.

Section II - Historical Background of the Manual

This Manual is the result of successive revisions, over a period of 30 years, of a document (AC/106-D/5 dated 1st September 1963) drafted by an AC/106 Restricted Sub-Group consisting of representatives of France, Germany, the United Kingdom, and the United States. These experts, meeting as specialists and not as national representatives, made a study of the systems used in France, the United Kingdom and the United States which took into account national trials and an analysis of archives relating to damage from accidental explosions or acts of war. This attempt at consolidation involved each member waiving some of his own nation´s regulations. This difficulty was overcome by accepting that each nation would be free when authorizing implementation of the NATO system in its territory to refrain from applying any regulation relating to particular items for which, in its view, no compromise was possible. It was hoped, however, that in view of the very abundant information which had been used to prepare the document new ideas would become acceptable in the interests of NATO even if they were not always in accordance with host nation practice up to that point.

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 classification tests, storage on military airfields, storage in ships and barges and underground storage. AC/106-D5(Revised) was issued in 1965.

The Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives (AC/258) was created in 1966 to continue this work. A Storage Sub-Group, set up under its aegis with broader representation, prepared a new revised version published under reference AC/258-D/70 dated December 1969. This was a very full document, including both the basic principles from the original document and recommendations dealing with special cases such as storage on military airfields, on board ship, underground, in the vicinity of petroleum products or near radio transmitters. The quantity-distance tables were produced in a new format, using metric units only, in order to simplify the presentation. Certain corrections and rationalizations were introduced 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. Also, detailed annexes were prepared describing tests to be applied to ammunition in order to decide on its hazard classification. The provisions for underground storage were completely re-written in the light of recent advances in this field of explosives technology. However, certain underground explosives storage criteria still remained to be formulated.

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 of 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 International 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.

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. Therefore 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.

In 1974 the Group, noted 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.

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 (in particular the "ESKIMO" series of trials in the United States). 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 under the reference AC/258-D/258.

Almost the whole of Part I of the Manual was published in 1976 followed by certain chapters of Part II and Part III in 1977. In the period 1976 to 1982 new chapter and sections were added and corrections were made to Parts I to III.

In 1981 during the work related to updating the chapter dealing with quantity-distance criteria for airfield, the Group found that 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 given. 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.

Since 1981, 23 corrigenda to the Manual were issued. In addition, the idea grew that a presentation more in accordance with NATO standards should be adopted. This was achieved by restructuring the Manual in the form of an Allied Publication (AP) and producing Standardization Agreements (STANAG) with which to implement the AP.

In late 2002 AC/258 was merged with AC/310 to form AC/326 and Sub-group 5, Logistics and Disposal was created in order to manage AASTP's 1 and 3. Work continued on the development of AASTP-1 and two important Changes to Edition 1 were published in May 2003 and May 2006.

In the meantime significant technical support began to be provided to AC/326, including Sub-group 5 by the creation of the NATO Insensitive Munitions Information Centre (NIMIC), which became the Munitions Safety Information Analysis Centre (MSIAC) in 2004.

During this period the Group realized – as NATO began conducting deployed operations – that two elements of ammunition safety – risk management and safety on operations – deserved special attention and created Sub-group 6 and began the development of AASTP's 4 and 5. In concert with the development of AASTP-5 it was determined that some portions of AASTP-1Part IV should be moved to AASTP-5 (BLAHA and Field Storage).

In 2009 considerable focus was put on the creation of Change 3, which aimed to better coordinate the four Parts, eliminate duplication, move Part IV portions to AASTP-5, update technical aspects and – most importantly – introduce a new format for QD Tables in Part I.

ALLIED AMMUNITION STORAGE AND TRANSPORT PUBLICATION 1 (AASTP-1)

MANUAL OF NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

PART I

GENERAL PRINCIPLES AND GUIDELINES FOR ALL EXPLOSIVES STORAGE AND QUANTITY DISTANCE TABLES FOR ABOVE GROUND STORAGE

May 2010

TABLE OF CONTENTS – PART I

CHAPTER 1 - INTRODUCTION

1.1.0.1 Purpose and Scope of the Manual

a) The primary object of this Manual is to establish safety principles to be used as a guide between host countries and NATO forces in the development of mutually agreeable regulations for the layout of ammunition storage depots and for the storage of conventional ammunition and explosives therein. These principles are intended also to form the basis of national regulations as far as possible.

b) The Manual is intended to serve as a guide for authorities who are engaged in the planning and construction of ammunition storage depots or facilities of a capacity of **not less than 500 kg of Net Explosives Quantity (NEQ) per storage site**, and for those who are responsible for the safe storage of ammunition. It also gives principles and criteria for other related matters such as design environment criteria, etc. The Manual does not authorize the use of the principles and criteria without consent of the host countries.

c) NEQ per storage site of less than 500 kg are given special treatment.

d) It is impracticable to prescribe distances which would be safe distances in the true sense, i.e. which would guarantee absolute immunity from propagation, damage or injury. An attempt has therefore been made in the recommendations in this Manual to allow for the probability of an accident and how serious the resulting damage or injury would be. The separation distances (quantity distances) between a potential explosion site and an exposed site recommended in this Manual therefore represent a compromise deemed tolerable by AC/326 between absolute safety and practical considerations including costs and operational requirements.

The risk deemed tolerable depends upon many factors, some of which are objective, such as the quantity of explosives involved, the nature of the explosives, the packaging of dangerous items, their distribution within premises or in the open air, distance, the nature of the terrain and its contours, etc. Other factors are subjective to what extent are damage and injuries resulting from an explosive accident tolerable? For example, how many deaths, how many serious injuries, how many buildings destroyed or damaged and other costs are tolerable? It is therefore clearly essential to have a good knowledge of the nature of the main hazard, namely blast or projections or fire, as well as the foreseeable development of the accident: instantaneous, progressive, sporadic etc.

Consideration of these factors will yield the concept of hazard divisions, the net explosives quantity and the mutual influence of potential explosion site and exposed site. Quantity-distances are proposed in each case in the form of tables. These quantity distances imply a degree of harm or damage which is difficult to quantify but which most NATO nations regard as tolerable.

There may be occasions when cogent economic or operational considerations, usually of a temporary nature, warrant the acceptance of a significantly greater risk to life and property. The granting of waivers or relaxations in such cases is outside the scope of this Manual. Nevertheless, it is stressed that a detailed assessment of the risks involved must be made by a competent agency before the appropriate authorities grant such dispensations. Conversely, authorities which might find unacceptable the risks deemed "tolerable" in this Manual can always reduce the risks by using suitable protective devices and/or by increasing the recommended distances. However, this will be possible only with a higher operating cost.

e) Under certain circumstances operational requirements demand a degree of relaxation from the guidelines given in Parts I-III of the Manual. This applies mainly to basic load holding areas, field storage and missile installations. In the same way, problems connected with airfields used only by military aircraft and those relating to transfer of ammunition in naval ports call for specific measures. The principles to be followed in preparing flexible but consistent safety guidelines in those cases will be found in Part IV of the Manual.

CHAPTER 2 - CLASSIFICATION CODES AND MIXING OF AMMUNITION AND EXPLOSIVES IN STORAGE

Section I - Hazard Divisions

1.2.1.1. *General*

In order to promote the safe storage and transport of dangerous goods, an International System for Classification has been devised. The system consists of 9 classes (1-9) of which Class 1 comprises ammunition and explosives. Class 1 is divided into six divisions. The hazard division indicates the primary type of hazard to be expected in the event of an accident: mass explosion (Division 1.1), projection but not mass explosion (Division 1.2), fire and radiant heat (Division 1.3), no significant hazard (Division 1.4), mass explosion with very low probability of initiation of substance (Division 1.5) and explosion of a single article, with low probability of initiation (Division 1.6). Ammunition and explosives must be classified in accordance with STANAG 4123. Guidance and Safety Principles for the hazard classification of military ammunition and explosives, and National Authorities competent for the classification of ammunition and explosives are given in AASTP-3.

1.2.1.2. *Definitions of the Hazard Divisions (definitions taken from AASTP 3 Edition 1):*

a) Hazard Division 1.1

Substances and articles which have a mass explosion hazard

1. The major hazards of this division are blast, high velocity projections and other projections of relatively low velocity.

2. The explosion results in severe structural damage, the severity and range being determined by the amount of high explosives involved. There may be a risk from heavy debris propelled from the structure in which the explosion occurs or from the crater.

b) Hazard Division 1.2

Substances and articles which have a projection hazard but not a mass explosion hazard

1. The explosion results in items burning and exploding progressively, a few at a time. Furthermore fragments, firebrands and unexploded items may be projected in considerable numbers; some of these may explode on or some time after impact and cause fires or explosions. Blast effects are limited to the immediate vicinity.

2. For the purpose of determining quantity-distances a distinction, depending on the size and range of fragments, is made between those items which give fragments of moderate range (classified as SsD 1.2.2) and those which give fragments with a considerable range (classified as SsD 1.2.1). SsD 1.2.2 items include HE projectiles (with or without propelling charges) with an individual NEQ less than or equal to 0.73 kg and other items not containing HE such as cartridges, rounds with inert projectiles, pyrotechnic items or rocket motors. SsD 1.2.1 items are generally HE projectiles (with or without propelling charges) with an individual NEQ greater than 0.73kg.

3. A special storage subdivision, SsD 1.2.3, with its own unique set of quantity-distances, is applicable to munitions that exhibit at most an explosion reaction in sympathetic reaction testing as per STANAG 4396 and a burning reaction in bullet impact, slow heating, and liquid fuel / external fire testing as per STANAGs 4241, 4382 and 4240, respectively.

c) Hazard Division 1.3

Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.

1. This division comprises substances and articles:

   (a) which give rise to considerable radiant heat, or

   (b) which burn one after another, producing minor blast or projection effects or both.

2. This division includes some items, which burn with great violence and intense heat emitting considerable thermal radiation (mass fire hazard) and others, which burn sporadically. Items in this division may explode but do not usually form dangerous fragments. Firebrands and burning containers may be

projected. For the purpose of determining quantity-distances and defining mixing and aggregations rules, a distinction is made between the more hazardous propellant explosives of HD 1.3 (classified as SsD 1.3.1) and the less hazardous items and substances of HD 1.3 (classified as SsD 1.3.2).

d) Hazard Division 1.4

Substances and articles which present no significant hazard

1. This division comprises substances and articles which present only a small hazard in the event of initiation. The effects are largely confined to the package and no projection of fragments of appreciable size or range are to be expected. An external fire shall not cause virtual instantaneous explosion of almost the entire contents of the package.

Note: Substances and articles of this division are in Compatibility Group S if they are so packaged or designed that any hazardous effects arising from accidental functioning are confined within the package unless the package has been degraded by fire, in which case all blast or projection effects are limited to the extent that they do not significantly hinder fire-fighting or other emergency response efforts in the immediate vicinity of the package.

e) Hazard Division 1.5

Very insensitive substances which have a mass explosion hazard

This division comprises substances which have a mass explosion hazard but are so insensitive that there is very little probability of initiation or of transition from burning to detonation under normal conditions.

NOTE 1: The probability of transition from burning to detonation is greater when large bulk quantities are transported or stored.

NOTE 2: For storage purposes, such substances are treated as Hazard Division 1.1 since, if an explosion should occur, the hazard is the same as for items formally assigned to Hazard Division 1.1 (i.e. blast).

f) Hazard Division 1.6

Extremely insensitive articles which do not have a mass explosion hazard.

This division comprises articles which contain only extremely insensitive detonating substances and which demonstrate a negligible probability of accidental initiation or propagation.

NOTE: The risk from articles of Hazard Division 1.6 is limited to the explosion of a single article.

1.2.1.3.

Information necessary for hazard classification of ammunition and explosives will be found in AASTP-3. Ammunition which does not contain any explosive or other dangerous goods (for instance dummy bombs, cartridges and projectiles) is excluded from the system of hazard classification.

1.2.1.4. *Depleted Uranium (DU) Ammunition*

Ammunition containing DU in the form of a penetrator or projectile is assigned to the Hazard Classification appropriate to the explosives content of the ammunition only. The normal storage rules associated with the Hazard Classification may need to be modified to take account of the slight radioactivity and chemical toxicity of DU and therefore rules may be prescribed for DU ammunition as a separate class of ammunition, or for specific types of DU ammunition (see Part I, Chapter 9).

1.2.1.5. *Effect of Package on Classification*

As the packaging may have a decisive effect on the classification, particular care must be taken to ensure that the correct classification is determined for each configuration in which ammunition and explosives are stored or transported. Therefore every significant change in the packaging (e.g. degradation) may well affect the classification awarded.

Section II - Compatibility Groups

1.2.2.1. *General Principles*

a) Ammunition and explosives are considered to be compatible if they may be stored together without significantly increasing either the probability of an accident or, for a given quantity, the magnitude of the effects of such an accident.

b) Ammunition and explosives should not be stored together with other goods which can hazard them. Examples are highly flammable materials, acids and corrosives.

c) The safety of ammunition and explosives in storage would be enhanced if each kind was kept separate. However, a proper balance of the interests of safety against other factors may require the mixing of several kinds of ammunition and explosives.

d) The principles of mixing compatibility groups may differ in storage and transport circumstances. Detailed information on mixing compatibility groups is to be found in AASTP-3.

1.2.2.2. *Determination of Compatibility Groups*

On the basis of the definitions in paragraph 1.2.2.3. ammunition and explosives are formally grouped into thirteen Compatibility Groups: A to H, J, K, L, N and S.

1.2.2.3. *Definitions of the Compatibility Groups (definitions taken from AASTP 3 Edition 1):*

Group A Primary explosive substance.

Group B Article containing a primary explosive substance and not containing two or more effective protective features.

Group C Propellant explosive substance or other deflagrating explosive substance or article containing such explosive substance.

Group D Secondary detonating explosive substance or black powder or article containing a secondary detonating explosive substance, in each case without means of initiation and without a propelling charge, or article containing a primary explosive substance and containing two or more effective protective features.

Group E — Article containing a secondary detonating explosive substance, without means of initiation, with a propelling charge (other than one containing a flammable liquid or gel or hypergolic liquids).

Group F — Article containing a secondary detonating explosive substance with its own means of initiation, with a propelling charge (other than one containing a flammable liquid or gel or hypergolic liquids) or without a propelling charge.

Group G — Pyrotechnic substance, or article containing a pyrotechnic substance, or article containing both an explosive substance and an illuminating, incendiary, tear- or smoke-producing substance (other than a water-activated article or one containing white phosphorus, phosphides, a pyrophoric substance, a flammable liquid or gel, or hypergolic liquids).

Group H — Article containing both an explosive substance and white phosphorus.

Group J — Article containing both an explosive substance and a flammable liquid or gel.

Group K — Article containing both an explosive substance and a toxic chemical agent.

Group L — Explosive substance or article containing an explosive substance and presenting a special risk (e.g. due to water activation or presence of hypergolic liquids, phosphides or a pyrophoric substance) and needing isolation of each type.

Group N — Articles which contain only extremely insensitive detonating substances.

Group S — Substances or articles so packed or designed that any hazardous effects arising from accidental functioning are confined within the package unless the package has been degraded by fire, in which case all blast or projection effects are limited to the extent that they do not significantly hinder or prohibit fire-fighting or other emergency response efforts in the immediate vicinity of the package.

1.2.2.4. *Classification Code*

The classification code is composed of the number of the hazard division (see Section I) and the letter of the compatibility group (see Section II) for example "1.1 B". Guidance on the practical procedure of classifying an item by hazard division and compatibility group is given in AASTP-3.

Section III - Mixing of Ammunition and Explosives in Storage

1.2.3.1. *Mixed Storage*

Ammunition and explosives of different hazard divisions may be stored together if compatible. The required quantity-distances and the permitted quantities for above ground storage must be determined in accordance with Part I Chapter 3 of this Manual.

1.2.3.2. *Storage Limitations*

The rules which apply to the mixing of hazard divisions and compatibility groups in above ground storage are detailed below. Special rules apply to underground storage (see Part III). The basic rules are given in the form of two tables as follows which have been taken from AASTP-3 Edition 1:

TABLE 4: Aboveground Storage - Mixing and Aggregation Rules for Hazard Divisions and Storage Sub-Divisions.

TABLE 5: Mixing of Compatibility Groups in Aboveground Storage.

Special circumstances are addressed at paragraph 1.2.3.3. and suspect ammunition and explosives at paragraph 1.2.3.4.

Mixed hazard divisions (HD) and Storage Sub-divisions should be aggregated as shown in the following table:

Table 4 - Aboveground Storage - Mixing and Aggregation Rules for Hazard Divisions and Storage Sub-Divisions

HD/ SsD	1.1	1.2.1	1.2.2	1.2.3	1.3.1	1.3.2	1.4	1.5	1.6
1.1	1.1	1)	1)	1)	1.1	1.1	3)	1.1	1.1
1.2.1	1)	1.2.1	2)	2)	2), 6)	2), 6)	3)	1)	4)
1.2.2	1)	2)	1.2.2	2)	2), 6)	2), 6)	3)	1)	4)
1.2.3	1)	2)	2)	1.2.3	2)	2)	3)	1)	4)
1.3.1	1.1	2), 6)	2), 6)	2)	1.3.1	5)	3)	1.1	4)
1.3.2	1.1	2), 6)	2), 6)	2)	5)	1.3.2	3)	1.1	4)
1.4	3)	3)	3)	3)	3)	3)	1.4	3)	3)
1.5	1.1	1)	1)	1)	1.1	1.1	3)	1.1	1.1
1.6	1.1	4)	4)	4)	4)	4)	3)	1.1	1.6

NOTES:

1) Select the larger QD associated with the following:

   a) Aggregate the NEQ for the HD 1.1 or HD 1.5 material and the HD 1.2 material and treat as HD 1.1.
   b) Consider only the HD 1.2 NEQ and apply appropriate HD 1.2 criteria.

2) The NEQ of the mixture is the NEQ of the sub-division requiring the largest QD. Do not aggregate the various SsD present, but determine QD for each individually.

3) HD 1.4 may be stored with any other HD without aggregation of the NEQ.

4) Treat the HD 1.6 material as SsD 1.2.3 and apply Note 2.

5) Sum the NEQ and use the larger QD associated with the following:

   a) Treat as SsD 1.3.1.
   b) Treat as SsD 1.3.2.

6) There is a significant risk that, in certain circumstances, a mix of SsD 1.2.1 and 1.2.2 and HD 1.3 will behave as an aggregated quantity of HD 1.1.

If any of the following circumstances exists the mix must be aggregated as HD 1.1 unless relevant trials or analyses indicate otherwise:

a) The presence of HD 1.2 shaped charges
b) High energy propellants (e.g., as used in some tank gun applications)
c) High loading density storage of HD 1.3 in conditions of relatively heavy confinement
d) HD 1.2 articles with an individual NEQ > 5 kg

There may also be other circumstances, not yet defined, under which the mix should be aggregated as HD 1.1.

Compatibility groups may be mixed in aboveground storage as shown in the following table:

Table 5 - Mixing of Compatibility Groups in Aboveground Storage

Compatibility Group	A	B	C	D	E	F	G	H	J	K	L	N	S
A	X												
B		X	1)	1)	1)	1)	1)						X
C		1)	X	X	X	2)	3)					5)	X
D		1)	X	X	X	2)	3)					5)	X
E		1)	X	X	X	2)	3)					5)	X
F		1)	2)	2)	2)	X	2), 3)						X
G		1)	3)	3)	3)	2), 3)	X						X
H								X					X
J									X				X
K										X			
L											4)		
N			5)	5)	5)							7)	6)
S		X	X	X	X	X	X	X	X			6)	X

LEGEND: X= Mixing permitted

NOTES

1) Compatibility Group B fuzes may be stored with the articles to which they will be assembled, but the NEQ must be aggregated and treated as Compatibility Group F.

2) Storage in the same building is permitted if effectively segregated to prevent propagation.

3) Mixing of articles of Compatibility Group G with articles of other compatibility groups is at the discretion of the National Competent Authority.

4) Compatibility Group L articles must always be stored separately from all articles of other compatibility groups as well as from all other articles of different types of Compatibility Group L.

5) Articles of compatibility N should not in general be stored with articles of other Compatibility Groups except S. However if such articles are stored with articles of Compatibility Groups C, D and E, the articles of Compatibility Group N should be considered as having the characteristics of Compatibility Group D and the compatibility groups mixing rules apply accordingly.

6) A mixed set of munitions HD 1.6N and HD 1.4S may be considered as having the characteristics of Compatibility Group N.

7) It is allowed to mix HD l.6N ammunition. The Compatibility Group of the mixed set remains N if the ammunition belongs to the same family or if it has been demonstrated that, in case of a detonation of one munition, there is no instant transmission to the munitions of another family (the families are then called “compatible”). If it is not the case the whole set of ammunition should be considered as having the characteristics of Compatibility group D and the compatibility groups mixing rules apply accordingly.

1.2.3.3. *Mixed Storage - Special Circumstances*

a) There may be special circumstances where the above mixing rules may be modified by the National Competent Authority subject to adequate technical justification based on tests where these are considered to be appropriate.

b) Very small quantity HD 1.1 and large quantity HD 1.2.
It should be possible to arrange storage in such a manner that the mixture will behave as HD 1.2.

c) Mixing of HD 1.1, HD 1.2 and HD 1.3
The quantity distance to be applied in these unusual circumstances is that which is the greatest when considering the aggregate NEQ as HD 1.1, HD 1.2 or HD 1.3.

d) With the exception of substances in Compatibility Group A, which should not be mixed with other compatibility groups, the mixing of substances and articles is permitted as shown in Table 5.

1.2.3.4. *Suspect Ammunition and Explosives (Mixed storage)*

Suspect ammunition and explosives must not be stored with any other ammunition and explosives.

Section IV – Sensitivity Groups

1.2.4.1. *General Principles*

a) In certain storage or operational situations, for example, where walls are used to prevent, or at least substantially delay, transmission of explosion between stacks of ammunition on opposite sides of the wall, initiation by either fragment impact or direct shock can be disregarded. In such situations, however, prompt acceptor detonation reactions may still occur because of mechanisms such as kinetic trauma—the initiation of acceptor munitions due to impacts with other acceptor munitions or with portions of the structure itself.

b) Sensitivity group is a classification category used to describe the susceptibility of HD 1.1 and HD 1.2 Articles and Explosives to sympathetic detonation (SD).

1.2.4.2. *Determination of Sensitivity Groups*

On the basis of the definitions in paragraph 1.2.4.3. ammunition and explosives are formally grouped into five Sensitivity Groups SG1, SG2, SG3, SG4, and SG5.

1.2.4.3. *Definitions of Sensitivity Groups (definitions taken from AASTP 3 Edition 1):*

SG1 Robust
SG2 Non-robust
SG3 Fragmenting
SG4 Cluster bombs/dispenser munitions
SG5 SD Sensitive

1.2.4.4 Guidance on the practical procedure for classifying an item in Sensitivity Groups is given in AASTP-3.

CHAPTER 3 - ABOVEGROUND STORAGE IN DEPOTS

Section I - Principles of the Quantity-Distances

1.3.1.1. *General*

PES such as buildings, stacks and vehicles (trucks, trailers and railcars) present an obvious risk to personnel and property. Such sites are located at carefully calculated distances from each other and from other buildings and installations to ensure the minimum practicable risk to life and property (including ammunition). These distances are called Quantity-Distances and are tabulated in Annex I-A, Section II.

1.3.1.2. *Basis of Quantity-Distances*

The quantity-distances are based on an extensive series of trials and a careful analysis of all available data on accidental explosions in different countries. However, quantity-distances are subject to uncertainty owing to the variability of explosions. These quantity-distances are generated by distance functions subject, in certain cases, to fixed minimum or maximum distances. The fixed values are independent of the NEQ because they are based on the projection hazard from individual rounds or operational factors (see Annex I-B). As regards the rounding of values of quantity-distances, see Annex I-A, paragraph A.1.2. Criteria and formulae for quantity-distances are given in Annex I-B.

1.3.1.3. *Kinds of Quantity-Distances*

a) There are two kinds of Interior Quantity-Distances for each hazard division/SsD:

1) Inter-Magazine Distances (see paragraphs 1.3.1.8. - 1.3.1.11)
2) Explosives Workshop Distances (see paragraphs 1.3.1.12. - 1.3.1.13)

b) There are two kinds of Exterior Quantity-Distances for each hazard division/SsD:

1) Public Traffic Route Distances (see paragraph 1.3.1.14)
2) Inhabited Building Distances (see paragraph 1.3.1.15)

1.3.1.4. *Quantity-Distances for Hazard Division 1.1*

Annex I-A, Tables 1 A-C give QD Matrices and Table 1D Interior and Exterior Quantity-Distances for ammunition and explosives of Hazard Division 1.1. The Inter-Magazine Distances should not be used for packages of primary explosives and other very sensitive explosive substances like blasting gelatine which require individual assessment when at an ES.

1.3.1.5. *Quantity-Distances for Hazard Division 1.2*

a) General

Annex I-A, Tables 2 A-F give QD Matrices and Table 2G Interior and Exterior Quantity-Distances for ammunition and explosives of SsDs 1.2.1 and 1.2.2. Before appropriate quantity-distances can be selected there are three factors to be considered. The first factor is the range of fragments and lobbed ammunition which are projected from a PES. The second factor is the total number of projections likely to hazard an ES. If comprehensive data are available for a particular item, then the quantity-distances for Hazard Division 1.2, which are based on trials with individual rounds considered to be representative, may be replaced by this more appropriate data taking into account the vulnerability of the ammunition, explosives and buildings at the Exposed Sites under consideration (see Part II, Chapter 5, Section II.). The third factor is the behavior of some types of HD 1.2 ammunition. Large NEQ items of SsD 1.2.1 (NEQ < 244 kg) in certain packaging configurations, may react in a manner more typical of an HD 1.1 event. When located in structures that stop primary fragments, but which generate a secondary debris hazard (e.g., certain ECM and other hardened structures), the structural damage and debris hazards produced from these events are more characteristic of an HD 1.1 explosion, rather than the progressive nature of an SsD 1.2.1 event. In these situations, it is appropriate to apply more restrictive quantity-distances.

b) Fragments and Lobbed ammunition from Rounds greater than 0.73 kg individual NEQ.

This, the most hazardous part of Hazard Division 1.2 comprises those rounds and ammunition which contain a high explosive charge and may also contain a propelling or pyrotechnic charge. The total explosives content of these rounds, etc will be greater than 0.73 kg. It is impractical to specify quantity-distances which allow for the maximum possible flight ranges of propulsive items but the likely range of packaged items, if involved in an accident during storage, is typical of this part of Hazard Division 1.2. Munitions which explode during an accident will rarely detonate in their design mode. In a fire situation explosive fillings may melt and expand, breaching their casings and then explode via cook-off or burning to detonation reactions. These explosions may involve anything from 100% to very little of the fill dependent on the amount of the filling that has escaped through the breach. The fragmentation produced by such reactions is totally different to that generated in a design detonation. The case splits open producing large (for a 105mm shell, for example 2-3kg) but comparatively few fragments with velocities of 100-500ms^{-1}. These are likely to be projected further than the smaller fragments from the full detonation of similar munitions in a HD 1.1 reaction. Quantities of unexploded munitions, sub-assemblies or sub-munitions also may be projected to considerable ranges and will, due to thermal or mechanical damage, be more hazardous than in their pristine state. Data on individual round characteristics obtained from tests and accidental explosions may be used to determine the validity of including a specific round in this category or to reduce it to the lesser category described in Paragraph c) below. These items are hereafter called rounds of SsD 1.2.1.

c) Fragments and Lobbed Ammunition from Rounds less than or equal to 0.73 kg individual NEQ.

This less hazardous part of Hazard Division 1.2 comprises those rounds and ammunition which contain a high explosive charge and may also contain a propelling or pyrotechnic charge. The total explosives content of these rounds, etc will be less than or equal to 0.73 kg. It will also typically comprise ammunition which does not contain HE and will include pyrotechnic rounds and articles, inert projectile rounds. Tests show that many items of this type produce fragments and lobbed ammunition with a range significantly less than that of items in b) above but of course greater than that of ammunition and explosives of Hazard Division 1.4. These items are hereafter called rounds of SsD 1.2.2.

d) Subdivisions for Storage

It is important not to exaggerate the significance of the value of 0.73 kg used in b) and c) above. It was based on a break point in the database supporting the Quantity Distance relationships and tables and the NEQ of the rounds tested. If comprehensive data is available for a particular item, then the item may be placed in that category of HD 1.2 supported by the data and allocated the relevant Quantity Distances. It may also be necessary to take into account the vulnerability of ammunition, explosives and buildings at the ES under consideration, see Part II, Chapter 5, Section II.

e) Number of Fragments and Lobbed Items at an Exposed Site

Following the initiation of an event in storage there will be a delay before there are any violent events and projections. This delay will be highly dependent on the nature, dimensions and packaging of the items involved. For 40mm HE rounds it can be as short as two or three minutes and for 105mm HE rounds 15-20 minutes. Once ammunition starts to react the rate of reactions increases rapidly and then decreases more slowly. Reactions may still occur hours after the event. The ability of the storage structure at the PES to contain the fragments etc will determine both in time and density the effects at the exposed site. For medium and lightly constructed PES where, at some stage, walls and/or roofs will be destroyed, the modifying effect of the building on the fragmentation is not taken into account. In the light of the indeterminacy of the fragmentation effects both in time and quantity, fire fighting will, in general, be inadvisable. However the installation of automatic fire-fighting arrangements could be invaluable from the stock preservation and event containment points of view. Evacuation from PTR and beyond may be possible. However the quantity-distances given at Annex I-A assume no amelioration from fire-fighting or evacuation. They are based on the total fragmentation at the exposed site from the event at the PES.

f) Arrangements for Fire-Fighting

The levels of protection afforded by the Inter-Magazine Distances in Annex I-A are based on the fragment density at the Exposed Site for the total incident and the degree of protection afforded by the structure at the Exposed Site. It is assumed that an incident involving Hazard Division 1.2 cannot be promptly curtailed by fire-fighting. It is considered unlikely that any significant attempts could be made to fight a fire involving Hazard Division 1.2 explosives as it is anticipated that such efforts would have to be made from such a distance and from behind protective cover so as to make those efforts ineffective. In addition some storage areas are too remote from professional fire-fighting services, and other lack suitable protective cover from behind which firemen could even attempt to attack a fire involving ammunition of Hazard Division 1.2. The levels of protection take into account the fact that the Explosives Area is endangered by firebrands, projections and lobbed ammunition which would most likely propagate fire or explosion if the quantity-distances were insufficient. The available fire-fighting effort should be directed at preventing the spread of fire and the subsequent propagation of explosions. Fuller recommendations are given in Chapter 4, Part II of the Manual.

g) To advise on Maximum Credible Event (MCE) calculation

The MCE for SsD 1.2.1 is the NEQ of an item times the number of items in three unpalletized, outer shipping packages, unless a different MCE is demonstrated by testing or analogy. The MCE for SsD 1.2.3 is the NEQ of one item.[1]

h) To advise situations which require structural debris distances

When located in structures that stop primary fragments, but which generate a secondary debris hazard, D2 for IBD and D6 for PTR from Table 2 will be used.

i) Situations which require no QDs

Where either the PES or the ES is an earth covered building or a building which can contain the effects generated in an accidental explosion of the HD 1.2 then, in general, no Q-Ds are necessary. The separation to other explosive storehouses, explosive workshops, public traffic routes or inhabited buildings will be dependent on constructional details, access for rescue and fire-fighting personnel or other administrative arrangements. For public traffic routes and inhabited buildings consideration should be given to the use of fixed distances of 30 m for ammunition of SsD 1.2.2 or 60 m for SsD 1.2.1. However where there is an aperture such as a door in the PES and the ES has either an unprotected and undefined door pointing towards the PES or offers little or no protection to its contents then the higher Q-Ds shown in the HD 1.2 Tables should be applied.

j) The Quantity-Distances for ammunition and explosives of SsD 1.2.3 is as follows:

The inhabited building distance for SsD 1.2.3 is determined using D4 of Annex I-A, Table 3G, for the NEQ of the rounds present, but with a minimum inhabited building distance determined as follows: If the SsD 1.2.3 items are situated such that primary fragments will not be interrupted, the minimum inhabited building distance is the hazardous primary fragment distance based on the hazardous fragment density criteria (1 per 55.7 square meters) applied to the worst single SsD 1.2.3 item at the PES. The public traffic route distance in this case is equal to inhabited building distance in high traffic density areas and equal to 67% of inhabited building distance where the traffic density is low. Unbarricaded open or light structure storage (intermagazine) and process building (workshop) distance is 67% of inhabited building distance and barricaded process building distance is 36% of inhabited

[1] For Change 3: MCE concept is accepted but not applied in current Table 2G for HD 1.2.1. PFP(AC/326-SG5)(UK)IWP/3-2005 dated 18 March 2005 “Inconsistencies between HD 1.1 and 1.2” would imply a D7 and a D8 column for applying MCE. This IWP and its implications will be dealt with in the next Change.

building distance, both with a minimum distance equal to the intermagazine distance of 31 m for items with a single-round NEQ equal to or less than 0.73 kg or 92 m for items with a greater NEQ. The intermagazine distance from a PES containing only SsD 1.2.3 items to an ES containing other than SsD 1.2.3 is based on the NEQ of a single round of the largest (greatest NEQ) SsD 1.2.3 item in the PES. If the SsD 1.2.3 items are situated such that primary fragments can be interrupted, the specific minimum separation distances (inhabited building, public traffic route, workshop, and intermagazine) are dictated by practical considerations. For any specific quantity or distance determination, as an alternative to the preceding SsD 1.2.3 QD criteria, when an increase in the allowable quantity or a reduction in the required distance will result, items hazard classified as SsD 1.2.3 may be treated as follows: If the single-round NEQ is greater than 0.73 kg, consider the items as SsD 1.2.1 (use the total NEQ present). If the single-round NEQ is equal to or less than 0.73 kg, consider the items as SsD 1.2.2, based on the total NEQ present.

1.3.1.6. *Quantity-Distances for Hazard Division 1.3*

a) General

Annex I-A, Tables 3A-F give QD Matrices and the Table 3G gives Interior and Exterior Quantity-Distances for ammunition and explosives of Hazard Division 1.3 but the selection of appropriate quantity-distances requires separate consideration of two types of explosives, namely propellants (classified as SsD 1.3.1 - Compatibility Group C) and other items (classified as SsD 1.3.2 - Compatibility Group G). Although many hazardous effects are common to both types, the dominant hazards used, as the bases of certain quantity-distances are different in the two cases hence there are two tables.

b) Explosives producing a mass fire effect

The explosives producing a mass fire effect are likely to be propellants, which produce a fireball with intense radiant heat, firebrands and some fragments. The firebrands may be massive fiery chunks of burning propellant. (The effect of quite normal winds may augment a calculated flame radius by 50 %. A building with marked asymmetry of construction such as an igloo or building with protective roof and walls, but with one relatively weak wall or a door, induces very directional effects from the flames and the projection of burning packages.). These items or substances are called items or substances of SsD 1.3.1.

c) Ammunition and Explosives not Producing a Mass Fire Effect

Items other than propellants produce a moderate fire with moderate projections and firebrands. The projections include fragments but these are less hazardous than those, which characterize Hazard Division 1.2. These items or substances are called items or substances of SsD 1.3.2.

1.3.1.7. *Distances for Hazard Division 1.4*

Separation distances from ammunition and explosives of Hazard Division 1.4 are not a function of the NEQ. Separation distances prescribed by fire regulations apply.

1.3.1.8. *Inter-Magazine Distances - General Considerations*

a) These distances are the minimum permissible distances between PES and storage sites containing ammunition or explosives. These distances are intended to provide specified degrees of protection to the ammunition and explosives at the ES. The degree of protection is highly dependent upon factors such as sensitiveness of explosives, type of ammunition, type of packaging, and type and construction of building at the PES or ES or both. In general the provision of stronger buildings allows the use of smaller quantity-distances for a given degree of protection, or achieves a better standard of protection at a given distance, especially in the case of a PES containing ammunition and explosives of Hazard Division 1.1 or 1.2.

b) The selection of the optimum combination of types of construction of the buildings, quantity-distance and degree of protection involves a balance between the cost of construction, the availability and cost of land, and the value of the stocks of ammunition and explosives which might be rendered unserviceable at ES in the event of an accident at the PES. The hazard divisions and compatibility groups of the ammunition and explosives and the need for flexibility in the use of the sites should be taken into account.

c) The following paragraphs describe the levels of protection corresponding to common combinations of buildings or stacks and quantity-distances for each hazard division as a guide for decisions on the optimum solution. These levels of protection are incorporated in the Inter-Magazine Distances in Annex I-A, Tables 1 to 3. Some entries in the tables show only one level of protection owing to a lack of information at the present time. In a few cases it is not possible to predict the level of protection as it depends on the type of structure at the ES and the sensitiveness of its contents. An indication of the full range of possibilities is given in Part II, Chapter 5.

1.3.1.9. *Inter-Magazine Distances for Hazard Division 1.1*

a) Protection of Stocks

The observed damage to stocks at an Exposed Site from an accidental explosion varies widely and, although detailed prediction of such effects is outside the scope of this Manual, a measure of guidance is given here. Since an igloo is designed to resist external blast, primary fragments or secondary projections, the design ensures that the stocks survive and would be expected to generally remain serviceable. However, at the D3-distances the ground shock may render unserviceable sensitive electrical and electronic components of guided missiles, etc. For open stacks and buildings, other than those covered with earth, a general assessment is that for distances less than D5-distances it is probable that, even though propagation may not have taken place, the stocks are likely to be unserviceable and covered by debris from the collapsed building. Stocks at D7-distances and greater are only likely to be serviceable if the building has not suffered serious structural damage although some structural damage at the D7-distances, dependent on the type of building, can be expected.

b) Alternative Levels of Protection at an ES

As described above, the igloo design affords extremely good protection to its contents. Weaker buildings and open stacks would not be expected to give such good protection although concrete structures are considered to be superior generally to brick from an Exposed Site point of view. The level of protection also depends on the vulnerability or robustness of the ammunition stored at the Exposed Site and the type of traversing used. The following paragraphs describe the three levels of protection which are incorporated in Annex I-A, Table 1 and which are intended to provide an adequate basis for the selection of a particular quantity-distance. Some entries in the table show only one level of protection due to a lack of data. The three levels of protection are:

1) There is virtually complete protection against practically instantaneous propagation of explosion by ground shock, blast, flame and high velocity projections. There are unlikely to be fires or subsequent explosions caused by these effects or by lobbed ammunition. The stocks are likely to be serviceable. However, ground shock may cause indirect damage and even explosions among specially vulnerable types of ammunition or in conditions of saturated soil. These exceptional circumstances require individual assessment rather than use of the quantity-distances in Annex I-A.

2) There is a high degree of protection against practically instantaneous propagation of explosion by ground shock, blast, flame and high velocity projections. There are occasional fires or subsequent explosions caused by these effects or by lobbed ammunition. Most of the stocks are likely to be serviceable although some are covered by debris.

3) There is only a limited degree of protection against practically instantaneous propagation of explosion by ground shock, flame and high velocity projections. There are likely to be fires or subsequent explosions caused by these effects or by lobbed ammunition. The stocks are likely to be heavily damaged and rendered unserviceable; they are sometimes completely buried by debris. This level of protection is not recommended for new construction.

1.3.1.10. *Inter-Magazine Distances for Hazard Division 1.2*

The Inter-Magazine Distances for Hazard Division 1.2 relate essentially to three levels of protection of ammunition and explosives at an ES:

1) There is virtually complete protection against immediate or subsequent fires and explosions caused by blast, flame, firebrands, projections and lobbed ammunition. The stocks are likely to be serviceable.

2) There is a high degree of protection against immediate or subsequent propagation of explosion by blast, flame, projections and lobbed ammunition. The larger the donor event the lower will be the degree of protection given, particularly where ammunition with NEQ greater than 0.73 kg is involved, propagation becoming more likely the longer the event continues. Local fire fighting measures may reduce stock losses. It is likely that stocks at the ES will not survive as a result of subsequent propagation.

3) There is only a limited degree of protection against immediate or subsequent propagation of explosion by blast, flame and projections and lobbed ammunition. The protection afforded may be minimal when the donor event involves large quantities of ammunition and continues for a prolonged period. Local fire fighting measures will be essential to the preservation of stocks. The stocks at the ES are not likely to survive as a result of subsequent propagation.

1.3.1.11. *Inter-Magazine Distances for Hazard Division 1.3*

The Inter-Magazine Distances for Hazard Division 1.3 relate essentially to two levels of protection of ammunition and explosives at an ES:

1) There is virtually complete protection against immediate or subsequent fires among the contents of an ES by flame, radiant heat, firebrands, projections and lobbed ammunition. There may be ignition of combustible parts of the building but this is unlikely to spread to the contents even if it were not possible to provide prompt and effective fire-fighting services.

2) There is a high degree of protection against immediate propagation of fire to the contents of an ES by flame, radiant heat, firebrands, projections and lobbed ammunition. There is a considerable risk that one or more of these effects, especially lobbed ammunition, is likely to ignite the contents directly or as the result of ignition of combustible parts of the building unless effective fire-fighting is able to prevent such consequences.

1.3.1.12. *Explosives Workshop Distances*

a) General Considerations

These distances are the minimum permissible distances between Potential Explosion Sites and explosive workshops. The distances are intended to provide a reasonable degree of immunity for personnel within the explosives workshops from the effects of a nearby explosion, such as blast, flame, radiant heat and projections. Light structures are likely to be severely damaged, if not completely destroyed. These distances also provide a high degree of protection against immediate or subsequent propagation of explosion.

b) Explosive Workshop Distance for HD 1.1

1) For HD 1.1 the standard Explosive Workshop Distance should be the D10 distances prescribed in Annex I-A Tables 1A-C. At this distance the major effects to be considered are the peak side-on overpressure, which is anticipated to be no greater than 20 kPa (3 psi) and debris, which is extremely difficult to quantify, but would be a very significant effect.

2) When siting and designing explosive workshops the following effects should be borne in mind amongst others. A person in a building designed to

withstand the anticipated blast loading and without windows would be merely startled by the noise of the explosion at an adjacent site whereas a person in a brick building with windows might suffer eardrum damage or suffer indirect injuries through his translation by blast and subsequent impact on hard objects or through possible collapse of the building upon him.

3) Where the quantity-distance tables specify a Explosive Workshop Distance less than 270 m this may not give protection to personnel in explosive workshops having light roofs from debris projected from the Potential Explosion Site. Therefore consideration should be given to maintaining this 270 m distance as the minimum separation from the nearest storage site containing explosives of HD 1.1, in order to provide additional protection from debris.

c) Explosive Workshop Distance for HD 1.2

1) Since debris and/or fragmentation hazards are considered to be dominant for HD 1.2 and the Inhabited Building Distance is based on an appreciation of this hazard then the Explosive Workshop Distance is generally determined as 36% of the IBD.

2) However where the PES is an earth covered building or a building which can contain the effects generated in an accidental explosion of the HD 1.2 then no Q-Ds are necessary to adjacent explosive workshops although the separation between them and the explosive storehouses will be dependent on constructional details and access for rescue and fire-fighting personnel.

3) Where the PES is an earth covered building or a building which can contain the effects generated in an accidental explosion of the HD 1.2 but has a door or other aperture in the direction of the ES then the Explosive Workshop Distance is determined as 36% of the IBD.

4) Where the explosive workshop is protected by a barricade and has a protective roof it is considered that the occupants are afforded a high degree of protection which decreases to limited if the building is either not barricaded or does not have a protective roof. In the absence of any protective features, such as a barricade or a protective roof, not only is the level of protection limited but it is recommended that such explosive workshops should only be sited at an increased separation equivalent to PTR.

d) Explosive Workshop Distance for HD 1.3

1) For the substances or items classified SsD 1.3.1, the D2 distances prescribed at Annex I-A Tables 3A-C should be used.

2) For the substances or items classified SsD 1.3.2, the distances are fixed values given in Annex I-A Tables 3D-F.

1.3.1.13. *Separation of Explosives Workshops from Storage Sites*

The D10-distances in Annex I-A, Table 1 less than 270 m may not give protection to personnel in Explosives Workshops having light roofs. If greater protection is required against projections than that provided by D10-distances for example to protect personnel and valuable test equipment, then the workshop must be provided with a protective roof. If there is a possibility of a serious fragment hazard then consideration should be given to observing a minimum separation distance of 270 m between Explosives Workshops having light roofs and storage sites containing ammunition and explosives of Hazard Division 1.1 as is already required in certain circumstances.

1.3.1.14. *Public Traffic Route Distances (PTRD)*

a) General Considerations

1) These distances are the permissible distances between a Potential Explosion Site and routes used by the general public, which are generically referred to as Public Traffic Routes, subject to the fragment minimum distances detailed at para 1.3.7.3. These routes include :

Roads
Railways
Waterways, including rivers, canals and lakes, and
Footpaths

2) Where debris or fragmentation hazards are considered to be dominant and the Inhabited Building Distance is based on an appreciation of this hazard then the PTR is determined as 67% (or 2/3) of the IBD. This rule is applied to both HD 1.1 and HD 1.2 situations. Attempts have been made within AC/258, which preceded AC/326, to determine a relationship between debris hazards for IBD and PTR

without success primarily because the variation of hazard with distance is too dependent on the specific hazard generator.

3) It is important to appreciate that PTR's or common access areas should not be treated independently of each other or of any other constraints around an explosives site. They should be viewed within the overall picture and the above guidelines used to indicate whether a particular situation is likely to be worth consideration. Ideally a full risk analysis should be conducted to ascertain how these additional risks would fit into the overall risk picture. Only then can informed decisions be made regarding the soundness of a particular license.

b) Traffic Density Considerations

1) Since the exposed sites presented by public traffic routes are so diverse three alternatives are provided as follows :

The use of full IBD protection for heavily used routes

The use of a reduced Public Traffic Route distance, generally 2/3 of the appropriate IBD for less heavily used routes, and

The use of a lower distance for routes which are used intermittently or infrequently by low numbers of people.

2) The dominant factors which determine the number and severity of road casualties are the traffic speed and density, the width of traffic lanes and their number, the presence of crash barriers, the surface condition and the radius of any curves. Factors of less importance are the presence or absence of roadside trees and ditches and of separated carriageways for opposing traffic. For other types of routes it is essentially the density and speed of the "traffic" which are the critical factors.

3) Because of the variety of waterway borne traffic some cognisance may need to be taken of special factors, e.g. passenger carrying ferries which, although traversing the hazarded area much quicker than other craft, may merit special consideration because of the number of passengers carried.

1.3.1.15. *Inhabited Building Distances*

a) General

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

b) Inhabited Building Distances for Hazard Division 1.1.

1) The distances for Hazard Division 1.1 are based on tolerable levels of damage expected from a side-on overpressure of 5 kPa. They are intended to ensure that the debris produced in an accidental explosion does not exceed one lethal fragment (energy > 80 J) per 56 m^2 at the Inhabited Building Distance. They are not sufficiently large to prevent breakage of glass and other frangible panels or cladding used in the three types of buildings of vulnerable construction. This broken glass, cladding etc. can cause injury to occupants and those in the immediate vicinity of the buildings. Such buildings of vulnerable construction should be situated as follows:

(a) Types 1 and 2: are considered to be of similar vulnerability and such buildings should normally be situated at distances not less than two times Inhabited Building Distances (i.e. > 44.4 $Q^{1/3}$) (see paragraph 1.3.7.6.). However, such buildings, but probably not schools or hospitals, may be acceptable within the 44.4 $Q^{1/3}$ distances, particularly if the population outside the building (on whom the displaced glass etc. would fall) is small or virtually nil. When vulnerable buildings have been allowed within the 44.4 $Q^{1/3}$ distances on these grounds, it will be necessary to check at regular intervals that the original conditions (i.e. area around building free of people) have not changed.

(b) Type 3: presents a difficult problem and it is intended to cover the multiplicity of new construction types which have been introduced since the curtain wall concept was first thought of. Each such building has to be treated on its merits, the hazard assessed and an appropriate quantity-distance selected. It is likely, however, that this will be in the 44.4 $Q^{1/3}$ region.

2) The Australian/UK Stack Fragmentation trials in the late 1980s have demonstrated that, for a Net Explosives Quantity of less than 5 600 kg, if the Potential Explosion Site is of light construction, typically 230 mm brick or equivalent or less, and barricaded, then the hazard from projection is tolerable at D12-distances subject to a minimum of 270 m. However, if a medium or heavy walled construction, typically 200 mm concrete or greater, is employed at the Potential Explosion Site, then the hazard from projection requires a minimum separation distance of 400 m. For a Net Explosives Quantity greater than 5 600 kg, the prescribed Inhabited Building Distance D13 will provide an acceptable degree of protection from both blast and projections. These trials also demonstrate that the hazard from projections is not constant and shows a marked directional effect. Basically, there is a very low density of projections in directions directly away from the corners of the structure. The projection density rises almost as an exponential function to a maximum in the direction normal to any face of the structure. This is repeated on all sides of the structure irrespective of whether the structure is barricaded or not. It is extremely difficult to interpret the results to give general guidelines and it is advised that where it is considered that siting of the Exposed Site with respect to the Potential Explosion Site might be beneficial, then the Stack Trial results should be considered in detail for each specific case.

3) A 400 m minimum Inhabited Building Distance is required to protect against structural debris from igloos, other earth-covered structures or unbarricaded buildings.

4) The distances for explosives of Hazard Division 1.1 are based on the behaviour of typical packaged military explosives. They take account of trials using bulk demolition explosives in wooden boxes or pallets in open stacks. In certain special circumstances, for Net Explosives Quantities of less than 4 500 kg, these distances would be unduly conservative, since hazardous projections cannot arise. Such circumstances may occur at test sites and factories where bulk explosives, devoid of metal casing or components, are in fibreboard packagings, not on pallets, and are either in open stacks or in light frangible buildings. In these special circumstances use D13-distances, as appropriate, without any overriding minimum distance for projections.

5) There is a significant hazard even at 270 m from ammunition and explosives of Hazard Division 1.1 due to fragments and a considerable amount of debris

unless these projections are intercepted by structural protection. This hazard may be tolerable for sparsely populated areas, where there would be a small expectation of damage and injury from such projections, but in densely populated areas considerations should be given to the use of a minimum Inhabited Building Distance of 400 m. This distance is required for earth-covered magazines and for heavy-walled buildings.

c) Inhabited Building Distances for Hazard Division 1.2.

The distances for Hazard Division 1.2 are based on an acceptable risk from fragments. Under normal conditions, for non-earth covered magazines, D1- or D2-distances given in Annex I-A, Tables 2 A-F must be used for inhabited buildings. For earth covered magazines 30m and 60m fixed distances may be applied as advised in Tables 2A and 2D.

d) Inhabited Building Distances for Hazard Division 1.3.

1) The distances for Hazard Division 1.3 are based on a thermal flux criterion of 1.5 cal per cm^2. It is anticipated that occupants of traditional types of inhabited buildings would not suffer injury unless standing in front of windows; such persons and other in the open are likely to experience reddening of any exposed skin areas.

2) If venting from the Potential Explosion Site is directed towards the Exposed Sites at Inhabited Building Distances, then a minimum distance of 60 m should be employed.

Section II - Determination of Quantity-Distances

1.3.2.1. *Quantity-Distances Tables*

a) The quantity-distances required for each hazard division are given in tables in Annex I-A, Section II.

b) For an intermediate quantity between those given in the tables, the next greater distance in the tables should be used when determining a quantity-distance. Conversely the next lesser quantity in the tables should be used when determining an explosives quantity limit for a given intermediate distance, alternatively, the distances corresponding to an intermediate quantity may be either calculated from the distance function shown in the tables of Annex I-A or found by interpolation and then rounded up in accordance with Annex I-A, Section I, paragraph A.1.2.

c) Quantity-distances for a quantity of explosives greater than 250 000 kg are determined by extrapolation using the appropriate formula in Annex I-B, as far as the explosives safety factors are concerned, but adequate consideration should be given to the economic and logistic implications of such a large quantity in a single storage site.

d) The tables in Annex I-A provide quantity-distances for an earth-covered magazine up to 250 000 kg NEQ. However, certain designs of earth-covered magazines require a lower limit in the case of Hazard Division 1.1. The reason is that the blast load from an exploding earth-covered magazine is a function of the NEQ, whereas the blast resistance of an exposed earth-covered magazine depends on its design. The limitation for a particular earth-covered magazine must be obtained from the design authority.

1.3.2.2. *Measuring of Quantity-Distances*

a) Quantity-distances are measured from the nearest point of the PES to the nearest point of the ES. Distances are measured along a straight line without regard to barricades.

b) Where the total quantity of ammunition and explosives in a storage site or explosives workshop is so separated into stacks that the possibility of mass explosion is limited to the quantity in any one stack, distances are measured from the outside of the wall adjacent to the controlling explosives stack to the nearest outside wall of another structure. If the separation to prevent mass explosion is provided by one or more substantial dividing walls, then the distances are measured from these walls, if appropriate, instead of from the outside walls of the building. Where not so separated the total quantity subject to mass explosion is used for quantity-distance computations.

1.3.2.3 *Net Explosives Quantity*

a) The total Net Explosives Quantity of ammunition in a single PES is used for the computation of quantity-distances unless it has been determined by testing or analogy to testing that the effective quantity is significantly different from the actual NEQ.

b) Where two or more PES are not separated by the appropriate Inter-Magazine Distances, they are considered as a single site and the aggregate NEQ is used for determining Quantity-Distances. If two or more hazard divisions are involved the principles in paragraph 1.3.2.5. apply.

c) The total explosives content of rounds or ammunition classified as HD 1.2 is used in the computation of the NEQ for quantity-distance purposes.

d) The NEQ does not include such substances as white phosphorous, chemical agents, smoke or incendiary compositions unless these substances have been shown to contribute significantly to the explosion hazard. Any other energetic materials such as liquid fuels should be aggregated with the explosives NEQ unless it has been determined by testing that they do not contribute to the overall hazard.

1.3.2.4. *Determination of Quantity-Distances*

a) The location of buildings or stacks containing ammunition or explosives with respect to each other and to other ES is based on the total NEQ in the individual buildings or stacks unless this total quantity is so subdivided that an incident involving any one of the smaller concentrations cannot produce a practically instantaneous explosion of the whole contents of the building or stack.

b) The quantity-distances required from each of two or more nearby storage sites or explosives workshops to contain ammunition and explosives of one hazard division are only determined by considering each as a PES. The quantity of explosives permitted in the storage sites or explosives workshops is limited to the least amount allowed by the appropriate table for distances separating the storage sites or explosives workshops concerned.

c) The quantity-distances required from each of two or more nearby storage sites to contain given quantities of ammunition and explosives of different hazard divisions at different times are determined as follows:

1. Consider each building or stack, in turn, as a PES.

2. Refer to the table of each hazard division which can be stored in the building or stack considered as a PES.

3. Determine the quantity-distances for each hazard division as the minimum to be required from the building or stack.

4. Record the quantity-distances in terms of each hazard division in each instance as those to be required from the building or stack.

d) Alternatively calculate the permitted quantity of each hazard division based upon the available distances.

1.3.2.5. Reserved (Original content "Required Quantity-Distances of Ammunition and Explosives of more than one Hazard Division in a Single Site" deleted). Refer to Part I, Section III for guidance.

1.3.2.6. Reserved (Original content "Permissable Quantities of Ammuniton or Exposives of more than one Hazard Division ina Single Site" deleted). Refer to Part I, Section III for guidance.

1.3.2.7. *Relaxation of Quantity-Distances*

a) Interior Quantity-Distances

1) Relaxation of Inter-Magazine Distances may result in the total loss of stocks in other buildings or stacks or at least their being rendered unserviceable. Furthermore, a much larger explosion may result than that used as basis for Exterior Quantity-Distances. Disastrous damage to property and injury to the general public may be the consequence.

2) Relaxation of Explosives Workshop Distances may be permitted when a specially constructed building is available to protect against blast and debris or where the number of persons in the workshop is small.

b) Exterior Quantity-Distances

Relaxation of Exterior Quantity-Distances may increase the hazard to life and property. Relaxation should therefore be permitted only with the written consent of the appropriate authorities (see also subparagraph 1.1.0.1.d)).

Section III - Quantity-Distances for Certain

Types of Ammunition and Explosives

1.3.3.1. *Barricaded Stacks of Ammunition*

a) Stacks (Modules) of Bombs etc.

D1-distances up to 30 000 kg and D2-distances from 30 001 to 120 000 kg as shown in Annex I-A, Section II, Table 1 may be used between unboxed bombs of Hazard Division 1.1 under the following conditions:

1) The stacks are to be separated by effective earth barricades.

2) The bombs must be relatively strong so as to withstand intense air shock without being crushed.

3) There should be the minimum of flammable dunnage etc., which could catch alight and lead to subsequent mass explosion of a stack.

4) When the D1-distances are used then the stacking height must not exceed 1 m.

In the event of an explosion in one stack the distances will provide a high degree of protection against simultaneous detonation of bombs in adjacent stacks. Some of the bombs in the ES may be buried and not immediately accessible, some may be slightly damaged. There may be occasional fires and delayed low order explosions, particularly if the bombs are stacked on concrete storage pads.

b) Other Unpackaged Ammunition of Hazard Division 1.1

In principle, the foregoing distances and conditions may be applicable to other kinds of unboxed ammunition of Hazard Division 1.1 and Compatibility Group D. An example is the 155 mm shell M107 which has a robust steel casing and a relatively insensitive high explosive filling. Each case must be judged on its merits, using ad hoc tests or analogy with existing test data as requisite.

c) Cluster Bomb Units

Tests have shown that certain packaged cluster bomb units (CBU) may be stored safely in accordance with subparagraph a) above. In this case, it is the robust containers rather than the heavy casings which prevent sympathetic detonation between stacks. Each type of bomblet and container must be carefully assessed to ensure a satisfactory combination for the application of this modular storage.

d) Buffered Storage

1) Tests have shown that stacks of certain types of bombs can be stored in the same facility in such a manner separated by using buffer materials (ammunition as well as inert materials), that even though a high order detonation will propagate through one stack it will not propagate to the second stack. Storage under these conditions presents the risk of explosion of a single stack only, rather than a mass risk involving all the stacks in one module, cell, or building. Hence, the Net Explosives Quantity (NEQ) of the larger stack plus the NEQ of the "buffer" material, if any, may be used to determine the quantity-distances requirement for each entire module or building so used.

2) The storage of bombs using the buffered storage concept and basing the NEQ of storage on the NEQ of the largest stack plus the buffer material is authorized provided nationally approved storage arrangements are used. See Part II, Chapter 3, Section I.

1.3.3.2. *Unbarricaded Stacks of TNT or Amatol Filled Shell*

Certain types of TNT or Amatol filled projectiles of Hazard Division 1.1 may be stored in stacks which comply with the principle that, although a high order detonation would propagate throughout a stack, it would be unlikely to propagate from stack to stack. Storage under these conditions presents the risk of explosion of a single stack only, rather than a mass risk involving all the stacks in one module or building. Hence the NEQ of the appropriate single stack may be used to determine the quantity-distances for each entire module or building so used. The special types of projectiles and the conditions are given in Part II, Chapter 3, Section I.

1.3.3.3. *Unbarricaded Storage of Fixed Ammunition with Robust Shell*

Trials show that ammunition comprising robust shell with an explosive content not exceeding about 20 % of the total weight (excluding propelling charges, cartridge cases and weight of packages) and with shell-walls sufficiently thick to prevent perforation by fragments produced by ammunition of Hazard Division 1.1 may be stored without barricades without the risk of practically instantaneous explosion provided an increased quantity-distance is used.

1.3.3.4. *Propulsive Rockets*

Rockets stored in a propulsive state (i.e. unpackaged propulsive rockets and missiles in the assembled condition, waiting to be placed upon a tactical launcher or vehicle) present special problems in which the flight range of the rocket is the main safety criterion rather than the explosive content. Consequently the rockets should be stored in special buildings or held by devices to prevent their flight (see Part II, Chapter 3, Section II). The quantity-distances for the appropriate hazard division apply only when these conditions are met, except for the special case of missiles on the launchers at a missile installation (see Part IV, Chapter 3). Rockets or missiles in either an assembled or unassembled condition, when packaged as for storage and transport, do not in practice present the risk of significant flight.

1.3.3.5. *Storage of Very Sensitive Explosives*

It is possible for the blast at an ES to cause practically instantaneous initiation of packaged primary explosive substances and certain other very sensitive explosive substances like blasting gelatine even when barricaded at the D4-distances in Annex I-A, Table 1. Storage conditions for such explosives are assessed individually taking account of the protection afforded by packaging and the building at the ES.

1.3.3.6. *Storage of Depleted Uranium (DU) Ammunition*

Quantity-distances will, in general, be those appropriate to the Hazard Classification of the particular ammunition stored. In some cases a special radiological safety distance may be required between a storehouse and the nearest point of public access if it is estimated that the adverse radiological/toxic effects of an atmospheric dispersion of DU could give rise to a possibility of injury to a member of the public comparable to that caused by the explosive components of the ammunition. In such a case the more restricted of the two distances, the radiological safety distance or the explosives quantity-distance, shall be the one applied.

Section IV - Quantity-Distances for Certain Exposed Sites

1.3.4.1. *Separation of Miscellaneous Occupied Buildings and Facilities in an Explosives Area*

Buildings containing empty packages or other inert materials should be separated from a PES by a distance based on the risk to the ammunition and explosives from a fire in the empty packages or other inert materials (minimum distance 25 m). Special consideration should be given to the separation of high value packages from a PES.

1.3.4.2. *Criteria for Siting of Holding, Marshalling and Interchange Yards*

a) Holding Yards

Each holding yard is considered to be a PES. Quantity-Distances and/or explosive limits are determined as for storage sites.

b) Marshalling Yards

1) Appropriate Inter-Magazine Distances must be applied to protect a marshalling yard from external explosions.

2) It is not necessary to treat a marshalling yard as a PES provided the vehicles are moved expeditiously (within 4 hours) from the yard. If a yard is used at any time for purposes other than marshalling, e.g. holding, it is considered to be a PES and appropriate quantity-distances as for storage site applied.

c) Interchange Yards

It is not necessary to treat an interchange yard as a PES, provided the vehicles are moved expeditiously from the yard. However, if a yard is used at any time for a purpose other than interchange, it is considered to be a PES and appropriate quantity-distances applied.

1.3.4.3. *Separation of Pipelines etc from an Explosives Area*

a) Aboveground Facilities

For the separation of POL facilities: see Chapter 5.

b) Underground Pipelines

For the separation of underground pipelines: see Chapter 5.

1.3.4.4. *Separation of Electric Supply and Communications Systems from an Explosives Area*

There may be mutual hazards created by siting an explosives area near to high voltage transmission lines, powerful transmitters, vital communications lines etc. Each case must be assessed individually to take account of the voltage and power involved, the importance of the transmission lines, the time for the necessary repairs and the consequences of losing communications at a time when assistance may be required following an explosion. The assessment should be based on the following factors:

1) Hazard from the Ammunition or Explosives

The Public Traffic Route Distance is a reasonable separation to protect public service or military emergency communication lines and overhead electrical power transmission lines exceeding 15 kV or associated substations. Particularly important installations such as the lines of a supergrid network should be given greater protection from fragments and debris by affording them one or even one and a half times the Inhabited Building Distance. This increased separation is also appropriate for microwave, ultra high frequency (UHF) reflectors which would be vulnerable to damage by air shock or debris and fragments. Minor transmission and communication lines such as those serving the buildings of the explosives area, may be sited in accordance with subparagraph 2) below.

2) Hazard to the Ammunition or Explosives

The quantity-distances determined on the basis of 1) above should be reviewed in the light of a possible hazard from electrical lines and transmitters to the ammunition and explosives themselves. If any overhead transmission line approaches nearer to a building containing ammunition or explosives than one span between the poles or pylons, consideration should be given to the consequences of mechanical failure in the line. Arcing and large leakage currents may be set up before the supply could be isolated. An overriding minimum separation of 15 m is prudent. Generating stations and substations should be at least 45 m from any building containing ammunition or explosives in view of the small but real risk of fire, explosions or burning oil in such electrical equipment. Powerful transmitters of electromagnetic energy may hazard electrically initiated ammunition. See Chapter 6.

1.3.4.5. *Explosives Storage Site/Depot Safety*

a) Protective Zones Around a Depot or Storage Site.

Subject to national regulations it is advisable that any depot or Potential Explosion Site be surrounded by zones, out to the distance at which the hazard is considered tolerable, within which construction is controlled or made subject to special authorization.

b) Procedures for Safety Site Plans.

1) Since all explosives areas require quantity-distance (QD) separations, a safety site plan is necessary to demonstrate these separation distances are provided before construction commences, or explosives are deployed into any given area. Maps and drawings will demonstrate graphically that separation distances are in compliance with appropriate tables in this Manual. The damaging effects of potential explosions may also be altered by barricades and specialized construction features. Site plan submissions will also demonstrate when these features exist and provide details for review by safety authorities. The following kinds of information constitute a safety site plan:

(a) A Q-D schedule providing the hazard division and net explosive quantity (NEQ) assigned to each potential explosion site (PES).

(b) A map of the explosives area in relation to other internal facilities and buildings, surrounding villages, highways and cities (exterior Q-D).

(c) Drawings showing the location of explosives buildings in relation to one another (interior Q-D).

(d) Drawings showing details of construction features which affect quantity-distances

2) The NATO force sponsoring the new facility should require the preparation of a safety site plan and its submission through appropriate military and national authorities for review and approval. Normally, the military command planning to use the new facility will provide the specific details to support preparation of the site plan document. However, administrative details are the business of individual member nations. The intent of this requirement is to ensure that documentation is provided for competent review before funds are committed.

1.3.4.6. *Levels of Protection*

A more detailed examination of the levels of protection afforded by the quantity-distances given in Annex I-A Tables 1A to 3G and of the structures and activities considered acceptable at each protection level is given in Part I, Chapter 3, Section VII for Hazard Division 1.1.

Section V - Storage Buildings: General Principles and Influence on Quantity-Distances

1.3.5.1. *General*

a) It is not considered practicable to construct surface buildings which withstand direct attack by hostile activities but in order to reduce the hazards and the quantity-distances as far as practicable, certain precautions in building construction should be observed.

b) The construction of buildings for one hazard division only is uneconomic. Buildings may be used for storage of different hazard divisions because storage requirements vary in the course of time.

c) The distances in Annex I-A, Tables 1 to 3 are based on explosives safety. They do not take account of structural requirements, space for roads and access for fire-fighting. These practical considerations may require greater distances than given in the tables. Guidance on structural requirements is given in Part II, Chapter 3, Section II.

1.3.5.2. *Igloos*

a) A storage site comprising igloos gives the simplest and safest set of Inter-Magazine Distances when it is a rectangular array with the axes of the igloos parallel and the doors all facing in one direction. A front-to-front configuration should be avoided since this requires a very large separation of the igloos. It may be expedient to arrange the igloos back-to-back in two rows, but this configuration may be less flexible for further development of the storage area.

b) Igloos which conform to the minimum design criteria in Part II, paragraph 2.3.2.2. qualify for reduced Inter-Magazine Distances compared with other types of aboveground magazines and open stacks. Igloos of a strength exceeding the minimum prescription may warrant further reductions in Inter-Magazine Distances. Conversely, the other earth-covered buildings depicted in the Annex I-A PES-ES matrices require larger Inter-Magazine Distances. It is for the National Authority to balance the cost of various types of construction against the cost and availability of real estate and to determine the optimum balance in any particular situation.

1.3.5.3. *Blast Resistance of Structures at Exposed Sites*

It may be possible for a structure at an ES to fail under blast loading so that its contents are initiated practically instantaneously. This may be the result of major internal spalling from walls, implosion of the door(s) or catastrophic failure of the entire structure. The quantity-distances in Annex I-A, Table 1 presume that a structure at an ES is designed either to be strong enough to withstand the blast or to be so light that secondary projections from the structure do not initiate the contents taking account of their sensitiveness. An ES containing ammunition vulnerable to attack by heavy spalling (e.g. missile warheads filled with relatively sensitive high explosives) requires special consideration, see Part II, Chapter 5.

1.3.5.4. *Influence of Protective Construction upon Quantity-Distances*

a) A building with marked asymmetry of construction, such as an igloo or another building with protective roof and walls, but with one relatively weak wall, induces very directional effects from the flames and the projection of burning packages containing ammunition and explosives of Hazard Division 1.3. However, it is assumed for simplicity that the effects from Hazard Division 1.3 are symmetrical about a PES, although it is known that other structural characteristics and the wind can be significant.

b) Roofs may be designed to have special functions, such as:

1) Containment of fragments and prevention of lobbing of ammunition (the roof on a PES).

2) Shielding against blast, projections and lobbed ammunition (the roof on an ES).

The quantity-distances for buildings which contain fragments etc. depend upon the particular design specifications. The reduced quantity-distances resulting from shielding roofs are incorporated in the Tables in Annex I-A.

c) Walls may be designed to exclude firebrands, projections and lobbed ammunition. The resultant reduced quantity-distances are incorporated in the Tables in Annex I-A. However, a reduction often depends also on the provision of shielding roofs.

1.3.5.5. *Construction to Contain Fragments and to Prevent Lobbing*

a) The design of structures to contain projections or lobbed ammunition of Hazard Division 1.1 is an extremely complicated procedure and, unless warranted due to other special circumstances, is prohibitive in cost.

b) In practice, it is generally only feasible to design a structure when the NEQ is small or when the total content of the building is divided into smaller units by dividing walls which prevent the mass explosion of the entire content of the building in the event of explosion of one of the units. The design of a structure to contain projections and lobbed ammunition represents a more stringent requirement than that for dividing walls to prevent propagation.

1.3.5.6. *Structures to Protect from Flame Projections and Lobbed Ammunition*

a) Protection from Effects of Ammunition of Hazard Division 1.1

1) Protection against High Velocity Projections from the Explosion of Stacks of Ammunition
Ammunition stacks in the open or in buildings can produce high velocity projections during an explosion. These projections may penetrate storage buildings and retain sufficient energy to initiate the contents practically instantaneously. Certain of the Q-Ds in Annex I-A (igloos) presume that the roof, headwall and door(s) of igloos at the ES will arrest these high velocity fragments. The presence of a barricade around the stack or building is always preferred because of the increased protection given against attack by high velocity projections.

2) Protection against the Explosion on Impact of Lobbed Ammunition

In the case of accident or fire, ammunition may be lobbed from any of the PES in Table 1. Ammunition is least likely to be lobbed from the PES described in columns a and b and more likely to be lobbed as the PES description changes from c to f. These lobbed items may explode on impact (see subparagraph 1.2.1.2.b)). The fragments from these may penetrate stacks in the open or in a storage building and retain sufficient energy to initiate the stacks practically instantaneously. Certain of the quantity-distances in Annex I-A (igloos) presume that the roof, headwall and door(s) at the ES will arrest these high velocity fragments, but not necessarily lobbed items larger than 155 mm shell (see subparagraph 1.2.1.2.b)). The presence of a barricade around a building is always preferred and gives increased protection against the high velocity projections, with the exception of those arising from items lobbed over the barricade.

b) Protection from Effects of Ammunition of Hazard Division 1.2 or 1.3

Certain types of construction provide a reasonable degree of protection against firebrands, comparatively low velocity projections, and lobbed ammunition (see Part II, paragraph 2.3.2.3.). Examples are:

1. An earth-covered building with a headwall and door(s) of 15 cm reinforced concrete or equivalent.

2. A heavy-walled building.

3. A barricaded explosives workshop with a protective roof.

In such cases the smaller Interior Quantity-Distances in Annex I-A, Table 2 or Table 3 are used. If the door or one weak wall etc. does not completely conform to the above requirements, such smaller distances should only be authorized after a special assessment of the relative orientation of the weak elements and the hazards involved.

Section VI - Barricades: General Principles and Influence on Quantity-Distances

1.3.6.1. *Functions of Barricades*

a) An effective barricade arrests high velocity projections at low elevation from an explosion which otherwise could cause direct propagation of the explosion.

b) A vertical faced barricade close to a PES also reduces the projection of burning packages, ammunition and debris.

c) A barricade may also provide limited protection against blast and flame arising either from an external or from an internal explosion when the quantity of explosives is relatively small as it usually is in explosives workshops.

1.3.6.2. *Influence of Barricades upon Quantity-Distances for Hazard Division 1.1*

a) Inter-Magazine Distances

An effective barricade avoids the use of very large Inter-Magazine Distances around a site containing ammunition of Hazard Division 1.1. This is a significant factor in the cost of a depot. The reduced quantity-distances are given in Annex I-A, Table 1.

b) Explosives Workshop Distances

An effective barricade avoids the use of large Explosives Workshop Distances from PES containing ammunition of Hazard Division 1.1. A barricade or heavy wall around an explosives workshop considered as an ES may provide some protection for personnel in the lee of the barricade.

c) Exterior Quantity-Distances

Investigation of damage caused by blast and projections in recorded accidents and trials shows that, in the case of Hazard Division 1.1, the difference between the Exterior Quantity-Distances required for barricaded and unbarricaded buildings or stacks respectively, is too small to be taken into account.

1.3.6.3. *Influence of Barricades upon Quantity-Distances for Hazard Division 1.2 or 1.3*

A barricade, other than a door barricade, does not itself generally provide sufficiently effective protection against flame, radiant heat, projections and lobbed ammunition to justify a reduction of the Inter-Magazine Distances around a PES containing Hazard Division 1.2 or 1.3. However, to achieve flexibility in the use of sites, each one should be effectively barricaded.

1.3.6.4. *Influence of Door Barricade upon Quantity-Distances for Hazard Division 1.1*

A door barricade is superfluous, as far as the use of Inter-Magazine Distances is concerned, when igloos or other earth-covered buildings are sited side-to-side or rear-to-rear. When the front of such a building at an ES faces the side or rear of an earth-covered building at a PES, a door barricade may intercept concrete debris but the major consideration is the blast resistance of the headwall and door(s) at the ES and this is not much affected by the barricade. When such buildings are sited front-to-front, a door barricade may be ineffective. As regards personnel hazards, a door barricade of reasonable height does not intercept debris which is lobbed or projected at a high elevation.

1.3.6.5. *Influence of Door Barricades upon Quantity-Distances for Hazard Division 1.2*

A fire in an earth-covered building containing ammunition of Hazard Division 1.2 produces a serious hazard through the doorway from fragments and ejected ammunition. This hazard is reduced by providing a separate barricade, with a vertical wall facing the door. Such a barricade at an ES permits reduced distances shown in Annex I-A, Tables 2 A-F.

1.3.6.6. *Influence of Door Barricades upon Quantity-Distances for Hazard Division 1.3*

a) The deflagration of items and substances classified SsD 1.3.1 in an igloo or similar earth-covered building produces marked directional effects in the hazardous sector, which is taken to be the area bounded by lines drawn from the centre of the door and inclined 30° on either side of a perpendicular to the door. This hazard is reduced by a door barricade, at the PES, which has a vertical wall facing the door and is preferably backed with earth. Such a barricade permits the use of the reduced quantity-distances in Annex I-A, Tables 3 A-C. This door barricade is not necessary when the door of the building at the PES faces an earth-covered rear or sidewall of a building at an ES, or faces an explosives workshop, which has both a barricade and a protective roof

b) The burning of items classified SsD 1.3.2 in an igloo or similar earth-covered building produces a hazard from fragments and projected items in the sector in front of the door. This hazard is reduced by providing a separate barricade, with a vertical wall facing the door. Such a barricade at both a PES and at an ES permits reduced distances shown in Annex I-A, Tables 3 D-F.

1.3.6.7. *Quantity-distances between earth-covered buildings with common earth cover*

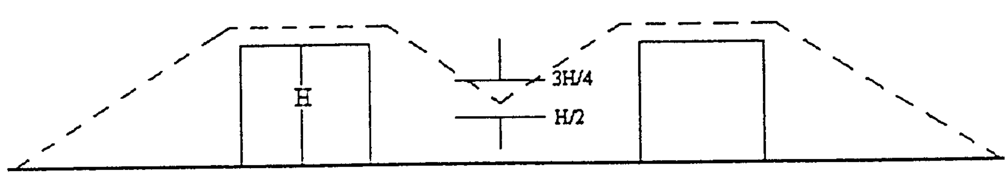
a) In the case of a detonation, the type of earth cover between earth-covered buildings affects the load on the acceptor igloo. The earth cover should be at least 0,6 m in depth. A slope of two to one, meaning one unit of vertical rise for every two units of horizontal run is recommended for the earth cover. The earth should comply with Part II, Para 2.3.3.3. An earth-covered building often provides virtually complete protection to its contents from the effects of an incident at a potential explosion site (PES) containing ammunition and explosives of Hazard Division 1.2 or 1.3. When two or more buildings share a common earth cover, the amount of ammunition and explosives permitted in them is less than it would be if the buildings had separate earth cover. This is due to the earth couple between the two PES´s, meaning the earth will transmit the explosive shock loading with greater efficiency than air. In order to accommodate various types of earth, the following Q-D is applied:

1) If the two earth covers intersect at a point 3/4 the height of the structures or higher, Column D5 distances apply.

2) If the two earth covers intersect at a point between 3/4 and 1/2 the height of the structures, Column D4 distances apply.

3) If the two earth covers intersect at, or below, a point 1/2 the height of the structures, there is no Q-D reduction and Column D3 applies.

These distances refer to earth-covered buildings as specified in Annex II B. In the case of unspecified earth-covered buildings in principle Column D6 distance applies.



b) When earth-covered buildings, which meet the requirements of subparagraph 1.3.6.7.a) and have an internal volume exceeding 500 m^3, are considered as PES, then for NEQ of Hazard Division 1.1 ammunition not exceeding 45 000 kg the following quantity-distances should be applied to side- and rear-configurations only:

1) Inhabited Building Distances

D15-distances in Table 1 may be used from the sides of the earth-covered building (PES) and D14-distances from the rear of the same building, but in no case must the quantity-distance be less than 400 m. Definitions of front/rear/side configurations are given in Annex I-A, Section I, Note A.1.5.1.

2) Public Traffic Route Distances

The Public Traffic Route Distances may be reduced to 2/3 of the Inhabited Building Distances (D14- and D15-distances respectively) as calculated in subparagraph 1), with a minimum of 270 m. These distances (D16- and D17-distances) are shown in Annex I-A, Tables 1 A-C. However, the full Inhabited Building Distances (D14- and D15-distances) with a minimum distance of 400 m should be used, when necessary, in accordance with subparagraph 1.3.1.15.b).

1.3.6.8. *Partly Barricaded Buildings or Stacks*

Partly barricaded buildings or stacks are considered effectively barricaded only when both ends of the barricade extend 1 m beyond the ends of the protected sides of the buildings or stacks.

1.3.6.9. *Natural Barricades*

It is acceptable to take advantage of natural terrain where this provides protection equivalent to that of artificial barricades. However, it is found that hills are usually insufficiently steep or close to the ammunition or explosives and woods cannot usually be relied upon to provide the required protection.

1.3.6.10. *Barricade Design Criteria*

The details of what constitutes an effective barricade are given in Part II, Chapter 3, Section III.

Section VII -Injury and Damage to be Expected at Different Levels of Protection for Hazard Division 1.1 and Grouping of Structures and Facilities

1.3.7.1. *Introduction*

a) The purpose of applying Hazard Division 1.1 quantity-distances between PES and ES is to ensure that the minimum risk is caused to personnel, structures and facilities. In principle, those functions and facilities not directly related to operating requirements or to the security of ammunition and explosives should be sited at or beyond the Inhabited Building Distance.

b) In practice, it may not always be possible to provide this level of protection and some activities and facilities will of necessity be sited at less than the Inhabited Building Distance. In other cases, the nature of the facility or structure requires that greater protection than that afforded by the Inhabited Building Distance, should be provided.

c) Damage to buildings and injury to personnel can result from either blast overpressure effects or from projections (ammunition fragments and building debris from the PES). The severity of the effects will be dependent on both the type of structure at the PES and at the ES. The levels of damage considered in this section are when the PES is an:

1) Open or lightly confined stack of ammunition and explosives.
2) Earth-covered building containing ammunition and explosives.

d) The blast overpressure predictions in this section are relevant for quantities in excess of 4 500 kg. For smaller quantities the damage and injury levels may be pessimistic.

1.3.7.2. *Purpose of the Section*

The aim of this section is to provide guidance on the kind of injuries and damage which can be expected at different levels of protection and to propose typical personnel or facilities for which these levels of protection might be considered acceptable. The standard base line for predicting blast parameters is that outlined in Part II, Chapter 5, Section III, modified as appropriate for the charge configuration, suppression by earth-cover or other technical considerations.

1.3.7.3. *Levels of Protection*

a) The blast overpressure effects to be expected at a given scaled distance can be predicted with a high degree of confidence. The technique is fairly well developed and the effects of blast may be treated deterministically, however, the techniques for determining the hazards from projections are considerably less developed and the effects require a probabilistic approach.

b) Blast Effects - Open Stacks and Light Structures

It can be assumed that the blast overpressure from a light structure is the same as that to be expected from a bare charge. This assumption is especially true as the scaled distance increases. The following levels of protection (scaled distances) are considered:

Scaled Distance (Q in kg, distance in m)	Peak Incident (Side-on) Overpressure Expected (bar)
$55.5\ Q^{1/3}$	0.015
$44.4\ Q^{1/3}$ to $33.3\ Q^{1/3}$	0.02 to 0.03
$22.2\ Q^{1/3}$	0.05
$14.8\ Q^{1/3}$	0.09
$9.6\ Q^{1/3}$	0.16
$8.0\ Q^{1/3}$	0.21
$7.2\ Q^{1/3}$	0.24
$3.6\ Q^{1/3}$	0.70
$2.4\ Q^{1/3}$	1.80

c) Blast Effects - Earth-Covered Magazines

Earth-covered magazines will generally attenuate the blast overpressure, although in the near field enhanced overpressure can be expected from the front of an earth-covered magazine. The degree of reduction in blast overpressure from the sides and rear of the magazine decreases as the scaled distance and/or as the NEQ increases. In general the greatest reduction will be obtained from the rear of the earth-covered building. The following levels of protection (scaled distance) are considered:

Direction	Scaled Distance (Q in kg) (distance in m)	Peak Incident (Side-on) Overpressure Expected (bar)
Side	$18.0\ Q^{1/3}$	0.05
Rear	$14.0\ Q^{1/3}$	0.05
Side	$12.0\ Q^{1/3}$	0.09
Rear	$9.3\ Q^{1/3}$	0.09

These overpressures do not apply when the NEQ is greater than 45 000 kg and when the volume of the building is less than 500 m^3.

d) Projection Hazards - All Types of Potential Explosion Sites

The projection hazard from a PES cannot be related to the scaled distance. However, for all practical purposes, there is likely to be a hazard from projections at all scaled distances less than 14.8 $Q^{1/3}$, this hazard will be greater when the PES is not barricaded. Unless the ES has been provided with protection against all projections, including high angle missiles, then minimum distances at which the projection hazard is considered to be acceptable for a particular situation, have been introduced as follows:

1) 180 m

There is a significant hazard from projections at 180 m. This hazard is tolerable for:

- Public traffic routes when the traffic is not dense and when the PES is an open stack or a light structure.

- The protection of unbarricaded ammunition i.e., to prevent propagation from low trajectory high velocity projections.

2) 270 m

There is a significant hazard from projections at 270 m. The hazard is tolerable for:

- Main public traffic routes or when the traffic is dense and when the PES is an open stack or light structure.

- Public traffic routes when the traffic is not dense and when the PES is a heavy-walled or earth-covered building.

- Sparsely populated areas when the PES is an open stack or a light structure; there would be a small expectation of damage or injury from projections.

3) 400 m

There is a minor hazard from projections at 400 m. This hazard is tolerable for:

- Main public traffic routes or when the traffic is dense and when the PES is a heavy-walled or earth-covered building

- Built-up areas when the PES is an open stack or a light structure.

- All "Inhabited Buildings" when the PES is a heavy-walled or earth-covered building.

1.3.7.4. *Reduction of the Hazard*

Strengthening of buildings to prevent or reduce the hazard is feasible and may not be prohibitively expensive. The hazard may be reduced by:

1) Suitably designed suppressive construction at the PES, this is only practicable when the NEQ is relatively small for example reinforced concrete cubicles used in explosive process building construction have a maximum practical limit of about 250 kg. Standard NATO igloos can suppress about 100kg as a PES.

2) By designing the structures at the ES to withstand the overpressures and the debris and fragment attack.

3) The use of light structures for ES which although they will be severely damaged by the overpressure will not produce hazardous debris. In this case protection from high velocity debris and fragments by receptor barricades is essential.

1.3.7.5. *Protection Level 55.5 $Q^{1/3}$ - Open Stacks and Light Structures*

a) Expected Blast Effects

1) The overpressure expected at this distance (55.5 $Q^{1/3}$) will cause little or no damage to unstrengthened structures.

2) Injuries and fatalities are very unlikely as a direct result of the blast effects. There may be a minor hazard from broken glass or cladding falling from a considerable height so as to strike people.

b) Personnel and Facilities Acceptable

At this distance and beyond there is no restriction on personnel, activities or facilities.

1.3.7.6. *Protection Level 44.4 $Q^{1/3}$ to 33.3 $Q^{1/3}$ - Open Stacks and Light Structures*

a) Expected Blast Effects

1) Unstrengthened structures are likely to suffer only superficial damage.

2) When large panes of glass are exposed so as to face the PES, 50 % or more breakages may occur.

3) Injuries and fatalities are very unlikely as a direct result of the blast effects. Injuries that do occur will be caused principally by flying glass.

b) Personnel and Facilities Acceptable

Because even superficial damage may in some instances be unacceptable, National Authorities may require siting at these distances for facilities of especially vulnerable construction or public importance. Examples are:

1) Large facilities of special construction of importance including:

- Large factories of vulnerable construction.
- Multi-storey office or apartment buildings of vulnerable construction.
- Public buildings and edifices of major value.
- Large educational facilities of vulnerable construction.
- Large hospitals.
- Major traffic terminals (e.g. large railway stations, airports etc.)
- Major public utilities (e.g. gas, water, electricity works).

2) Facilities of vulnerable construction used for mass meetings:

- Assembly halls and fairs.
- Exhibition areas.
- Sports stadiums.

3) Built-up areas which are both large and densely developed.

1.3.7.7. *Protection Level 22.2 $Q^{1/3}$ - Open Stacks and Light Structures*

The equivalent protection levels in respect of earth-covered buildings greater in volume than 500 m^3 and when containing a NEQ of Hazard Division 1.1 less than 45 000 kg are:

- From the side: 18.0 $Q^{1/3}$
- From the rear: 14.0 $Q^{1/3}$

a) Expected Blast Effects

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

2) Injuries and fatalities are very unlikely as a direct result of the blast effects. Injuries that do occur will be caused principally by glass breakage and flying/falling debris.

b) Personnel and Facilities Acceptable

This distance is termed "Inhabited Building Distance" and is the minimum distance, in conjunction with the overriding minimum distances given in paragraph 1.3.7.3., at which inhabited buildings not directly connected with the functions of the Explosives Area should be sited. This level of protection is proposed as acceptable for the following kinds of facility:

1) Unbarricaded stacks of ammunition and explosives.

2) Structures and facilities in the administration area of a depot or factory with a considerable number of occupants (more than 20), examples are:

- Main office buildings.
- Non-explosives workshops.
- Mess halls and kitchens.
- Main canteens.
- Main shower and changing facilities.

3) Structures and facilities in the administrative area of a depot or a factory which are important for the functioning of the installation, examples are:

- Manned fire stations.
- Central heating plants.
- Main vehicle pools.
- Gasoline storage and dispensing facilities.
- Unprotected water supply and power installations.

4) Inhabited buildings (as defined by the National Authority), whether single buildings, communities or areas of scattered habitations.

5) Structures and facilities in which people assemble, except as indicated in subparagraph 1.3.7.6.b) above.

6) Facilities serving the safety and needs of the general public, examples are:

- Gas, water and electricity supply installations.
- Radar and communications stations.

7) Important lines of transport, examples are:

- Main railway lines.
- Motorways and major roads.
- Major navigable waterways.

1.3.7.8. *Protection Level 14.8 $Q^{1/3}$ - Open Stacks and Light Structures*

The equivalent protection levels in respect of earth-covered buildings greater in volume than 500 m^3 and when containing a NEQ of Hazard Division 1.1 less than 45 000 kg are:

- From the side: 12.0 $Q^{1/3}$
- From the rear: 9.3 $Q^{1/3}$

a) Expected Blast Effects

1) Unstrengthened buildings will suffer average damage costing in the range of 10 % of the total replacement costs to repair.

2) Personnel in the open are not likely to be seriously injured by blast.

3) There is a fairly high probability that injuries will be caused by glass breakage and flying/falling debris.

b) Personnel and Facilities Acceptable

This distance is termed the "Public Traffic Route Distance" and is the minimum distance, in conjunction with the overriding minimum distances given in paragraph 1.3.7.3., at which routes used by the general public, for purposes unconnected with the explosives facility, should be sited (except when the PES is a heavy-walled building and when the route is a main route or when the traffic is dense). This level of protection is proposed as acceptable for the following kinds of facility:

1) Structures and facilities within an administration area connected with the explosives installation with a limited number of occupants (less than 20).

2) Facilities in which people assemble only temporarily and which can be quickly cleared. Examples are:

- Public paths.
- Recreational areas where no structures are involved.
- Parking places.
- Small arms ranges.

3) Railways, public roads and navigable waterways of minor to medium importance. (For public roads the risk of secondary injury can be reduced by ensuring that the road sides are free from obstacles which are likely to result in injuries to the occupants of vehicles leaving the road as a result of the driver's reaction to the explosion).

1.3.7.9. *Protection Level 9.6 $Q^{1/3}$ - Open Stacks and Light Structures*

a) Expected Blast Effects

1) Buildings which are unstrengthened can be expected to suffer damage to main structural members. Repairs may cost more than 20 % of the replacement cost of the building. Strengthening of buildings to prevent damage and secondary hazards is feasible and not prohibitively expensive.

2) Cars may suffer some damage to metal portions of the body and roof by blast. Windows facing the blast may be broken, however, the glass should not cause serious injuries to the occupants.

3) Aircraft will suffer some damage to appendages and sheet metal skin. They should be operational with only minor repair (see also Part IV, Chapter 5).

4) Cargo type ships will suffer minor damage from blast to deck houses and exposed electronic gear (see also Part IV, Chapter 6).

5) Personnel may suffer temporary loss of hearing, permanent ear damage is not to be expected. Other injuries from the direct effects of blast overpressure are unlikely, although there are likely to be injuries from secondary effects, i.e. translation of objects.

b) Personnel and Facilities Acceptable

This should normally be the minimum distance at which unprotected duty personnel (troops, military and civilian maintenance and security personnel and crews of ships) should be permitted when their duties are not closely and specifically related to the PES. Examples are:

1) Open air recreation facilities used only by military personnel and where dependants and the general public are not involved.

2) Training areas for unprotected military personnel.

3) All military aircraft when the PES is not for the immediate service of the aircraft.

1.3.7.10. *Protection Level 8.0 $Q^{1/3}$ - Open stacks and Light Structures*

a) Expected Blast Effects

1) Buildings which are unstrengthened can be expected to suffer serious damage which is likely to cost above 30 % of the total replacement cost to repair.

2) Serious injuries to personnel, which may result in death, are likely to occur due to building collapse or loose translated objects.

3) There is some possibility of delayed communication of the explosion as a result of fires or equipment failure at the ES, direct propagation of the explosion is not likely.

4) Cargo ships would suffer damage to decks and superstructure. In particular doors and bulkheads on the weather-deck are likely to be buckled.

5) Aircraft are expected to sustain considerable structural damage.

b) Personnel and Facilities Acceptable

This distance is termed "Explosives Workshop Distance", the level of protection is proposed as acceptable for the following kinds of facility:

1) Explosives workshops in which the personnel present are kept to the minimum essential for the task.

2) Packing and shipping (transit) buildings in the Explosives Area.

3) Minor transmission and communication lines.

1.3.7.11. *Protection Level 7.2 $Q^{1/3}$*

This distance is used by US Authorities to define explosives workshop separation in the US and is comparable to Protection Level 8.0 $Q^{1/3}$. However, a great deal of information is available in the US for Protection Level 7.2 $Q^{1/3}$ and is included in this section for completeness.

a) Expected Blast Effects

1) Damage to unstrengthened buildings will be of a serious nature. Repair is likely to cost 50 % or more of the total replacement cost.

2) Personnel injuries of a serious nature or possible death are likely from debris of the building at the ES and from translation of loose objects.

3) There is a 1 % chance of eardrum damage to personnel.

4) Some possibility of delayed communication of explosion as a result of fires or equipment failure at the ES. There is a high degree of protection against direct propagation of an explosion.

5) Cargo ships would suffer some damage to decks and superstructure by having doors and bulkheads buckled by overpressure.

6) Aircraft can be expected to suffer considerable structural damage from blast overpressure.

b) Personnel and Facilities Acceptable

1) Workers engaged in major construction in the vicinity of ammunition production areas, waterfront areas where ammunition is being handled or areas used for the loading of aircraft with explosives.

2) Labour intensive operations closely related to the PES, including inert supply functions serving two or more identical or similar PES.

3) Rest and buildings for light refreshment for use of workers in the immediate vicinity. Such facilities will normally only be used when work is stopped in the nearby explosives buildings and should be limited to a maximum of 6 persons.

4) Area offices with a permanent occupancy of a small number of person, directly supporting the work of the Explosives Area or process buildings.

5) Guard buildings in which those security personnel directly responsible for the security of the Explosives Area are housed when not on patrol.

6) Unmanned buildings containing immediate reaction fire-fighting appliances.

7) Operations and training functions that are exclusively manned or attended by personnel of the unit operating the PES. This includes day rooms, squadron operations offices and similar functions for units such as individual missile firing batteries, aircraft squadrons, or ammunition supply companies. Manoeuvre area, proving grounds tracks and similar facilities for armoured vehicles together with the armoured vehicles themselves may provide adequate protection to the crew from fragment and debris.

8) Areas used for the maintenance of military vehicles and equipment (trucks, tanks) when the PES is basic load or ready storage limited to 4 000 kg or less at each end when the maintenance work is performed exclusively by and for military personnel of the unit for which the basic load of ammunition is stored.

9) Auxiliary power and utilities functions, inert storage and issue sites and mechanical support at naval dock areas when not continuously manned, when serving only the waterfront area, and when the PES is a ship or an ammunition handling location at the waterfront. When loss of the facility would cause an immediate loss of a vital function, Inhabited Building Distance must be used.

10) Minimum distance between separate groups of explosives loaded combat-configured aircraft or between aircraft and a PES such as a preload site which serves to arm the aircraft. The use of intervening barricades is required to further reduce communication and fragment damage and eliminate the necessity for totalling the NEQ. The loading of ammunition and explosives aboard aircraft can be accomplished within each group of aircraft without additional protection.

11) Parking lots for privately owned automobiles belonging to the personnel employed or stationed at the PES.

12) Separation of naval vessels from PES consisting of other naval vessels to which quantity-distance standards apply. When the PES is an ammunition ship or an ammunition activity, the separation will be determined by reference to special regulations established for piers and wharves of ammunition shiploading activities.

13) Container "stuffing" and "unstuffing" operations which are routine support of the PES. When the PES is a magazine in a storage area, containerizing operations may be considered as part of the magazine and separate quantity-distance rules will not be applied.

1.3.7.12. *Protection Level 3.6 $Q^{1/3}$ - Open Stacks and Light Structures*

a) Expected Blast Effects

1) Unstrengthened buildings will suffer severe structural damage approaching total demolition.

2) Severe injuries or death to occupants of the ES are to be expected from direct blast effects, building collapse or translation.

3) Aircraft will be damaged by blast to the extent that they will be beyond economical repair. If aircraft are loaded with explosives, delayed explosions are likely to result from subsequent fires.

4) Explosions may occur in ES containing ammunition as a result of fire spread by lobbed debris or blast damage. A high degree of protection against direct propagation of an explosion is to be expected providing direct attack by high velocity fragments is prevented.

b) Personnel and Facilities Acceptable

1) Buildings housing successive steps of a single process in an explosives factory.

2) Separation of buildings for security guards from explosives locations, provided the risk of the personnel becoming militarily ineffective in the event of an explosive accident can be accepted.

3) Separations among buildings and facilities of a tactical missile site where greater distances cannot be provided due to technical reasons.

4) Temporary holding areas for trucks or railcars containing explosives to service production or maintenance facilities provided barricades are interposed between the explosives locations.

5) Unmanned auxiliary power facilities, transformer stations, water treatment and pollution abatement facilities and other utility installations which serve the PES, and loss of which will not create an immediate secondary hazard or prejudice vital operations.

1.3.7.13. *Protection Level 2.4 $Q^{1/3}$ - Open Stacks and Light Structures*

a) Expected Blast Effects

Unstrengthened buildings will almost certainly suffer complete demolition.

b) Personnel and Facilities Acceptable

1) Personnel stationed in magazine areas for one or two men.

2) Crews performing storage and shipping functions in the magazines may operate for short periods of time at adjacent magazines. In large magazine areas controls should be exercised by management to reduce the length of time that unrelated operations are exposed to one another at distances less than 9.6 $Q^{1/3}$.

Section VIII - Q-D Rules in the Particular case of Aboveground Storage of Ammunition Classified 1.6N

1.3.8.1. *Preliminary remark*

This section of the Manual is reserved for ammunition classified 1.6N It was written at a time when very few statistical data were known on the behaviour of these articles in transport and in storage. Therefore it was difficult to derive from experience what should be the behaviour of a set of 1.6N ammunition of the same family in case of an accidental stimulus. Among several options, the AC/258 Group took the decision to choose a middle way solution which leads to the recommendations listed below. In the future when the behaviour in storage of 1.6N ammunition will be better known it may be necessary to revise this decision.

1.3.8.2. *Most credible accidental event*

During storage of 1.6N ammunition belonging to the same family the most credible accidental event resulting from an accidental stimulus is the detonation of a single munition without instant transmission of the detonation to other munitions of the same family and/or moderate combustion of the whole quantities of ammunition.

1.3.8.3. *Q-D rules*

The Q-D distances between an ES and a PES which are given by the Q-D rules, are derived from the above-mentioned "most credible accidental event". The assessment of the hazard generated by the detonation of a single munition takes into account only the blast effect and neglects the projection effect of a single munition. The Q-D distances are obtained by taking, for a given configuration "ES, PES" the largest distance determined by applying

a) the Annex I-A, Tables 1 A-C (1.1 Q-D rules) to a single munition
b) the Annex I-A, Tables 3 D-F (SsD 1.3.2 Q-D rules) to the whole quantities of ammunition with aggregation of the NEQ.

CHAPTER 4 – RESERVED

All underground storage requirements previously found here (in Change 3) have been moved to PART III.

CHAPTER 5 - SEPARATION OF POL-FACILITIES WITHIN MILITARY INSTALLATIONS

1.5.0.1. *Separation of Small Quantities of POL*

Small quantities (not exceeding 100 litres) of petroleum, oils, and lubricants (POL) held as immediate reserves for operational purposes within a military installation require no specific quantity-distances from buildings or stacks containing ammunition or explosives.

1.5.0.2. *Separation of Unprotected Aboveground POL Tanks and Drums*

If required, unprotected aboveground POL steel tanks and drums are separated from buildings or stacks containing ammunition or explosives by the Inhabited Building Distance (Annex I-A, Section II). Where the POL-facilities are vital they should be sited at IBD and a minimum distance of 400 m must be observed from buildings or stacks containing ammunition or explosives of Hazard Divisions 1.1.

1.5.0.3. *Separation of Protected Aboveground POL Tanks and Drums*

a) If required, quantity-distances less than those for unprotected tanks and drums (see paragraph 1.5.0.2.) may be used where a surface storage tank or a drum storage area is provided with structural protection against blast and fragment hazards. For purposes of applying this paragraph, "protected" will be considered to mean that the POL storage tank or drum as an ES is provided with structural protection sufficient to ensure that the POL storage tank or drum and contents will experience no more damage than if sited at inhabited building distance.

b) The criteria specified for the separation of POL from explosives areas are intended primarily for use in determining separations at large permanent ammunition depots. It may be desirable to weigh the cost of distance/protective construction against strategic value of the POL supplies and the ease of replacement in the event of an incident. Reduced distances may be approved if the POL loss can be accepted, and if the POL-facilities are sited and provided spill containment so as not to endanger the explosives. Such reduced distances must be acceptable to both host and user nations.

1.5.0.4. *Separation of Buried POL Tanks or Pipelines*

Buried POL tanks or pipelines should be separated from buildings or stacks containing ammunition or explosives of Hazard Divisions 1.2, 1.3 and 1.4 by a minimum distance of 25 m. The distances from ammunition in Hazard Division 1.1 are given in Annex I-A, Tables 1A-C (0.5 x D7-distances) with a minimum of 25 m.

CHAPTER 6 - HAZARD FROM ELECTROMAGNETIC RADIATION TO AMMUNITION CONTAINING ELECTRO-EXPLOSIVE DEVICES

1.6.0.1. *Introduction*

a) Over recent years there has been a significant increase in the use of communications equipment throughout the military and civil environment including all forms of transportation in support of management functions, control of resources and area security. These equipments produce electro-magnetic radiation of varying intensity according to their output and antenna gain and are potentially hazardous when used in close proximity to explosive devices which have an installed electrical means of initiation known as electro-explosive devices (EED).

b) The advice contained in this chapter represents the minimum precautions to be observed in order to prevent hazard to EED resulting from exposure to the radio frequency (RF) environment at frequencies up to 40 GHz. It is intended that this chapter should provide guidance of officials concerned with the storage, movement and processing of EED or stores containing EED and the control of RF equipment which may be used within, or enter, those establishments/vehicles used for these purposes.

c) Consideration is not given to the precautions to be taken with regard to lightning and electrostatic discharge. These areas are also considered by AC/327 Working-Group 6 and published in associated STANAGs.

d) More detailed Information regarding NATO’s electromagnetic radiation management and environment assessment programs can be found in Allied Environmental Conditions Publications (AECP)-2 and AECP-250.

1.6.0.2. *General*

a) Any firing circuit associated with an EED, or other electrical conductors such as wires, tools and fingers in contact with the EED, when placed in a RF field will act as an antenna with the inherent capability of picking up some electrical energy from the field.

b) When the leading wires of an EED are separated they could form a dipole antenna and provide an optimum match between the dipole and the EED leading to maximum transfer of power to the EED from the radiated source. Unseparated (short circuited) leading wires could form circular antennae which may also constitute good receiving systems.

c) Unless appropriate precautions are taken, the power/energy levels induced into the firing circuits from the standing RF fields may be sufficient to inadvertently initiate the EED.

d) Design criteria for the modern EED when installed in weapon systems require electromagnetic (EM) screening and specified orientation of firing leads to reduce the RADHAZ. For this reason, EED separated from their parent system are regarded as less safe than when installed into the system with all leads connected as intended by the designer.

e) The attachment of external cables and test sets to systems containing EED will usually increase their susceptibility to EM energy pick-up.

f) 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 electromagnetic (EM) energy.

1.6.0.3.

a) An EED is a one shot explosive or pyrotechnic devie used as the initiating element ina an explosive or mechanical train and which is designe to ctivate by application of electrical energy. In present use foru techniques of electrical intiation are employed:

1) Bridge-wire (BW) and Film bridge (FB) EED.
2) Conducting Composition (CC) EED.
3) Exploding Bridge-wrie (EBW) EED.
4) Slapper Detonator.

1.6.0.4. *Storage and Transport*

a) EED are encountered in a variety of configurations between their manufacturing stage and their ultimate disposal. These configurations range from trade packaging in bulk, military packaging and sub-packages, and installed in munitions, to various stages of separate and exposed states which occur in processing and training.

b) It is important for users to understand how these configurations can influence the basic precautions to be adopted in storage and transportation. Precautions in transport should include measures to be covered in emergencies from straightforward vehicle breakdown to accidents involving fire and/or casualty evacuation.

c) Process and Storage Building

1) Building materials are generally ineffective in affording EM protection to EED. Structures provide no protection at all in transmission loss from frequencies below 1 MHz but may provide some protection in the form of reflection loss if the polarization and angle of incidence of the EM energy happens to be favourable, although this is rarely the case. Also, bars in reinforced concrete do not provide any significant degree of protection.

2) For all practical purposes, it should be assumed that the field strength which exists inside a building is as high as it would be if the building did not exist. However, if the protection level across the frequency spectrum for a specific building has been determined (screened room) then this level may be used to determine a safe distance from sources of electromagnetic radiation although it should be borne in mind that, if doors or windows are opened, the screening integrity may be adversely affected.

3) EED and systems containing EED should be stored/processed in authorized depot and unit process and storage areas. These areas should be sited taking into account the following:

- The susceptibility of the EED, store or weapon system during processing or storage as appropriate.
- The radiated power of transmitters in the area related to the susceptibility radius of the most sensitive EED present.

1.6.0.5. *Assessment of Hazard*

a) It will be evident from the previous paragraphs that degrees of risk of unintended operation arise in any situation in which EED are introduced into close proximity with RF fields. The degree of risk ranges from negligible to acute in terms of both the susceptibility of the EED and the power output of the transmitters creating the RF field.

b) There are no simple rules or procedures for assessing risk. An Electromagnetic Radiation Hazard Assessment should be conducted by a trained and competent person to ensure the latest information and guidance found in AECTP 500 (category 508) are applied.

1.6.0.6. *System Susceptibility*

a) Each situation requires individual examination which must consider the:

1) Susceptibility of EED whether:

- Installed.
- Exposed.
- Packaged.
- Specifically protected.

2) Characteristics of transmitters.

3) Distance between the EED and radiating systems such as radios etc.

b) For systems with an unknown susceptibility pending a detailed inspection, ie structural or packaging, the restrictions below on RF transmissions in the immediate vicinity should be imposed:

- No radio to be allowed within 2 metres.

- No radio to be allowed within 10 metres unless authorised as being intrinsically safe.

- No radio with an ERP greater than 5 watts to be allowed within 50 m.

CHAPTER 7 - FIRE FIGHTING PRINCIPLES AND PROCEDURES

Section I - General

1.7.1.1. *Introduction*

The aim of these principles is to establish measures and procedures to ensure a minimum practicable risk in fighting fires involving ammunition and explosives at explosives areas.

These identification measures are based on the classification of fires into four fire divisions according to the hazard they present. This Chapter also establishes minimum guidelines for the development of emergency plans, including safety, security, and environmental protection, which have to be coordinated with local authorities.

Firefighting procedures, training of firefighting personnel, the use and maintenance of firefighting equipment and vehicles, the provision of water supply and alarm systems, the first aid measures, and other measures required in firefighting are outside the scope of this Chapter and shall be the responsibility of the national authority.

The ammunition hazard symbols and supplemental symbols including chemical agent symbols (see Figure F.2 below) are for firefighting situations only and are not necessarily applicable to normal operating conditions.

Section II - Fire Divisions

1.7.2.1. *Ammunition and Explosives Hazard Divisions involved:*

1.1 Mass explosion hazard

1.2 Projection hazard but not a mass explosion hazard

1.3 Fire hazard and either a minor blast hazard or minor projection hazard or both, but a mass explosion hazard

1.4 No significant hazard

1.5 Very insensitive subsatances which have a mass explosion hazard

1.6 Extremely insensitive articles which do not have a mass explosion hazard

1.7.2.2. *Fire Divisions Involved:*

Fire division 1 indicates the greatest hazard. The hazard decreases with ascending fire division numbers as follows:

Hazard Division	Fire Division	Hazard involved
1.1; 1.5	1	Mass explosion
1.2; 1.6	2	Explosion with projection
1.3	3	Mass fire, or fire with minor blast or projections
1.4	4	No significant hazard

The fire divisions are synonymous with the Storage Hazard Divisions 1.1 through 1.4 ammunition and explosives. But in this case, as described in Part I, Chapter 3, the HD 1.5 belongs to Fire Division 1 (mass explosion) and HD 1.6 belongs to Fire Division 2 (non mass explosion). Fire Division 1 indicates the greatest hazard. The hazard decreases with ascending fire division numbers as follows:

1.7.2.3. *Fire Division Symbols:*

Each of the four fire divisions is indicated by distinctive symbols (see Figure F.1) in order to be recognized by fire-fighting personnel approaching a scene of fire. To assist with identifying at long range, the symbols differ in shape as follows:

Shape F	ire Division
Octagon	1
Cross	2
Inverted triangle	3
Diamond	4

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

- 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.

1.7.2.3. *Supplementary Symbols:*

a) Due to the peculiarity of hazardous substances in certain types of ammunition (Compatibility Groups G,H,J and L), the storage of this ammunition requires supplementary symbols. Those supplementary “Chemical Hazards Symbols“ are used to indicate the precautions to be taken against the additional hazards proceeding from the chemical agents of that ammunition (see Figure F.2). The Chemical Hazard Symbols indicate the following precautions:

b) wear full protective suit,

c) wear respirator facepiece,

d) apply no water.

e) All three Chemical Hazard Symbols are circular in shape. They correspond to the ISO 3864 "Safety colours and safety signs". The symbols, their meanings and their sizes are shown in Figure F.2.

f) The Apply No Water(symbol No. 3 of Figure F.2) may be placed together with one of the other if required.

g) The 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.

h) The chemical agents mostly used in ammunition, the compatibility groups of that ammunition and the required in storage are specified in Table T.1

1.7.2.4. *Protective Clothing:*

The following sets of full protective clothing are recommended:

- Protective clothing against casualty agents, consisting of protective respirator facepiece, impermeable suit, hood and boots, protective footwear and splash suit.
- Protective clothing against harassing agents, consisting of protective respirator facepiece.
- Protective clothing against white phosphorus (WP) smoke, consisting of fire-resistant gloves, chemical safety goggles and respirator facepiece.

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.

Section III - Firefighting Principles

1.7.3.1. *Fire Prevention (preventive fire protection)*

Preventive fire protection comprises all measures suited to prevent the development and spreading of a fire. These are to develop a plan based on an estimate of the hazards and risk.. This analysis should comprise:

- employees,
- infrastructure and stockpile,
- exposed sites,
- public and the local environment.

The following measures are to addressed in all cases:

1.7.3.2 *Constructional Fire Prevention Measures*

The following basic criteria apply:

- Buildings designed for the processing or storage of ammunition shall be built of non-combustible or at least fire-resistant., (according to national standards) construction material. Supporting and surrounding structural elements shall resist to fire for at least 30 minutes in accordance with national standards.
- Chimneys in an explosives area must be provided with a trap to prevent flying sparks.
- Heating systems must not have uncovered glowing parts. The temperatures of exposed heating surfaces and lines must not exceed 120° C.
- An efficient fire alarm system shall be installed and maintained.
- Ammunition sites are to be equipped with an adequate fire fighting water supply according to national standards. Fire fighting water supply points shall not be sited closer than 25m to any process or storage building. They are to be positioned beside -not in - roads or traffic-ways and be provided with an area of clearance, such that vehicles will not cause an obstruction. Where alternative water supply points are not available, protection should be provided for the fire fighting vehicle and it's crew (e. g. barriers or traverses).
- Type, quantity and locations of fire fighting equipment are determined according to facility-related assessments and shall be adapted to the local conditions during annual fire fighting demonstrations.

- Fire prevention also includes lightning protection.

1.7.3.3 *Organizational Fire Prevention Measures:*

These are to be organized according to national regulations within the scope of general fire protection taking into account the following criteria:

- order and cleanness as well as strict observance of safety precautions count among the most effective fire prevention measures, equal to prohibition of smoking, fire and naked light,
- handling of flammable substances,
- prevention of additional fire loads such as stacking material, packaging material and the like,
- fire hazards of machines, equipment and tools during ammunition operations or in the case of overload of electrical lines,
- inflammable undergrowth, laying out fire lanes,
- clear zones, trimming of branches and the like,
- regular instruction of the personnel about actions to be taken in case of fire and in the use of first aid fire fighting equipment,
- preparation of an emergency planning[2] and an emergency map[3]:

[2] emergency planning: see section V

[3] emergency map: a map containing the essential details of a facility or an installation from the point of view of fire protection.

Section IV - Fire- Fighting Procedures

1.7.4.1. *General*

a) According to the stage of the fire, ammunition fires are divided into:

b) The following regulations deal with the special hazards connected with ammunition fires.

- developing ammunition fires and
- established ammunition fires.

1) Developing ammunition fires are fires in the vicinity of ammunition, but which do not immediately hazard it. The fire brigade should be notified as soon as possible if a fire is developing in the vicinity of ammunition. Evacuate all non-essential personnel and fight the fire for as long as it is safe to do so, in accordance with the pre-arranged plan. On arrival of the fire brigade, the competent person will advise them of the state of the fire. Provided that the explosives are still not hazarded, they will take immediate action to fight it. A close watch must be kept upon the fire, so that evacuation of the remaining personnel can be ordered immediately if it appears that the explosives are about to become hazarded.

2) Established ammunition fires are those which are hazarding or about to hazard the explosives.

The term 'established ammunition fire' will be applied to all fires which cannot be positively identified as 'developing ammunition fires'.

Firefighters of ammunition and explosives fires shall have a thorough knowledge of the specific reactions of ammunition and explosives exposed to the heat or to the fire itself. The firefighting forces and other essential personnel shall be briefed before approaching the scene of the fire. They shall be informed of the known hazards and conditions existing at the scene of the fire before proceeding to the location of the fire.

Fire involving ammunition and explosives shall be fought according to the hazard classification, fire division, the stage of the fire, and the procedures specified by the Defense Component concerned. Special firefighting instructions addressing ammunition hazards shall be developed according to the needs of the Defense Components.

All fires starting in the vicinity of ammunition or explosives shall be reported and shall be fought immediately with all available means and without awaiting specific instructions. However, if the fire involves explosive material or is supplying heat to it, or if the fire is so large that it cannot be extinguished with the equipment at hand, the personnel involved shall evacuate and seek safety. Before fighting ammunition fires in an unknown situation, the fire brigade has to analyze the situation.

The presence of buildings, earth barricades etc. to protect fire-fighting personnel during operations is a crucial factor for effective fighting of fires involving ammunition or explosives. The fire-fighting personnel, their vehicles and equipment must not be endangered unnecessarily.

1.7.4.2. *Detailed Fire Fighting Procedures*

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

(a) Fire Division 1

1. Fully developed fire: these must not be fought. The fire alarm will be sounded and all personnel must evacuate immediately to a safe distance and take cover, in accordance with the pre-arranged plan. The fire brigade will be called from the vicinity of this point, giving its location and emphasizing that the fire is fully developed. If the brigade has already been summoned (e. g. from the incident site during the developing stage), a further call must be made to warn the fire brigade the fire is now fully developed. The brigade will rendezvous at the evacuation point to be briefed by the competent person.

2. Once the mass explosion has taken place, fire fighters should assess the situation and extinguish any secondary fires, concentrating upon those which hazard other explosives stores, as advised by the Control Officer, who should be available by this time.

(b) Fire Division 2

1. Established ammunition fire: In the case of earth covered or heavy walled ammunition storage magazines the effects of the exploding ammunition will be contained within the magazine except possibly for those in the direction of the headwall or doors. Therefore external fires can be fought in close proximity of the magazines except in the direction of the head-wall or doors. An established fire must not be fought inside such a magazine nor external fires in front of it and no firefighting at all in case of light structure magazines. In all cases the fire alarm will be sounded, all personnel must evacuate immediately to a safe distance and take cover, in accordance with the pre-arranged that may take account of the above. The fire brigade is to be withdrawn behind the front wall line of the magazine or completely from the vicinity of this point, giving its location and emphasizing that the fire is fully developed. If the brigade has already been summoned (e. g. from the incident site during the developing stage), a further call must be made to warn the fire brigade that the fire is now fully developed. The brigade will rendezvous at the evacuation point to be briefed by the competent person.

2. Once the explosives have become involved, lobbed and self propelled items can be expected, some of which may function on impact. Secondary fires may be started. Where these hazard other explosives, attempts should be made to extinguish them without exposing crews to undue risk.

(c) Fire Division 3

1. Fully developed fire: these must not be fought. The fire alarm will be sounded and all personnel will evacuate immediately to a safe distance and take cover in accordance with the pre-arranged plan. The fire brigade is to be called from the vicinity of this point, giving its' location and emphasizing that the fire is fully developed. If the brigade has already been summoned (e. g. from the incident site during the developing stage), a further call must be made to warn the fire brigade that the fire is now fully developed. The brigade will rendezvous at the evacuation point to be briefed by the competent person.

2. Once the explosives have become involved a particularly intense fire can be expected, with high levels of radiant heat, probably with flame jets from

openings in the building. Packages may burst, some violently, but there will be no explosions. Secondary fires may be started by radiation or projected fire brands. Once the main fire is seen to be reducing to a level that enables these to be fought, action should be taken to extinguish them, keeping crews away from openings in the building. Visors and gloves are advised.

(d) Fire Division 4

1 Fires involving items of Fire Division 4 may be fought as dictated by the situation.

2 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 necessity dictates, certainly not any closer than 25 m. When possible the fire should be fought from a protected location.

(e) Ammunition requiring Supplementary Symbols

Ammunition containing explosives and additional hazardous agents (see Figure F.2) 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 l. The issue of the corresponding special fire-fighting regulations is left to the discretion of the national authorities.

(f) Ammunition Containing Depleted Uranium:

1. Combustion of DU

i) The combustion properties of DU metal must be taken into account when dealing with a fire involving DU ammunition.

(ii) The colour of smoke produced by burning DU may be yellow but the absence of colour is not a reliable indication that DU metal is not involved; therefore 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. Precautions

Once uranium metal has ignited and a vigorous self-sustaining oxidation reaction is started, the application of small quantities of conventional extinguishing agents 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. For a small fire involving uranium and no explosives, the most effective extinguishing agent is one of the inert powdered smothering agents (e. g. Pyromet) but when explosives are present the closeness of approach necessary to deliver such an extinguishing agent to the seat of the fire would be hazardous to the firefighters. In particular, propellants, the most likely explosives to be closely associated with the DU, may produce intense radiant heat, firebrands and some ejected fragments. The firebrands may be only small glowing of packaging materials but it is possible that they could be fiery fragments of burning propellant

3. Fire Fighting Methods

i) In all cases, treat as a radiological risk - i. e. wear respirator facepiece, ensure all parts of the body are covered and fight fire from up-wind direction. Put down smoke with spray jet. Prevent water from flowing-off, if possible (dikes).

(ii) DU without an explosive component. Use copious water at optimum jet/spray range. Do not use halons. No projections are likely, other than the minor spallations associated with metal fires hit by water.

(iii) DU with an explosive component. Fight in accordance with the fire division concerned.

Section V - Emergency Planning

1.7.5.1. *Standard Operating Procedures*

Installations or responsible activities shall develop standard operating procedures (SOPs) or plans designed to provide safety, security and environmental protection. Plans shall be coordinated with the applicable national, regional and local emergency response authorities (e.g. law enforcement, fire departments and hospitals etc.) and any established Local Emergency Planning Committees (LEPC).

At a minimum, those SOPs or plans shall include the following:

- Specific sections and guidance that address emergency preparedness, contingency planning and security. For security, those SOPs or plans shall limit access to trained and authorized personnel.
- Procedures that minimize the possibility of an unpermitted or uncontrolled detonation, release, discharge or migration of military munitions or explosives out of any storage unit when such release, discharge or migration may endanger human health or the environment.
- Provisions for prompt notification to emergency response and environmental agencies and the potentially affected public for an actual or potential detonation or uncontrolled release, discharge or migration (that may endanger human health or the environment).

To produce the necessary SOP's is in the responsibility of national authorities.

The commanding leaders of the installations are responsible for the training of their personnel and the coordination with the LEPC. They also have to ensure that all SOP's and Emergency Plans belonging to the special installation are reachable to external security and emergency authorities.

Competent persons belonging to the depot or to an external fire brigade are to be regularly trained to be available to advise the fire chief and external fire fighters.

Emergency withdrawal distances for nonessential personnel are intended for application in emergency situations only and are not to be used for facility siting.

Emergency withdrawal distances depend on fire involvement and on whether or not the hazard classification, fire division and quantity of explosives are known. The withdrawal distance for essential personnel at accidents shall be determined by emergency authorities on site. Emergency authorities shall determine who are essential personnel.

If a fire involves explosives or involvement is imminent, then the initial withdrawal distance applied shall be at least the inhabited building distance while the appropriate emergency withdrawal distance for nonessential personnel is being determined. When emergency authorities determine that the fire is or may become uncontrollable and may result in deflagration and/or detonation of nearby ammunition or explosive material, all nonessential personnel shall be withdrawn to the appropriate emergency withdrawal distance listed in Table.T.2

Table T.1 Compatibility Gr oup an d C hemical Hazard Symbols Required for Storage of Chemical Ammunition and Substances.

Chemical Ammunition and Substances	Compatibility Group[2]	Full Protective Clothing			Breathing Apparatus	Apply No Water
		Set 1	Set 2	Set 3		
1	2	3	4	5	6	7
Toxic Agents[1]	K	X				
Tear Gas, O-Chlorobenzol	G		X			
Smoke, Titanium Tetrachloride (FM)	G		X			
Smoke, Sulpher trioxide-chlorosulphonic acid solution (FS)	G		X			
Smoke, Aluminum-zinc oxide-hexachloroethane (HC)	G				X	X
White Phosphorous (WP)	H			X		
White Phosphorous plasticized (PWP)	H			X		
Thermite or Thermate (TH)	G				X	X
Pyrotechnic Material (PT)	G				X	X
Calcium Phosphide	L				X	X
Signaling Smokes	G				X	
Isobutyl methacrylate with oil (IM)	J				X	
Napalm (NP)	J			X	X	X
Triethylaluminim (TEA)(TPA)	L			X		X

Notes:

1 Toxic Agents without explosives components that normally would be assigned to Hazard Division 6.1 may be stored as compatibility group K.

2 See Chapter 2.

Table T.2 Emergency Withdrawal Distances for Nonessential Personnel.

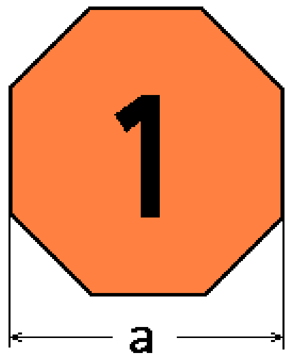
HD	Unknown Quantity	Known Quantity
Unknown, located in facility, truck and or tractor trailer	1250m	1250m
Unknown, located in railcar	1500m	1500m
1.1[1] and 1.5	Same as unknown facility, truck trailer or railcar as appropriate	For transportation, ≤ 7500kg → 870m; 7500<NEM≤16000 kg →1120m 1.5 → 1100m For facilities, ≤7000kg → 850m 7000 <NEM≤ 25000kg →1300m >25000kg → 1300m – 44,4 $Q^{1/3}$
1.2[1] and 1.6	560m	560m
1.3[2]	405m	6,4 $Q^{1/3}$ with a 120m minimum.
1.4	100m	100m

Notes:

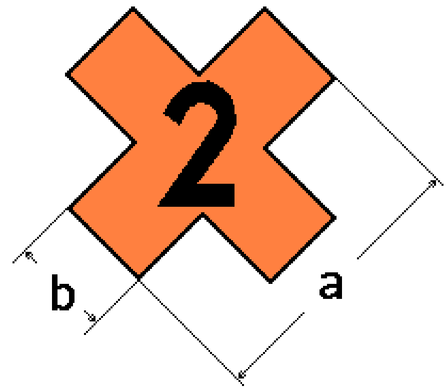
1 For HD 1.1 and HD 1.2 AE, if known, the maximum range fragments and debris will be thrown (including the interaction effects of stacks of items, but excluding lugs, strongbacks, and/or nose and tail plates) may be used to replace the distances given.

2 Emergency withdrawal distances do not consider the potential flight range of propulsion units.

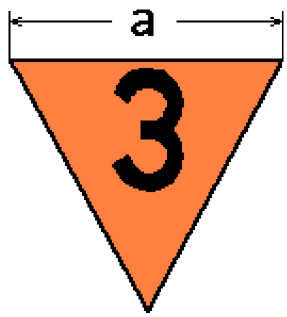
Figure F.1 Fire Division Symbols



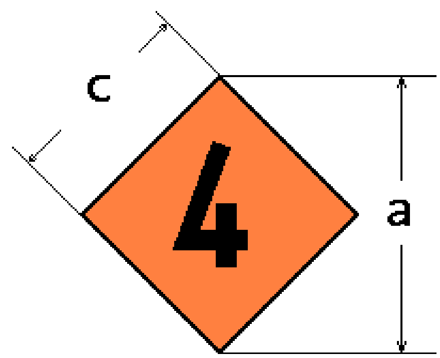
Fire Division 1



Fire Division 2



Fire Division 3



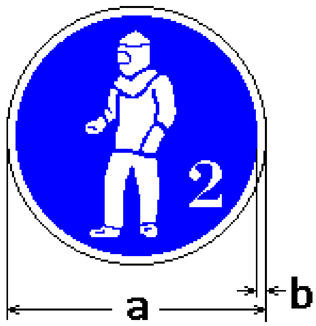
Fire Division 4

Sizes	large	small
	[mm]	[mm]
a	600	300
b	200	100
c	~424	~212
Letters (height)	~315	~158
Letters (width)	~50	~25

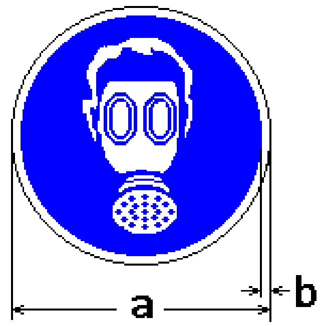
Colours*	
Background	orange
Numbers	black

* The specification of the colours is left to the discretion of the national authorities.
(Specification of signs and colours – except orange – is given in ISO 3864 "Safety colours and safety signs")

Figure F.2 Chemical Hazard Symbols



Symbol 1 Wear full protective clothing



Symbol 2 Wear breathing apparatus

Colours:*

Background is blue

Figure, rim and number are white when set-no. is indicated by number;

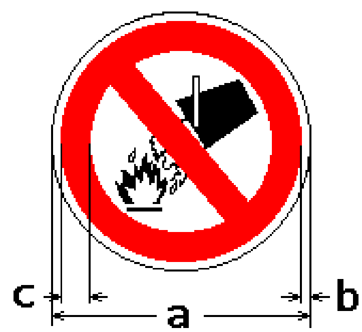
Figure and rim when used to indicate set-no. by colour:

- Red for Set 1 Protective Clothing
- Yellow for Set 2 Protective Clothing
- White for Set 3 Protective Clothing

Colours:*

Background is blue

Figure and rim are white



Symbol 3 Apply no water

Colours:*

Background is white

Circle and diagonal are red

Figure is black

* The specification of the colours is left to the discretion of the national authorities.

(Specification of signs and colours – except orange – is given in ISO 3864 "Safety colours and safety signs")

Sizes	Large	small
	[mm]	[mm]
a	630	315
b	12	6
c	63	32

Figure F.3 Supplemental Chemical Hazard Symbols.[4]

G – Type Nerve Agents **VX Nerve Agents** **H – Type Mustard Agents**

Colours:*

Background: yellow

Letters: black

*The specification of the colours is left to the discretion of the national authorities.

(Specification of signs and colours – except orange – is given in ISO 3864 "Safety colours and safety signs")

	large	small
	[mm]	[mm]
Diameter	630	315
Letters (height)	315	158
Letters (width)	50	25

4 Given as an example; Nations may use additional symbols which may differ in size, form and colour.

CHAPTER 8 - REPORTS ON ACCIDENTAL EXPLOSIONS

1.8.0.1. *Information Required*

In order that reports on damage resulting from accidental explosions be of value to the "NATO Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives (AC/326)" and useful in verifying the safety principles, the information should include the following:

1) Type and quantity of ammunition or explosives in the stack or building where the accident occurred.

2) NEQ and name of filling and weight of filled items.

3) Method of packing of the ammunition or explosives where the initial accident occurred and material of packages.

4) Distances between the articles in the packages.

5) Method of storing the ammunition or explosives where the initial accident occurred.

6) Information as above for neighbouring storage places of ammunition and explosives stating whether such neighbouring stacks were set off or otherwise affected.

7) The thickness of walls and roofs if ammunition or explosives were stored in buildings and whether there were windows through which fragments or debris got into the buildings.

8) Distances between buildings, or stacks, if buildings were not used.

9) The presumed influence of barricades upon the protection of neighbouring buildings and stacks.

10) Fire-fighting measures (attempts to fight fire).

11) The time between the first and last propagation from stack to stack.

12) The general effect on inhabited buildings in the vicinity and their inhabitants.

13) A map indicating the size and distribution of fragments and debris.

14) A brief summary of the causes and the effects.

1.8.0.2. *Summary Report*

A summary report is first required for translation and distribution by NATO. A full report should be forwarded to NATO as soon as possible. This report would be available on loan to NATO-countries in the language of the country of origin. A copy of the report should be forwarded to: Armaments Directorate Secretary, Defense Investment Division, Rm J34 5 , NATO Headquarters, B1110 Brussels.

CHAPTER 9 - DEPLETED URANIUM AMMUNITION

1.9.0.1. *Use of Depleted Uranium*

Ammunition containing Depleted Uranium (DU) has been developed as an improved armour piercing weapon, mainly for anti-tank warfare. A round of DU ammunition may consist of a DU penetrator made of DU metal (or of a DU alloy) and a propellant charge which may be integral with the penetrator or loaded into the gun separately. The use of DU in armour piercing ammunition exploits the high density of the metal, which, when propelled at high velocity, results in the delivery of sufficient kinetic energy to effect penetration. The penetration is accompanied by disintegration of the projectile and a violent combustion of the fragments thus formed.

1.9.0.2. *Radioactivity*

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.

1.9.0.3. *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.

1.9.0.4. *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.

1.9.0.5. *Fire-fighting*

a) 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:

1) 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) 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.

3) Disposition of water contaminated with DU particulates should be based on the advice of the local National Authority.

ANNEX I-A

QUANTITY-DISTANCE TABLES FOR ABOVEGROUND STORAGE

Net Explosives Quantities in Kilograms

Quantity-Distances in Metres

It is essential to study the text in Chapter 3
when using this Annex since they are complementary.

SECTION I : GENERAL NOTES AND EXPLANATION OF SYMBOLS

A.1.1 Quantity-Distance Criteria

Quantity-Distance criteria and the formulae used to generate values in the Q-D Tables are given in Part II Annex II-A.

A.1.2 Rounding of Quantity-Distances

The values of quantity-distances in the Q-D Tables 1 to 3 have been rounded up in accordance with the Table below. It is permitted to determine a QD using the formulae at the foot of the appropriate column. A calculated distance, in full metres, rounded up in accordance with the table below, may be used in place of any value in the QD Tables. If an NEQ is back calculated from a distance, using the appropriate QD formula, the answer should be rounded down to the nearest kg.

ROUNDING OF QUANTITY-DISTANCES	
Range of value of Quantity-Distance (m)	Rounding up the nearest (m)
3 to <100	1
≥ 100 to < 500	5
≥ 500 to < 1000	10
≥ 1000	20

A.1.4 General Note on Pictographs

The pictographs are intended to simplify the presentation of information in the Q-D Tables. The tables are intended to be used in conjunction with the principles given in the text of this Leaflet. The pictographs are purely diagrammatic; their shapes do not imply that actual structures should have similar shapes and proportions. The orientation shown is intended to indicate the direction of principal concern for blast, flame, radiant heat and projections as shown by arrows. In an actual situation every direction must be considered in turn. At a Potential Explosion Site there are relatively few significant variations but at an Exposed Site it is necessary to distinguish among different types of construction and among different functions of buildings.

A.1.5 DEFINITIONS OF FRONT/SIDE/REAR CONFIGURATIONS FOR EARTH-COVERED BUILDINGS

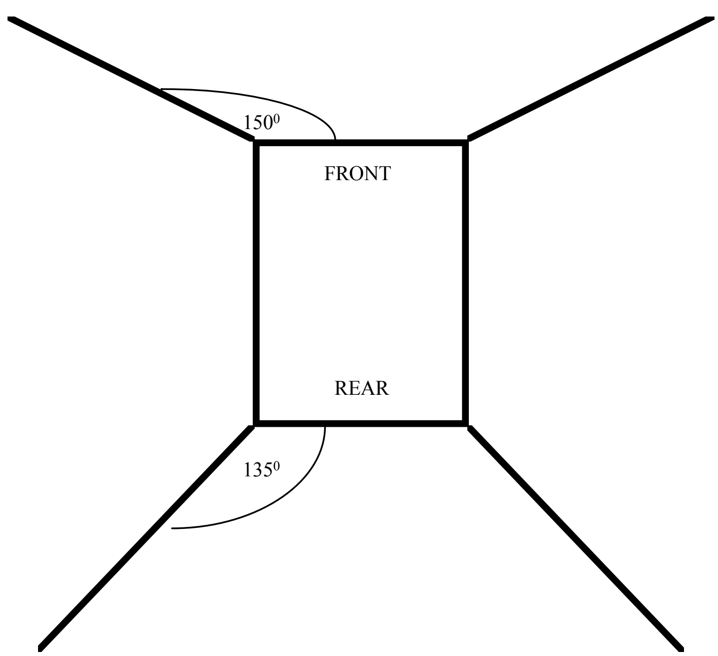
A.1.5.1 DIRECTIONAL EFFECTS FROM IGLOOS WITH HD 1.1

The directional effects for HD 1.1 or HD 1.3 from buildings which meet the design criteria for standard igloos are considered to occur :

a. through the front in the area bounded by lines drawn at 150^{o} to the front face of the PES from its front corners.

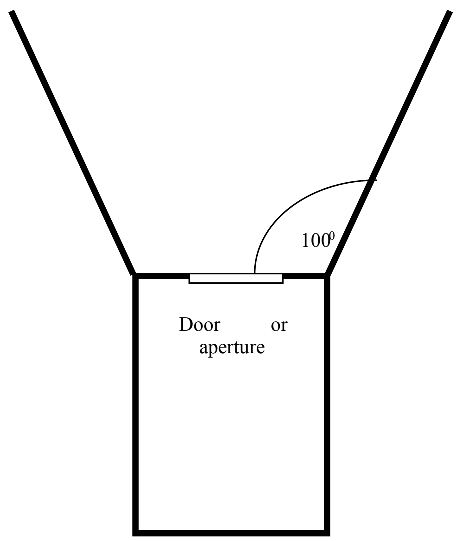
b. through the rear in the area bounded by lines drawn at 135^{o} to the rear face of the PES from its rear corners.

c. all area around a PES not included in a. or b. above are considered to be to the side of the PES. In those cases where an Exposed Site (ES) lies on the line separating rear/side etc. of a PES, the greater quantity-distance should be observed.



A.1.5.2 DIRECTIONAL EFFECTS FROM IGLOOS WITH HD 1.2

The directional effects for HD 1.2 from buildings which meet the design criteria for standard igloos or HD 1.2 containment buildings are considered to occur through the front in the area bounded by lines drawn at 100° to the front face of the PES from its front corners.



SECTION II – QUANTITY DISTANCES TABLES (Q-D TABLES)

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 1A HD 1.1 QD Matrix for Earth Covered Storage

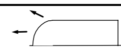
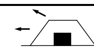
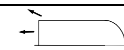
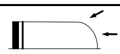
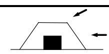
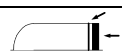
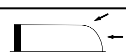
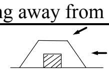
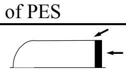
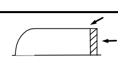
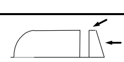
PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	D3 Virtually complete protection 1.3.3.5 No primary explosives	D3 Virtually complete protection 1.3.3.5 No primary explosives	D4 Virtually complete protection 1.3.3.5 No primary explosives
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D3 Virtually complete protection 1.3.3.5 No primary explosives	D3 Virtually complete protection 1.3.3.5 No primary explosives	D5 Virtually complete protection 1.3.3.5 No primary explosives
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	D4 Virtually complete protection 1.3.3.5 No primary explosives	D5 Virtually complete protection 1.3.3.5 No primary explosives or D4 High degree of protection	D8 High degree of protection 1.3.5.6 a1 Effect of high velocity projections 1.3.5.6 a2 Effect of lobbed ammunition
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	D3 Virtually complete protection 1.3.3.5 No primary explosives	D3 Virtually complete protection 1.3.3.5 No primary explosives	D4 Virtually complete protection 1.3.3.5 No primary explosives
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D3 Virtually complete protection 1.3.3.5 No primary explosives	D3 Virtually complete protection 1.3.3.5 No primary explosives	D5 Virtually complete protection 1.3.3.5 No primary explosives
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	D6 Virtually complete protection	D6 Virtually complete protection	D8 High degree of protection 1.3.5.6 a1 Effect of high velocity projections 1.3.5.6 a2 Effect of lobbed ammunition
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D9 High degree of protection

Table 1A HD 1.1 QD Matrix for Earth Covered Storage

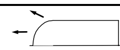
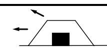
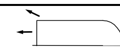
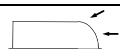
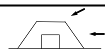
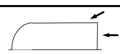
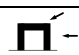
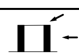
PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	D4 Virtually complete protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D5 Virtually complete protection 1.3.3.5 No primary explosives	D4 Virtually complete protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D5 Virtually complete protection 1.3.3.5 No primary explosives	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D6 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	D6 Virtually complete protection or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall	D6 Virtually complete protection or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D7 High degree of protection D5 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D7 High degree of protection D5 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall

Table 1A HD 1.1 QD Matrix for Earth Covered Storage

PES ➤ ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D9 Limited degree of protection or D12 High degree of protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall or D7 High degree of protection	D9 Limited degree of protection or D12 High degree of protection
18 Explosives Workshop with protective roof, barricaded	D10 High degree of protection for personnel	D10 High degree of protection for personnel	D10 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded	D10(≥270m) Limited degree of protection for personnel	D10(≥270m) Limited degree of protection for personnel	D10(≥270m) Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	D10(≥270m) Limited degree of protection for personnel	D10(≥270m) Limited degree of protection for personnel	D13 Limited degree of protection for personnel
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	0.5 x D12 or 0.5 x D14 1.3.6.7 b Reduced QD for standard igloos No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 or 0.5 x D15 1.3.6.7 b Reduced QD for standard igloos No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way

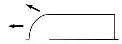
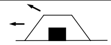
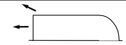
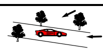
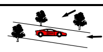
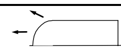
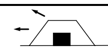
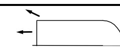
Table 1A HD 1.1 QD Matrix for Earth Covered Storage			
PES ES	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **22** Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D11(≥270m) or D16 1.3.6.7 b Reduced QD for standard igloos	D11(≥270m) or D17 1.3.6.7 b Reduced QD for standard igloos	D11(≥270m)
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D13(≥400m) or D14 1.3.6.7 b Reduced QD for standard igloos	D13(≥400m) or D15 1.3.6.7 b Reduced QD for standard igloos	D13(≥400m)
 **24** Inhabited Building Places of Assembly	D13(≥400m) or D14 1.3.6.7 b Reduced QD for standard igloos	D13(≥400m) or D15 1.3.6.7 b Reduced QD for standard igloos	D13(≥400m)
25 Vulnerable Constructions (1.3.1.15 b for full definition)	2 x D12 or 2 x D14 1.3.6.7 b Reduced QD for standard igloos	2 x D12 or 2 x D15 1.3.6.7 b Reduced QD for standard igloos	2 x D12
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8) Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D11(≥270m) or D16 1.3.6.7 b Reduced QD for standard igloos D13(≥400m) or D14 1.3.6.7 b Reduced QD for standard igloos	D11(≥270m) or D17 1.3.6.7 b Reduced QD for standard igloos D13(≥400m) or D15 1.3.6.7 b Reduced QD for standard igloos	D11(≥270m) D13(≥400m)

Table 1A HD 1.1 QD Matrix for Earth Covered Storage

PES ➤ / ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D13 D14 1.3.6.7 b Reduced QD for standard igloos	D13 D15 1.3.6.7 b Reduced QD for standard igloos	D13
Normal Network and associated substations	D11 D16 1.3.6.7 b Reduced QD for standard igloos	D11 D17 1.3.6.7 b Reduced QD for standard igloos	D11
Minor Network and associated substations	D10 1.3.6.7 b Reduced QD for standard igloos	D10	D10
<u>28 POL Facilities inc pipelines</u> Protected or Underground	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)
Unprotected, aboveground vital	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)
Unprotected, aboveground, non-vital	D13	D13	D13
Small Quantities (1.5.0.1)	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary.

Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage

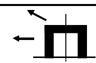
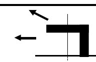
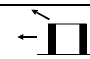
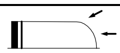
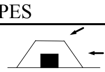
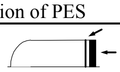
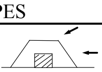
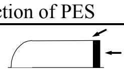
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	D5 Virtually complete protection	D5 Virtually complete protection	D5 Virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D6 High degree of protection	D6 High degree of protection	D6 High degree of protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition 1.3.5.6 a2 Effect of lobbed ammunition or D12 Virtually complete protection 1.3.5.6 a2 Effect of lobbed ammunition

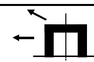
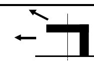
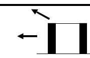
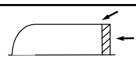
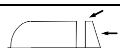
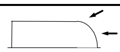
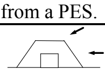
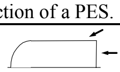
Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage			
PES ➤ **ES** ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	D9 High degree of protection	D9 High degree of protection	D9 High degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition

Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage

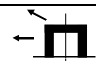
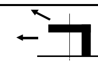
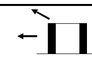
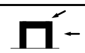
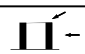
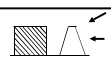
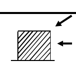
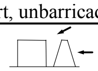
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition

Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage			
PES ➤ ES ▼	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition
18 Explosives Workshop with protective roof, barricaded	D10 High degree of protection for personnel	D10 High degree of protection for personnel	D10 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded	D10(≥270m) Limited degree of protection for personnel	D10(≥270m) Limited degree of protection for personnel	D10(≥270m) Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	D13 Limited degree of protection for personnel	D13 Limited degree of protection for personnel	D13 Limited degree of protection for personnel
21 Low Density UsageRoads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D11 (≥270m)	D11 (≥270m)	D11 (≥270m)

Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage

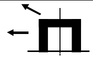
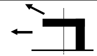
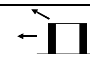
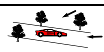
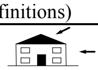
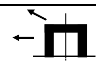
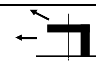
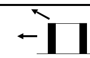
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)
 **24** Inhabited Building Places of Assembly	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)
25 Vulnerable Constructions (1.3.1.15 b for full definition)	2 x D12	2 x D12	2 x D12
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8) Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D11 (≥270m) D13 (≥400m)	D11 (≥270m) D13 (≥400m)	D11 (≥270m) D13 (≥400m)

Table 1B HD 1.1 QD Matrix for Non Earth Covered Heavy Storage

PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D13	D13	D13
Normal Network and associated substations	D11	D11	D11
Minor Network and associated substations	D10	D10	D10
<u>28 POL Facilities inc pipelines</u>	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)
Protected or Underground	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)
Unprotected, aboveground vital	D13	D13	D13
Unprotected, aboveground, non-vital	10m	10m	10m
Small Quantities (1.5.0.1)			

It is essential to study the text in Chapter 3 when using this table since they are complementary.

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

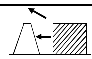
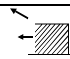
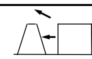
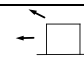
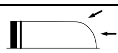
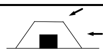
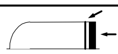
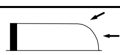
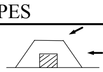
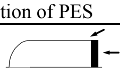
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	D5 Virtually complete protection	D5 Virtually complete protection	D5 Virtually complete protection	D5 Virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection	D5 High degree of protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	D6 High degree of protection	D6 High degree of protection	D6 High degree of protection	D6 High degree of protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D8 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

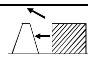
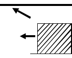
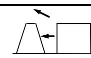
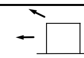
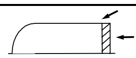
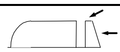
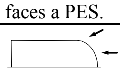
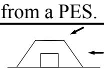
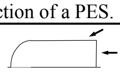
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 Limited protection only 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 Limited protection only 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	D9 High degree of protection	D9 High degree of protection	D9 High degree of protection	D9 High degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D6 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 Limited protection only 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 Limited protection only 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
12 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
13 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 Limited degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.3.3. Unbarricaded storage robust munitions 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition D1 or D2 High degree of protection 1.3.3.1 Open bomb bay storage 1.3.5.6 a2 Effect of lobbed ammunition	D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition or D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition D1 or D2 High degree of protection 1.3.3.1 Open bomb bay storage 1.3.5.6 a2 Effect of lobbed ammunition
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition	D7 High degree of protection 1.3.5.6 a2 Effect of lobbed ammunition or D4 High degree of protection 1.3.3.5 No primary explosives 1.3.5.3 No items vulnerable to spall 1.3.5.6 a2 Effect of lobbed ammunition D1 or D2 High degree of protection 1.3.3.1 Open bomb bay storage 1.3.5.6 a2 Effect of lobbed ammunition	D9 Limited degree of protection 1.3.3.3. Unbarricaded storage robust munitions 1.3.5.6 a2 Effect of lobbed ammunition or D12 1.3.5.6 a2 Effect of lobbed ammunition

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
18 Explosives Workshop with protective roof, barricaded	D10 High degree of protection for personnel	D10 High degree of protection for personnel	D10 High degree of protection for personnel	D10 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded	D10 Limited degree of protection for personnel	D10 Limited degree of protection for personnel	D10 Limited degree of protection for personnel	D10 Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	D10 Limited degree of protection for personnel	D13 High degree of protection for personnel	D10 Limited degree of protection for personnel	D13 High degree of protection for personnel
21 Low Density UsageRoads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D12 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D11 (≥270m)	D11 (≥270m)	D11	D11

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

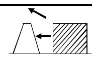
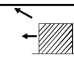
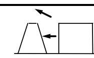
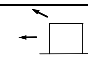
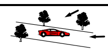
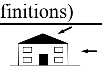
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D13 (≥400m)	D13 (≥400m)	D13	D13
 **24** Inhabited Building Places of Assembly	D12 (≥270m) 1.3.1.15 b)2) or D13 (≥400m)	D13 (≥400m)	D12 (≥270m) 1.3.1.15 b)2) or D13 (≥400m)	D13 (≥400m)
25 Vulnerable Constructions (1.3.1.15 b for full definition)	2 x D12	2 x D12	2 x D12	2 x D12
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D11	D11 (≥270m)	D11	D11 (≥270m)
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D13	D13 (≥400m)	D13	D13 (≥400m)

Table 1C HD 1.1 QD Matrix for Non-Earth Covered Storage

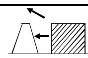
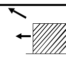
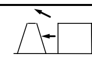
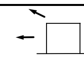
PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded (a)	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded (b)	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. (c)	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. (d)
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D13	D13	D13	D13
Normal Network and associated substations	D11	D11	D11	D11
Minor Network and associated substations	D10	D10	D10	D10
<u>28 POL Facilities inc pipelines</u> Protected or Underground	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)	0.5 x D7 (≥25m)
Unprotected, aboveground vital	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)	D13 (≥400m)
Unprotected, aboveground, non-vital	D13	D13	D13	D13
Small Quantities (1.5.0.1)	10m	10m	10m	10m

TABLE 1D QUANTITY DISTANCES FOR HAZARD DIVISION 1.1

NEQ (kg)	Quantity- Distances (m)												
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
500	3		5	7	9	15	20	29	39	64	180	180	270
600	3		5	7	10	16	21	31	41	68	180	190	270
700	4		5	8	10	16	22	32	43	72	180	200	270
800	4		5	8	11	17	23	34	45	75	180	210	270
900	4		5	8	11	18	24	35	47	78	180	215	270
1 000	4		5	8	11	18	24	36	48	80	180	225	270
1 200	4		6	9	12	20	26	39	52	86	180	240	270
1 400	4		6	9	13	21	27	41	54	90	180	250	270
1 600	5		6	10	13	22	29	43	57	94	180	260	270
1 800	5		7	10	14	22	30	44	59	98	180	270	270
2 000	5		7	11	14	23	31	46	61	105	180	280	270
2 500	5		7	11	15	25	33	49	66	110	185	305	280
3 000	6		8	12	16	26	35	52	70	120	205	325	305
3 500	6		8	13	17	28	37	55	73	125	220	340	330
4 000	6		8	13	18	29	39	58	77	130	235	355	350
5 000	6		9	14	19	31	42	62	83	140	255	380	380
6 000	7		10	15	20	33	44	66	88	150	270	405	405
7 000	7		10	16	22	35	46	69	92	155	285	425	425
8 000	7		10	16	22	36	48	72	96	160	300	445	445
9 000	8		11	17	23	38	50	75	100	170	310	465	465
10 000	8		11	18	24	39	52	78	105	175	320	480	480
12 000	9		12	19	26	42	55	83	110	185	340	510	510
14 000	9		13	20	27	44	58	87	120	195	360	540	540
16 000	10		13	21	28	46	61	91	125	205	375	560	560
18 000	10		14	21	29	48	63	95	130	210	390	590	590
20 000	10		14	22	30	49	66	98	135	220	405	610	610
25 000	11		15	24	33	53	71	110	145	235	435	650	650
30 000	11		16	25	35	56	75	115	150	250	460	690	690
35 000		15	17	27	36	59	79	120	160	265	485	730	730
40 000		16	18	28	38	62	83	125	165	275	510	760	760
50 000		17	19	30	41	67	89	135	180	295	550	820	820
60 000		18	20	32	44	71	94	145	190	315	580	870	870
70 000		19	21	33	46	75	99	150	200	330	610	920	920
80 000		19	22	35	48	78	105	160	210	345	640	960	960
90 000		20	23	36	50	81	110	165	220	360	670	1000	1000
100 000		21	24	38	52	84	115	170	225	375	690	1040	1040
120 000		22	25	40	55	89	120	180	240	395	730	1100	1100
140 000			26	42	58	94	125	190	250	420	770	1160	1160
160 000			28	44	60	98	135	200	265	435	810	1220	1220
180 000			29	46	63	105	140	205	275	455	840	1260	1260
200 000			30	47	65	110	145	215	285	470	870	1300	1300
250 000			32	51	70	115	155	230	305	510	940	1400	1400

Distance Functions

$D1 = 0.35Q^{1/3}$ $D2 = 0.44Q^{1/3}$ $D3 = 0.5Q^{1/3}$ $D4 = 0.8Q^{1/3}$ $D5 = 1.1Q^{1/3}$ $D6 = 1.8Q^{1/3}$ $D7 = 2.4Q^{1/3}$	$D8 = 3.6Q^{1/3}$ $D9 = 4.8Q^{1/3}$ $D10 = 8.0Q^{1/3}$ $D11 = 1.0Q^{2/3}$ for $Q \leq 2500$ $D11 = 3.6Q^{1/2}$ for $Q > 2500$ to ≤ 4500 $D11 = 14.8Q^{1/3}$ for $Q \geq 4500$	$D12 = 22.2Q^{1/3}$ $D13 = 1.5Q^{2/3}$ for $Q \leq 2500$ $D13 = 5.5Q^{1/2}$ for $Q > 2500 \leq 4500$ $D13 = 22.2Q^{1/3}$ for $Q > 4500$

TABLE 1D QUANTITY DISTANCES FOR HAZARD DIVISION 1.1

NEQ (kg)	Quantity-Distances (m)			
	D14	**D15**	**D16**	**D17**
500	400	400	270	270
600	400	400	270	270
700	400	400	270	270
800	400	400	270	270
900	400	400	270	270
1000	400	400	270	270
1200	400	400	270	270
1400	400	400	270	270
1600	400	400	270	270
1800	400	400	270	270
2000	400	400	270	270
2500	400	400	270	270
3000	400	400	270	270
3500	400	400	270	270
4000	400	400	270	270
5000	400	400	270	270
6000	400	400	270	270
7000	400	400	270	270
8000	400	400	270	270
9000	400	400	270	270
10000	400	400	270	270
12000	400	415	270	275
14000	400	435	270	290
16000	400	455	270	305
18000	400	475	270	315
20000	400	490	270	330
25000	410	530	275	355
30000	435	560	290	375
35000	460	580	305	395
40000	480	620	320	415
45000	500	640	335	430
Distance Functions	$D14 = 14.0\ Q^{1/3}$	$D15 = 18.0\ Q^{1/3}$	$D16 = 9.3\ Q^{1/3}$	$D17 = 12.0\ Q^{1/3}$

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 2A SsD 1.2.1 QD Matrix for Earth Covered Storage

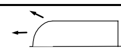
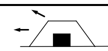
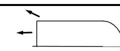
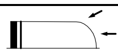
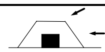
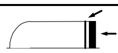
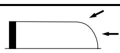
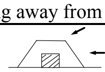
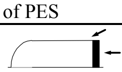
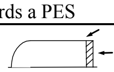
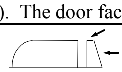
PES ➤ **ES** ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection

Table 2A SsD 1.2.1 QD Matrix for Earth Covered Storage

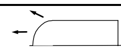
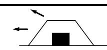
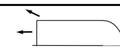
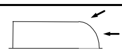
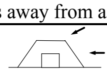
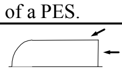
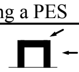
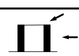
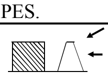
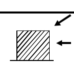
PES ES	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection

Table 2A SsD 1.2.1 QD Matrix for Earth Covered Storage

PES ➤ ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D6 Limited degree of protection
18 Explosives Workshop with protective roof, barricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D4 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D4 Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D6 Limited degree of protection for personnel
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D2 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	No QD	No QD	D6

Table 2A SsD 1.2.1 QD Matrix for Earth Covered Storage

PES ES	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. (a)	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. (b)	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site (c)
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	60m	60m	D2
24 Inhabited Building Places of Assembly	60m	60m	D2 Para 1.3.1.15 c
25 Vulnerable Constructions (1.3.1.15 c for full definition)	60m	60m	D2
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8) Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	40m 60m	40m 60m	D6 D2
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations Normal Network and associated substations Minor Network and associated substations	60m 30m No QD	60m 30m No QD	D2 D6 D4
<u>28 POL Facilities inc pipelines</u> Protected or Underground Unprotected, aboveground vital Unprotected, aboveground, non-vital Small Quantities (1.5.0.1)	25m 60m 30m No QD	25m 60m 30m No QD	25m D2 D6 No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

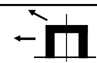
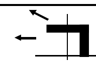
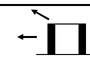
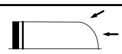
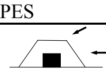
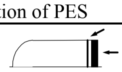
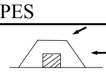
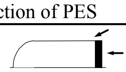
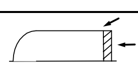
Table 2B SsD 1.2.1 QD Matrix for Non-Earth Covered Heavy Storage			
PES ➤ **ES** ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 2B SsD 1.2.1 QD Matrix for Non-Earth Covered Heavy Storage

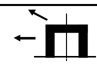
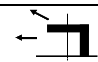
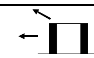
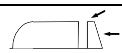
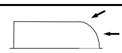
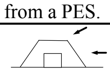
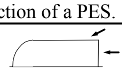
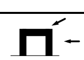
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 High degree of protection	D6 High degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 2B SsD 1.2.1 QD Matrix for Non-Earth Covered Heavy Storage

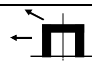
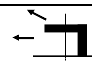
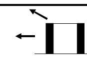
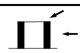
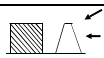
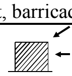
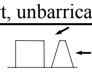
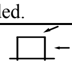
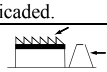
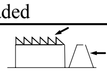
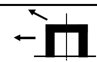
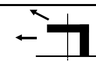
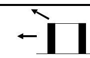
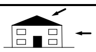
PES ➤ / ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 Limited degree of protection	D6 Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 Limited degree of protection	D6 Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 Limited degree of protection	D6 Limited degree of protection
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 Limited degree of protection	D6 Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D6 Limited degree of protection	D6 Limited degree of protection
 **18** Explosives Workshop with protective roof, barricaded	No QD High degree of protection for personnel	D4 High degree of protection for personnel	D4 High degree of protection for personnel
 **19** Explosives Workshop without protective roof, barricaded	No QD High degree of protection for personnel	D4 Limited degree of protection for personnel	D4 Limited degree of protection for personnel

Table 2B SsD 1.2.1 QD Matrix for Non-Earth Covered Heavy Storage

PES ➤ / ES ▼	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
20 Explosives Workshop with or without protective roof, unbarricaded Para 1.3.1.12 c)	No QD High degree of protection for personnel	D6 Limited degree of protection for personnel	D6 Limited degree of protection for personnel
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	No QD	D6	D6
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	60m	D2	D2

Table 2B SsD 1.2.1 QD Matrix for Non-Earth Covered Heavy Storage

PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **24** Inhabited Building Places of Assembly Para 1.3.1.15 c)	60m	D2	D2
25 Vulnerable Constructions (1.3.1.15 b for full definition)	60m	D2	D2
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	40m	D6	D6
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	60m	D2	D2
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	60m	D2	D2
Normal Network and associated substations	30m	D6	D6
Minor Network and associated substations	No QD	D4	D4
<u>28 POL Facilities inc pipelines</u> Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	60m	D2	D2
Unprotected, aboveground, non-vital	30m	D6	D6
Small Quantities (1.5.0.1)	No QD	No QD	No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
1 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
2 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
3 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
4 Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
5 Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
6 Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

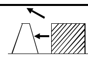
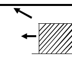
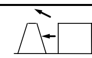
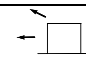
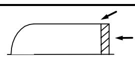
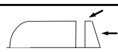
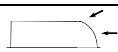
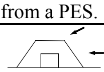
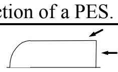
Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage				
PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D6 High degree of protection	D6 High degree of protection	D6 High degree of protection	D6 High degree of protection

Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
12 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
13 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection	D6 Limited degree of protection

Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
18 Explosives Workshop with protective roof, barricaded	D4 High degree of protection for personnel	D4 High degree of protection for personnel	D4 High degree of protection for personnel	D4 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded	D4 High degree of protection for personnel	D4 High degree of protection for personnel	D4 Limited degree of protection for personnel	D4 Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	D6 High degree of protection for personnel	D6 High degree of protection for personnel	D6 Limited degree of protection for personnel	D6 Limited degree of protection for personnel
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD2 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D6	D6	D6	D6

Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage

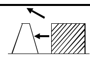
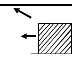
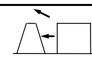
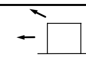
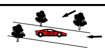
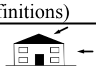
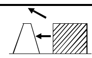
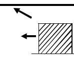
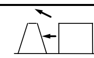
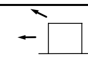
PES / ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D2	D2	D2	D2
 **24** Inhabited Building Places of Assembly	D2	D2	D2	D2
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D2	D2	D2	D2
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D6	D6	D6	D6
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D2	D2	D2	D2

Table 2C SsD 1.2.1 QD Matrix for Non-Earth Covered Storage

PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D2	D2	D2	D2
Normal Network and associated substations	D6	D6	D6	D6
Minor Network and associated substations	D4	D4	D4	D4
<u>28 POL Facilities inc pipelines</u> Protected or Underground	25m	25m	25m	25m
Unprotected, aboveground vital	D2	D2	D2	D2
Unprotected, aboveground, non-vital	D6	D6	D6	D6
Small Quantities (1.5.0.1)	No QD	No QD	No QD	No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

Table 2D SsD 1.2.2 QD Matrix for Earth Covered Storage

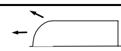
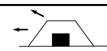
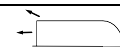
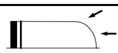
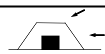
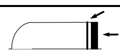
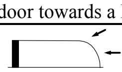
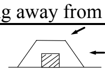
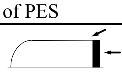
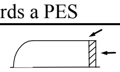
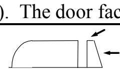
PES / ES	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection

Table 2D SsD 1.2.2 QD Matrix for Earth Covered Storage

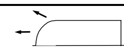
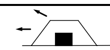
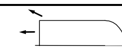
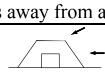
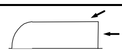
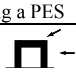
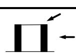
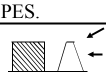
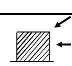
PES ➤ / ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD Virtually complete protection	No QD Virtually complete protection	D5 High degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	No QD Virtually complete protection
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	No QD Virtually complete protection	No QD Virtually complete protection	D5 Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D5 Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D5 Limited degree of protection

Table 2D SsD 1.2.2 QD Matrix for Earth Covered Storage

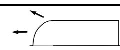
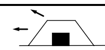
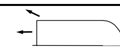
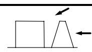
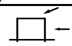
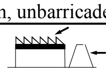
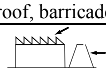
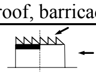
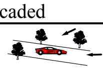
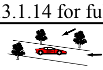
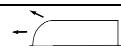
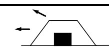
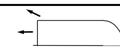
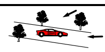
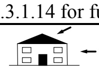
PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D5 Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	No QD Virtually complete protection	No QD Virtually complete protection	D5 Limited degree of protection
 **18** Explosives Workshop with protective roof, barricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D3 High degree of protection for personnel
 **19** Explosives Workshop without protective roof, barricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D3 Limited degree of protection for personnel
 **20** Explosives Workshop with or without protective roof, unbarricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D5 Limited degree of protection for personnel
 **21** Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	0.5 x D1 No QD for Very Low Density Usage Roads and Public Rights of Way
 **22** Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	20m	20m	D5

Table 2D SsD 1.2.2 QD Matrix for Earth Covered Storage

PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	30m	30m	D1
 **24** Inhabited Building Places of Assembly	30m	30m	D1
25 Vulnerable Constructions (1.3.1.15 c for full definition)	30m	30m	D1
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	20m	20m	D5
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	30m	30m	D1
27 Overhead Power Grid Supergrid Network and associated substations	30m	30m	D1
Normal Network and associated substations	15m	15m	D5
Minor Network and associated substations	No QD	No QD	D3
28 POL Facilities inc pipelines Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	30m	30m	D1
Unprotected, aboveground, non-vital	15m	15m	D5
Small Quantities (1.5.0.1)	No QD	No QD	No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

Table 2E SsD 1.2.2 QD Matrix for Non-Earth Covered Heavy Storage

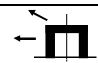
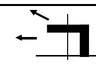
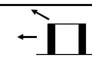
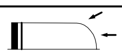
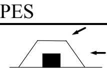
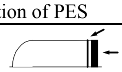
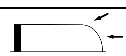
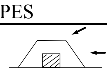
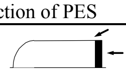
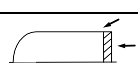
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 2E SsD 1.2.2 QD Matrix for Non-Earth Covered Heavy Storage

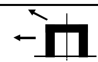
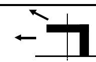
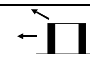
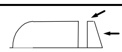
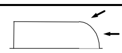
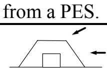
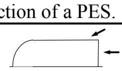
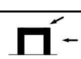
PES ES	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 High degree of protection	D5 High degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 2E SsD 1.2.2 QD Matrix for Non-Earth Covered Heavy Storage

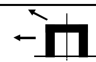
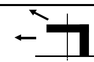
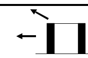
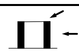
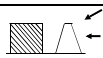
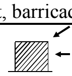
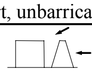
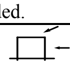
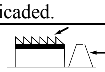
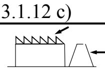
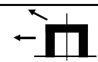
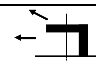
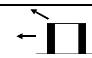
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 Limited degree of protection	D5 Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 Limited degree of protection	D5 Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 Limited degree of protection	D5 Limited degree of protection
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 Limited degree of protection	D5 Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	No QD These combinations of structures would always be deemed to provide virtually complete protection	D5 Limited degree of protection	D5 Limited degree of protection
 **18** Explosives Workshop with protective roof, barricaded Para 1.3.1.12 c)	No QD High degree of protection for personnel	D3 High degree of protection for personnel	D3 High degree of protection for personnel
 **19** Explosives Workshop without protective roof, barricaded	No QD High degree of protection for personnel	D3 Limited degree of protection for personnel	D3 Limited degree of protection for personnel

Table 2E SsD 1.2.2 QD Matrix for Non-Earth Covered Heavy Storage

PES ➤ ES ▼	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
20 Explosives Workshop with or without protective roof, unbarricaded	No QD High degree of protection for personnel	D5 Limited degree of protection for personnel	D5 Limited degree of protection for personnel
21 Low Density UsageRoads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	No QD No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	20m	D5	D5
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	30m	D1	D1
24 Inhabited Building Places of Assembly	30m	D1	D1

Table 2E SsD 1.2.2 QD Matrix for Non-Earth Covered Heavy Storage

PES / ES	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
25 Vulnerable Constructions (1.3.1.15 c for full definition)	30m	D1	D1
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	20m	D5	D5
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	30m	D1	D1
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	30m	D1	D1
Normal Network and associated substations	15m	D5	D5
Minor Network and associated substations	No QD	D3	D3
<u>28 POL Facilities inc pipelines</u> Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	30m	D1	D1
Unprotected, aboveground, non-vital	15m	D5	D5
Small Quantities (1.5.0.1)	No QD	No QD	No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

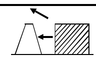
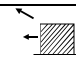
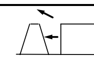
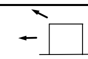
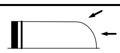
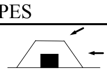
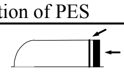
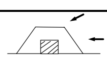
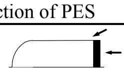
Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage				
PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage

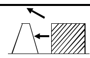
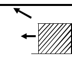
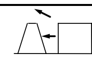
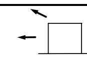
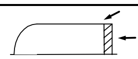
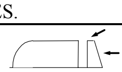
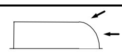
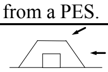
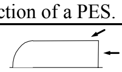
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD High degree of protection	No QD High degree of protection	D5 High degree of protection	D5 High degree of protection

Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ► / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded (a)	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded (b)	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. (c)	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. (d)
12 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
13 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	No QD Limited degree of protection	No QD Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	No QD Limited degree of protection	No QD Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection	D5 Limited degree of protection

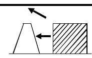
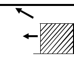
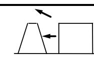
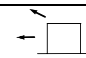
Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
18 Explosives Workshop with protective roof, barricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D3 High degree of protection for personnel	D3 High degree of protection for personnel
19 Explosives Workshop without protective roof, barricaded Para 1.3.1.12 c)	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D3 Limited degree of protection for personnel	D3 Limited degree of protection for personnel
20 Explosives Workshop with or without protective roof, unbarricaded	No QD High degree of protection for personnel	No QD High degree of protection for personnel	D5 Limited degree of protection for personnel	D5 Limited degree of protection for personnel
21 Low Density UsageRoads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way	0.5xD1 No QD for Very Low Density Usage Roads and Public Rights of Way
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D5	D5	D5	D5

Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D1	D1	D1	D1
24 Inhabited Building Places of Assembly	D1	D1	D1	D1
25 Vulnerable Constructions (1.3.1.15 c for full definition)	D1	D1	D1	D1
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D5	D5	D5	D5
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D1	D1	D1	D1

Table 2F SsD 1.2.2 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations Normal Network and associated substations Minor Network and associated substations	D1 D5 D3	D1 D5 D3	D1 D5 D3	D1 D5 D3
<u>28 POL Facilities inc pipelines</u> Protected or Underground Unprotected, aboveground vital Unprotected, aboveground, non-vital Small Quantities (1.5.0.1)	25m D1 D5 No QD	25m D1 D5 No QD	25m D1 D5 No QD	25m D1 D5 No QD

It is essential to study the text in Chapter 3 when using this table since they are complementary.

TABLE 2G QUANTITY DISTANCES FOR STORAGE SUB-DIVISIONS 1.2.1 AND 1.2.2

NEQ (kg)	Quantity -Distances (m)					
	D1	D2	D3	D4	D5	D6
10	30	60	20	20	30	60
20	36	60	20	20	30	60
50	44	88	20	32	30	60
70	47	110	20	39	32	73
80	49	120	20	42	33	78
90	50	125	20	45	34	83
100	51	130	20	47	35	87
120	53	140	20	51	36	94
140	55	150	20	54	37	100
160	57	160	21	57	39	105
180	59	165	22	59	40	110
200	60	170	22	61	41	115
250	64	185	24	66	43	125
300	66	195	24	70	45	130
350	69	200	25	72	47	135
400	71	210	26	75	48	140
500	75	220	27	80	51	150
600	78	230	29	83	53	155
700	81	240	30	86	55	160
800	83	245	30	89	56	165
900	86	255	31	91	58	170
1000	88	260	32	93	59	175
1200	91	270	33	96	61	180
1400	94	275	34	99	63	185
1600	97	285	35	105	65	190
1800	100	290	36	105	67	195
2000	105	295	37	110	69	200
2500	110	305	39	115	72	205
3000	115	315	40	115	75	210
3500	115	320	42	120	77	215
4000	120	330	43	120	80	220
4500	120	335	44	120	81	225
5000	125	340	45	125	83	230
6000	130	350	46	125	86	235
7000	135	355	48	130	88	240
8000	135	360	49	130	91	245
9000	140	365	50	135	93	245
10000	145	370	51	135	95	250
12000	150	380	53	140	98	255
14000	150	390	54	140	105	260
16000	155	395	56	145	105	265
18000	160	400	57	145	110	270
20000	160	405	58	145	110	275
25000	170	415	60	150	115	280
30000	175	420	62	155	120	285
35000	180	430	64	155	120	290
40000	185	435	66	160	125	295
45000	185	440	67	160	125	295
50000	190	445	68	160	130	300
60000	195	450	70	165	130	305
70000	200	455	72	165	135	305
80000	205	465	74	170	140	310
90000	210	470	75	170	140	315
100000	215	470	76	170	145	315
120000	220	480	79	175	150	320
140000	225	485	80	175	150	325
160000	230	490	82	180	155	330

TABLE 2G QUANTITY DISTANCES FOR STORAGE SUB-DIVISIONS 1.2.1 AND 1.2.2

NEQ (kg)	Quantity -Distances (m)					
	D1	D2	D3	D4	D5	D6
180000	235	495	84	180	155	335
200000	235	500	85	180	160	335
250000	245	510	88	185	165	340
500000	270	540	97	195	185	360

D1 = 28.127-2.364*LN(NEQ)+1.577*((LN(NEQ))^2) D2 = -167.648+70.345*LN(NEQ)-1.303*((LN(NEQ))^2) D1 NEQ = exp[0.7495+ (-17.274 + 0.6341*IBD)^{½}] D2 NEQ = exp[27.000- (600.287 – 0.768*IBD)^{½}]	D3 = 0.36*D1 D4 = 0.36*D2 D5 = 0.67*D1 D6 = 0.67*D2

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 3A SsD 1.3.1 QD Matrix for Earth Covered Storage

PES ► / ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
1 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection
2 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection
3 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
4 Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection
5 Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection
6 Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
7 Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection

Table 3A SsD 1.3.1 QD Matrix for Earth Covered Storage

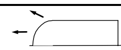
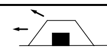
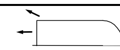
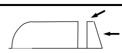
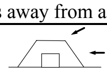
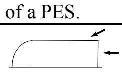
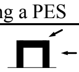
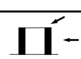
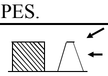
PES ➤ / ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection

Table 3A SsD 1.3.1 QD Matrix for Earth Covered Storage

PES ➤ / ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	240m These combinations of structures would always be deemed to provide virtually complete protection
18 Explosives Workshop with protective roof, barricaded	D2	D2	D2
19 Explosives Workshop without protective roof, barricaded	D2	D2	D2
20 Explosives Workshop with or without protective roof, unbarricaded	D2	D2	D2
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	D2 No QD for Very Low Density Usage Roads and Public Rights of Way	D2 No QD for Very Low Density Usage Roads and Public Rights of Way	D2 No QD for Very Low Density Usage Roads and Public Rights of Way

Table 3A SsD 1.3.1 QD Matrix for Earth Covered Storage

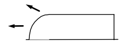
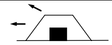
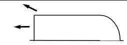
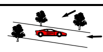
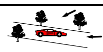
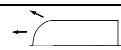
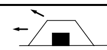
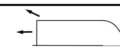
PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **22** Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4
 **24** Inhabited Building Places of Assembly	D4	D4	D4
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D3	D3	D3
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D4	D4	D4

Table 3A SsD 1.3.1 QD Matrix for Earth Covered Storage

PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D4	D4	D4
Normal Network and associated substations	D3	D3	D3
Minor Network and associated substations	D2	D2	D2
<u>28 POL Facilities inc pipelines</u> Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

Table 3B SsD 1.3.1 QD Matrix for Non-Earth Covered Heavy Storage

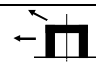
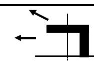
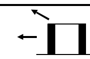
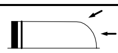
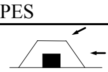
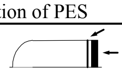
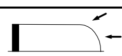
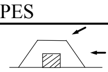
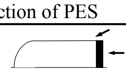
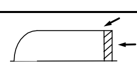
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

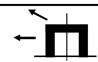
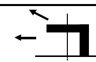
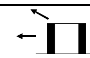
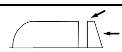
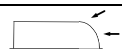
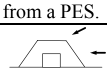
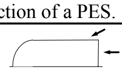
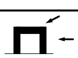
Table 3B SsD 1.3.1 QD Matrix for Non-Earth Covered Heavy Storage			
PES ➤ **ES** ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection	25m High degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	D1 High/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection	D1 High degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m Hi/Limited degree of protection	No QD These combinations of structures would always be deemed to provide virtually complete protection

Table 3B SsD 1.3.1 QD Matrix for Non-Earth Covered Heavy Storage

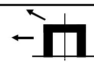
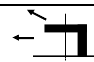
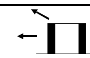
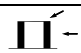
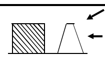
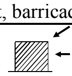
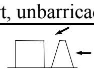
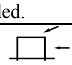
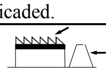
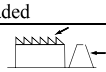
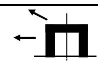
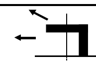
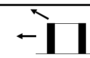
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
 **18** Explosives Workshop with protective roof, barricaded	D2	D2	D2
 **19** Explosives Workshop without protective roof, barricaded	D2	D2	D2

Table 3B SsD 1.3.1 QD Matrix for Non-Earth Covered Heavy Storage			
PES ➤ / **ES** ▼	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
20 Explosives Workshop with or without protective roof, unbarricaded	D2	D2	D2
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	D2	D2	D2
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4
24 Inhabited Building Places of Assembly	D4	D4	D4

Table 3B SsD 1.3.1 QD Matrix for Non-Earth Covered Heavy Storage

PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D3	D3	D3
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D4	D4	D4
27 Overhead Power Grid Supergrid Network and associated substations	D4	D4	D4
Normal Network and associated substations	D3	D3	D3
Minor Network and associated substations	D2 (≥15m)	D2 (≥15m)	D2 (≥15m)
28 POL Facilities inc pipelines Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
1 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
2 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
3 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
4 Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
5 Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
6 Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection

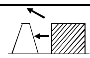
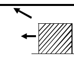
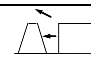
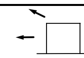
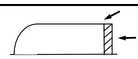
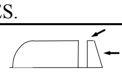
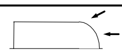
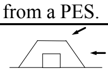
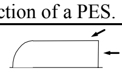
Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage				
PES **ES**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection

Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage

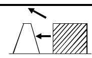
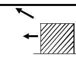
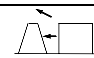
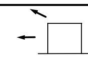
PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded (a)	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded (b)	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. (c)	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. (d)
12 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection
13 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection	D1 These combinations of structures would always be deemed to provide virtually complete protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection

Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection	D1 High/Limited degree of protection
18 Explosives Workshop with protective roof, barricaded	D2	D2	D2	D2
19 Explosives Workshop without protective roof, barricaded	D2	D2	D2	D2
20 Explosives Workshop with or without protective roof, unbarricaded	D2	D2	D2	D2
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	D2	D2	D2	D2

Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage

PES ➤ / ES ▼	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded (a)	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded (b)	Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. (c)	Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. (d)
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3	D3
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4	D4
24 Inhabited Building Places of Assembly	D4	D4	D4	D4
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4	D4

Table 3C SsD 1.3.1 QD Matrix for Non-Earth Covered Medium/Light Storage				
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D3	D3	D3	D3
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D4	D4	D4	D4
<u>27 Overhead Power Grid</u> Supergrid Network and associated substations	D4	D4	D4	D4
Normal Network and associated substations	D3	D3	D3	D3
Minor Network and associated substations	D2 (≥15m)	D2 (≥15m)	D2 (≥15m)	D2 (≥15m)
<u>28 POL Facilities inc pipelines</u> Protected or Underground	25m	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where “No QD” is shown on the matrix practical considerations will dictate actual separation distances.

Table 3D SsD 1.3.2 QD Matrix for Earth Covered Storage

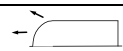
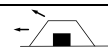
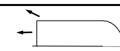
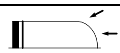
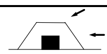
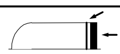
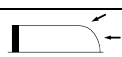
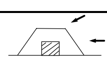
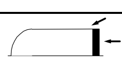
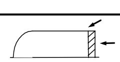
PES ➤ **ES** ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection

Table 3D SsD 1.3.2 QD Matrix for Earth Covered Storage

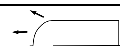
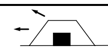
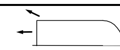
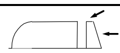
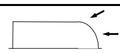
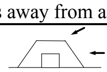
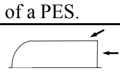
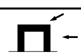
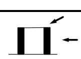
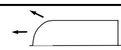
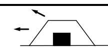
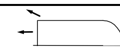
PES ➤ ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	10m High/Limited degree of protection
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection

Table 3D SsD 1.3.2 QD Matrix for Earth Covered Storage

PES ➤ / ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. (a)	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. (b)	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site (c)
14 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection
15 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection
16 Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection
17 Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection
18 Explosives Workshop with protective roof, barricaded	25m	25m	25m
19 Explosives Workshop without protective roof, barricaded	60m	60m	60m

Table 3D SsD 1.3.2 QD Matrix for Earth Covered Storage			
PES ➤ ES ▼	Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
20 Explosives Workshop with or without protective roof, unbarricaded	60m	60m	60m
21 Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	60m	60m	60m
22 Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3
23 High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4
24 Inhabited Building Places of Assembly	D4	D4	D4
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4

Table 3D SsD 1.3.2 QD Matrix for Earth Covered Storage

PES ES	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D3	D3	D3
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D4	D4	D4
27 Overhead Power Grid			
Supergrid Network and associated substations	D4	D4	D4
Normal Network and associated substations	D3	D3	D3
Minor Network and associated substations	D2	D2	D2
28 POL Facilities inc pipelines			
Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage

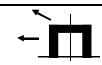
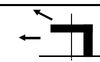
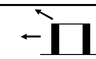
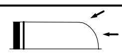
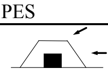
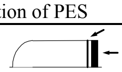
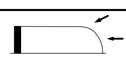
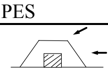
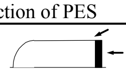
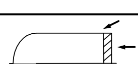
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection

Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage

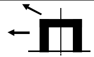
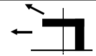
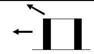
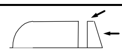
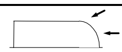
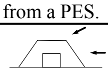
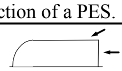
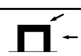
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	25m These combinations of structures would always be deemed to provide virtually complete protection 10m High/Limited degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection

Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage

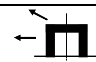
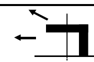
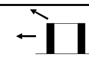
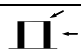
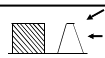
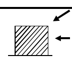
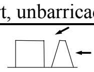
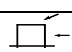
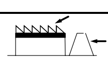
PES ➤ / ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	10m These combinations of structures would always be deemed to provide virtually complete protection	60m High/Limited degree of protection	10m High degree of protection
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **18** Explosives Workshop with protective roof, barricaded	25m	25m	25m

Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage

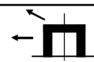
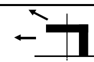
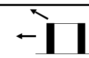
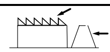
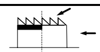
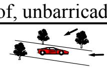
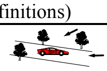
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **19** Explosives Workshop without protective roof, barricaded	60m	60m	60m
 **20** Explosives Workshop with or without protective roof, unbarricaded	60m	60m	60m
 **21** Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	60m	60m	60m
 **22** Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3

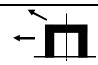
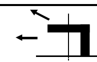
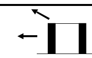
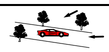
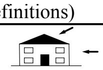
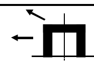
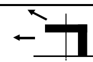
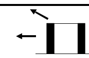
Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage			
PES ➤ ES ▼	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4
 **24** Inhabited Building Places of Assembly	D4	D4	D4
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8)	D3	D3	D3
Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D4	D4	D4
27 Overhead Power Grid			
Supergrid Network and associated substations	D4	D4	D4
Normal Network and associated substations	D3	D3	D3
Minor Network and associated substations	D2	D2	D2

Table 3E SsD 1.3.2 QD Matrix for Non-Earth Covered Heavy Storage

PES ES	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. **(a)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. Door or other large aperture faces an ES. **(b)**	 Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) without a protective roof. **(c)**
28 POL Fac ilities inc pipelines			
Protected or Underground	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m

It is essential to study the text in Chapter 3 when using this table since they are complementary. Where "No QD" is shown on the matrix practical considerations will dictate actual separation distances.

Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage

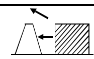
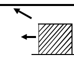
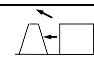
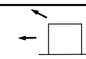
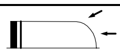
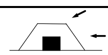
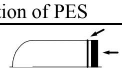
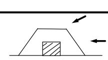
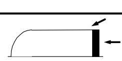
PES ➤ / ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **1** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **2** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **3** Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door towards a PES	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **5** Igloo designed for 3 bar in accordance with Part 2, with the door facing perpendicularly to the direction of PES	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **6** Igloo designed for 3 bar in accordance with Part 2, with the door towards a PES	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection

Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage

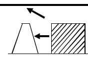
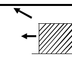
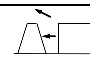
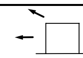
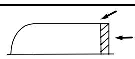
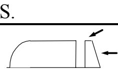
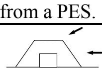
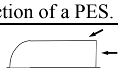
PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **7** Earth-covered building not complying with Part 2, but with a headwall and door(s) resistant to high velocity projections (see 1.3.5.6 a). The door faces a PES.	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	25m These combinations of structures would always be deemed to provide virtually complete protection
 **8** Earth-covered building not complying with Part 2, but with a door barricade, (see 1.3.6.4-1.3.6.6). The door faces a PES.	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection	60m These combinations of structures would always be deemed to provide virtually complete protection 25m High/Limited degree of protection
 **9** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces away from a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **10** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), but the door faces perpendicularly to the direction of a PES.	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection	No QD These combinations of structures would always be deemed to provide virtually complete protection
 **11** Earth-covered building not complying with Part 2, with or without a headwall and door(s) resistant to fire and low velocity projections, (see 1.3.5.6 b), with the door facing a PES	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection

Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage

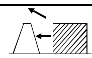
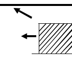
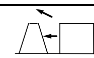
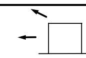
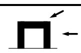
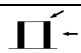
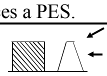
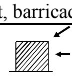
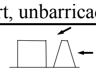
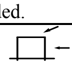
PES ES	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded (a)	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded (b)	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. (c)	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. (d)
 **12** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent) and protective roof of 150 mm RC with suitable support. The door is barricaded if it faces a PES.	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection	10m These combinations of structures would always be deemed to provide virtually complete protection
 **13** Building of non-combustible construction with walls of nominal 450 mm RC (680 mm brick or equivalent), without a protective roof. The door is barricaded if it faces a PES.	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **14** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded.	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **15** Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **16** Open air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded.	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **17** Open air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded.	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection

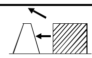
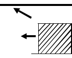
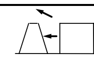
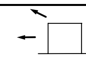
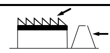
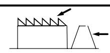
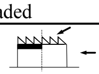
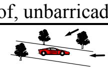
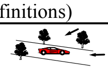
Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage				
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **18** Explosives Workshop with protective roof, barricaded	25m	25m	25m	25m
 **19** Explosives Workshop without protective roof, barricaded	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **20** Explosives Workshop with or without protective roof, unbarricaded	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection	60m High/Limited degree of protection
 **21** Low Density Usage Roads – Less than 1000 vehicles per day Railways – Less than 1000 passengers per day Waterways – Less than 400 users per day Public Rights of Way or Recreational Facilities – Less than 200 users per day (See 1.3.1.14 for full definitions)	60m	60m	60m	60m
 **22** Medium Density Usage Roads – 1000 or more but less than 5000 vehicles per day Railways – 1000 or more but less than 5000 passengers per day Waterways – 400 or more but less than 1800 users per day Public Rights of Way or Recreational Facilities – 200 or more but less than 900 users per day (See 1.3.1.14 for full definitions)	D3	D3	D3	D3

Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage

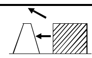
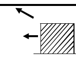
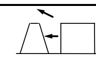
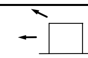
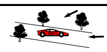
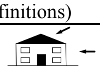
PES ➤ ES ▼	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
 **23** High Density Usage Roads – 5000 or more vehicles per day Railways – 5000 or more passengers per day Waterways – 1800 or more users per day Public Rights of Way or Recreational Facilities – 900 or more users per day (See 1.3.1.14 for full definitions)	D4	D4	D4	D4
 **24** Inhabited Building Places of Assembly	D4	D4	D4	D4
25 Vulnerable Constructions (1.3.1.15 b for full definition)	D4	D4	D4	D4
26 Office, Non-explosives workshop, Canteen with less than 20 persons who are directly associated with the explosives task in a support role (1.3.7.8) Office, Non-explosives workshop, Canteen with 20 or more persons who are directly associated with the explosives task in a support role (1.3.7.7)	D3 D4	D3 D4	D3 D4	D3 D4
27 Overhead Power Grid Supergrid Network and associated substations Normal Network and associated substations Minor Network and associated substations	 D4 D3 D2	 D4 D3 D2	 D4 D3 D2	 D4 D3 D2

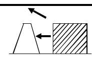
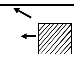
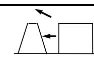
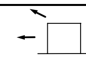
Table 3F SsD 1.3.2 QD Matrix for Non-Earth Covered Storage				
PES **ES**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded. Process Facility, barricaded **(a)**	 Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded. Process Facility, unbarricaded **(b)**	 Open-air stack or light structure, barricaded. Truck, trailer, rail-car or freight container loaded with ammunition, barricaded. **(c)**	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with ammunition, unbarricaded. **(d)**
28 POL Fac ilities inc pipelines				
Protected or Underground	25m	25m	25m	25m
Unprotected, aboveground vital	D4	D4	D4	D4
Unprotected, aboveground, non-vital	D3	D3	D3	D3
Small Quantities (1.5.0.1)	10m	10m	10m	10m

TABLE 3G QUANTITY-DISTANCES FOR STORAGE SUB-DIVISIONS 1.3.1 AND 1.3.2

NEQ (kg)	Quantity Distances (m)			
	D1	D2	D3	D4
500	25	60	60	60
600	25	60	60	60
700	25	60	60	60
800	25	60	60	60
900	25	60	60	62
1000	25	60	60	64
1200	25	60	60	69
1400	25	60	60	72
1600	25	60	60	75
1800	25	60	60	78
2000	25	60	60	81
2500	25	60	60	87
3000	25	60	62	93
3500	25	60	65	98
4000	25	60	68	105
5000	25	60	73	110
6000	25	60	78	120
7000	25	62	82	125
8000	25	64	86	130
9000	25	67	89	135
10 000	25	68	92	140
12 000	25	74	98	150
14 000	27	78	105	155
16 000	28	81	110	165
18 000	30	84	115	170
20 000	32	87	120	175
25 000	35	94	125	190
30 000	39	100	135	200
35 000	42	105	140	210
40 000	44	110	150	220
50 000	50	120	160	240
60 000	54	130	170	255
70 000	59	135	180	265
80 000	63	140	185	280
90 000	66	145	195	290
100 000	70	150	200	300
120 000	77	160	215	320
140 000	83	170	225	335
160 000	88	175	235	350
180 000	94	185	245	365
200 000	99	190	250	375
250 000	110	205	270	405
Distance Functions	$D1 = 0.22\ Q^{1/2}$	$D2 = 3.2\ Q^{1/3}$	$D3 = 4.3\ Q^{1/3}$	$D4 = 6.4Q^{1/3}$

STORAGE OF 1.6N AMMUNITION WITH A UNIT NEQ EQUAL TO 1000 Kg

REMARKS

1. Inhabited Building Distance (IBD)

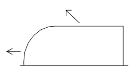
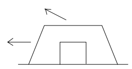
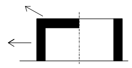
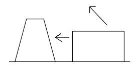
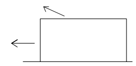
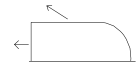
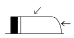
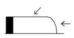
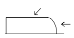
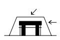
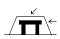
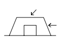
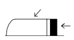
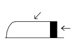
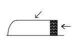
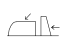
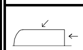
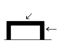
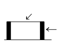
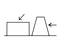
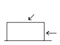
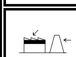
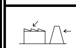
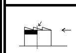
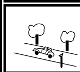
Line 20 gives the Inhabited Building Distance (IBD).
IBD is equal to D4 or to 174m if D4 < 174m.

D4 = 6.4 $Q^{1/3}$ and D4 $\geq$ 60m (For values of D4 according to values of Q: see Table 3D-F).
Q is the aggregated NEQ of the PES.

2. Legend

a.	see 1.3.1.15 d) 1)	High/limited degree of protection against thermal flux
b.	see 1.3.5.6 a) 1)	Resistance of headwall and door(s) at ES
c.	see 1.3.3.4	Building (PES) with heavy walls with protective roof
d.	see 1.3.3.4	Building (PES) with heavy walls without protective roof
e.	see 1.3.6.7.b)	Reduced Q/D for large earth-covered buildings containing NEQ < 45 000 kg

TABLE 4 – QD TABLE FOR HAZARD DIVISION 1.6 (over page)

TABLE 4	Q-D TABLE FOR HAZARD DIVISION 1.6 STORAGE OF 1.6N AMMUNITION WITH A UNIT NEQ EQUAL TO 1000 Kg					
PES ES	 (a)	 (b)	 (c)	 (d)	 (e)	 (f)
 1	5m	5m	11m	11m	11m	8m
 2	5m	5m	11m	11m	11m	8m
 3	8m	8m	8m	18m	18m	8m
 4	5m	5m	11m	11m	11m	11m
 5	5m	5m	18m	18m	18m	11m
 6	8m	8m	18m	18m	18m	18m
 7	8m	8m	36m	25m	25m	25m[b] or 60m
 8	18m	18m	36m, 48m[d]	36m	36m	36m[b] or 60m
 9	8m	8m	48m	10m	48m	48m
 10	8m	8m	48m	48m	48m[b] or 68m	48m[b] or 68m
 11	25m[b] or 60m	25m[b] or 60m	48m[b] or 60m	60m[b]	60m[b]	60m[b]
 12	8m	8m	10m	10m	10m	10m
 13	25m[a] or 60m	25m[a] or 60m	25m[ac] or 60m[acd]	60m[a]	60m[a]	60m[a]
 14	25m[b] or 60m	25m[b] or 60m	25m[bc] or 60m[bcd]	60m[b]	60m[b]	60m[b]
 15	25m[a] or 60m	25m[a] or 60m	48m[ac] or 60m[acd]	60m[a]	60m[a]	60m[a]
 16	80m	80m	80m	80m	80m	80m
 17	80m	80m	80m	80m	80m	80m
 18	80m	80m	174m	80m	174m	174m
	107, 174m 93m[e], 140m[e]	107, 174m 93m[e], 180m[e]	107 174m	107 174m	107 174m	107 174m
 20	D4 > 174m	D4 > 174m	D4 > 174m	D4 > 174m	D4 > 174m	D4 > 174m

ANNEX I-B

QUANTITY DISTANCE CRITERIA FOR ABOVEGROUND STORAGE

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 at the end of this Annex.

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 ♋	***d* = 0.3967 *k Q*** ♋
d* = *k W 🗎	***d* = 0.4526 *k Q*** 🗎
d* = *k W ♌	***d* = 0.5136 *k Q*** ♌
$RB = \dfrac{14\ W^{\frac{1}{3}}}{\sqrt[6]{\left(1 + \left(\frac{7000}{W}\right)^2\right)}}$	$RB = \dfrac{5.6\ Q^{\frac{1}{3}}}{\sqrt[6]{\left(1 + \left(\frac{3175}{Q}\right)^2\right)}}$

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 Tables 1A-1C

In this section the different types of distances are covered as follows:

- Inter-Magazine Distances :	paragraphs	1-8
- Explosives Workshop Distances:	paragraph	9
- Inhabited Building Distances/PTRD's:	paragraphs	10-14

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 for Design Load for Head-Wall and doors in Protection of Igloos against Blast specified for face-to-face exposure is greater than that for those in parallel despite the greater inter magazine distance.[5] 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).

[5] Change 2 Part II Paras 2.3.2.2.b)1) and 2). Part II Para 2.3.2.2.b) now refers to these details contained in a D-doc, Nationally Approved Structures

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 over-pressure 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 $Q \leq 3\ 600$ 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 to the 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 Tables 2A-2F

In this section the different types of distances are covered as follows:

- Inter-Magazine Distances :	paragraphs	1-2
- Explosives Workshop Distances:	paragraph	3
- Public Traffic Route Distances:	paragraphs	4-5

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 Tables 3A-3C

In this section the different types of distances are covered as follows:

- Fixed Distances	:	paragraphs	1-5
- Distance Functions Distances	:	paragraphs	6-9

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 resistant 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 Tables 3D-3F

In this section the different types of distances are covered as follows:

- Fixed Distances	:	paragraphs	1-4
- Distance Function Distance	:	paragraph	5

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.

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

ALLIED AMMUNITION STORAGE AND TRANSPORT PUBLICATION 1 (AASTP-1)

MANUAL OF NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

PART II

EXPLOSIVES STORAGE MAGAZINE DESIGN AND OPERATIONAL GUIDELINES FOR EXPLOSIVES FACILITIES

May 2010

TABLE OF CONTENTS – PART II

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.

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 minimize 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 buffered 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 meters.

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/326.

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
For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

b) Design Load for Head-Walls and Doors

For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

c) Design Load for Roof and Earth-Covered Walls
For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

d) Ventilation Openings
For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

2.3.2.3. *Protection against Projections*

a) Buildings: For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

b) earth-covered buildings: For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

2.3.2.4. *Pressure Release*

For detailed information see PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010.

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 utilized 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 electro-conductive 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 conductors 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 consists 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 packaging 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 mm^2 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 sufficient 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 magazine 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

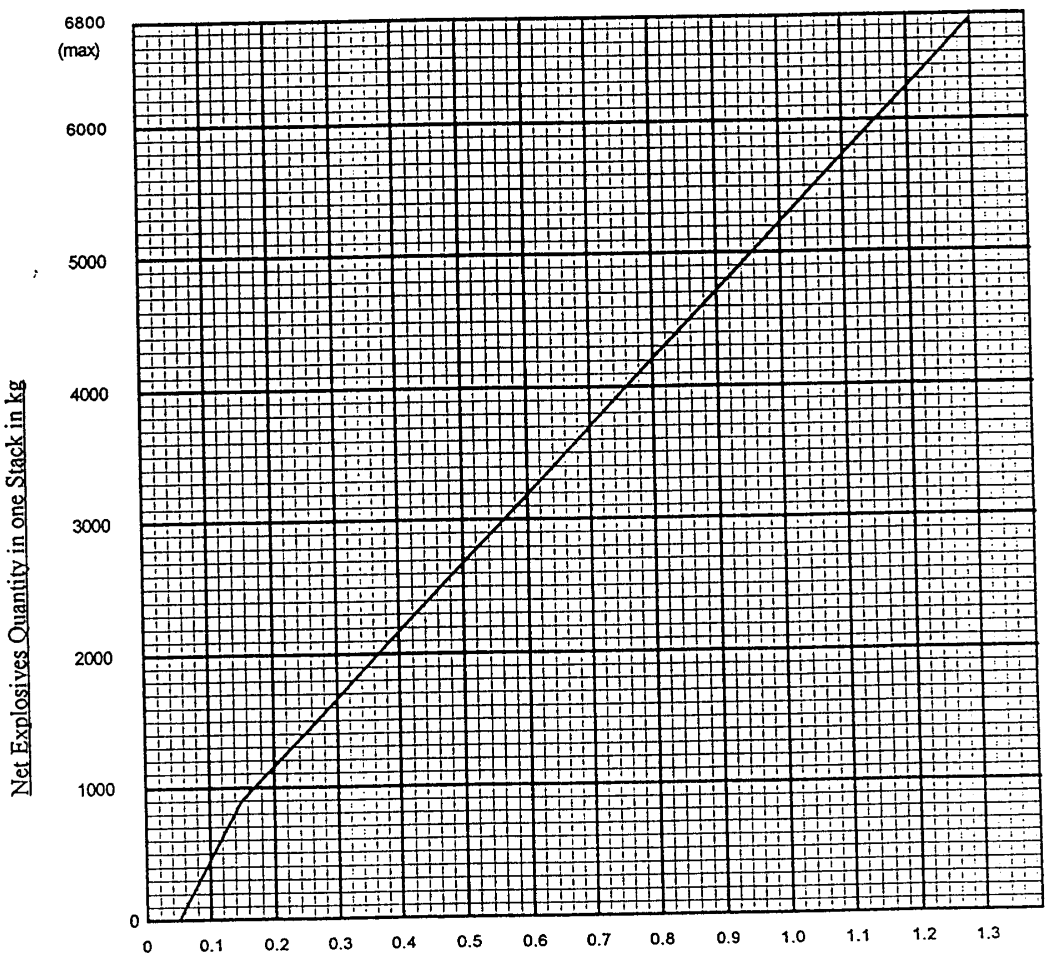
2.3.5.1. *General*

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.



Nose-to-Nose or Base-to-Base distances in m

Figure 3 -II Determination of Barricade Height on Level Terrain

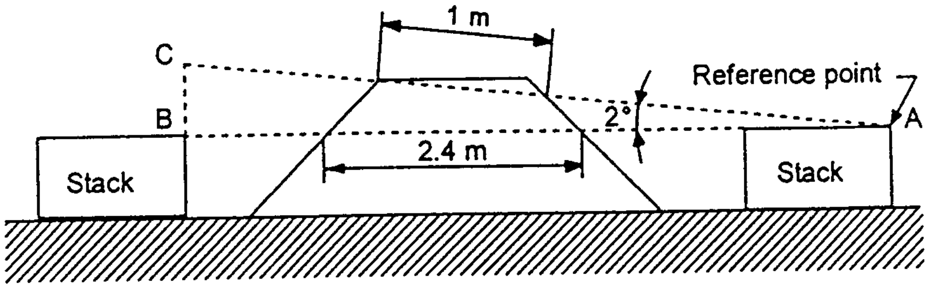


Figure 3 -III Determination of Barricade Height on Sloping Terrain

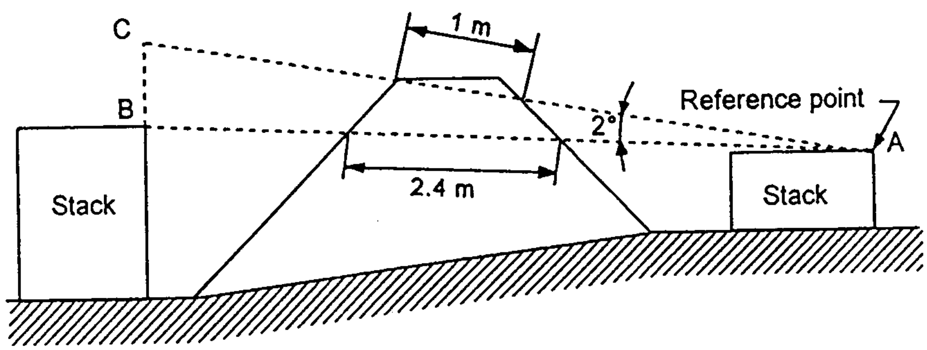


Figure 3 -IV Determination of Barricade Lenght

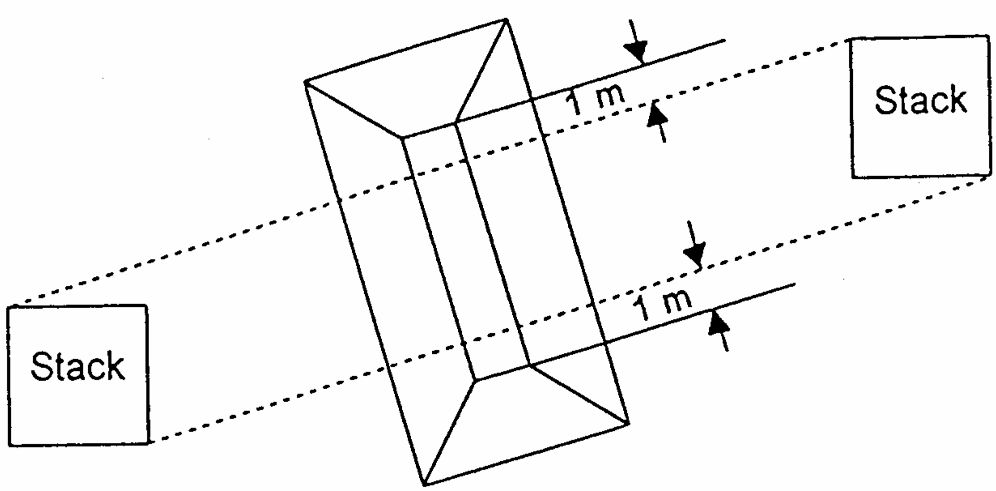


Figure 3 - V Zone of protection of a horizontal suspended air termination network (ridge network)

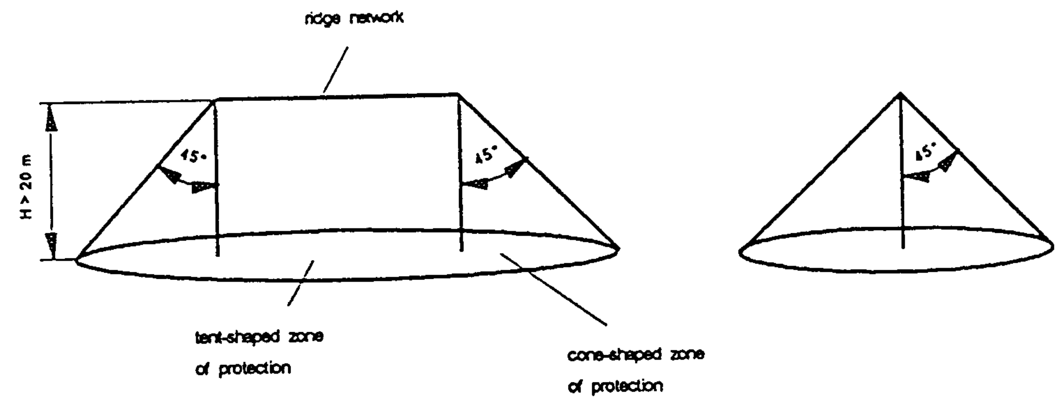


Figure 3 - VI
Schematic presentation of an earth-covered magazine with interconnecting reinforced steel

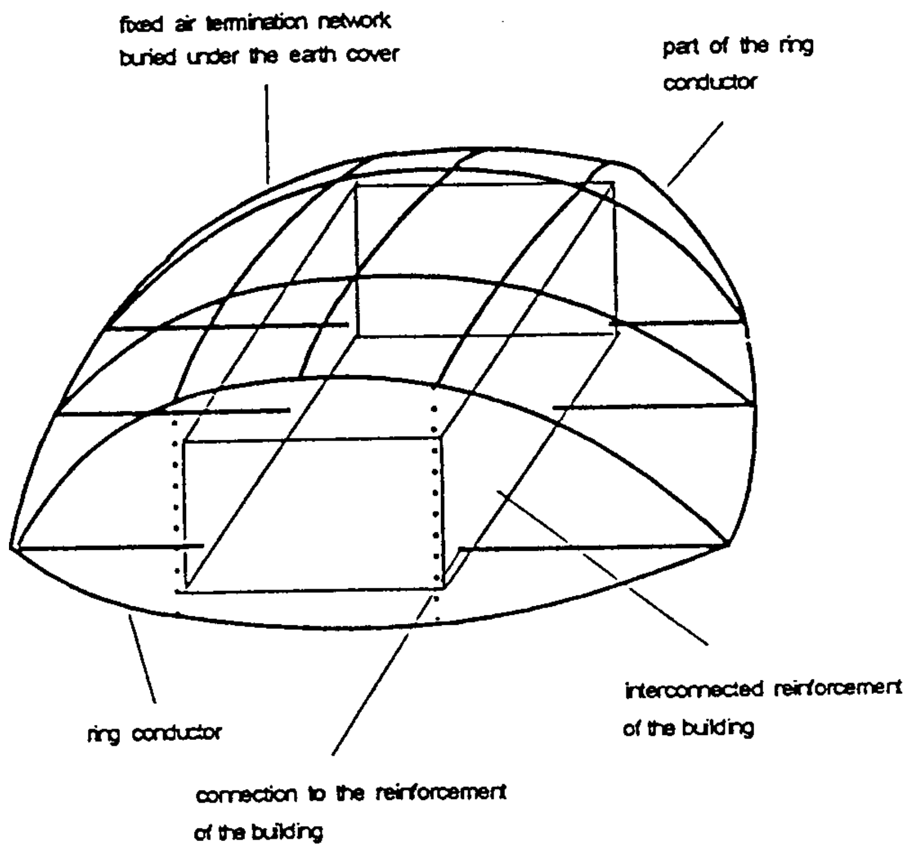


Figure 3 - VII

Lightning protection system for open stacks of ammunition

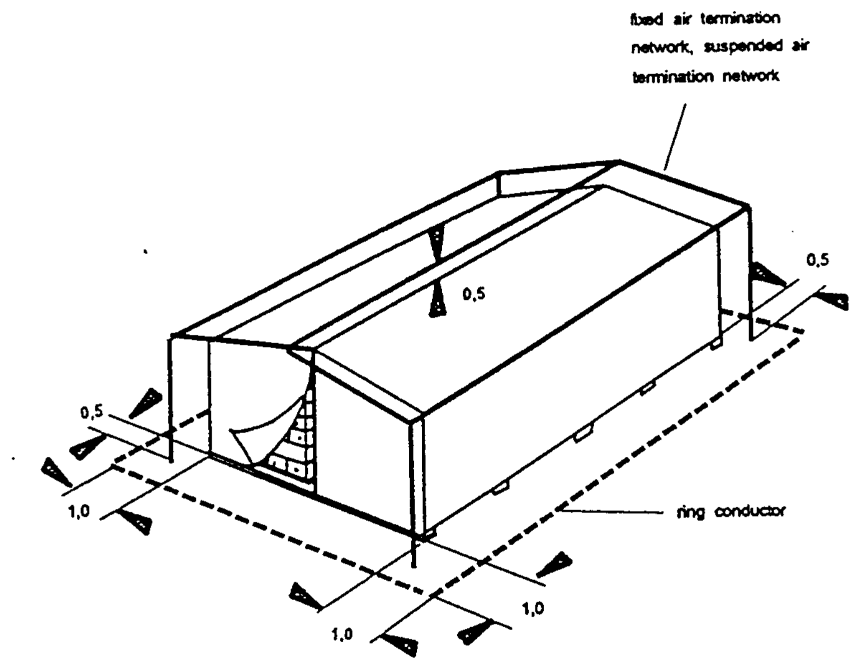
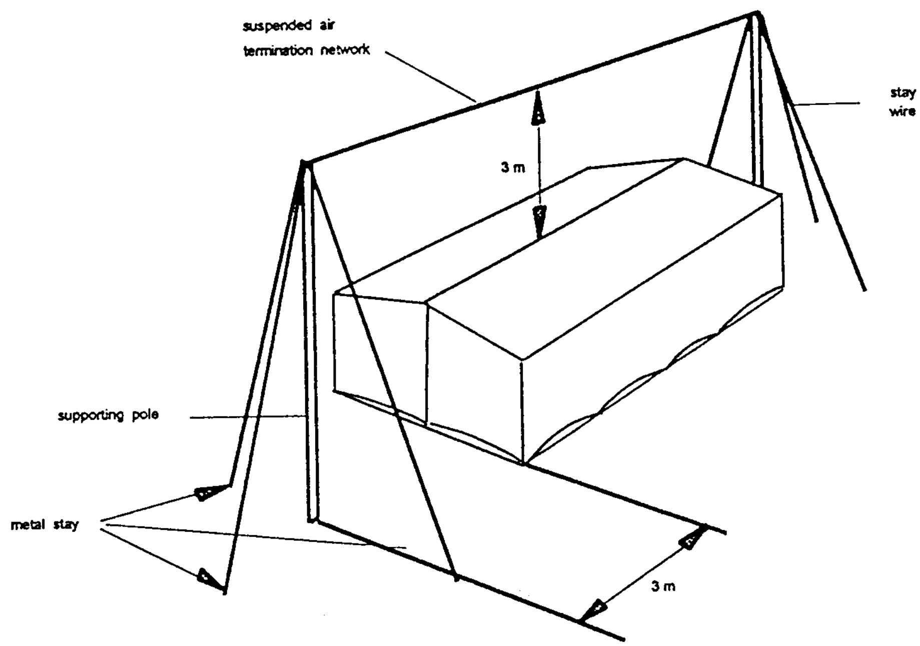


Figure 3 - VIII

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



CHAPTER 4

Reserved

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

SYMBOL	DIMENSION	DESCRIPTION
GOF		Terrain surface
g	(9.81 m/s^2)	Gravity acceleration
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	($Pa\text{-}s/kg^{1/3}$)	Scaled positive side-on impulse
i_r	($Pa\text{-}s/kg^{1/3}$)	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

SYMBOL	DIMENSION	DESCRIPTION
PES	(-)	Potential explosion site
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	(^{o}C)	Ambient temperature
$T_{a,s}$	(^{o}C)	Ambient temperature at standard sea level
T_c, t_c	(s)	Clearing time of blast wave at target
T_o	(K)	Temperature

SYMBOL	DIMENSION	DESCRIPTION
T_r, t_r	(s)	Time of load increase
t	(s)	Time
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

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.

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

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

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.

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 $I \leq 100$ 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)**

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.

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.

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

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.

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.

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.

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.

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])

t

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

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

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

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

eq [5-09]

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

eq [5-10]

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.

$$Q_{TNT,e} = \left[\frac{E^d{}_{exp}}{E^d{}_{TNT}} \right] \cdot Q_{exp}$$

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^dexp (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

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.

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

- **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:

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

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

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:

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

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

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 **$Z \approx 10$ 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	$P_{so} = 0.435 \cdot \quad z^{(1\text{-}541)}$
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	$i_s = 0.263627 \cdot z^{(-1\text{-}027171)}$
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]**

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.

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)

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

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.

Basic equations

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

S Building height H_s or **0.5 · building width**, whichever is the smaller value
$L_{w,x}/L$ 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**

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

$L_{w,x} = U_{,x} \cdot t_{o,x}$ **(approximate value)** **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 ….

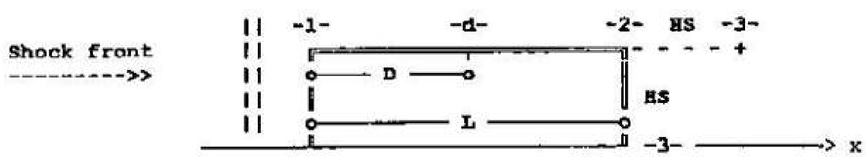
$$C = L_{w,x} / L$$

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

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

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

(4) **Determination of Characteristic Airblast Parameters**



Pos (x)	$P_{so,x}$ MPa	$I_{s,x}$ MPa-ms	$P_{r\,x}$ MPa	$I_{r,x}$ MPa-ms	$t_{a,x}$ ms	$t_{o,x}$ ms	$U_{,x}$ m/s	$L_{w,x}$ 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:**

$$t_{of} = \frac{2 \cdot I_s}{P_{so}} \quad \text{(ms)}$$

eq [5-32]

- **Pressure duration, reflected overpressure:**

$$t_r = \frac{2 \cdot I_r}{P_r} \quad \text{(ms)}$$

eq [5-33]

- **Dynamic impulse:**

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

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

- **Duration of peak reflected overpressure:**

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

- **Total impulse:**

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

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

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

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

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

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

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

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

- **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:**

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

- **Pressure drop constant:**

$\beta \approx Po / Io$ (---) **eq [5-35]**

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

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

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

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

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

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

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

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

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

- 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**

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

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

<u>Rear Wall</u>

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]** ...

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

. . . Determination of factors $\mathbf{C_E}$ and **D/L** or **D** as functions of the ratio $\mathbf{L_{w,3} / H_s}$ 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: $P_o = C_E \cdot P_{so,3} + C_D \cdot q_{o,3}$

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

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

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

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

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

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.

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.

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

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.

Fragment Mass Distribution

(1) **Constant**

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

B_x $(kg^{1/2})$ / $(m^{7/6})$	explosive constant in accordance with **Table [5-6]**
t_c (m)	casing thickness
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 N_f, individually heavier than a defined mass M_f, as a function of M_f. Such a function may be derived directly from the results obtained by testing or determined analytically using the Mott distribution:

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

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

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

Total number of fragments:

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

Mass of nominal fragment for design purpose:

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

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

Number of fragments individually heavier than M_f :

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

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.

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 :

$$V_o = G / ((M_c/_{Mex}) + (n/ (n+2)))^{1/2}$$ **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] :**

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

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

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

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

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

$\mathbf{V_i = V_o \cdot e^{(-(0.004 \cdot R_e \cdot / M_f^{(1/3)})}}$ **(m/s)** **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. $\boldsymbol{a_i} = \mathbf{90^o}$, 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: $\mathbf{E_{kin} = E_i = \frac{M_f \cdot V_i^2}{2}}$ **(J)** **eq [5-47]**

Impact impulse: $\mathbf{I_i = M_f \,.\, V_i}$ **(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 $\mathbf{q_f}$ of fragments is given by:

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

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 $\mathbf{N_E}$.

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

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

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

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

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

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.

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:

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

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

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

. . . $\mathbf{A_T \approx 0.56\ m^2}$

(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:

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

- Impact impulse of the individual fragment:

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

- 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

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.

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

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

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

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

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

Notes:

- Whichever gives the smaller value of $\mathbf{M_f}$ will be used.
- For **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:

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

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

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 . . .

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

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**

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

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

$$M_g = f_1 . V_i \quad (to)$$

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

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

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

Estimates: **$M_m \approx 0.0$** **mines and high explosive**
$M_m \approx 0.25 \cdot V_i$ **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]) …

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

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**

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

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

  $$M_g = f_1 \cdot V_i \quad \text{(to)}$$

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

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

- **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) <u>**Ballistics**</u>

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.

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. .

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

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 . . .

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

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

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

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

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

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

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:

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

. . . 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

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**

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.

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

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.

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.

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

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.

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.

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.

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])

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

<u>Decisive Parameters</u>

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.**

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.

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.

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:

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

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

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.

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 . . .

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

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

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:

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

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:

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

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

	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

$$R_{a,f} = \frac{C}{2} \cdot NEQ_{TNT}^{1/3} \quad (m)$$ **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

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

(3) **Burst Inside a Detached Aboveground Magazine**

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

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

with eq [5-67] . . .

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

(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 **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:

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

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

(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.

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

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

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 . . .

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

. . . 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.

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

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]

Type of Injury / Position	P %	T_o ms	P_s Mpa	I_s MPa-ms	Ref
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	**1** **50** **99**		**0.035** **0.044** **0.086**		**[74]** **[4]**
-Temporary loss of hearing			**< 0.035**		
-Threshold inside a shelter			**> 0.017**		
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		**2.4**	
Injury		**3.0-3.6**	**[19]**
Fracture		**3.6-4.8**	

SITTING PERSON			
No Effect		**2.4**	**[19]**
Injury		**4.5-7.8**	

PUNCH against entire ABDOMINAL WALL	**1**	**3.0**	
	50	**7.8**	**[19]**
Injury	**99**	**9.0**	

(-->> Figure [5-27]

SKULL INJURY; FRACTURED SKULL BASE	**1**	**3.0**	
	50	**5.5**	
Blunt Impact	**99**	**9.0**	**[4]**
Edgewise Impact		**< 3.0**	

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 ($58 \text{ ft/lb}_f$)**

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

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

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 ($kW \cdot s / m^2$			
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

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]

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).

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^$^{1/3}$)**		
	(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 . small engines > 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

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

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**

Ref [1], [3], [4], [9], [10], [18], [19], [20], [21], [22], [23], [31], [33], [118], [119], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [157], [203], [205], [206]

Section IX - References/PC Codes/Figures/Tables

2.5.8.1 References

[1] **TM 5-855-1 FUNDAMENTAL OF PROTECTIVE DESIGN**
USAWES/CoE
U.S. Army Waterways Experiment Station
Vicksburg, Mississippi USA November 1986

[2] **TM 5-855-1 /FUNDAMENTAL OF PROTECTIVE DESIGN / Edition 1991, PC-Programm**
Hyde,David,W
USAWESCoE /Department of the Army
Washington DC USA October 1989

[3] **PROTECTIVE CONSTRUCTION DESIGN MANUAL / ESL-TR-87-57 Final Report**
Drake,J.L;Twisdale,R,A;Frank,W,C;Dass,C,E; et al
AFESC / Engineering & Services Laboratory
Tyndall AFB,FL USA November 1989

[4] **STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS / TM 5-1300**
Department of the Army, the Navy and the Air Force
TM 5-1300, NAVFAC P-397, AFR 88-22
Washington DC USA November 1990

[5] **AIRBLAST PARAMETERS FROM TNT SPHERICAL AIR BURST AND HEMISPHERICAL SURFACE BURST /ARBRL-TR-02555**
Kingery,C,N; Bulmash,G
Ballistic Research Laboratory, ARBRL-TR-02555
Aberdeen ProvGr,MD USA April 1984

[6] **ENGINEERING DESIGN HANDBOOK - PRINCIPLES OF EXPLOSIVE BEHAVIOR**
US Army Materiel Command, Headquarters
US Army Materiel Command, AMCP 706-180
Washington DC USA April 1972

[7] **STRUCTURAL DYNAMICS**
Biggs,John,M
McGraw Hill, ISBN 07-005255-7
New York USA 1964

[8] **DESIGN OF STRUCTURES TO RESIST NUCLEAR WEAPONS EFFECTS**
ASCE
American Society of Civil Engineers ASCE No 42
USA

[9] **SCHWEDISCHES SCHUTZBAUHANDBUCH / FORTH 1**
FORTF
Schwedische Schutzbauverwaltung /Fortifikationsförvaltningen, Forskningsbyran
Stockholm Sweden 1987

[10] **MILITÄRISCHE SPRENGTECHNIK - LEHRBUCH -**
Autorenkollektiv
Militärverlag DDR
Berlin Germany 1984

[11] **JOINT MUNITIONS EFFECTIVENESS MANUAL - AIR TO SURFACE - TARGET VULNERABILITY (U) - BOOK 1 OF 2**
US DOD -SECRET-
US Department of Defense
USA 1986

[12] **STRUCTURAL DESIGN FOR DYNAMIC LOADS**
Norris,C,H et al
McGraw-Hill
USA 1959

[13] **DYNAMIC PROPERTIES OF RESIDENTAL STRUCTURES SUBJECTED TO BLAST LOADING**
Dowding,C,H
Journal for the Hydraulic Division,ASCE, Vol 107, ST7
USA 1981

[14] **PRINCIPLES AND PRACTICES FOR DESIGN OF HARDENED STRUCTURES**
Newmark,N,M et al
US Department of Commerce, AB-295 408,
USA 1962

[15] **DYNAMICS OF STRUCTURES**
Clough,R,W;Penzien,J
McGraw-Hill
USA 1975

[16] **APPROXIMATE FORMULATE FOR PERIOD OF VIBRATIONS OF BUILDING SYSTEMS**
Adeli,H
Civil Engineering for Practising and Design Engineers, Vol 4
USA 1985

[17] **THE DYNAMICS OF EXPLOSION AND ITS USE**
Henrych,Josef
Technical University of Prague, Building Research Institute
New York USA 1979

[18] **HANDBUCH DER WAFFENWIRKUNGEN FÜR DIE BEMESSUNG VON SCHUTZBAUTEN**
Schindler,G;Haerter,A
Arbeitsgruppe für den baulichen Zivilschutz
Bern Switzerland 1964

[19] **VAPENVERKAN FORTH 1 - SCHWEDISCHES HANDBUCH FÜR WAFFENWIRKUNGEN -**
MOD Schweden
Schwedische Schutzbauverwaltung / MOD Schweden
Stockholm Sweden June 1973

[20] **FEUERBALLMESSUNGEN UND FEUERBALLDAUER**
Janser,P
Basler & Partner, Gruppe für Rüstungsdienste
Zürich Switzerland May 1981

[21] **THERMAL RADIATION FLUX OF FIREWORKS**
Harmanny,A
Prins Maurits Laboratorium, Report Nr T 1022 / 02/84
Den Haag Netherlands February 1984

[22] **DESIGN AND SITING OF BUILDINGS TO RESIST EXPLOSIONS AND FIRE**
Oyer Publishing Limited
London United Kingdom 1980

[23] **COMBUSTION OF GUN PROPELLANT IN IGLOO - THERMAL FLUX MEASUREMENTS**
Allain,L
SNPE-Defense Espace-Direction de la Technologie et de la Recherche;NT153/91/CRB-S/TS/NP
Vert-le-Petit France December 1991

[24] **PROJECTILE PENETRATION IN SOIL AND ROCK. ANALYSIS FOR NON-NORMAL IMPACT. - TECHREP SL-79-15 -**
Bernard,R,S
USAEWES, VICKSBURG, MS
Vicksburg, MS USA 1979

[25] **DEPTH AND MOTION PREDICTION FOR EARTH PENETRATORS - TECHREP S-78-4 -**
Bernard,R,S
USAEWES
Vicksbury,MS USA 1978

[26] **PENETRATION DEPTH OF CONCRETE FOR NONDEFORMABLE MISSILES.**
Haldar,A;Miller,F,J
School of Civil Engineering, Georgia Institute of Technology
Atlanta USA 1982

[27] **ASSESSMENT OF EMPERICAL CONCRETE IMPACT FORMULAS.**
Sliter,G
Journal of the Structural Division
USA 1980

[28] **CRATERING BY EXPLOSIONS - A COMPENDIUM AND AN ANALYSIS**
Rooke,A,D; Carnes,B,L; Davis,L,K
US Army Waterways Experiment Station, TR-N-74-1
Vicksburg,MS USA January 1974

[29] **DIAL PACK : CRATER AND EJECTA**
Rooke,A,D; Meyer; Conway
US Army Waterways Experiment Station, MP-N-72-9
Vicksburg,MS USA December 1972

[30] **EXPLOSIVE EXCAVATION TECHNOLOGY**
Johnson,S,M
US Army Engineer Nuclear Crater Group, NCG TR-Nr 21
USA June 1971

[31] **LETALITÄT VON PERSONEN INFOLGE KRATERAUSWUFS**
Basler & Partner
Basler & Partner, B 3113-2,Grp Für RüDst
Zürich Switzerland October 1984

[32] **GRÖSSE UND AUSWURFMASSEN VON KRATERN IN LOCKERGESTEIN BEI OBERFLÄCHENDETONATIONEN**
Basler & Hofmann
Baserl & Partner
Zürich Switzerland April 1979

[33] **TRÜMMERMASSENDICHTE UND MAXIMALE TRÜMMERFLUGWEITE BEIM KRATERAUSWURF**
Basler & Hofman
Basler & Partner
Zürich Switzerland January 1980

[34] **ESTIMATES OF CRATER DIMENSIONS FOR NEAR-SURFACE EXPLOSIONS**
Copper,H,J
R & D ASSOCIATES - RDA-TR-2604-001
USA 1976

[35] **DEFORMATIONAL ANALYSIS OF SEVERAL REPRESENTATIVE LARGE-SCALE CRATERS**
Tremba,E
US Air Force Weapons Laboratory - AFWL-TR-79-159
USA 1981

[36] **DIAL PACK: CRATER AND EJECTA. MEASUREMENT FROM A SURFACE-TANGENT DETONATION ON A LAYERED MEDIUM. * PAPER N-72-9 ***
Rooke;Meyer:Conway
U.S. AWEWS
Vicksbury, MS USA 1972

[37] **CRATER AND EJECTA DATA FROM THE DETONATION OF A 100 TON SPHERICAL CHARGE OF TNT TANGENTIAL TO THE SURFACE.**
Diehl,C,H,H;Pinnell,J,H;Jones,G,H,S
Canada Defence Research Establishment Suffield
Ralston,Alberta Canada 1968

[38] **CRATER AND EJECTA DATA FROM THE DETONATION OF A 40 000 LB SHERICAL CHARGE OF TNT TANGENTIAL TO THE SURFACE**
Diehl;Pinell
Canada Defence Research Establishment Suffield
Ralston,Alberta Canada 1968

[39] **THE FORMATION OF A CRATER AS OBSERVED IN A SERIES OF LABORATORY-SCALE CRATERING EXPERIMENTS**
Bening,R,B;Kurtz,M,K
U.S. Army Corps of Engineers
Livermore,CA USA 1967

[40] **KRATERVERSUCHSREIHE - MIDDLE COURSE II - AUSWERTUNG**
Sprague,K,E
USAEWES, VICKSBURY, MS
Vicksbury,MS USA 1973

[41] **FRAGMENT AND DEBRIS HAZARDS**
Department of Defense Explosives Safety Board
DODESB
USA 1975

[42] **RESPONSE OF BURIED STRUCTURES TO EARTH-PENETRATING CONVENTIONAL WEAPONS / ESL-TR-85-09**
Baylot,J,T;Kiger,S,A;Marchand,K,A;Painter,J,T
USAWES / AFESCS
Tyndal AFB,FL USA November 1985

[43] **BLAST RESPONSE TESTS OF REINFORCED CONCRETE STRUCTURES / METHODS FOR REDUCING SPALL**
Cotharp,D,R;Kiger,S,A;Vitayandon,K,P
2nd Symposium on Interaction of Non-Nuclear Munitions with Structures 1985
Panama City, Florida USA April 1985

[44] **THE DEPENDENCE OF BLAST ON AMBIENT PRESSURE AND TEMPERATURE**
Sachs,R,G
Ballistic Research Laboratory, Report 466
Aberdeen ProvGrd,MD USA 1944

[45] **BLAST PARAMETERS FROM CYLINDRICAL CHARGES DETONATED ON THE SURFACE OF THE GROUND**
Guerke,G;Schecklinski-Glück,G
Ernst Mach Institut
Freiburg Germany June 1983

[46] **SOME EFFECTS OF LIGHT SURROUNDS AND CASINGS ON THE BLAST FROM EXPLOSIVES**
Dewey,J,M; Johnson,O,T; Patterson,J,D
Ballistic Research Laboratories Report No 1218
Aberdeen PrvGrd,MD USA September 1963

[47] **AN IMPROVED COMPUTER PROGRAM TO CALCULATE THE AVERAGE BLAST IMPULSE LOADS ACTING ON A WALL OF A CUBICLE.**
Levy,S
TR 4070
Dover,NJ,Picatinny Arsen. USA May 1970

[48] **EFFECTS OF FRANGIBLE PANELS ON INTERNAL GAS PRESSURES**
Tancreto,J,E; Helseth,E,S
21st Explosives Safety Seminar, DODESB
USA August 1984

[49] **EFFECTS OF COMBUSTIBLES ON INTERNAL QUASI-STATIC LOADS**
Sandoval,N,R; Hokanson,J,C; Esparza,E,D; Baker,W,E
21st Explosives Safety Seminar, DODESB
USA August 1984

[50] **BARRICADED AND UNBARRICADED BLAST MEASUREMENTS**
Wentzel,A,B; Bessey,R,L
Southwest Research Institute, Contract No DAHC04-69-C-0028
USA October 1969

[51] **AIRBLAST LOADING OF WALL PANELS**
Forsén, Rickard
Försvarets Forskningsanstalt FOA Rapport C20586-D6
Stockholm Sweden 1985

[52] **OBERFLÄCHENDETONATIONEN VON EXPLOSIVSTOFFLADUNGEN**
Gürke,G; Schecklinski-Glück,G
EMI-Berichte 6/82,12/85,15/85,16/85,17/85,19/85
Freiburg Germany 1985

[53] **DER LUFTSTOSS VON HEXOGENZYLINDERN MIT STAHLHÜLLEN - Casing Faktoren**
Gürke,G
EMI-Bericht 13/88
Freiburg Germany 1988

[54] **TNT-ÄQUIVALENTFAKTOREN FÜR PROJEKTILE UNTER BERÜCKSICHTIGUNG VON FORM- UND CASINGFAKTOREN**
EMI-Bericht V 2/84
Freiburg Germany 1984

[55] **TNT-ÄQUIVALENT**
Held,M
Pyrotechnics 8 pp. 158-167 (1983)
Schrobenhausen Germany 1983

[56] **THE EFFECTS OF EARTH COVER ON THE RESPONSE OF REINFORCED CONCRETE SLABS**
Kiger,S,A
US Army Waterways Experiment Station
Vicksbury,MS USA September 1984

[57] **ULTIMATE CAPACITY OF EARTH-COVERED SLABS**
Kiger,S,A
Journal of Structural Engineering 114(1988)10
Vicksburg USA October 1988

[58] **THE RESPONSE OF REINFORCED CONCRETE STRUCTURES UNDER IMPULSIVE LOADING**
Millavec,W,A; Isenverg,J
Weidlinger Associates
Menlo Park,CA USA

[59] **SYSTEMS FOR SHIELDING ABOVEGROUND STRUCTURES FROM NEAR-HIT BOMB DETONATIONS**
McVay,Mark,K
US Army Division, West Germany, ESL-TR-88-83
USA January 1989

[60] **BLAST LOADING OF CLOSURES FOR USE ON SHELTERS - PART I -**
Coulter,G,A
Ballistic Research Laboratories,ARBRL-MR-03279
Aberdeen PrvGrd,MD USA June 1983

[61] **UNTERSUCHUNG DER DETONATIONSÜBERTRAGUNG MITTELS DES BLASTMESSVERFAHRENS DER WTD91-DEZ 334. - SPRENGUNG MATRA UND MK82 -**
Böhlke
BWB / WTD91
Meppen Germany 1987

[62] **AIR BLAST PARAMETERS VERSUS DISTANCE FOR HEMISPHERICAL TNT SURFACE BURSTS**
Kingery,C,N
Ballistic Research Laboratories BRL-Report No 1344
Aberdeen PrvGrd,MD USA September 1966

[63] **BLAST ENVIRONMENT FROM FULLY AND PARTIALLY VENTED EXPLOSIONS IN CUBICLES**
Keenan,W,A;Tancreto,J,E
CEL Technical Report R-828
Port Hueneme,CA USA November 1975

[64] **EXPERIMENTS USED FOR COMPARISON OF BLAST DAMAGE TO FULL SCALE AND ONE FOURTH SCALE REINFORCED CONCRETE STRUCTURES**
Forsén,R
PAPER DODES Seminar
St. Louis USA August 1990

[65] **REVISED AIRBLAST PREDICTIONS FOR EARTH-COVERED IGLOOS**
Swisdak,M jr
Naval Surface Warfare Center, 9 January, 1992
USA November 1982

[66] **BLAST EFFECTS FROM CYLINDRICAL EXPLOSIVE CHARGES; EXPERIEMENTAL MEASUREMENTS**
Plooster,M,N
Naval Weapons Center, NWC TP 6382
USA November 1982

[67] **EFFECTS OF TERRAIN ON BLAST PREDICTION METHODS AND PREDICTIONS**
Scientific Services Inc.
Ballistic Research Laboratories, ARBRL-CR-00355
Aberdeen PrvGrd,MD USA January 1978

[68] **EFFECTS OF TERRAIN ON BLAST WAVES**
Keefer,J,H;Watson,G,T;Coulter,G,A;King,V,L
Ballistic Research Laboratories, ARBRL-MR-02949
Aberdeen PrvGrd,MD USA August 1979

[69] **EXPLOSION AIR BLAST PREDICTIONS ON A PERSONAL COMPUTER AND APPLICATIONS TO THE HENDERSON, NEVADA, INCIDENT**
Reed,J;W
23rd DOD Explosives Safety Seminar
USA August 1988

[70] **REFLECTED OVERPRESSURE IMPULSE ON A FINITE STRUCTURE**
Kingery,C,N
Ballistic Research Laboratories ARBRL-TR-02537
Aberdeen, PrvGrd,MD USA 1983

[71] **TEST DATA REPORT FOR DEVELOPMENT OF CRITERIA FOR DESIGN BLAST LOADS - BEHIND A BLAST DEFLECTOR WALL -**
Beyer,B
Naval Civil Engineering Laboratory/NCEL TM 51-8605
USA 1986

[72] **EXPLOSIONS IN AIR**
Baker,W,E
University of Texas Press
Austin,Texas USA 1973

[73] **AIRBLAST MEASUREMENTS AND EQUIVALENCY FOR SPHERICAL CHARGES AT SMALL SCALED DISTANCES**
Esparza,E,D
22 nd Department of Defense Explosives Safety Seminar
San Antonio,Texas USA August 1986

[74] **DAMAGE-RISK CRITERIA FOR PERSONNEL EXPOSED TO REPEATED BLASTS**
Richmond,D,R et al
20th DODES Seminar
Norfolk,VA USA August 1982

[75] **MODEL STUDIES OF EXPLOSIVE STORAGE CUBICLES**
Altman,F,D
Naval Weapons Laboratory, Report 1917
USA May 1964

[76] **TECHNISCHE RICHTLINIEN FÜR DIE SICHERHEITSBEURTEILUNG VON MUNITIONSLAGEREINRICHTUNGEN**
Basler und Partner
Ernst Basler und Partner
Zürich Switzerland December 1983

[77] **MODELLVERSUCHE FÜR OBERIRDISCHE EXPLOSIVSTOFFMAGAZINE, Teil III - Auswertung und Resultate -**
Basler & Partner
Amt für Bundesbauten, Abt. Ingenieurwesen, Bern
Zürich Switzerland March 1980

[78] **PROPAGATION AMONG EARTHCOVERED MAGAZINES**
Basler & Partner
Basler & Partner
Zürich Switzerland January 1986

[79] **BLAST LOADING ON ABOVE GROUND BARRICADED MUNITION STORAGE MAGAZINES**
Kingery, Bulmash, Muller
Ballistic Research Laboratories, ARBRL-TR-02557
Aberdeen PrvGrd,MD USA May 1984

[80] **ANALYSIS AND DESIGN RECOMMENDATIONS FOR THE HAYMAN IGLOO CONVENTIONAL WEAPONS STORAGE FACILITY**
Lawoer,D,J
4th International Symposium on Interaction of Non-Nuclear Munitions with Structures 1989
Panama City,Florida USA April 1989

[81] **EFFECT OF LOW LOADING DENSITY ON BLAST PROPAGATION FROM EARTH COVERED MAGAZINES**
Kingery,C; Coulter,G
Ballistic Research Laboratories, ARBRL-TR-02453
Aberdeen PrvGrd,MD USA December 1982

[82] **BLAST LOADING IN EARTH COVERED MAGAZINES**
Kingery,C
Ballistic Research Laboratories, ARBRL-TR-02092
Aberdeen PrvGrd,MD USA August 1978

[83] **DESIGN CRITERIA FOR SOIL COVER OVER BOX MAGAZINES**
Keenan,W,A
DODES 19th Explosives Safety Seminar
Los Angeles,CA USA September 1980

[84] **BLAST PARAMETER FROM EXPLOSIONS IN MODEL EARTH-COVERED MAGAZINES**
Kingery,C; Coulter,G; Watson,G,T
Ballistic Research Laboratories, ARBRL-MR-2680
Aberdeen PrvGrd,MD USA September 1976

[85] **EXPLOSIVE SAFETY SITING OF CORPS OF ENGINEERS STANDARD IGLOO DESIGNS**
Williams,Earl,H; Farsoun,Adib; Watanabe,Wallace
DODES, Minutes of 24th Explosives Safety Seminar
St Louis,Missouri USA August 1990

[86] **JOINT AUSTRALIAN/UK STACK FRAGMENTATION TRIALS - PHASE 4, Test 1 -**
Henderson,J
ESTC Report No. 1/91
London UK November 1990

[87] **BLAST PRESSURE QUANTITY DISTANCE REDUCTIONS FOR DOUBLE BAY UK RC-BOX IGLOOS**
Connell,M; Poynton,J
Ref UB 822/12/1/3 MC, DCES,EEB
Croydon CR9 3RR UK January 1991

[88] **A REEXAMINATION OF THE AIRBLAST AND DEBRIS PRODUCED BY EXPLOSIONS INSIDE EARTH-COVERED IGLOOS**
Swisdak,Michael,M jr;
Naval Surface Warfare Center / Explosion Dynamics Branch
White Oak,MD USA January 1991

[89] **MANUAL ON NATO SAFETY PRINCIPLES FOR THE STORAGE OF AMMUNITION AND EXPLOSIVES 1976/77 /AC/258-D/258**
NATO Group of Experts on the Safety Aspects of Transportation and Storage of Mil.Ammo and Explosives
Brussels Belgium October 1976

[90] **MUNITIONSLAGERUNG - AC/258 (ST) WP/154 (2nd REVISE)**
AC/258
NATO / North Atlantic Council, Working Paper 154
Brussels Belgium 1988

[91] **REDUCED QUANTITY DISTANCES FROM EARTH-COVERED IGLOOS**
NATO
Ref: NATO/AC258-US (ST) IWP/13-82, 8 October 1982
Brussels Belgium October 1982

[92] **DATA SUPPORTING REDUCED QUANTITY DISTANCES FOR EARTH-COVERED IGLOOS**
NATO
Ref: NATO/AC258-US-(ST) IWP78-83, 3 August, 1983
Brussels Belgium August 1983

[93] **IGLOO TRIAL (45000 KGS COMP B IN 8 x 18M STEEL ARCH IGLOO)**
NATO
TRP401 NOTS3843 (TEST 6)
Brussels Belgium July 1965

[94] **REDUCED QUANTITY DISTANCES (QDs) FROM EARTH-COVERED IGLOOS, FAR FIELD BLAST DATA FROM UK MODEL TRIALS IN 1976 AND 1971**
NATO
Ref: NATO/AC258-UK (ST) IWP 144, 18.Juni 1984
Brussels Belgium June 1984

[95] **NEW MODEL IGLOO TRIALS**
UK MOD
P&EE REPORT NO SXR/662/013,30.12.1971
London UK December 1971

[96] **BLAST AND PROJECTIONS FROM MODEL IGLOOS**
UK MOD
P&EE REPORT NO ETN 124/76, 25.03.1977
London UK March 1977

[97] **WES AIR BLAST DIAGNOSTIC MEASUREMENTS USING HDAS SELF-RECORDING TECHNOLOGY**
Ingram,J;Franco,R jr
SFTP4S1 EVENT, WES AIRBLAST RECORDS FOR STACK TRIALS PHASE 4-TEST1
Woomera Australia August 1990

[98] **COALESCED DEFENCE TRIALS 6/445 EXPLOSIVE STOREHOUSE DESIGN AND 6/447 STACK FRAGMENTATION PHASE 4-STAGE ONE, 22.MAY-5.JUNE 1990**
OSD-WSR Laboratory Australia 18 October, 1990, OSD Results, Stage 2, bare Stack Far Field pressure
Australia October 1990

[99] **ESKIMO IV TEST RESULTS**
Tafoya,P,E
NCEL TR R889
Port Hueneme USA November 1981

[100] **MODULAR IGLOO TEST**
Lewis,M et al
SWRI No 06-247D, THE HAYMAN IGLOO TEST
USA March 1989

[101] **AN AUDIT OF THE QDs TO EXPOSED SITES AT DISTANCES BETWEEN 8Q^1/3 AND 22.2Q^1/3 FROM EARTH-COVERED BUILDINGS CONTAINING AMMUNITION AND EXPLOSIVES OF HAZ.DIV 1.1**
Cantrell,F LtCol
Ref: NATO AC/258-UK (ST) IWP 195, RMCS TR DR/9
Brussels Belgium November 1987

[102] **AMMUNITION AND EXPLOSIVES SAFETY STANDARDS, DOD 6055.9-STD**
US MOD
DOD 6055.9-STD, change 2, 28 October, 1988
Washington USA October 1988

[103] **SCALE MODEL IGLOO MAGAZINE TESTS**

ASESB Technical Paper No 4, AD 223 342
USA August 1946

[104] **IGLOO AND REVETMENT TESTS**
ASESB Technical Paper No 5
USA October 1946

[105] **SUMMARY REPORT OF EARTH COVERED, STEEL-ARCH MAGAZINE TESTS**
Sound,A,R
NOTS TP 3843, AD 619 241
USA July 1965

[106] **ESKIMO I MAGAZINE SEPARATION TEST**
Weals,F,H
NWC TP 5430, April 1973
USA April 1973

[107] **ESKIMO II MAGAZINE SEPARATION TEST**
Weals,F,H
NWC TP 5557, September 1974
USA September 1974

[108] **ESKIMO III MAGAZINE SEPARATION TEST**
Weals,F,H
NWC TP 5771, February 1976
USA February 1976

[109] **ESKIMO IV MAGAZINE SEPARATION TEST**
Weals,F,H;Wilson,C,H
NWC TP 5873, March 1977
USA March 1977

[110] **ESKIMO V MAGAZINE SEPARATION TEST**
Weals,F,H;Finder,B
NWC TP 6076, February 1979, AD A070 918
USA February 1979

[111] **ESKIMO VII: TEST DATA REPORT**
Murtha,R,N;Beyer,M,E
NCEL TM 51-86-26
USA December 1986

[112] **MK82 BUFFERED STORAGE TEST SERIES:PART I -- TECHNICAL REPORT**
Lewis,M,J;Friesenhahn,G,J;Nash,P,T
MMW-TR-87-C77865A
USA December 1988

[113] **MK82 BUFFERED STORAGE TEST SERIES:PART II -- TECHNICAL REPORT**
Lewis,M,J;Friesenhahn,G,J;Nash,P,T
MMW-TR-87 C77865A
USA December 1988

[114] **MK84 BUFFERED STORAGE TEST SERIES: PART I -- TECHNICAL REPORT**
Lewis,M,J;Friesenhahn,G,J;Nasch,P,T
MMW-TR-87-50102AC
USA December 1988

[115] **MK84 BUFFERED STORAGE TEST SERIES: PART II - TECHNICAL REPORT**
Lewis,M,J;Friesenhahn,G,J;Nasch,P,T
MMW-TR-87-50102AC
USA December 1988

[116] **MODULAR IGLOO TEST : DATA REPORT**
Lewis,M,J;Friesenhahn,G,J;Nsh,P,T
MMW-TR-88-71002 AC
USA December 1988

[117] **HASTINGS IGLOO HAZARDS TESTS FOR SMALL EXPOSIVE CHARGES**
Reeves,H;Robinson,W
Ballistic Research Laboratories ARBRL-MR-03356
Aberdeen PrvGrd,MD USA May 1984

[118] **RESULTS OF AN EXPLOSION IN A SWEDISH MUNITION STORAGE**
Vretblad,Bengt;Eriksson,Siwet
FORTF,Sweden, Report C5:88
Stockholm Sweden August 1988

[119] **THE EXPLOSION IN THE ABOVEGROUND MAGAZINE AT SAIGNELEGIER ON OCTOBER 1, 1987**
Swiss Source
Schweizer Quelle
Switzerland 1988

[120] **QUANTITY DISTANCES FOR EARTH-COVERED MAGAZINES**
AstudÜbBw/BerSdAufgInfrastr
Amt für Studien und Übungen der Bundeswehr, Bericht (Report)
Bergisch-Gladbach Germany August 1981

[121] **VERSUCHE ZUR ERMITTLUNG DER BELASTUNG ERDEINGEDECKTER MUNITIONSLAGERHÄUSER (MLH)**
BMVg
Bundesminister der Verteidigung, Versuchsbericht (Test Report)
Bonn Germany 1981

[122] **EXPLOSIVE SAFETY REGULATIONS**
ESTC
ESTC Leaflet No 5 to 6
London UK December 1979

[123] **DESIGN CRITERIA FOR SOIL COVER OVER BOX-SHAPED AMMUNITION MAGAZINES**
Keenan,W,A;Nichols,L,C
CEL Technical Report R-878
Port Hueneme,CA USA May 1980

[124] **UNTERSUCHUNG DER BELASTBARKEIT VON MUNITIONSLAGERHÄUSERN (MLH-TYP CC) DER EHEMALIGEN WEHRMACHT IM MUNDP D.BW HOHENBRUNN**
Mett, Hans-Georg
Technischer Bericht des AStudÜbBw/BerSdAufgInfrastr (Technical Report)
Cologne Germany March 1990

[125] **VERSUCH DES NACHWEISES DER TRÜMMER-,SPLITTER- UND LUFTSTOSSGEFÄHRDUNG AUSSERHALB EINES FSB-GE 3.GEN NACH DETONATION KONVENTIONELLER MUNITION IM SHELTERINNENRAUM**
Mett, Hans-Georg
Technische Untersuchung (Technical Analysis)
Cologne Germany December 1987

[126] **UK (ST) IWP 240 - QUANTITY DISTANCES FOR STANDARD IGLOOS**
Henderson,J
UK-MOD; Explosives Storage and Transport Committee; AC 258 Storage Sub-Group
Bromley, Kent United Kingdom March 1992

[127] **UK (ST) IWP 241 - FURTHER INVESTIGATION OF QD REDUCTIONS FOR IGLOOS**
Henderson,J
UK-MOD; Explosives Storage and Transport Committee; AC 258 Storage Sub-Group
Bromley, Kent United Kingdom March 1992

[128] **JOINT AUS/UK STACK FRAGMENTATION TRIALS PHASE 3 REPORT**
Henderson,J
ESTC-REPORT No 2/90
Bromley, Kent United Kingdom November 1990

[129] **MODELLVERSUCHE FÜR OBERIRDISCHE EXPLOSIVSTOFFMAGAZINE, TEIL II - Daten und Fotodokumentation**
Basler & Partner
Amt für Bundesbauten, Abt. Ingenieurwesen, Bern
Zürich Switzerland August 1979

[130] **MODELLVERSUCHE FÜR OBERIRDISCHE EXPLOSIVSTOFFMAGAZINE, TEIL I - Konzeption und Durchführung**
Basler & Partner
Amt für Bundesbauten, Abt. Ingenieurwesen, Bern
Zürich Switzerland November 1979

[131] **ERMITTLUNG DER AUSWIRKUNGEN VON DETONATIONEN IM INNERN EINES FLUGZEUGSCHUTZBAUS DER 3. GENERATION - MODELLVERSUCHE M 1:3 (Teilberichte I bis III)**
Glaser; Wilkens et al
Wehrtechnische Dienststelle 91, Dezernat 131, Contr. No E/K47C/I1009/G5125 dated 12 July, 1988
Meppen Germany July 1988

[132] **UNTERSUCHUNG DER DETONATIONSÜBERTRAGUNG MITTELS DES BLASTMESSVERFAHRENS DER WTD 91**
Bölke et al
Wehrtechnische Dienststelle 91, Dezernat 334, Report No 14/87/91-334 dated 14 October, 1987
Meppen Germany October 1987

[133] **LUFTSTOSSBELASTUNG NACH EINEM EXPLOSIONSUNFALL IN EINEM ERDEINGEDECKTEN MUNITIONSLAGERHAUS / Gebrauchsformeln für Entwurf und sicherheitstechnische Untersuchung**
Mett,Hans-Georg
Amt für Studien and Übungen der Bundeswehr/Bereich Sonderaufgaben-Infrastruktur
Cologne Germany May 1992

[134] **BELASTUNG ERDEINGEDECKTER MUNITIONSLAGERHÄUSER DURCH MUNITIONSUNFÄLLE**
WTD 131
Wehrtechnische Dienststelle 131, A0201/A61110
Meppen Germany September 1989

[135] **EXPLOSION HAZARDS AND EVALUATION**
Baker,W,E;Cox,P;Westine,P;Kulesz,J;Strehlow,R
Elseviers Scientific Publishing Company (1983)
USA 1983

[136] PREDICTION OF INJURY LEVELS FOR HUMANS IN THE VICINITY OF AN ACCIDENTAL EXPLOSION INSIDE A THIRD GENERATION NORWEGIAN SHELTER
Moseley,Patricia,K;Whitney,Mark,G
SwRI Project 02-6863 -Final Report-
Oslo Norway September 1982

[137] HANDBOOK OF HUMAN VULNERABILITY CRITERIA -Chapter 9- Projectile-Induced Blunt Trauma
Clare,Victor,R;Lewis,James,H;Mickiewicz,A,P;Sturdivan,L,M
Handbook
Edgewood Arsenal USA May 1976

[138] AN EMPIRICAL/MATHEMATICAL MODEL TO ESTIMATE THE PROBABILITY OF SKIN PENETRATION BY VARIOUS PROJECTILES
Lewis,James,A;Coon,Phillip,A;Clare,Victor,R;Sturdivan,L,M
ARRADCOM Technical Report ARCSL-TR-78004
Edgewood Arsenal USA April 1978

[139] BALLISTIC LIMITS OF TISSUE AND CLOTHING
Butler,Stanley,C;
Addendum to BRL Technical Note No 1645 / AMSAA Technical Report No 230
USA July 1978

[140] METHODS FOR CALCULATION OF DAMAGE RESULTING FROM PHYSICAL EFFECTS OF THE ACCIDENTAL RELEASE OF DANGEROUS MATERIALS
Opschoor,G; Loo, R,O,M van;Pasman,H,J
TNO Prins Maurits Laboratory, Ministry of Housing, Physical Planning and the Environment
Rijswijk Netherlands 1990

[141] SUMMARY OF THE STATISTICAL-MODEL FOR INJURY WITH HEAT RADIATION
TNO Prins Maurits Laboratory, AC/258 (NL) (ST) IWP/5-92
Rijswijk Netherlands January 1992

[142] METHODS FOR ESTIMATING THE PHYSICAL EFFECTS OF THE ESCAPE OF DANGEROUS MATERIALS (TNO YELLOW BOOK)
Publication of the Directorate General of Labour, Ministry of Social Affairs and Employment
Netherlands 1979

[143] THE IMPACT OF EXPLOSION-EFFECTS ON STRUCTURES
Mercx,W,P,M
Prins Maurits Laboratorium TNO
Rijswijk Netherlands June 1988

[144] THE EFFECT OF EXPLOSION PHENOMENA ON HUMANS
Mercx,W,P,M
Prins Maurits Laboratorium TNO
Rijswijk Netherlands June 1988

[145] STRUCTURAL VIBRATION AND DAMAGE
Steffens,R,J
Department of the Environment, Building Research
London United Kingdom 1974

[146] GLASS FRAGMENT HAZARD FROM WINDOWS BROKEN BY AIR BLAST
Fletcher,E,R;Richmond,D,R
Lovelance Biomedical and Environmental Research Institute
Albuquerque, NM USA 1980

[147] **THE INFLUENCE OF THE WINDOW-FRAME ON THE DYNAMIC FAILURE LOAD OF WINDOWS**
Nowee,J;Harmanny,A
PML-TNO USA 1983

[148] **DAMAGE TO BUILDINGS RESULTING FROM THE EXPLOSION OF A GAS-CLOUD**
Dragosvic et al
IBBC-TNO
Netherlands 1976

[149] **CASUALTIES AND DAMAGE FROM ACCIDENTAL EXPLOSIONS**
DODESB
DODESB, Technical Paper No 11
USA May 1975

[150] **A SIMPLIFIED METHOD FOR THE PREDICTION OF THE GROUNDSHOCK LOADS ON BURIED STRUCTURES**
Drake,J.L;Frank,R,A;Rochefort,M,A
Int. Symposium on Interaction of Conventional Munitions with Shelters
Mannheim Germany March 1987

[151] **FREE-FIELD GROUND SHOCK PRESSURES FROM BURIED DETONATIONS IN SATURATED AND UNSATURATED SOILS**
Westine,P,S; Friesenhahn,G,J
San Antonio,Texas USA May 1983

[152] **GROUND SHOCK FROM PENETRATING CONVENTIONAL WEAPONS**
Drake,J,L; Little,C jr
US Army Waterways Experiment Station
Vicksburg USA May 1983

[153] **GROUND SHOCK FROM THE DETONATION OF BURIED EXPLOSIVES**
Westine,Peter,S
Journal of Terramechanics, Vol 15 No 2
USA 1978

[154] **IMPACT EFFECTS OF FRAGMENT STRIKING STRUCTURAL ELEMENTS**
Williamson,R,A;Alvy,R,R
Holmes and Narver Inc
USA 1973

[155] **UNTERSUCHUNGEN DER TRÜMMER- UND SPLITTERWIRKUNGEN BEI EXPLOSIONSEREIGNISSEN IN MUNITIONSLAGERHÄUSERN**
EMI-Bericht (Report) E 16/83
Freiburg Germany 1983

[156] **PROCEDURES FOR THE ANALYSIS OF THE DEBRIS PRODUCED BY EXPLOSION EVENTS**
Swisdak,Michael,M Jr
DODES, Minutes of 24th Explosives Safety Seminar
St Louis,Missouri USA August 1990

[157] **BUILDING DEBRIS HAZARD PREDICTION MODEL**
Bowles, Patricia; Oswald,Charles,J;Vargas,L,M;Baker,W,E
Southwest Research Institute Project 06-2945, Government Contract DE-AC04-76DP-00487
USA November 1990

[158] **DRAG COEFFICIENT MEASUREMENTS FOR TYPICAL BOMB AND PROJECTILE FRAGMENTS**
Miller, Miles,C
DODES, Minutes of 24th Explosives Safety Seminar
St Louis,Missouri USA August 1990

[159] **A COMPARISON OF TWO PERSONELL INJURY CRITERIA BASED ON FRAGMENTATION**
McCleskey, Frank
DODES, Minutes of 24th Explosives Safety Seminar
St Louis,Missouri USA August 1990

[160] **AN INVESTIGATION OF FRAGMENT STOPPING BARRICADES**
McCleskey, Frank
DODES, Minutes of 24th Explosives Safety Seminar
St Louis,Missouri USA August 1990

[161] **PREDICTION OF BUILDING DEBRIS FOR QUANTITY DISTANCE SITING**
DODESB-Paper
DODESB Technical Paper No 13
Alexandria,VA USA April 1991

[162] **DRAG COEFFICIENTS FOR IRREGULAR FRAGMENTS**
McCleskey,F
Naval Surfaces Weapons Center, NSWC-TR-87-89
USA February 1988

[163] **GESETZE FÜR DIE MASSEN. UND FORMENVERTEILUNG VON NATÜRLICHEN SPLITTERN**
Heiser,R,Dr.
Bundesamt für Wehrtechnik und Beschaffung WM VI 2, Handbuch Munitionsbewertung
Weil am Rhein Germany 1979

[164] **AUSSENBALLISTIK DER SPLITTER**
Heiser,R,Dr
Bundesamt für Wehrtechnik und Beschaffung WM VI 2, Handbuch Munitionsbewertung
Germany 1979

[165] **APPLICATION OF SIACCIS METHOD TO FLAT TRAJECTORIES**
Hitchcock,H, P;Kent,R,H
Ballistic Research Laboratories, BRL Report No 114
Aberdeen PrvGrd,MD USA August 1938

[166] **THE INITIAL VELOCITIES OF FRAGMENTS FROM BOMBS, SHELLS AND GRENADES**
Gurney
Ballistic Research Laboratories, BRL-R-405
Aberdeen PrvGrd,MD USA 1943

[167] **FRAGMENTATION OF SHELL CASES**
Mott
Proceedings of the Royal Society
London UK 1947

[168] **FRAGMENTATION HAZARDS FROM DETONATIONS OF MULTIPLE MUNITIONS IN OPEN STORES**
Feinstein,Nagacka
Armed Services Explosives Safety Board
USA 1971

[169] **THE GURNEY FORMULA: VARIATIONS ON THEME BY LAGRANGE**
Jacobs,S,J
Naval Ordnance Laboratory,NOLTR 74-36
White Oak,MD USA 1974

[170] **METAL ACCELERATION BY CHEMICAL EXPLOSIVES**
Kury,J et al
4th Symposium on Detonation, NOL
USA 1965

[171] **AN IMPROVED EQUATION FOR CALCULATING FRAGMENT PROJECTION ANGLES**
Randers-Pehrson,G
2nd International Symposium on Ballistics
Daytona Beach USA March 1976

[172] **ÜBER DIE ZERLEGUNG VON SPRENGGESCHOSSEN**
Lukanow,H;Molitz,H
Wehrtechnische Monatshefte 10/1959, p.334ff.
Germany October 1959

[173] **METODER FOR BESTÄMNING AV EN GRANATS FRAGMENTERING OCH SPLITTERNS HASTIGHET OCH RIKTNING**
Hörner,S;Kemgren,E
FOA Rapport C 2196-44
Stockholm Sweden 1967

[174] **SPLITTERBALLISTIK**
Held,M
Explosivstoffe 12/1967,3/1968,4/1968
Schrobenhausen Germany April 1968

[175] **FRACTURE AND FRAGMENTATION UNDER SHOCK LOADING**
Seaman,L
The Shock and Vibration Information Center, Pilkey "Shock and Vibration Computer Programs"
Washington USA 1975

[176] **CALCULATION OF FRAGMENT VELOCITIES FROM FRAGMENTATION MUNITIONS**
Karpp,R,R;Predebon,W,W
First International Symposium on Ballistics
Orlando,FL USA November 1974

[177] **AIR DRAG MEASUREMENTS OF FRAGMENTS**
Dunn,D,J;Porter,W,R
Ballistic Research Laboratories BRL Memorandum Report No 915
Aberdeen PrvGrd,MD USA 1955

[178] **RETARDATION OF FRAGMENTS**
Braun,W,F;Charters,A,C;Thomas,R,N
Ballistic Research Laboratories BRL Report No 425
Aberdeen PrvGrd,MD USA 1943

[179] **A THEORY OF FRAGMENTATION**
Mott,N,F;Linfoot,E,H
Bristol University, Extra-Mural-Group,MOS-AC-3348
USA January 1943

[180] **FRAGMENTATION OF H.E. SHELLS, A THEORETICAL FORMULA FOR THE DISTRIBUTION OF WEIGHTS OF FRAGMENTS**
Mott,N,F
A.O.R.G. Memo Report No 24, MOS-AC-3642
USA March 1943

[181] **EINIGE BEMERKUNGEN ZU DEN VERTEILUNGSFUNKTIONEN DER SPLITTERGRÖSSEN**
Molitz,H
Explosivstoffe 21, p.33ff.
Germany 1973

[182] **THE MASS DISTRIBUTION OF FRAGMENTS FROM BOMBS, SHELLS AND GRENADES**
Gurney,R,W;Sarmousakis,J,N
Ballistic Research Laboratories, BRL Report Nr 448
Aberdeen PrvGrd,MD USA 1944

[183] **FRAGMENT MASS DISTRIBUTION**
Huygen,R,W,G
Technologisches Laboratorium (TNO), TL 1974-15
Rijswijk Netherlands 1974

[184] **FRAGMENT WEIGHT DISTRIBUTIONS FROM NATURALLY FRAGMENTING CYLINDERS LOADED WITH VARIOUS EXPLOSIVES**
Sternberg,H,M
Naval Ordnance Laboratory (NOL) TR 73-83
White Oak,Silv Spring,MD USA 1973

[185] **MASSEN- UND FORMENVERTEILUNGEN VON SPLITTERN DER STATISCH GESPRENGTEN 155 MM SPRENGGRANATE M 107**
Senf,H
Arbeitsgruppe für ballistische Forschung ABF V 6/75
Weil am Rhein Germany 1976

[186] **FRAGMENTATION DATA ANALYSIS- I. COMPUTER PROGRAM FOR MASS AND NUMBER DISTRIBUTIONS AND EFFECTS OF ERRORS ON MASS DISTRIBUTION**
Krauklis,P;Bedford,A,J
Australian Defence Scientific Service, Materials Research Laboratories (AMRL)
Report 549
Maribyrnong,Victoria Australia 1974

[187] **COMPUTATION OF WEIGHT, VELOCITY AND ANGULAR DISTRIBUTIONS OF FRAGMENTS FROM NATURALLY FRAGMENTING WEAPONS**
Sternberg,H,M
Naval Ordnance Laboratory NOL TR 74-77
USA 1974

[188] **SPLITTERMASSENVERTEILUNG UND SPLITTERGESCHWINDIGKEIT VON 105 MM GRANATEN**
Husman,R,E;Thomas,G,G
TNO
Netherlands 1971

[189] **DARSTELLUNG DER GRÖSSENVERTEILUNG VON SPLITTERN NACH DER ROSIN-RAMMLER-SPERLING-VERTEILUNG**
Busch
Erprobungsstelle 91, E/Bal III,1,1966
Meppen Germany 1966

[190] **EINE BEMERKUNG ZUR VERTEILUNGSFUNKTION DER SPLITTERGRÖSSEN**
Molitz, H
ISL N 16/70
Saint Louis France 1970

[191] **EINE NEUE METHODE ZUR BESTIMMUNG DER SPLITTERMASSENVERTEILUNG VON SPLITTERMUNITION**
Lindeijer,E,W;Leemans,J,S
Explosivstoffe 16,1968, S.145ff
Germany/Netherlands 1968

[192] **BERECHNUNG DER SPLITTERMASSENVERTEILUNG VON SPLITTERMUNITION**
Held,M
Explosivstoffe 16,1968, S.241ff
Germany 1968

[193] **CONSIDERATION TO THE MASS DISTRIBUTION OF FRAGMENTS BY NATURAL-FRAGMENTATION ON COMBINATION WITH PREFORMED FRAMGENTS**
Held,M;Kühl,P
Propellants and Explosives 1, p.20ff.
Germany 1976

[194] **PHAENOMENOLOGIE DER NATÜRLICHEN SPLITTERBILDUNG**
Freymond,P,H
Vortragsmanuskript im Carl-Cranz-Lehrgang "Splitterballistik" 4. -8.10.1976
(Script)
Weil am Rhein Germany 1976

[195] **ENDBALLISTISCHE UNTERSUCHUNGEN MIT GESCHOSSSPLITTERN**
Senf,H
Ernst-Mach Institut E 3/70
Weil am Rhein Germany 1970

[196] **ENDBALLISTISCHE WIRKUNG VON MODELLSPLITTERN VERSCHIEDENER L/D VERHÄLTNISSE UND SPITZENFORMEN GEGEN PANZERSTAHLPLATTEN**
Rothenhäusler,H;Senf,H
ABF V 7/75
Weil am Rhein Germany 1976

[197] **STATISTISCHE SPLITTERAUSWERTUNG DER SPRENGGRANATE 105 MM HE/FH 155-1, UK-SERIE 204**
Schneider,E
Ernst-Mach Institut V 7/78
Freiburg Germany 1978

[198] **PRIMARY FRAGMENT CHARACTERISTICS AND IMPACT EFFECTS ON PROTECTIVE BARRIERS**
Healey,J;Werner,H;Weismann,S;Dobbs,N;Price,P
Picatinny Arsenal Technical Report No 4903
Dover USA December 1975

[199] **DEBRIS HAZARDS FROM EXPLOSIONS IN ABOVE-GROUND MAGAZINES**
Merz,Hans
Minutes of the 19th Explosives Seminar
Los Angeles,C USA September 1980

[200] **TRÜMMERWURF BEI EXPLOSIONEN IN OBERIRDISCHEN MUNITIONSMAGAZINEN**
Basler & Partner
TM 3113-34
Zürich Switzerland 1984

[201] **THEORY AND COMPUTER PROGRAM FOR THE MULTIPLE DEBRIS MISSILE IMPACT SIMULATION (MUDEMIMP)**
Huang,L,C,P
Naval Facilities Engineering Command,NCEL, Program No Y0995-01-003-331
USA June 1984

[202] **EXPLOSIVE FRAGMENTATION OF DIVIDING WALLS**
Vargas,L,M;Hokanson,J,C;Rinder,R,M
Southwest Research Institute Project 02-5793
USA August 1980

[203] **QUANTITY-DISTANCE FRAGMENT HAZARD COMPUTER PROGRAM (FRAGHAZ)**
McCleskey,F
NSWC TR-87-59, Kilkeary, Scott & Associates Inc
USA February 1988

[204] **PREDICTION OF CONSTRAINED SECONDARY FRAGMENT VELOCITIES**
Westine,P,S;Kineke,J,H
The Shock and Vibration Bulletin, Bulletin 48, Part 2
USA September 1978

[205] **EJECTA HAZARD RANGES FROM UNDERGROUND MUNITIONS STORAGE MAGAZINES**
Joachim,Charles,E
DODES, Minutes of 24th Explosives Safety Seminar
St. Louis,Missouri USA August 1990

[206] **LETHALITY OF UNPROTECTED PERSONS DUE TO DEBRIS AND FRAGMENTS**
Janser,Paul,W
Basler & Partner
Zürich Switzerland August 1982

[207] **DIREKTE LUFTSTOSSVERLETZUNGEN**
Werner, Frank
Universität der Bundeswehr Hamburg;Seminarvorträge (Seminar Presentation)
Hamburg Germany 1984

[208] **HARD MISSILE IMPACT ON REINFORCED CONCRETE**
Hughes,Gareth
Nuclear Engineering and Design 77 (1984)
Slough UK January 1984

[209] **PENETRATION DEPTH IN CONCRETE FOR NONDEFORMABLE MISSILES**
Haldar,A;Miller,Frank,J
Nuclear Engineering and Design 71 (1982)
Atlanta USA July 1982

[210] PERFORMATION OF REINFORCED CONCRETE SLABS BY RIGID MISSILES
Degen,Peter,P
Journal of the Structural Division, 106 (1980)
USA July 1980

[211] MANUAL FOR THE PREDICTION OF BLAST AND FRAGMENT LOADING ON STRUCTURES
DOE/TIC-11268
USA 1992

2.5.8.2 PC - Codes

[1] AMMORISK
NDRE
Norwegian Defence Research Establishment - Division for Weapons and Equipment Analysis of explosion effects on all kinds of ammunition installations; lethality calculation; analysis of exposure; risk calculation
Kjeller N

[2] BLASTINW
Britt,Drake et al
U.S. Army Engineers Waterways Experiment Stations (USAE WES)
Calculation of combined shock wave (multiple reflections off walls) and explosive gas pressure by HE in a closed, non-responding, rectangular box-shaped room
Vicksburg,MS USA April 1986

[3] BREACH
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Calculation of required thickness of reinforced structures (aboveground and underground) due to nearby or contact detonations; empirical findings
Cologne GE Jun 1988

[4] CONWEP
Hyde, David
U.S. Army Engineers Waterways Experiment Station (USAE WES)
Complex calculations of most conventional weapons effects as described in the Army TM 5-855-1 for protective design of structures
Vicksbury,MS USA

[5] DISPRE
Bowles, P,M et al
Southwest Research Institute (SwRI)
Calculations of initial debris parameters for accidental detonations in magazines; debris and fragment distribution; only for small quantities, NEQ= 150 kg
San Antonio,TX USA November 1990

[6] FRAGHAZ
McCleskey,F
Naval Surface Warfare Center and DoDESB
Estimation of the fragment hazards produced by the inadvertent detonation of munitions stacks;
Silver Spring,MD USA February 1988

[7] FRANG Vers 1.0
Wager,P;Connett,J
Naval Civil Engineering Laboratory (NCEL)
Calculation of a time history of gas pressure and impulse which result from an explosion inside a room; Constant and variable venting is included.
Port Hueneme,CA USA May 1989

[8] FRCO_84
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Calculation of the pressure history from internal explosion considering constant and variable venting; plot of the pressure history and the cover movement
Cologne GE January 1993

[9] **GASEX**
Kulez,Moseley,Baker
Southwest Research Institute (SwRI)
Calculation of change in velocity of each surface of a structure due to the expansion of gaseous explosion products following a detonation within a structure
San Antonio,TX USA November 1978

[10] **HEXDAM-III**
Tatom,F,B;Roberts,M
Engineering Analysis Inc
Prediction of building damage to a limited range of structures, all of which are up to 200 US defined structures
Huntsville,AL USA November 1989

[11] **L_STO2**
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Calculation of characteristic airblast parameters in a tunnel system from an explosion of HE in the main tunnel entrance; plot of pressure history
Cologne GE June 1989

[12] **M_EC-DET**
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Prediction of pressure and impulse due to an accidental explosion in an earth-covered magazine; a reexamination and data regression of relevant events
Cologne GE April 1992

[13] **MUDEMIMP**
Huang,L,C,P
Naval Civil Engineering Laboratory (NCEL)
Calculation of debris dispersion including the max debris distance and the hazardous debris distance
Port Hueneme,CA USA June 1984

[14] **PROMIX**
Forsen,Jonasson
National Defence Research Establishment
Computation of the effects of explosions in a multi-room structure; gas pressure, leakage, venting, building damage
Stockholm S September 1989

[15] **REDIPT**
Tancreto; Helseth
Naval Civil Engineering Laboratory (NCEL)
Calculation of pressure-time history by simulating a variable vent opening; no calculation of shock pressure;pre-runner of FRANG
Port Hueneme,CA USA March 1987

[16] **REICON**
Ross et al
USAF Armament Laboratory
Determination of response, through a variety of failure mechanisms, of a reinforced concrete structure subjected to an explosion load;based on energy principles
Eglin AFB,FL USA December 1981

[17] **RISKANAL**
TNO
TNO Prins Maurits Laboratory
Handling of the internal safety as well as the external safety for an ammunition or explosive storage site; performance of risk or effects analysis respectively
Rijswijk NE 1990

[18] **SDOF**
SwRI
Southwest Research Institute (SwRI)
Calculation of the response of an equivalent single-degree-of-freedom system with the resistance-deflection characteristics determined by TMSLAB
San Antonio,TX USA

[19] **SHOCK Vers 1.0**
NCEL
Naval Civil Engineering Laboratory (NCEL)
Calculation of blast impulse and pressure on all or part of a surface, which is bounded by one to four non-responding reflecting surfaces
Port Hueneme,CA USA January 1988

[20] **SOILCOVER**
Wager
Naval Civil Engineering Laboratory (NCEL)
Calculation of the soil-covered roof and one other panel (door or wall) as they break away and move out from a structure;similar logic as in FRANG code
Port Hueneme,CA USA

[21] **SPLIBALL**
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Two dimensional numeric computation of final ballistic parameters and trajectories of irregular fragments considering atmospheric drag and density
Cologne GE January 1988

[22] **TMSLAB**
SwRI
Southwest Research Institute (SwRI)
Calculation of the resistance-deflection curve of a two-way slab following the method described in TM 5-1300
San Antonio,TX USA

[23] **TRADIA**
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Reproduction of the 'Debris-Energy-Number' Diagramm; Computation of ballistic parameters of debris in case of an accidental explosion in an EC-AMMO Storage
Cologne GE September 1993

[24] **TRAJ**
Porzel,F,B
Naval Civil Engineering Laboratory (NCEL)
Two dimensional trajectory program; prediction of the trajectories of individual fragments and debris; ricochet; terrain effects
Port Hueneme,CA USA September 1980

[25] **TRBALL**
Mett, H-G
FAF of Germany / Armed Forces Office - Infrastructure Division
Two dimensional numeric computation of final ballistic parameters and trajectories of debris considering atmospheric drag and density
Cologne GE January 1988

[26] **VAULTVENT**
Oswald, Ketchum,White
Southwest Research Institute (SwRI)
Calculation of pressure history of a gasoline vapor explosion within a rectangular vault by considering the combustion process and the vault structural response
San Antonio, TX USA January 1991

[27] **WATOMA**
Basler & Partner
Basler & Partner
Calculation of the fragmentation of a build□rom an internal explosion; fragments distribution
Zürich CH 1984

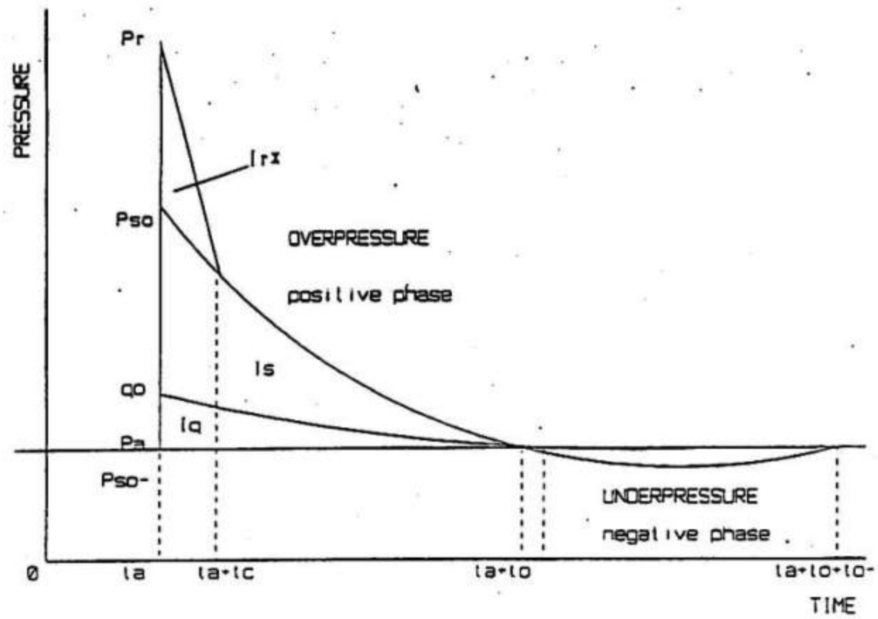
2.5.8.3. Figures

FIGURES

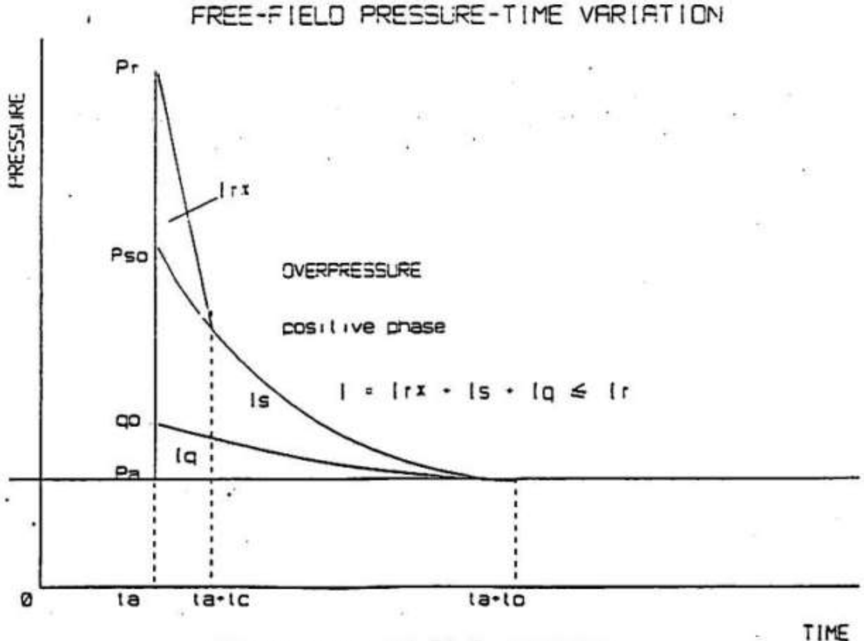
FIG [5- 1]

BLAST LOADING
- Schematic of Blastwave -

Source: FGAF



FREE-FIELD PRESSURE-TIME VARIATION



DESIGN PRESSURE-TIME VARIATION

FIG [5- 2a]

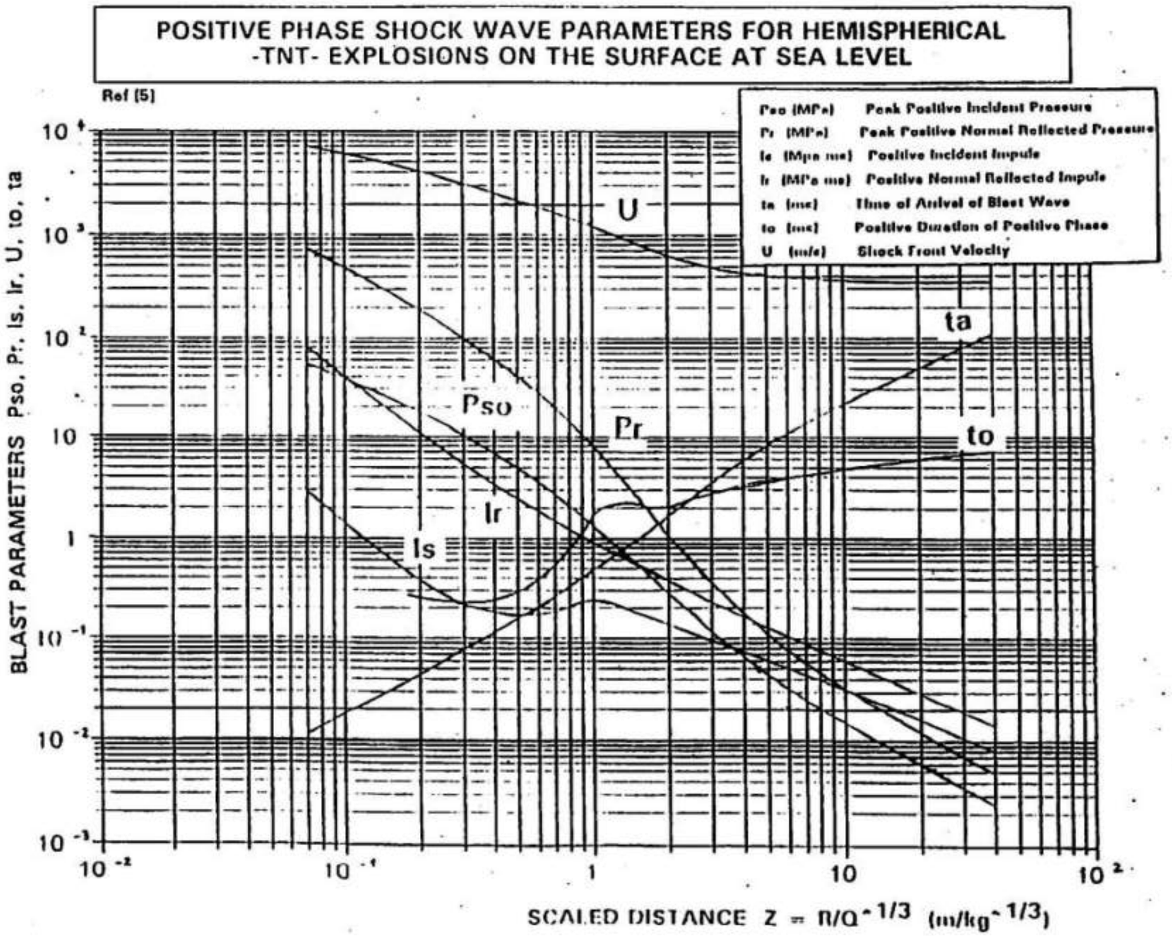

POSITIVE PHASE SHOCK WAVE PARAMETERS FOR HEMISPHERICAL
-TNT- EXPLOSIONS ON THE SURFACE AT SEA LEVEL
Ref [5]
Pso (MPa) Peak Positive Incident Pressure
Pr (MPa) Peak Positive Normal Reflected Pressure
Is (Mpa ms) Positive Incident Impulse
Ir (MPa ms) Positive Normal Reflected Impulse
ta (ms) Time of Arrival of Blast Wave
to (ms) Positive Duration of Positive Phase
U (m/s) Shock Front Velocity
U
ta
Pso
Pr
to
Ir
Is
BLAST PARAMETERS Pso, Pr, Is, Ir, U, to, ta
SCALED DISTANCE Z = R/Q^1/3 (m/kg^1/3)

FIG [5- 2b]

POSITIVE PHASE SHOCK WAVE PARAMETERS FOR HEMISPHERICAL
-TNT- EXPLOSIONS ON THE SURFACE AT SEA LEVEL

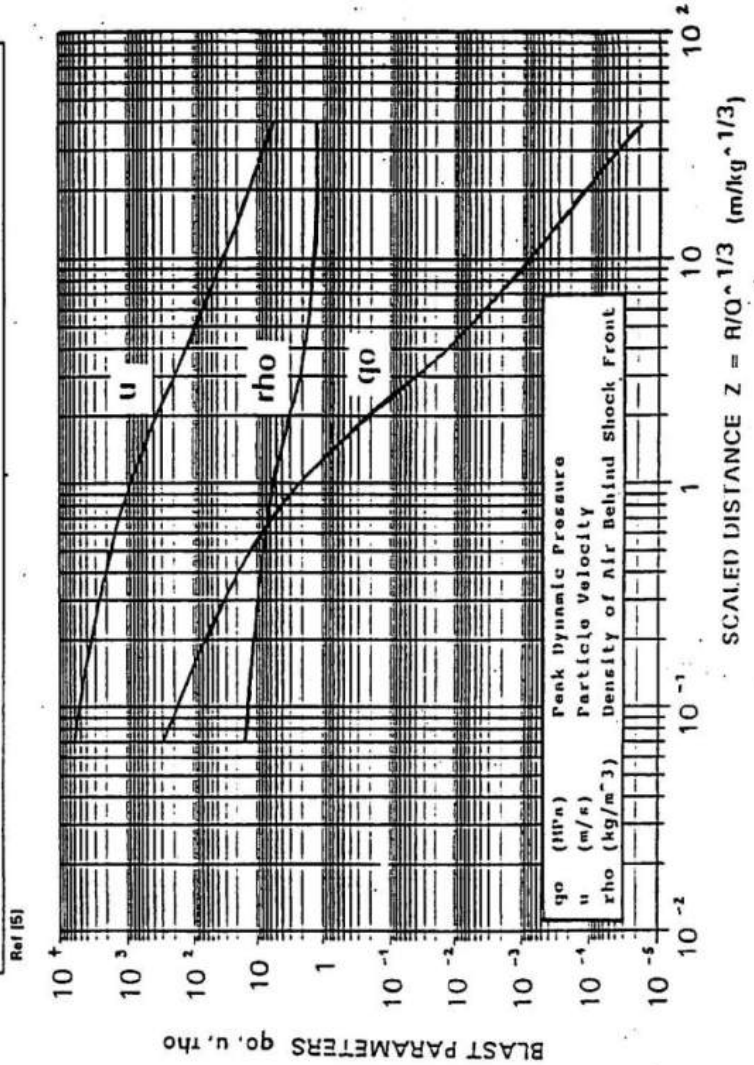
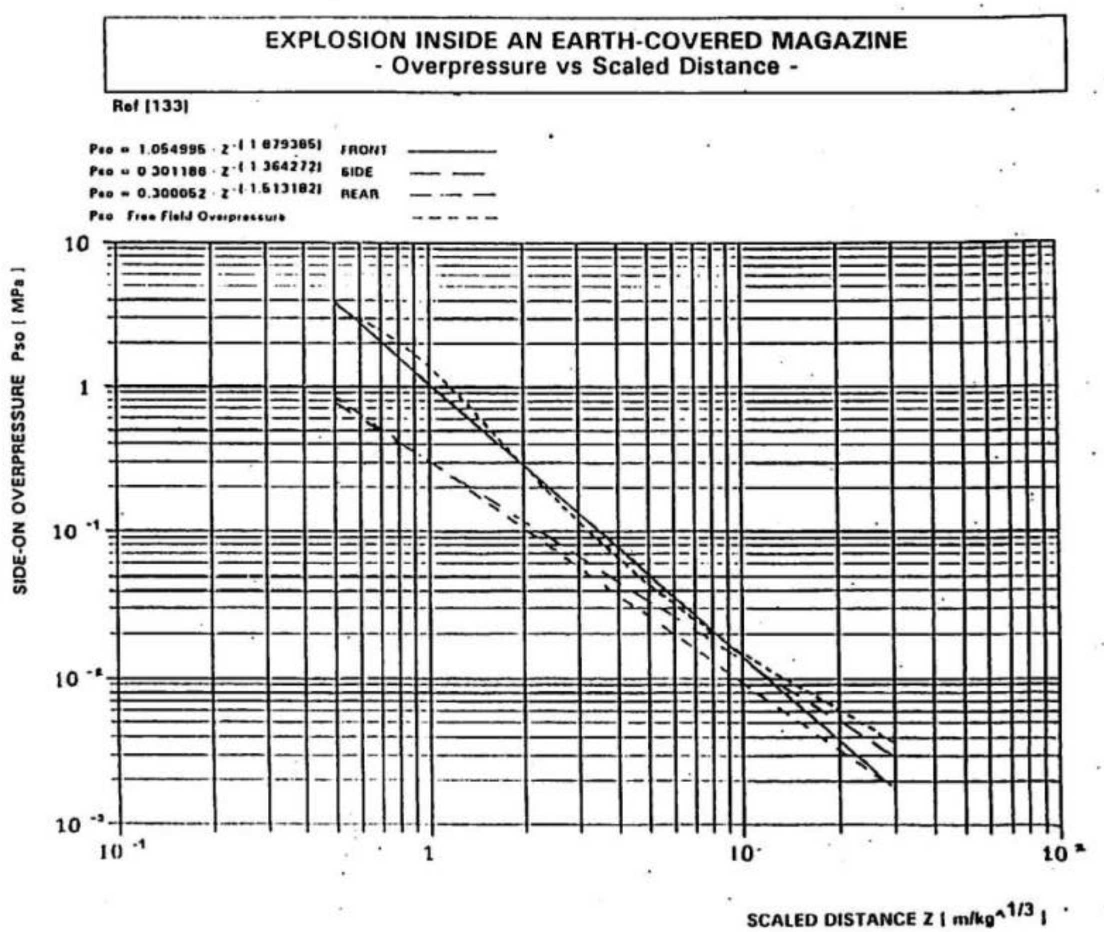


FIG [5- 2c]


EXPLOSION INSIDE AN EARTH-COVERED MAGAZINE
- Overpressure vs Scaled Distance -
Ref [133]
Pso = 1.054995 · Z^-(1.879385) FRONT
Pso = 0.301186 · Z^-(1.364272) SIDE
Pso = 0.300052 · Z^-(1.513182) REAR
Pso Free Field Overpressure
SIDE-ON OVERPRESSURE Pso [MPa]
SCALED DISTANCE Z [m/kg^1/3]
10
1
10^-1
10^-2
10^-3
10^-1
1
10
10^2

AASTP-1
(Edition 1)

EXPLOSION INSIDE AN UNCOVERED MAGAZINE

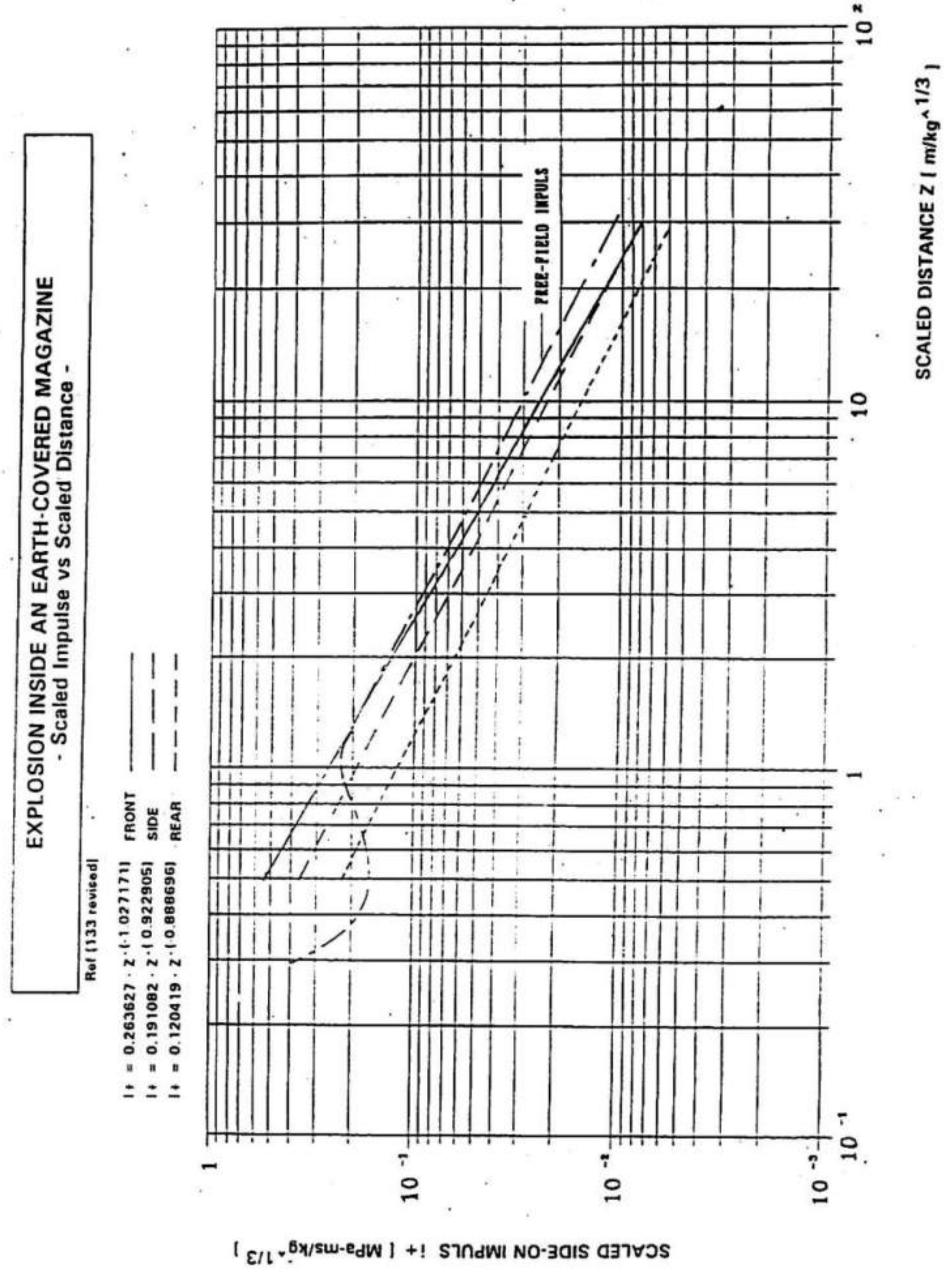
- Overpressure vs Scaled Distance -

(reserved)

FIG 5-2d

2. Amendment of the Revision

FIG [5- 2e]


EXPLOSION INSIDE AN EARTH-COVERED MAGAZINE
- Scaled Impulse vs Scaled Distance -
Ref [133 revised]
I+ = 0.263627 · Z^(-1.027171) FRONT
I+ = 0.191082 · Z^(-0.922905) SIDE
I+ = 0.120419 · Z^(-0.888696) REAR
FREE-FIELD IMPULS
SCALED DISTANCE Z [m/kg^1/3]
SCALED SIDE-ON IMPULS i+ [MPa-ms/kg^1/3]
1
10⁻¹
10⁻²
10⁻³
10⁻¹
1
10
10²

AASTP-1
(Edition 1)

EXPLOSION INSIDE AN UNCOVERED MAGAZINE

- Scaled Impulse vs Scaled Distance -

(reserved)

FIG 5-2f

FIG [5- 2g]

DAMPING EFFECTS DUE TO SOIL BERM SHIELDING

Ref [59]

INTERFACE CONDITION		LOADING
-1-	Air - Structure	Pr: norm. refl. pressure
-2-	Saturated Clay - Structure	Psoil: norm.refl. stress
-3-	Sandy Clay - Structure	
-4-	Loam - Structure	
-5-	Loose Sand-Gravel - Structure	

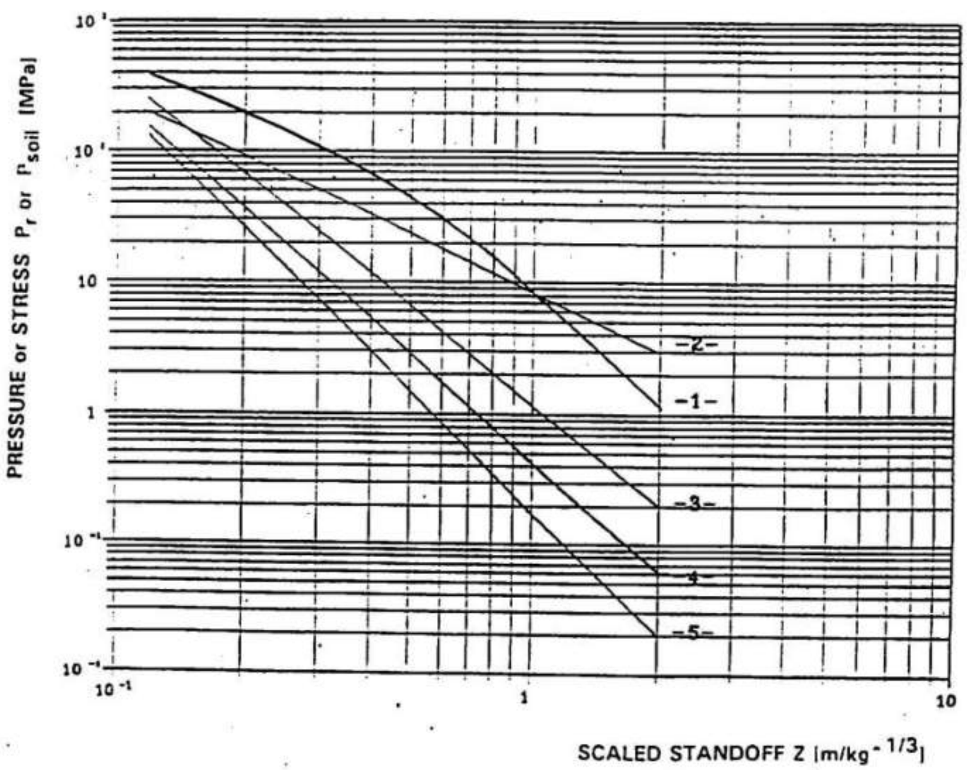


FIG [5- 3]

EQUIVALENT LOAD FACTOR -CE- AND
BLAST WAVE POSITION FACTOR D/L

Ref [1] [4]

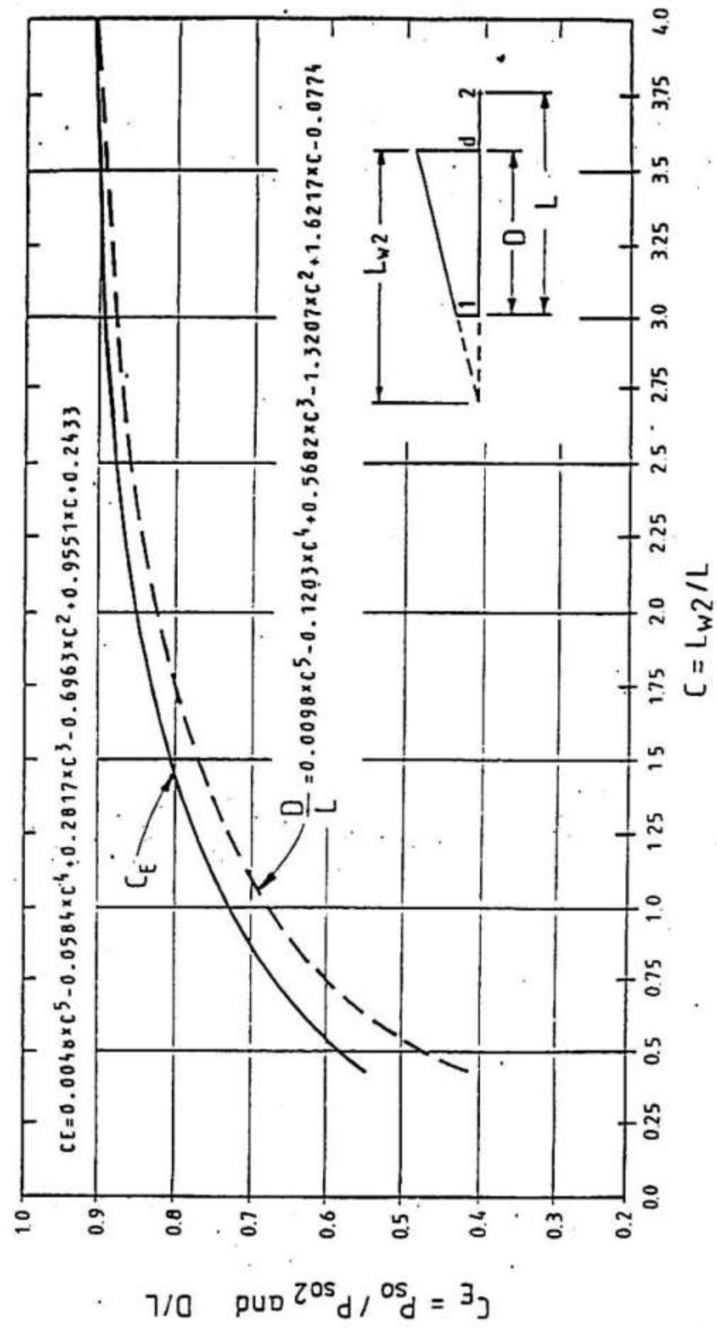
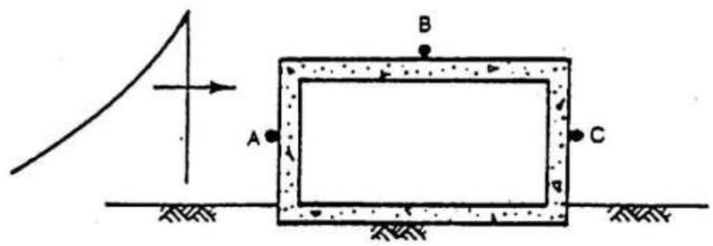
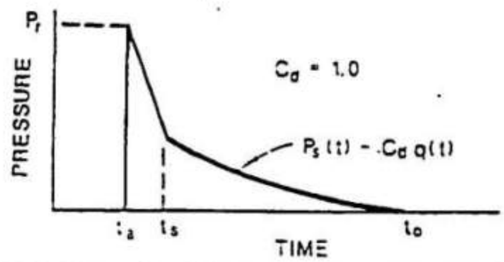


FIG [5- 4]

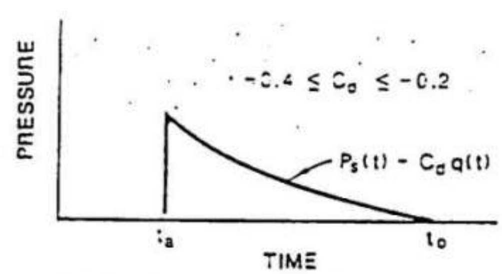
AIRBLAST LOADS ON AN ABOVEGROUND RECTANGULAR STRUCTURE
(simplified approach)

Ref [3]

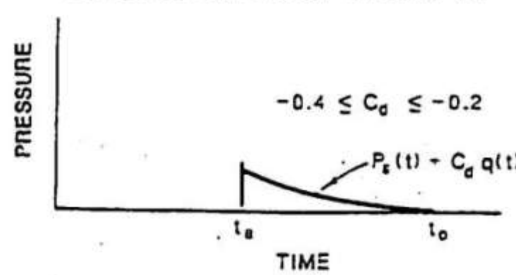




LOADING ON FRONT WALL (POINT A)



LOADING ON ROOF (POINT B)



LOADING ON REAR WALL (POINT C)

FIG [5- 5]

FRONT LOADING OF BOX-TYPE STRUCTURE
- Schematic of Equivalent Waveform -

Ref [1] [3]

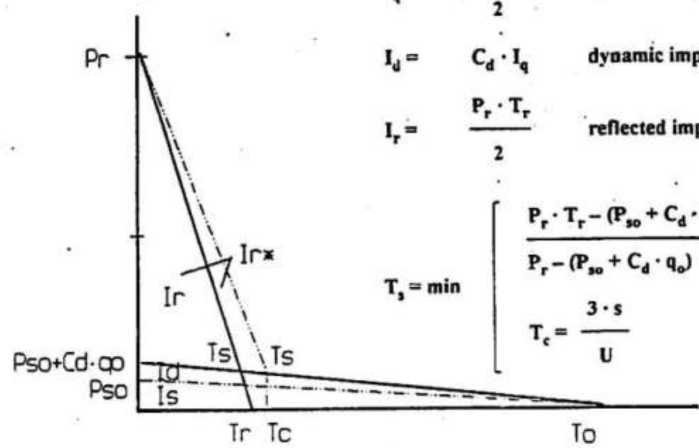
$I_s = \dfrac{P_{so} \cdot T_o}{2}$ side-on impulse

$I_q = \dfrac{q_o \cdot T_o}{2}$ dynamic impulse

$I_d = C_d \cdot I_q$ dynamic impulse including drag effect

$I_r = \dfrac{P_r \cdot T_r}{2}$ reflected impulse

$$T_s = \min \left\{ \begin{array}{l} \dfrac{P_r \cdot T_r - (P_{so} + C_d \cdot q_o) \cdot T_o}{P_r - (P_{so} + C_d \cdot q_o)} \\ T_c = \dfrac{3 \cdot s}{U} \end{array} \right.$$



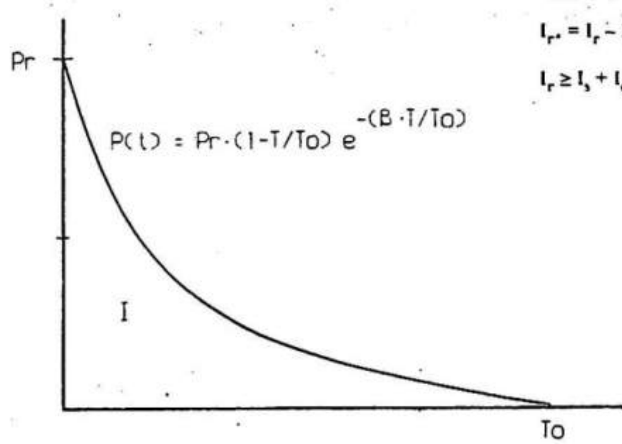
Equivalent Bilinear Waveform

$I_{r^*} = \dfrac{P_r - (P_{so} + C_d \cdot q_o) \cdot T_s}{2}$

$I_{total} = I_{r^*} + I_s + I_d \quad \leq I_r$

$I_{r^*} = I_r - I_s - I_d \quad \leq I_r$

$I_r \geq I_s + I_d$

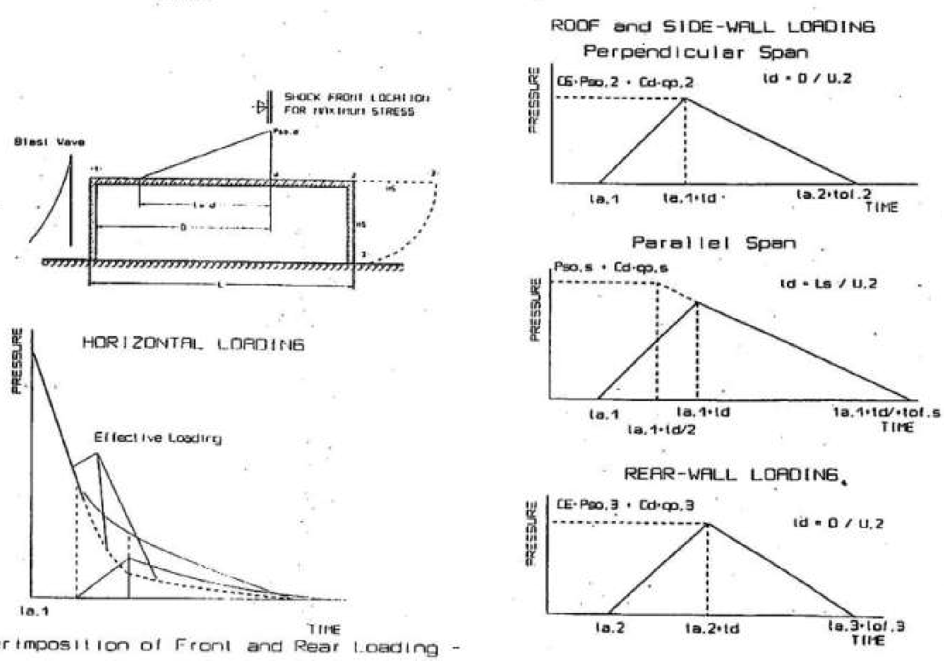


Equivalent Exponential Waveform

FIG [5- 6]

AVERAGE PRESSURE-TIME VARIATION OF CLOSED BOX-TYPE STRUCTURE

Ref [1] [3]



- Superimposition of Front and Rear Loading -

FIG [5- 7]

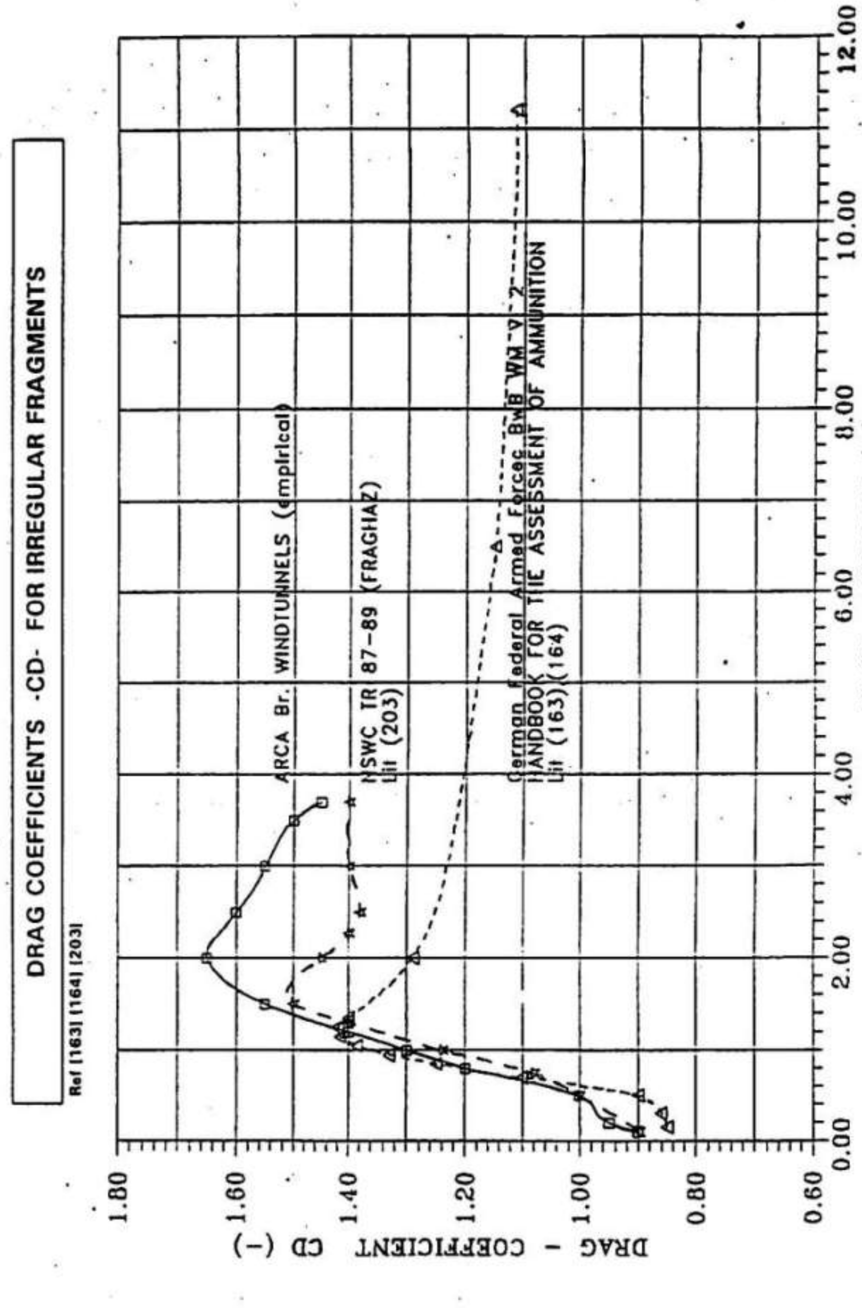

DRAG COEFFICIENTS -CD- FOR IRREGULAR FRAGMENTS
Ref [163] [164] [203]
ARCA Br. WINDTUNNELS (empirical)
NSWC TR 87-89 (FRAGHAZ)
Lit (203)
German Federal Armed Forces BWB WM V 2
HANDBOOK FOR THE ASSESSMENT OF AMMUNITION
Lit (163)(164)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
DRAG - COEFFICIENT CD (-)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
MACH - NUMBER (-)

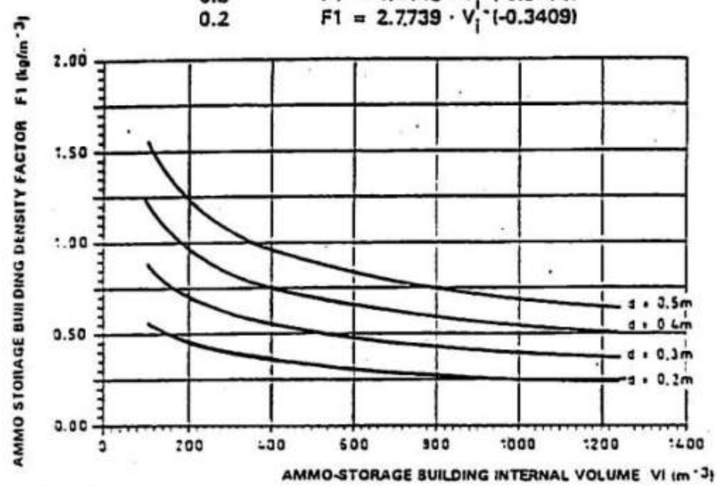
FIG [5- 8]

**AMMUNITION STORAGE BUILDING-DENSITY FACTOR F1 (kg/m^{-3})
FOR ROUGH COMPUTATION OF BOX-TYPE STRUCTURES DEBRIS MASS**

Source: GFAF

$$M_{debris} = F1 \cdot V_i \cdot 1000 \quad (kg)$$

wall thickness d (m)	Density Factor F1 (kg/m^{-3})
0.5	$F1 = 8.0157 \cdot V_i{}^{\wedge}(-0.3536)$
0.4	$F1 = 6.0551 \cdot V_i{}^{\wedge}(-0.3473)$
0.3	$F1 = 4.4149 \cdot V_i{}^{\wedge}(-0.3470)$
0.2	$F1 = 2.7739 \cdot V_i{}^{\wedge}(-0.3409)$



**AMMUNITION STORAGE BUILDING-DENSITY FACTOR F1 (kg/m^{-3})
FOR ROUGH COMPUTATION OF ARCH-TYPE STRUCTURES DEBRIS MASS**

Source: GFAF

wall thickness d (m)	Density Factor F1 (kg/m^{-3})
0.5	$F1 = 6.0989 \cdot V_i{}^{\wedge}(-0.3980)$
0.4	$F1 = 4.9710 \cdot V_i{}^{\wedge}(-0.4028)$
0.3	$F1 = 3.3626 \cdot V_i{}^{\wedge}(-0.3873)$
0.2	$F1 = 2.4017 \cdot V_i{}^{\wedge}(-0.4032)$

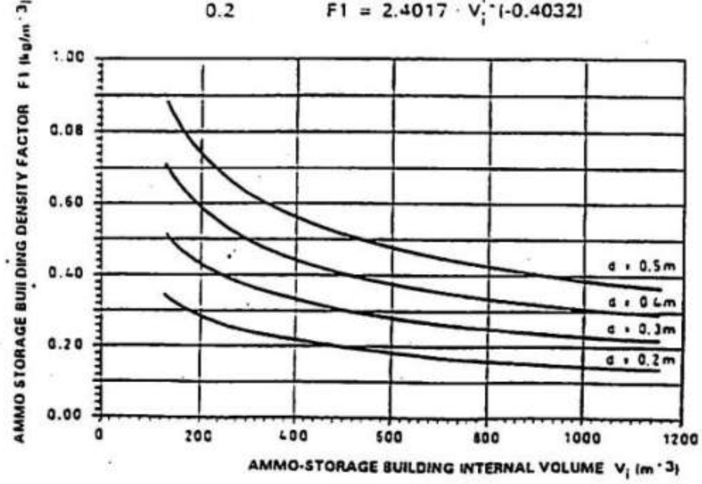


FIG [5- 9]

PENETRATION OF MILD STEEL PLATE BY EJECTA (ROCK MISSILES)

Ref [89]

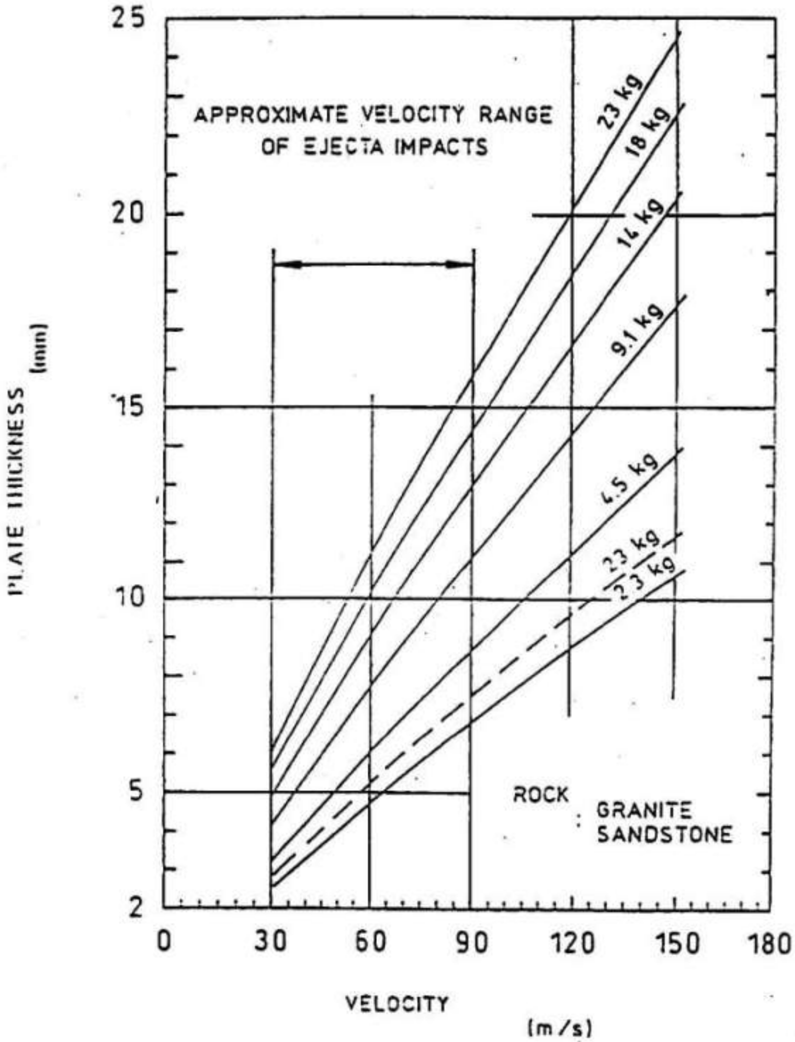


FIG [5- 10]

CONCRETE PENETRATION CAPABILITIES (right ordinate) AND SHOCK LOAD (left ordinate) FOR EJECTA (HARD ROCK PARTICLES) IMPACT

Ref [89]

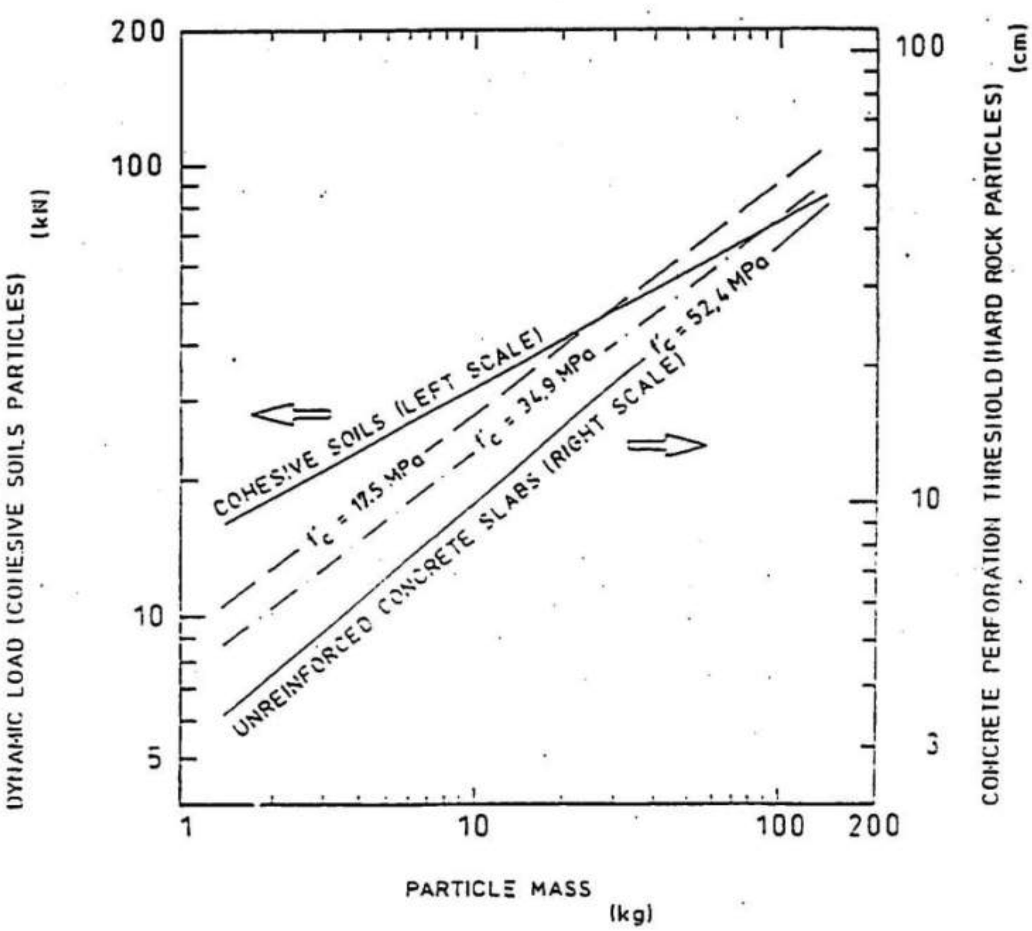
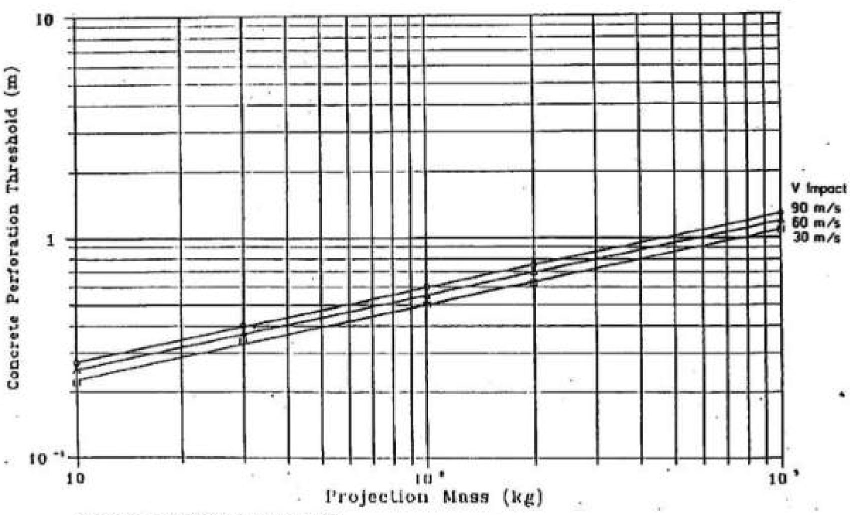


FIG [5- 11]

CONCRETE PENETRATION CAPABILITIES DUE TO HARD MISSILE IMPACT
Concrete 35 MPa, DIF 2.0
Reference : Hard Missile Impact on Reinforced Concrete, Hughes G.
Impact Velocity, Vi:30 m/s, 60 m/s, 90 m/s

Source: GFAF



Xperf,30 = 0.102031 * M**0.341075
Xperf,60 = 0.115003 * M**0.338055
Xperf,90 = 0.120407 * M**0.330700

FIG [5- 12]

HALF-CRATER PROFILE TAKEN ABOUT A VERTICAL CENTERLINE THROUGH GROUND ZERO AND SHOWING CRATER NOMENCLATURE AND NOTATION

Ref [1]

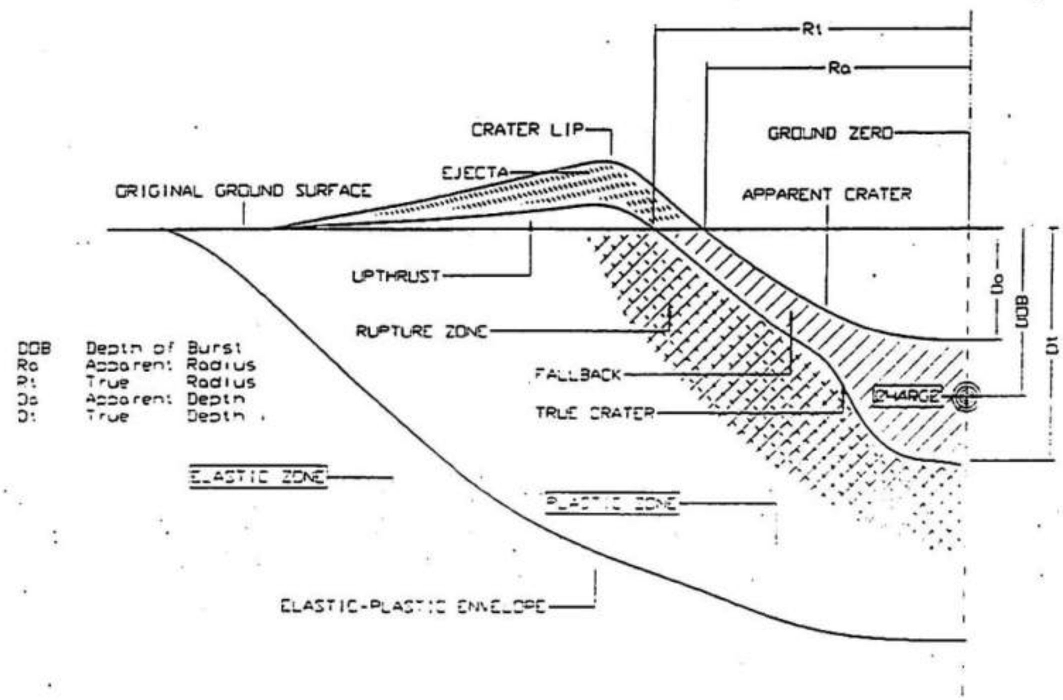


FIG [5- 13]

VARIATION IN CRATER SIZE AND SHAPE WITH DEPTH OF BURST

Ref [1] , Source: GFAF

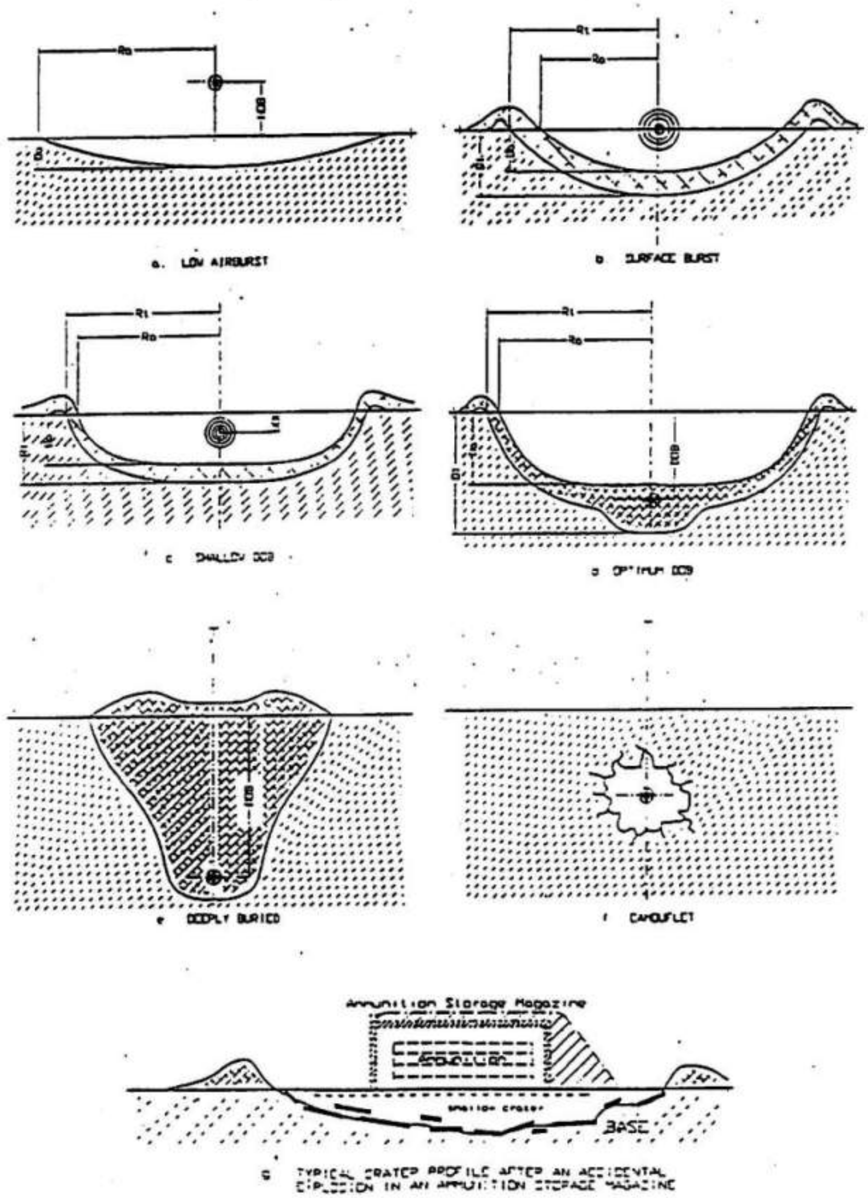


FIG [5- 14]

APPARENT CRATER DIMENSIONS FROM EXPLOSIONS IN VARIOUS SOILS AS A FUNCTION OF DEPTH OF BURST AND GENERAL SOIL TYPE

Ref [1] [3]

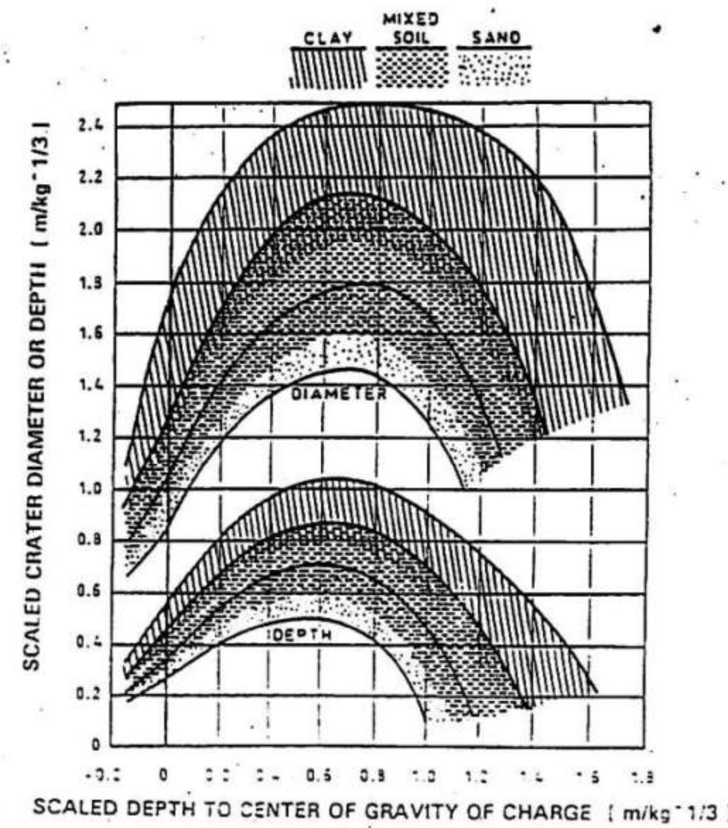


FIG [5- 15]

TRUE CRATER RADIUS -R_c- AS A FUNCTION OF CHARGE MASS

Ref [76]

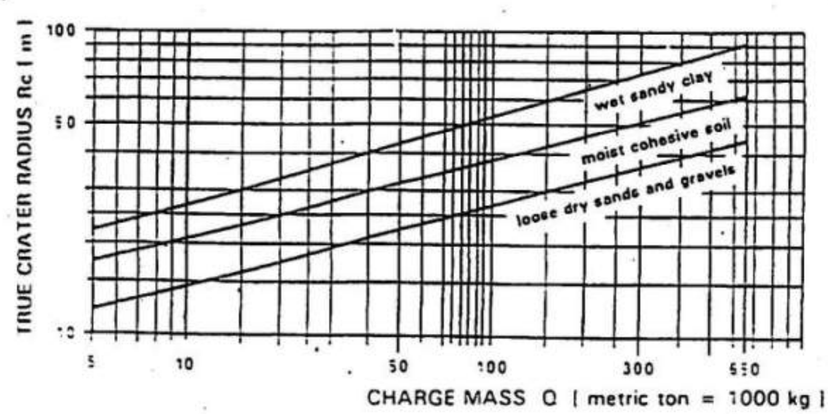


FIG [5- 16]

APPARENT CRATER DIMENSIONS FROM EXPLOSIONS IN ROCK AS A FUNCTION OF DEPTH OF BURST

Ref [89]

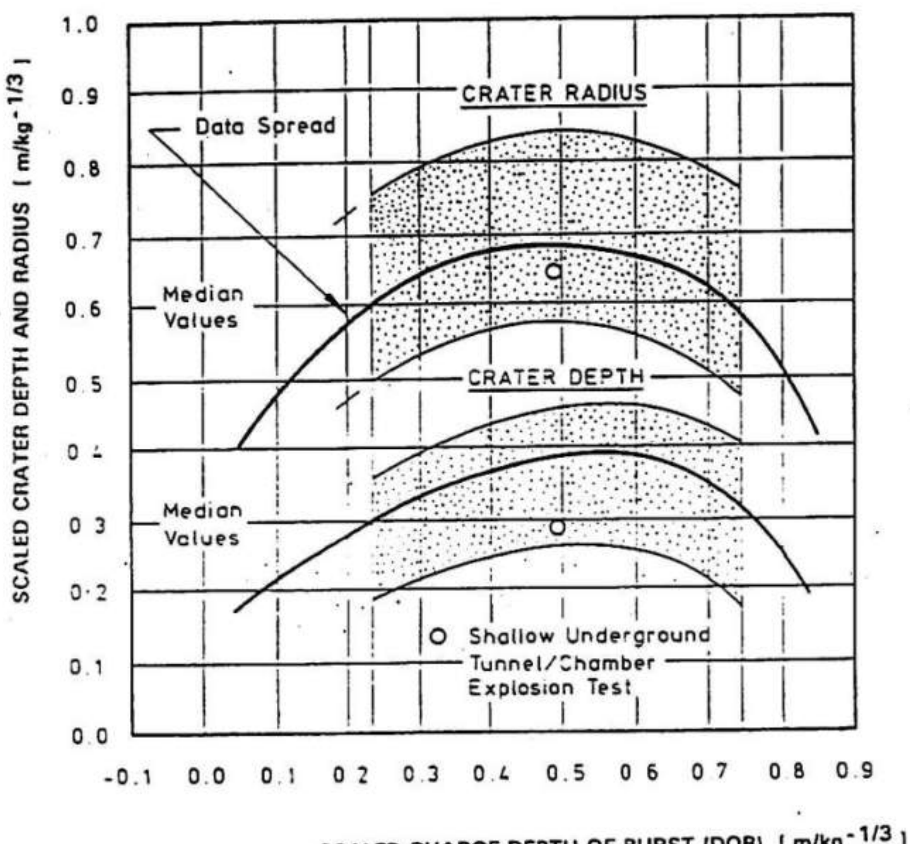


FIG [5- 17]

CRATER SIZE AS A FUNCTION OF NET EXPLOSIVES QUANTITY, FOR EXPLOSIONS ON THE GROUND SURFACE IN MOIST-TO-WET SOIL

Ref [36]

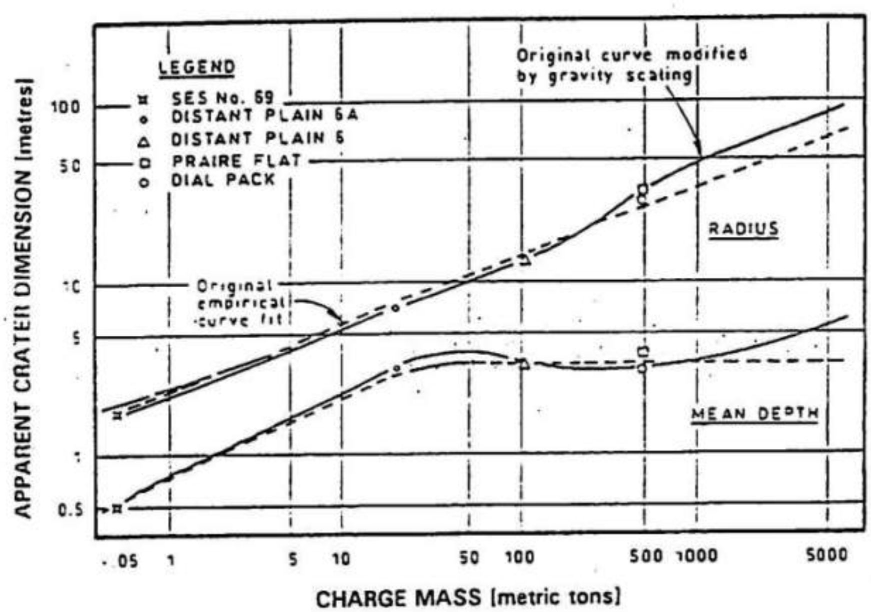
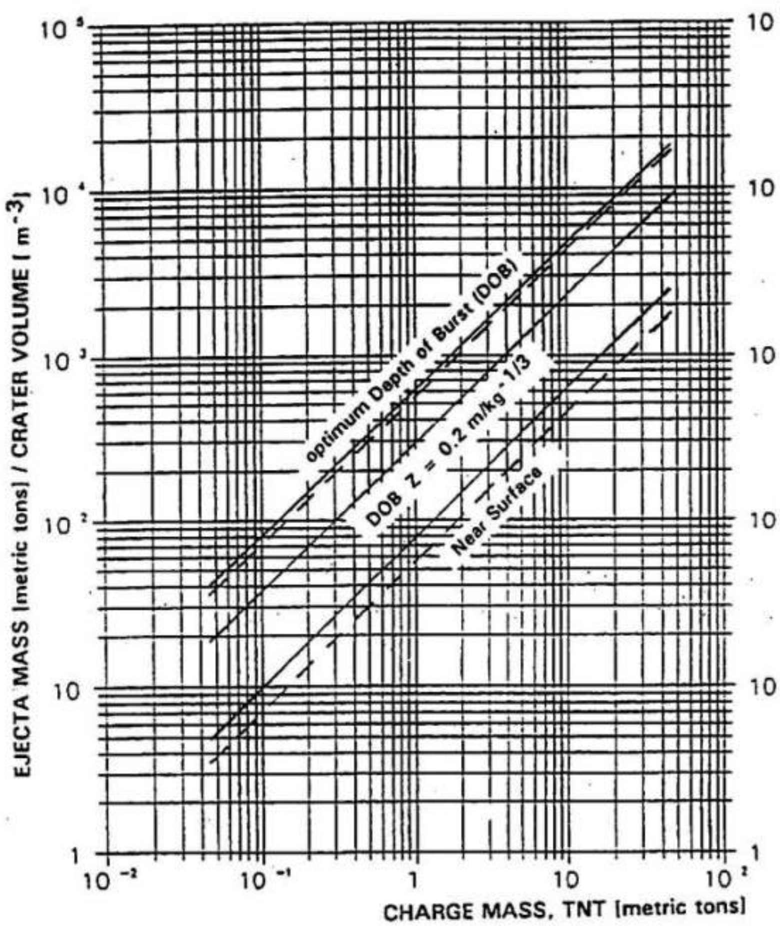


FIG [5- 18]

CRATER VOLUME AND TOTAL EJECTA MASS FOR DETONATIONS ON OR IN SOFT ROCK AND COHESIVE SOILS

Ref [1]



——— EJECTA [soft rock, cohesive soil]

- - - - - CRATER VOLUME

FIG [5- 19]

CRATER VOLUME AND TOTAL EJECTA MASS FOR DETONATIONS ON OR IN HARD ROCK

Ref [1]

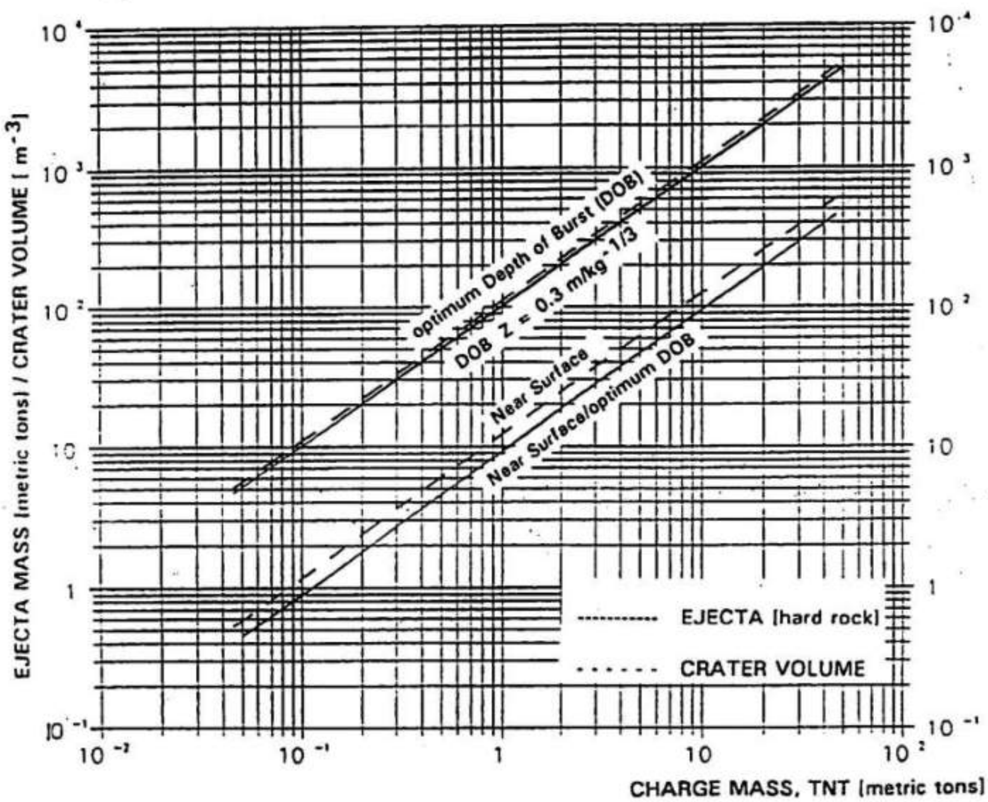
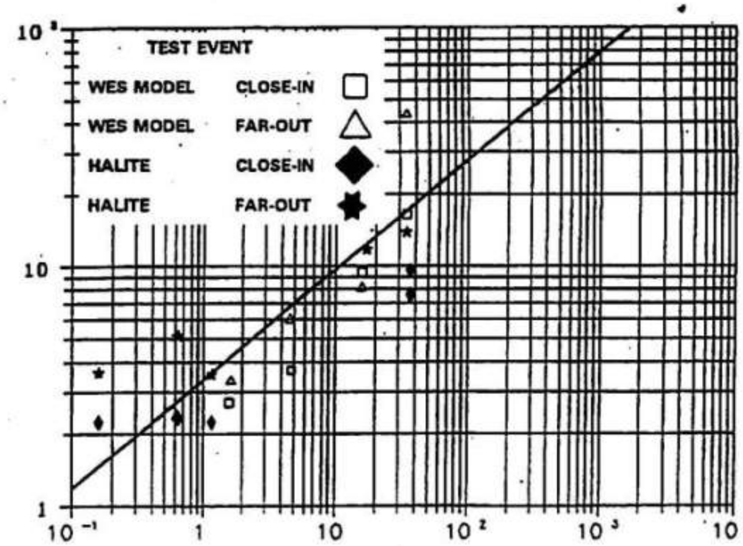


FIG [5- 20]

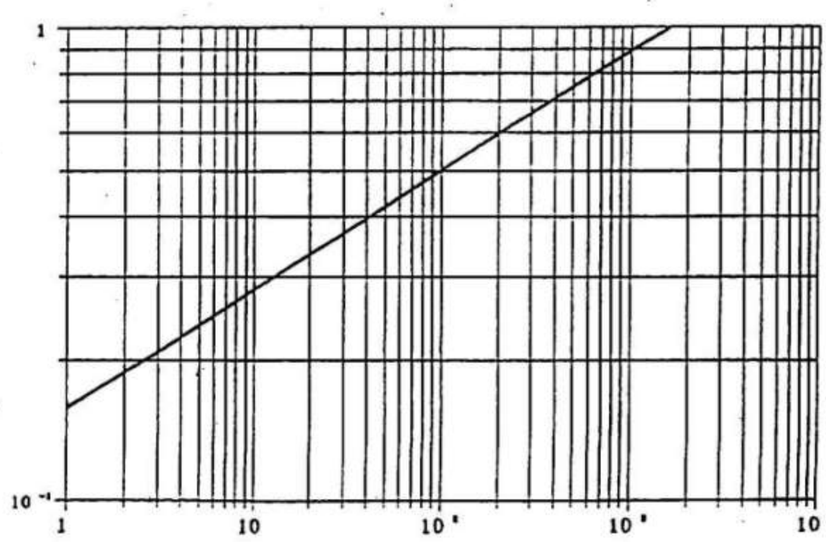
DETONATION COUPLING FACTOR -fc (%)- AS A FUNCTION OF CHAMBER LOADING DENSITY FOR UNDERGROUND EXPLOSIONS

Ref [89]



DETONATION COUPLING FACTOR - fc - vs LOADING DENSITY FOR EARTHCOVERED MAGAZINES

Ref [78]

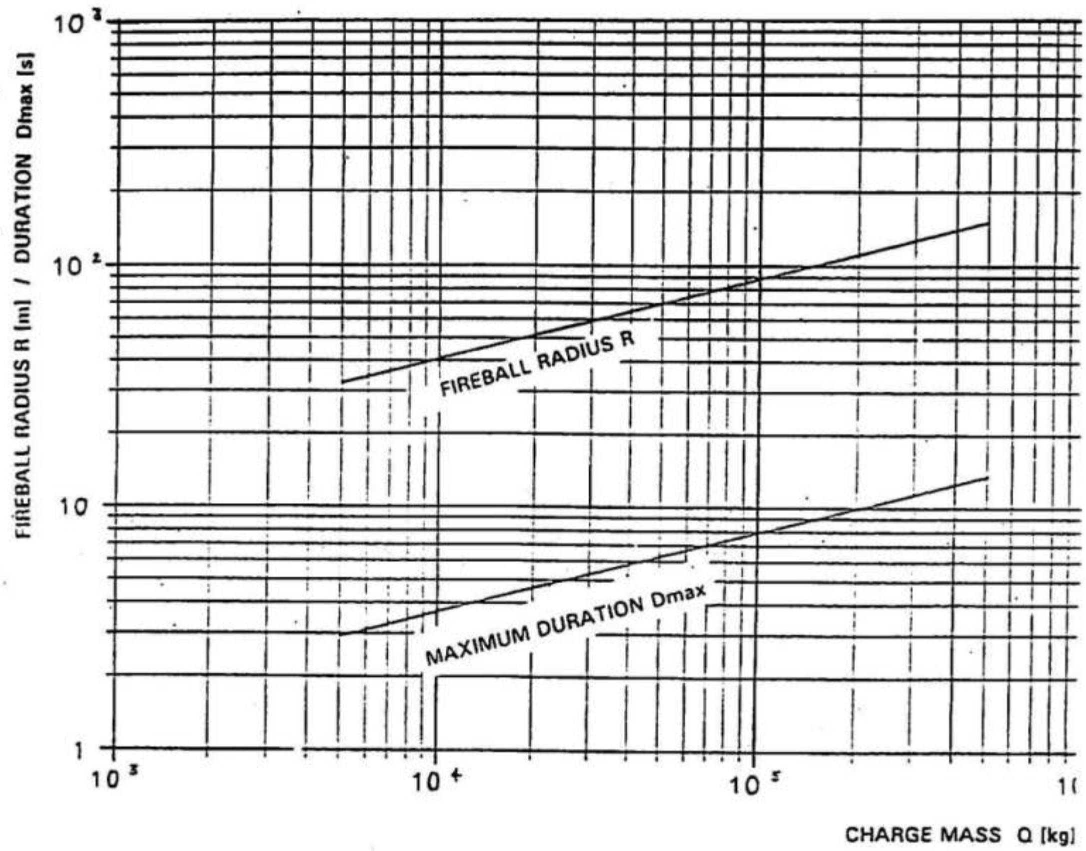


$$Fc = 0.15795 \times De\,\hat{}\,(0.25)$$

FIG [5- 21]

FIREBALL RADIUS -R- AND DURATION TIME -Dmax- AS A FUNCTION OF THE CHARGE MASS -Q-

Ref [78]



R = 1.90 · Q · 1/3
Dmax = 0.17 · Q · 1/3

FIG [5-.22]

PROBABILITY OF SURVIVAL IN THE CASE OF LUNG DAMAGE

Ref [144]

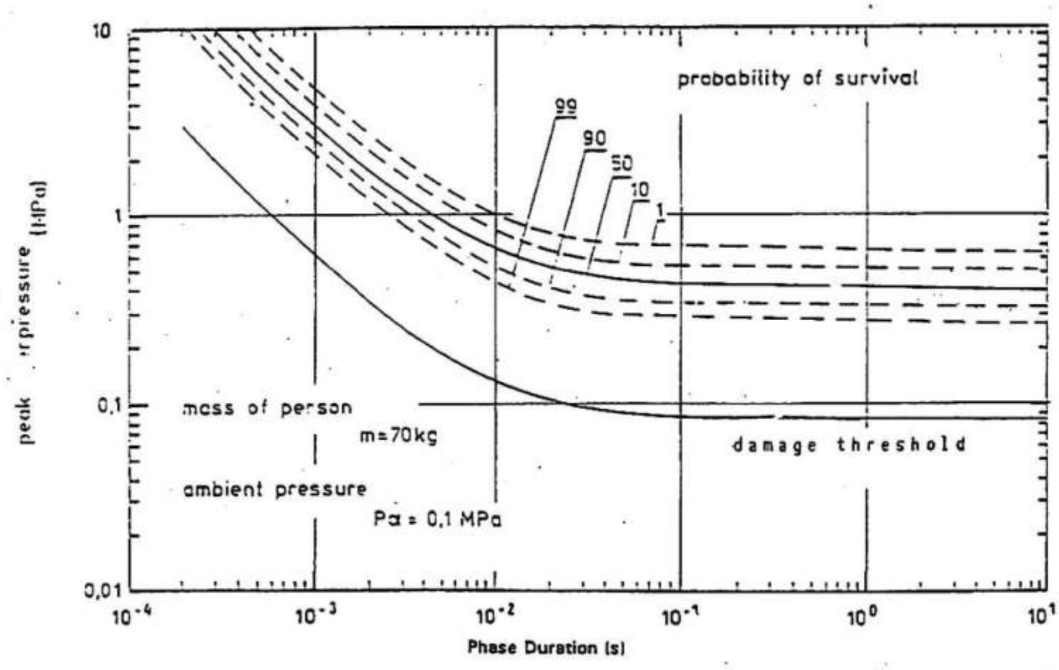


FIG [5- 23]

PRESSURE-IMPULSE GRAPH FOR LUNG DAMAGE

Ref [144]

Body Mass (kg)	
5	Baby
25	Small Children
55	Adult Women
75	Adult Man

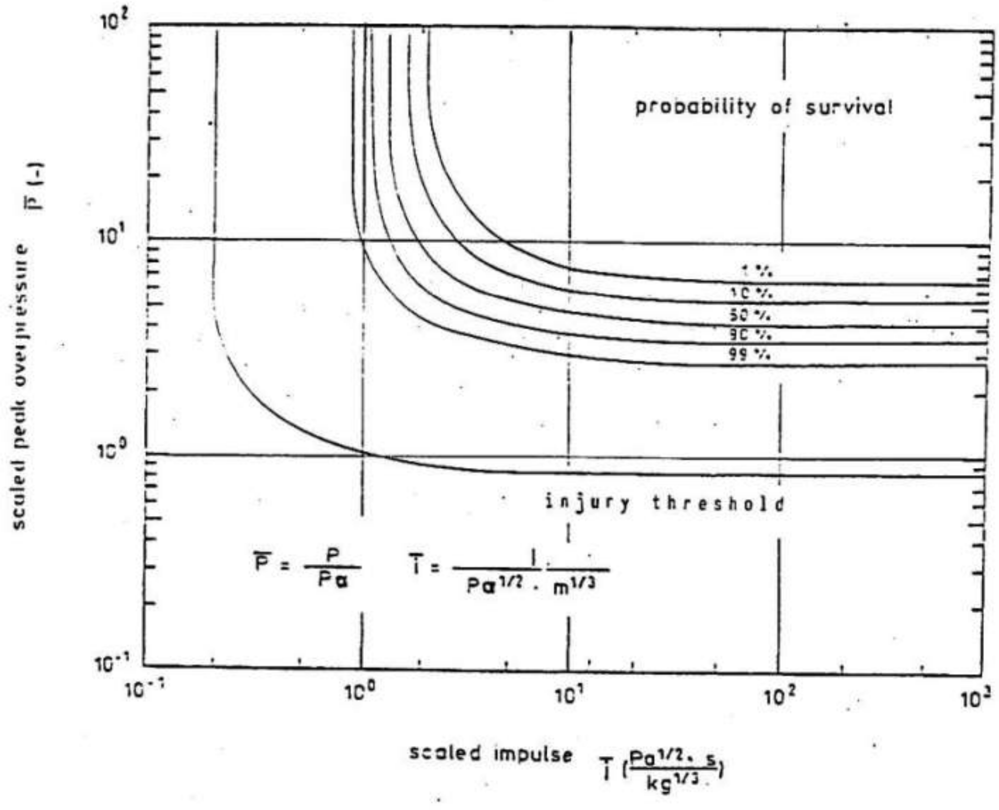


FIG [5- 24]

RUPTURE OF THE EARDRUM AS A FUNCTION OF OVERPRESSURE

Ref [144]

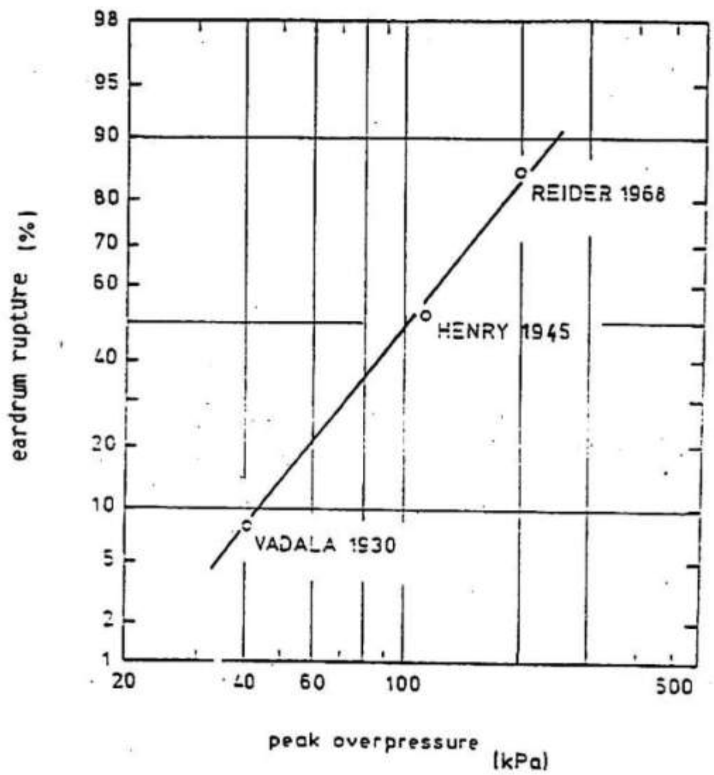


FIG [5- 25]

PRESSURE-IMPULSE GRAPH FOR IMPACT OF WHOLE BODY

Ref [144]

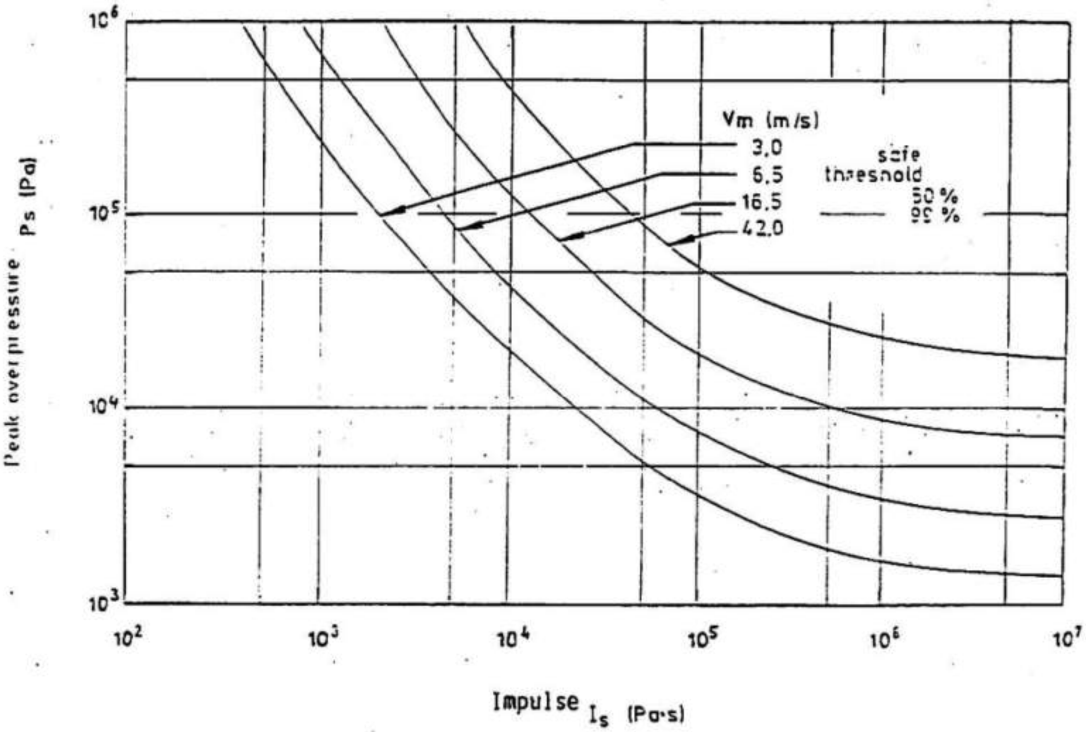


FIG [5- 26]

PERCENTAGE DEATHS AMONG PERSONS FALLING ONTO CONCRETE

Ref [144]

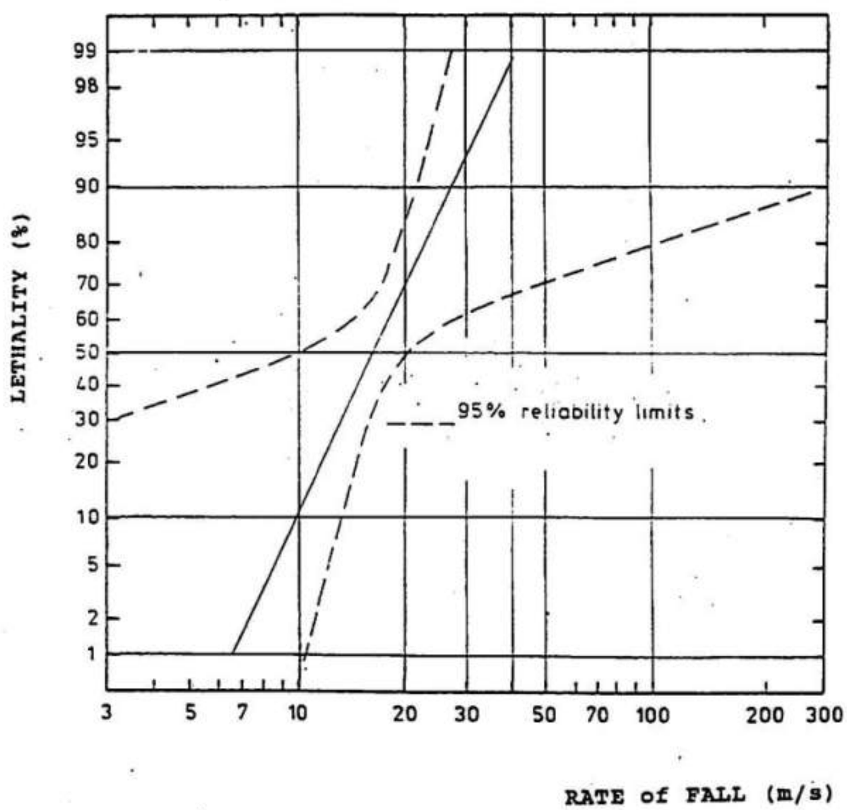


FIG [5- 27]

PRESSURE-IMPULSE GRAPH FOR FRACTURE OF THE BASE OF THE SKULL

Ref [144]

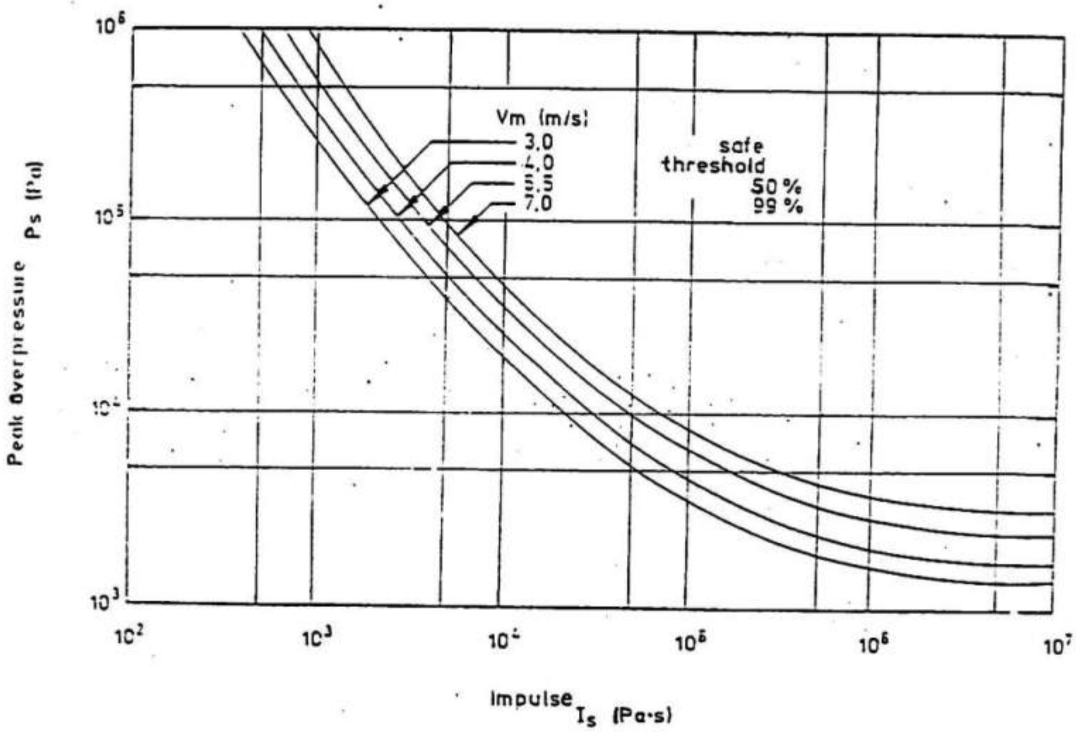


FIG [5- 28]

IMPACT VELOCITY OF FRAGMENT AT WHICH 50% PENETRATION OCCURS

Ref [144]

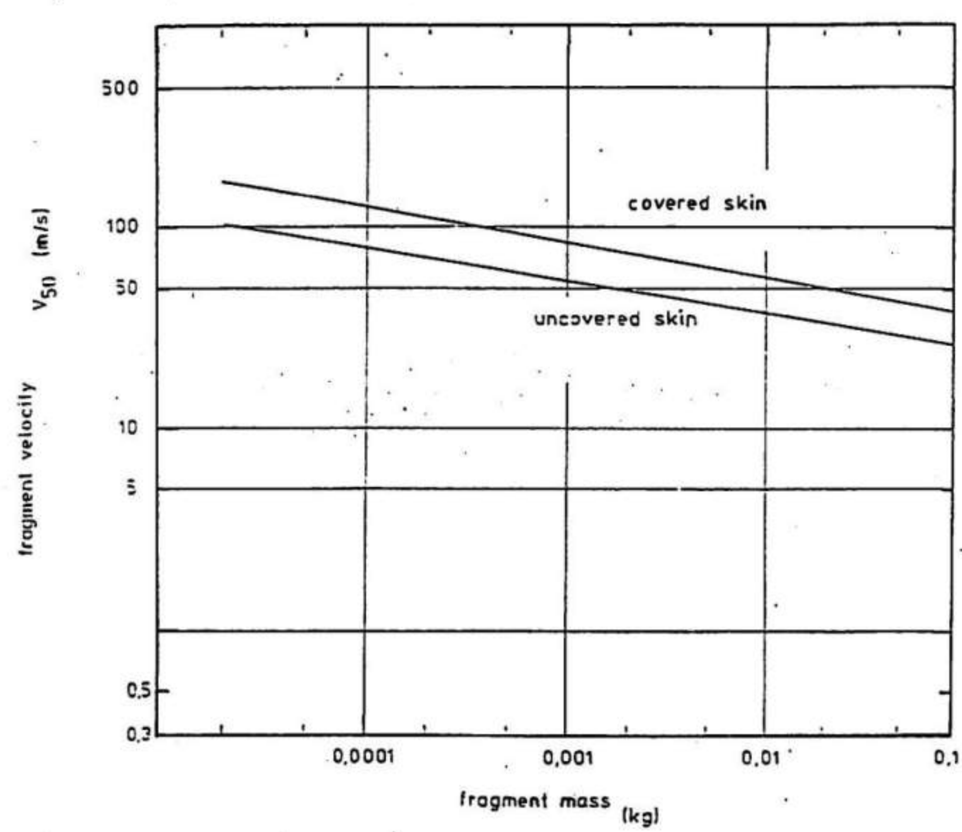


FIG [5- 29]

INJURY CRITERIA FOR FRAGMENTS AND DEBRIS

Ref [31]

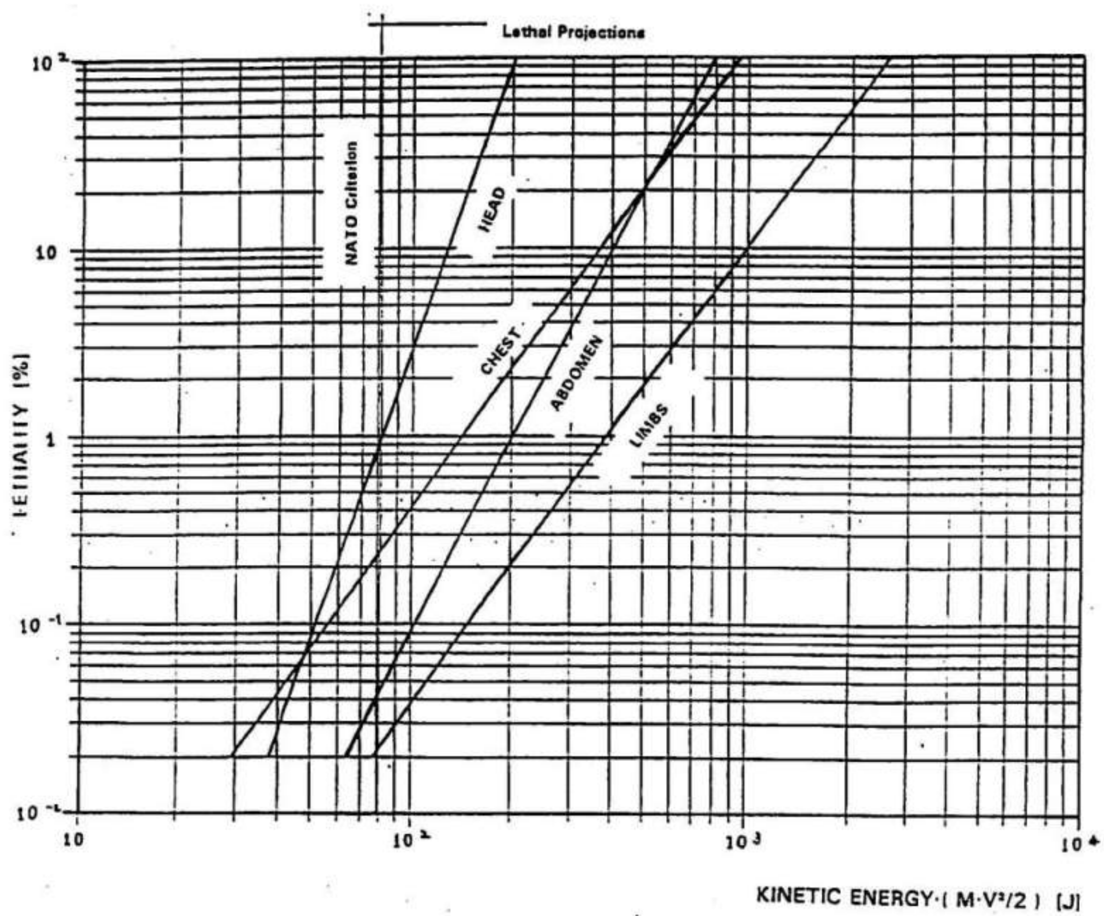


FIG [5- 30]

INJURY CRITERION FOR FRAGMENTS AND DEBRIS

Ref [144]

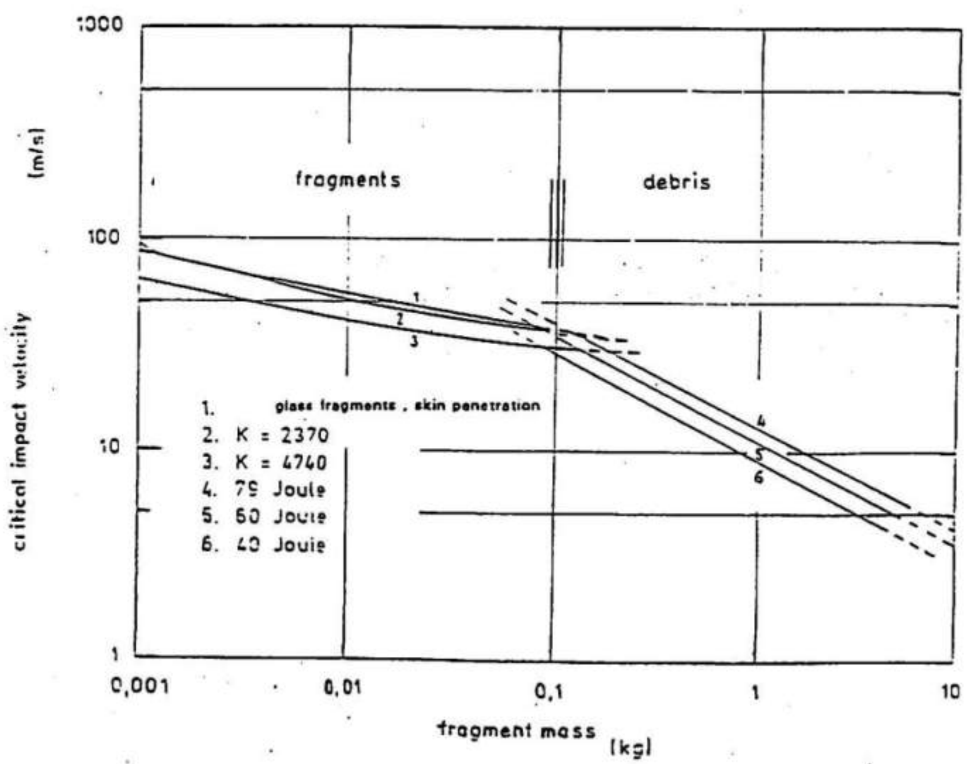
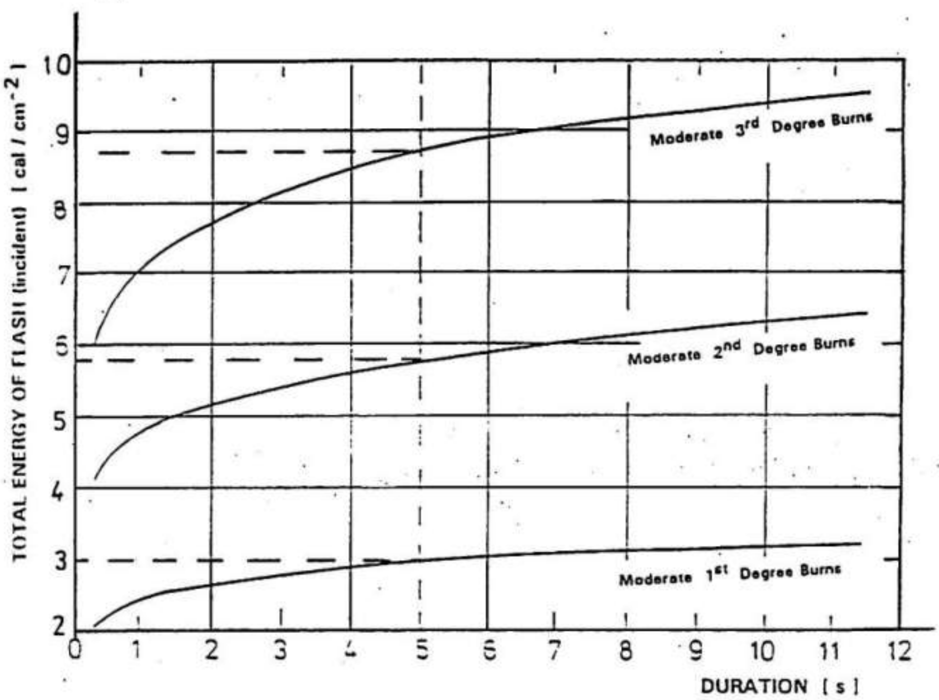


FIG [5- 31]

VARIATION OF THE RADIATION ENERGY REQUIRED TO CAUSE FLASH BURNS WITH THE DURATION OF THE FLASH

Ref [89]



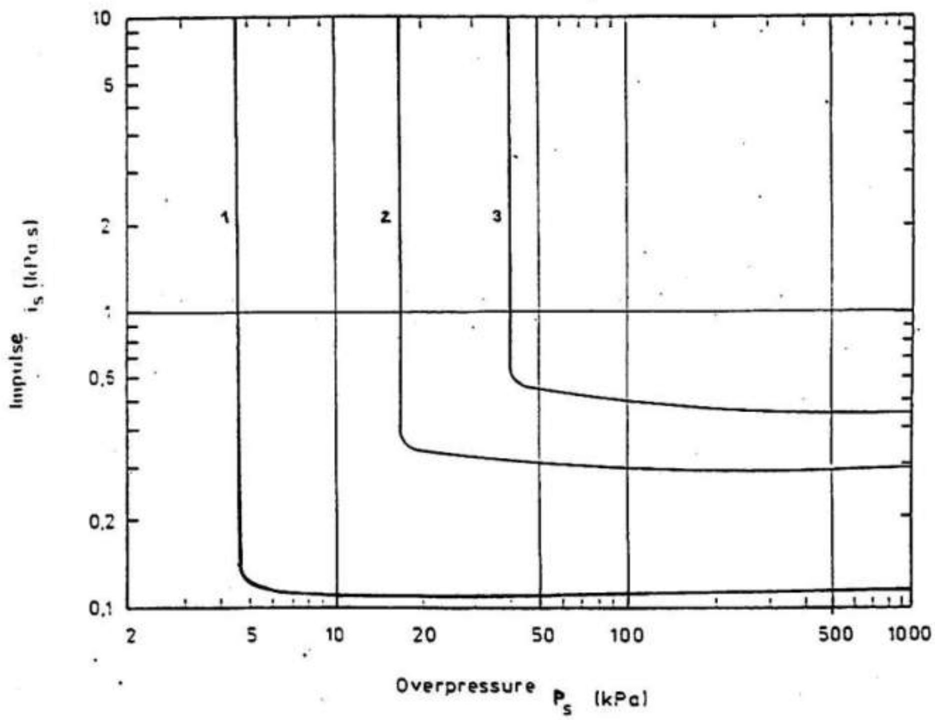
Time for Delivery of 80% of Total Flash Energy

FIG [5- 32]

PRESSURE-IMPULSE DIAGRAM OF DAMAGE TO A BRICK-BUILT BUILDING

Ref [143]

1. Lower limit of slight damage, distorted elements
2. Lower limit of heavy damage, partial damage of the roof, bearing walls partial,unsafe
3. Lower limit of total collapse:50 to 75 % of bearing walls devastated or unsafe



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		**5**	**0.12**	**0.030**	**0.59**	**1.08**
155 mm		**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 [MPa]	[psi]	DRAG COEFFICIENT [--]
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
$U = K_o + K_1T$

Y = common logarithm of the airblast parameter in metric units
$Y = C_o + C_1U + \ldots C_NU^N$

1. **Incident Pressure (kPa, psi)**

Range of applicability: (0.170 - 100.0 feet) **0.0674 - 40.0 meters**

(-0756579301809)
$U = -0.214362789151 + 1.35034249993T$

(1.9422502013)
$$\begin{aligned} Y = {} & 2.78076916577 - 1.6958988741U - 0.154159376846U^2 \\ & + 0.514060730593U^3 + 0.0988534365274U^4 \\ & - 0.293912623038U^5 - 0.0268112345019U^6 \\ & + 0.109097496421U^7 + 0.00162846756311U^8 \\ & - 0.0214631030242U^9 + 0.0001456723382U^{10} \\ & + 0.00167847752266U^{11} \end{aligned}$$

2. **Incident Impulse (kPa - msec, psi - msec)**

Two funktions are required:

Function I

Range of applicability: (0.170 - 2.41 feet) **0.0674 - 0.955 meters**

(0.832468843425)
$$U = 2.06761908721 + 3.0760329666T$$

(1.57159240621)
$$Y = 2.52455620925 - 0.502992763686U + 0.171335645235U^2 + 0.0450176963051U^3 - 0.0118964626402U^4$$

Function II

Range of applicability: **(2.41 - 100.0 feet) 0.955 - 40.0 meters**

(-2.91358616806)
$$U = 1.94708846747 + 2.40697745406T$$

(0.719852655584)
$$Y = 1.67281645863 - 0.384519026965U - 0.0260816706301U^2 + 0.00595798753822U^3 + 0.014544526107U^4 - 0.00663289334734U^5 - 0.00284189327204U^6 + 0.0013644816227U^7$$

3. Reflected Pressure (kPa, psi)

Range of applicability: **(0.170 - 100.0 feet) 0.0674 - 40.0 meters**

(-0.789312405513)
$$U = 0.24657322658 + 1.36637719229T$$

(2.56431321138)
$$Y = 3.40283217581 - 2.21030870597U - 0.218536586295U^2 + 0.895319589372U^3 + 0.24989009775U^4 - 0.569249436807U^5 - 0.11791682383U^6 + 0.224131161411U^7 + 0.0245620259375U^8 - 0.0455116002694U^9 - 0.00190930738887U^{10} + 0.00361471193389U^{11}$$

4. Reflected Impulse (kPa - msec, psi - msec)

Range of applicability: **(0.170 - 100.0 feet) 0.0674 - 40.0 meters**

(-0.781951689212
$$U = -0.246208804814 + 1.33422049854T$$

(1.75291677799)
$$Y = 2.70588058103 - 0.949516092853U + 0.112136118689U^2$$

$- 0.0250659183287U^3$

5. Shock Front Velocity (m/msec, ft/msec)

	(0.170 - 100.0 feet)
Range of applicability:	**0.0674 - 40.0 meters**

$$U = -0.202425716178 + 1.37784223635T^{(-0.755684472698)}$$

$$Y = -0.06621072854 - 0.698029762594U + 0.158916781906U^2 + 0.443812098136U^3 - 0.113402023921U^4 - 0.369887075049U^5 + 0.129230567449U^6 + 0.19857981197U^7 - 0.0867636217397U^8 - 0.0620391900135U^9 + 0.0307482926566U^{10} + 0.0102657234407U^{11} - 0.00546533250772U^{12} - 0.000693180974U^{13} + 0.0003847494916U^{14}$$

(the line above the Y equation reads **(0.449774310005)**)

6. Arrival Time (msec)

	(0.170 - 100.0 feet)
Range of applicability:	**0.0674 - 40.0 meters**

(-0.755684472698)

$$U = -0.202425716178 + 1.37784223635T$$

(-0.173607601251)

$$Y = -0.0591634288046 + 1.35706496258U + 0.052492798645U^2 - 0.196563954086U^3 - 0.0601770052288U^4 + 0.0696360270981U^5 + 0.0215297490092U^6 - 0.0161658930785U^7 - 0.00232531970294U^8 + 0.00147752067524U^9$$

7. Positive Phase Duration (msec)

Three functions are required:

Function I

	(0.450 - 2.54 feet)
Range of applicability:	**0.178 - 1.01 meters**

(-0.1790217052)

$$U = 1.92946154068 + 5.25099193925T$$

(-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**

(-5.85909812338)

$$U = -2.12492525216 + 9.2996288611T$$

(0.20096507334)

$$Y = 0.315409245784 - 0.0297944268976U + 0.030632954288U^2 + 0.0183405574086U^3 - 0.0173964666211U^4 - 0.00106321963633U^5 + 0.00562060030977U^6 + 0.0001618217499U^7 - 0.0006860188944U^8$$

Function III

Range of applicability: **(7.00 - 100.0 feet)** **2.78 - 40.0 meters**

(-4.92699491141)

$$U = -3.53626218091 + 3.46349745571T$$

(0.572462469964)

$$Y = 0.686906642409 + 0.0933035304009U - 0.0005849420883U^2 - 0.00226884995013U^3 - 0.00295908591505U^4 + 0.00148029868929U^5$$

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^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 · [$\sin^{-1}$ · (c_p / U)] ≥ 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

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

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	**$\leq$ 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 $\frac{q}{t_w}$ ($kW \cdot s / m^2$)			
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	**$V_{V/h,max}$**	**SCALED DISTANCE Z (m/kg^1/3)**		
	(m/s)	**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 containers 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, fire retardant 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 VI – 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

Chapter 7 is pending further review

Refer to AASTP-1 Part I Chapter 6

ANNEX II-A

RESERVED

ANNEX II-B

DETAILED INFORMATION RELATED TO EARTH-COVERED MAGAZINES (IGLOOS)

SECTION I - TYPES OF IGLOOS

SECTION II - BLAST DATA FOR DESIGN OF IGLOOS

Detailed information can be found

PFP(AC/326-SG/5)D(2010)0001 Nationally Approved Structures, Ed 2, 2 December 2010

ALLIED AMMUNITION STORAGE AND TRANSPORT

PUBLICATION 1

(AASTP-1)

MANUAL OF NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

PART III

UNDERGROUND EXPLOSIVES STORAGE

April 2010

TABLE OF CONTENTS

PART III

CHAPTER 1 - GENERAL

Section I - Introduction

3.1.1.1. Purpose

This part of the Manual [1][†] deals with special types of storage of ammunition and explosives such as underground storage and storage aboveground in circumstances other than normal for an aboveground depot. Although each chapter contains both principles and technical details, it is necessary to refer to Part I and Part II of the Manual for an explanation of the fundamental concepts and the definitions of certain terms.

3.1.1.2. Design Environment Criteria

This part uses distances, specified by the criteria below, to achieve desired levels of protection to personnel and property. Distances provided by the criteria do not guarantee absolute safety. However, assuming an event, these distances do limit the expectation of a severe injury or fatality to normally less than 1% for personnel in the open or in a conventional building at Inhabited Building Distance (IBD).

Advisable criteria at IBD are:

Air blast overpressure:	5 kPa
Fragments and debris:	1 hazardous fragment per 56 m^2

Actual particle velocity to be used at IBD for groundshock should depend on the robustness of the structure under consideration and is discussed in page III.2.3

The criteria listed above are used in Part III, Chapter 3 to obtain required distances.

Special considerations that are not discussed in detail here are required to provide levels of protection for historical monuments and sites, high-rise buildings, and locations where many people are assembled.

When they are available, site-specific and configuration-specific tests and/or analyses may be used to determine recommended distances.

[†] References are in Annex III A

When deciding distances that provide protection for personnel , the requirements of Part II, para 2.5.5.5.d, para 2.5.5.6, Fig 5-XV, and Annex II A-D10 distance should be considered. These are:

Airblast overpressure: 20-kPa side-on overpressure will not cause severe injury to persons in the open.

Ground shock: A velocity change of less than 3 m/s will not cause severe injury to personnel.

Public Traffic Route Distance (PTRD) is normally 2/3 of IBD because moving traffic is not continuously exposed. However, IBD should be used instead of PTRD where there is a heavy traffic.

3.1.1.3. Limitations

Configurations of underground facilities will vary from site-to-site. Only a limited number of possible configurations have been investigated. Site-specific tests and analyses will be necessary if high-levels of confidence are required for the more complex configurations.

Recommendations for underground storage are based on the best-available, worldwide database of information. Recommendations are based on accidents or scaled tests with non-responding steel models (1/100th to 1/20th scale) or rock tunnels (1/8th to 1/3rd scale).

3.1.1.4. Requirements

Engineered structures and devices related to explosives safety must be designed to 90% confidence levels for collapse or failure with a given load (Part II, Para 2.3.2.2).

QD distances provided in this document are based on TNT-equivalencies for the energetic materials that are involved. Significant differences in the TNT-equivalency must be considered [3].

See Part I, Annex IA, Section 1, Para 2 [1] for rounding of Quantity-Distances.

Section II - Definitions

3.1.2.1. General

The following definitions are used in connection with underground storage. For additional definitions, see Part I, Chapter 2, Section 2 [1].

3.1.2.2. Definitions

a) Adit

A passage or tunnel leading into an underground storage site

b) Chamber Interval

The interval between the natural or artificial walls of adjacent underground storage chambers/sites

c) Cover

The solid ground situated between the ceiling or the wall of an underground chamber and the nearest exterior surface

d) Crack

A short, primary discontinuity, which is not pervasive and may not be visible

e) Crater

A hole or chasm in the cover (burden) caused by an underground explosion.

f) Faulting

Motions in the earth's crust resulting in failure of the rock mass and concentrated displacements along failure planes, for instance discontinuities (joints, fractures)

g) Filled Joints

A clearly visible, pervasive discontinuity of geological origin which has a mineral filling of loose or porous materials and which may be several tens of millimetres thick

h) Fissure

A short, hardly visible and partly irregular, secondary discontinuity, which appears in conjunction with prepared planes, for instance a blasting fissure or a rock pressure fissure

i) Joint

A term in rock mechanics for a mechanical discontinuity in rock, with a thickness less than a few tens of millimetres. Joints (fractures, discontinuities) may be open or filled with some material.

j) Single Chamber Storage Site

A chamber storage site with one chamber, which has its own entrance from the exterior and is not connected by air ducts or passageways to any other storage chamber

k) Shot Gun Type Magazine

A single chamber storage site with one exit and a direct line-of-sight from the chamber to the outside of the underground installation.

l) Underground Storage

Storage, normally in solid rock, in a cavern or chamber storage

m) Venting

The reduction of internal pressure due to release of gases into a passageway, other chambers, adits, and any aperture in the cover

CHAPTER 2 - BACKGROUND INFORMATION

Section I - General

3.2.1.1. Optimized Underground Ammunition Storage Site (General Description)

a) Underground storage facilities may consist of a single chamber or a series of connected chambers. The chamber(s) may be either excavated or natural geological cavities. Figures 2-I and 2-II[†] illustrate general concepts for several possible configurations of underground facilities. Underground ammunition storage sites should be located in sound rock. A storage site may consist of one or more storage chambers with usually one access tunnel in each chamber. The number of chambers depends upon prevailing topographical and geological circumstances and safety aspects in the environment of the storage site. Potential blockage should be considered for multi-chamber sites.

b) The thickness of the rock formation surrounding an underground storage site should be designed so cratering hazards, in case of an explosion, can be practically excluded. Then the only significant external hazards will be the ground shock and the explosion effects coming from the adit tunnel. The effects coming from the adit may be considerably reduced by means of structural measures in or in front of the tunnel or even eliminated by the installation of tunnel closing devices.

c) Adequate separations and tunnel closing devices should be used to prevent the propagation of an explosion from chamber-to-chamber.

d) Provided the access openings are adequately hardened, underground storage is relatively well-protected against enemy attack..

e) Geological aspects have a great influence on building costs and, in terms of the construction cost alone, underground storage is often more costly than aboveground storage. However, when estate, operating, maintenance and lifetime costs are considered, at least for larger underground facilities, it may be less than for comparable aboveground facilities. Generally, the most economical are chambers measuring from 100 to 200 m in length with a volume between 5,000 and 15,000 m^3. This provides a total gross capacity between 1000 and 2000 tonnes of ammunition. The length of the access tunnel may be 50 to 150 m, depending on topographical conditions and the desired rock thickness.

[†] Figures are included in Text

Figure 2-I: Layouts of Underground Facilities

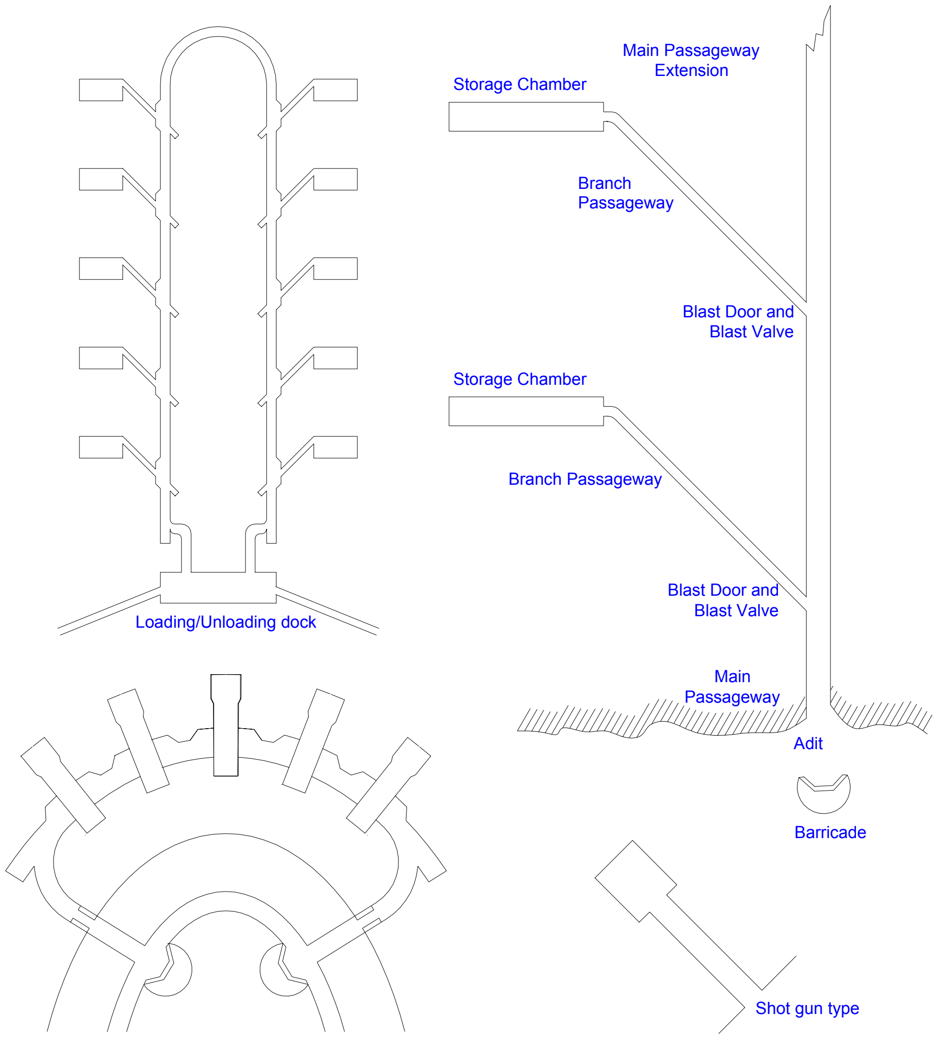
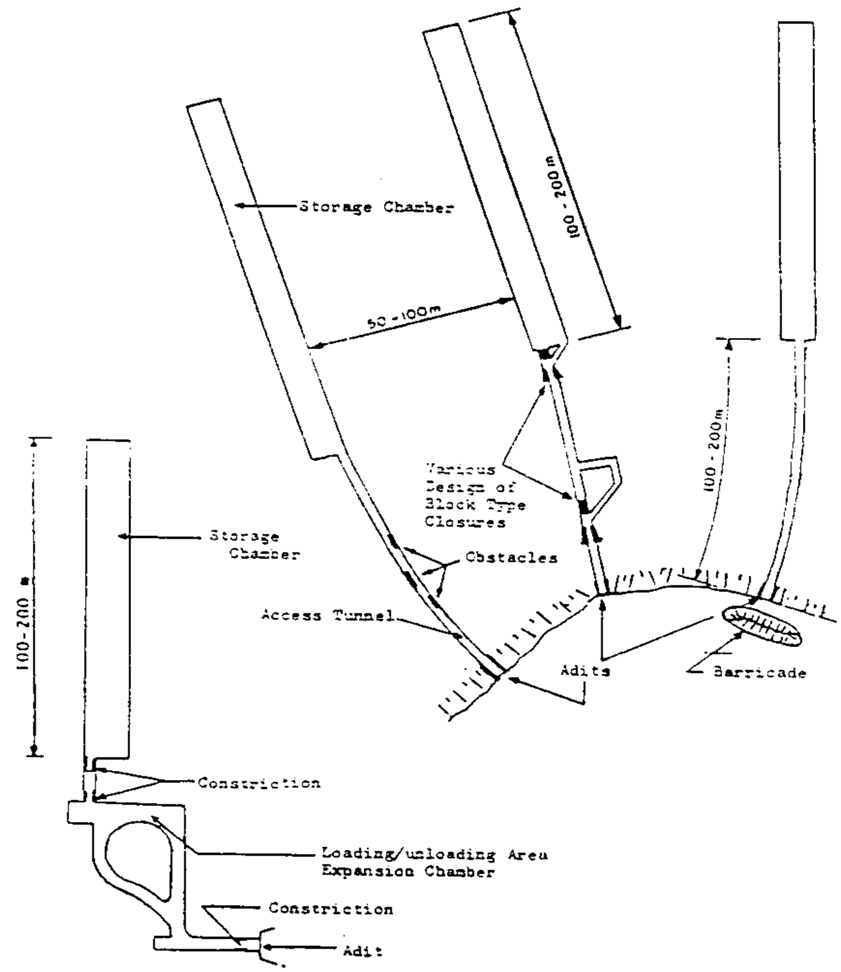


Figure 2-II: Layouts of an Underground Storage Site



3.2.1.2. Explosion Effects in Underground Ammunition Storage Sites

a) The blast wave originating from an explosion in an underground storage chamber will surge through the rock formation as ground shock and will escape as blast through the access tunnel into the open air. The strong confining effect of an underground storage site and the large amount of hot explosion gases generated will produce a relatively constant high pressure in the chamber. This pressure may break up the rock formation and produce a crater. The kinetic energy (dynamic pressure impulse) of the blast in the main passageway is very high compared to an explosion in free air. Objects like unexploded ordnance, rock, gravel, equipment, and vehicles will be picked up and accelerated up to velocities of several hundred metres per second before leaving through adits. In addition, engineered features can collapse and cause debris hazards. Break-up of the cover will cause projection of a heavy fall of rock and earth in all directions onto the surrounding surface area.

b) The explosion gases will surge at a high velocity through the access tunnel into the open air where they will burn completely. The escaping gases will carry along ammunition, rock debris, installations, and lining onto surrounding areas.

c) A disturbance near the surface of the ground will emit compression P-waves, shear S-waves, and Rayleigh surface R-waves in a semi-infinite elastic medium. Deeply buried disturbances will emit only P-waves and S-waves, but in the far field, interface effects will result in R-waves being produced. For all of these waves types, the time interval between wave front arrivals becomes greater and the amplitude of the oscillations becomes smaller with increasing standoff distance from the source.

The first wave to arrive is the P-wave, the second the S-wave, and the third the R-wave. The P-wave and S-wave are minor tremors, as these waves are followed by a much larger oscillation when the R-wave arrives. The R-wave is the major tremor because: 1) about two-thirds of the ground shock energy at the source goes into the R-wave, and 2) the R-wave dissipates much less rapidly with distance than either the less energetic P-wave or S-wave. P-waves and S-waves dissipate with distance r to a power of r^{-1} to r^{-2}. At the surface, P-waves and S-waves dissipate with distance as r^{-2}, while R-waves dissipate with distance as $r^{-0,5}$. The greater energies being transmitted by R-waves and the slower geometric dissipation of this energy causes R-waves to be the major tremor, the disturbance of primary importance for all disturbances on the surface.

d) Small-Scale Model Tests and Validity of Scaling Laws

1. A portion of the blast energy from an underground detonation is used to compress the surrounding geological media. This allocation of energy should be considered when evaluating the experimental results of underground tests.

2. Small-scale, modeling tests that are constructed of non-responding materials do not exhibit the non-linear energy loss effects typical of an underground explosion. Therefore, air blast results from non-responding models tend to be safety conservative for predicting hazards that would occur in an actual underground event. In spite of this, small-scale model tests are still of value for design purposes.

3.2.1.3. Advantages of Underground Storage

Advantages of underground storage are:

1. A smaller total land area is required than for an aboveground storage.

2. A high degree of protection is afforded against bombing or terrorist attack.

3. The area is easier to camouflage and to guard than an aboveground area.

4. In case of an incident in an underground chamber, damage to ammunition in other chambers is preventable. Damage to ammunition in aboveground buildings, other than earth-covered magazines, is usually more extensive.

5. The temperature in underground storage sites is almost constant. The deleterious aging effects on munitions and explosives caused by extreme temperatures and temperature cycling is mitigated.

6. Effects of sand, snow, and ice, which may cause difficulties in aboveground storage, may be avoided.

7. Inherent protection may be afforded against external fire.

8. Estate costs, as well as maintenance and operation may be less costly as for an aboveground storage site, thus more than offsetting the construction costs.

3.2.1.4. Disadvantages of Underground Storage

Disadvantages of underground storage may be:

1. The choice of localities is restricted.

2. The costs of the original excavation or the modification of an existing excavation and the installation and maintenance of special equipment may increase the initial costs of underground storage over that of aboveground.

3. Extra handling equipment may be required.

3.2.1.5. Work Prohibited in Underground Storage Sites

The opening of packages or the removal of components from unpacked ammunition or similar operations should be prohibited in the storage chamber, but could be done in the loading/unloading dock or in a separate chamber if suitable measures are taken to prevent a propagation into the storage chambers.

3.2.1.6. Storage Limitations

Limitations on underground storage are:

1. Ammunition containing Flammable Liquids or Gels

   Ammunition containing flammable liquids is only permitted in underground storage sites if proper protection against fuel leakage is established. The possible energy release of a stochiometric combustion should be considered as part of the total energy release. Multi-chamber sites should be arranged and/or sealed in such a way that fuel-fire or gas explosion should not increase the likelihood of reaction in neighbouring chambers more than established through interior distances to prevent detonation transfer.

2. Ammunition containing Toxic Agents

   Because of the difficulties of decontamination underground, ammunition containing toxic agents should only be stored under special provisions.

3. Suspect Ammunition and Explosives

   Suspect ammunition and explosives should not be stored.

4. Ammunition containing Pyrotechnics

Ammunition containing pyrotechnics, such as illuminating, smoke and signal ammunition, could in some cases be more vulnerable to mishaps or self ignition, and thereby increase the likelihood of an accident. The decision to store ammunition that contains pyrotechnics underground must be made on a site-specific basis and provisions must be taken to mitigate the peculiar hazards of pyrotechnic materials.

5. Ammunition containing Depleted Uranium

Before ammunition containing depleted uranium is permitted in underground sites, the slight radioactivity and chemical toxicity that would result from an accidental fire or explosion should be assessed and accepted.

Section II - Design

3.2.2.1. General

Planning of new underground storage facilities must account for site conditions, storage requirements, and operational needs. Only when these are established can the design be developed. An optimal compromise between the sometimes-contradictory demands for planning, construction and operation of storage sites must consider safety, military and cost requirements.

3.2.2.2. Safety Requirements

Operational procedures should be planned and conducted so that, to the best extent possible, explosives mishaps are prevented. Facility configurations are to be designed so that, if an explosives mishap should occur, its hazards are mitigated to acceptable levels. Safety efforts that are essential for ammunition storage sites include:

1. Surveillance and maintenance to ensure that only safe ammunition is stored

2. Well-designed and environmentally controlled chambers and facilities to protect the ammunition against unintended events

3. Suitable structural designs and operating procedures (doors and guards, for example) to protect the ammunition against deliberate action by third parties

4. Structural designs and operating procedures to

    a) mitigate explosion propagation outside the area of initial occurrence, and

    b) provide desired levels of personnel, facility, and asset protection

5. The construction and operation of ammunition storage sites should only be entrusted to qualified and trained personnel who have clearly defined responsibilities.

6. Evaluate a suitable location for the installation taking into account the site-specific use of surrounding (inhabited buildings, roads, etc.).

3.2.2.3. Military Requirements

Functional requirements that dictate the geographical location of a storage site or its storage and transfer capacity, may sometimes run counter to desirable safety considerations, thereby requiring innovative designs to provide required levels of explosives safety. Military requirements often involve protection against enemy weapons, intruder protection, etc.

3.2.2.4. Financial Aspects

The lifetime cost of a storage facility (construction, operation, and maintenance) should be considered during the planning phase. Where possible, designs should be selected that minimize total cost while providing required safety and operational capabilities.

Section III - Equipment

3.2.3.1. Humidity Control and Ventilation

a) High humidity may be a problem in underground sites. Dehumidifying equipment may then be necessary to control relative humidity to 60%. Certain types of ammunition may require lower relative humidity (50%). The chambers may be lined with concrete or coated fabric to better control humidity. The roof lining should be strong enough to withstand minor rock falls.

b) The type of transportation equipment used may govern ventilation requirements. Ventilation shafts to the exterior should be designed to prevent trespass and sabotage.

3.2.3.2. Electric Installations and Equipment

a) Electric installations and equipment for underground storage sites should conform to the national standards of the host nation.

b) An emergency lighting system should be installed. Otherwise transportable battery operated lights of an appropriate standard should be provided and kept at suitable points.

c) A portion of the personnel employed underground should be equipped with hand lamps of an appropriate standard.

3.2.3.3. Lightning Protection

An underground storage site does not normally require a system of protection against lightning. Metal and structural parts of the site which have less than 0.6 m cover should be protected as for an aboveground site, see Part II, Chapter 3, Section IV. However, each underground storage site should be considered individually to take account of possible conducting faults in the cover.

3.2.3.4. Transport and Handling Equipment

Rail vehicles, road vehicles, mobile lifting or stacking appliances and cranes of the fixed or gantry type, when operated electrically or by diesel engine, may be permitted in underground storage sites subject to the following conditions:

1. Electrical equipment should conform to the national standards of the host nation for underground storage sites.

2. Diesel operated equipment should be fitted with an effective means of preventing sparks or flames from exhaust outlets. Any portion of the exhaust system or exposed parts of the engine, which may develop a surface temperature exceeding 100^{o} C, should be suitably screened to ensure that all exposed surfaces are below that temperature. If the engine is to be kept running during loading and unloading within the storage site, it should conform to the host nation standards for underground (confined space) operations.

3. The flash point of the fuel oil for diesel engines should be not less than 55^{o} C. Fuel tanks should be filled only at authorized places and no spare fuel should be carried.

4. Where fuel oil filling stations are authorized in the underground area, the fuel should be taken underground in strong closed containers in quantities not exceeding that required for one working day. The filling station should have a concrete floor with a sill of sufficient height to contain the quantity of fuel authorized to be stored there.

3.2.3.5. Fire-fighting Equipment

Equipment should conform to the national standards of the host country with particular consideration given to the following:

1. Reduce the probability that a small fire will escalate by installing an automatic smoke-detecting and fire-extinguishing system.

2. Consideration should be given to protecting reserve water tanks from potential explosives effects.

3. An alarm system should be provided to operate throughout the whole area, both above and below ground.

4. In air-conditioned sites or in sites provided with forced ventilation, the need to shut these down on an outbreak of fire must be considered.

5. Fire-fighting equipment retained underground should be positioned for accessibility and potential use.

6. For large underground areas, detector devices, to specify the location of a fire, and communication capabilities, to issue instruction throughout the underground facility, should be installed.

7. Self-contained breathing apparatus and training in its use are essential for underground fire fighting or rescue operations, etc.

Section IV – Explosives Hazards Mitigation Methods.

3.2.4.1. Facility Layout

a) A single-chamber facility with a straight access tunnel leading from the chamber to the portal is a “shotgun” magazine because blast and debris behave as if fired from a gun. More complex facility layouts will provide reductions in exit pressures.

b) The side on pressure, the side on pressure impulse, dynamic pressure and the dynamic pressure impulse decrease as the volume increases.

c) Distributing munitions over several storage chambers may control the size of an initial explosion. Proper separation or hazard mitigating constructions can limit subsequent damage.

3.2.4.2. Exits

a) The exits from underground storage sites should not emerge where they direct blast, flame, and debris hazards to Exposed Sites, ES, such as other entrances, buildings, or traffic routes.

b) Connected chambers and cave storage sites should have at least two exits. Exits should be separated by at least the chamber interval.

3.2.4.3. Branch Passageways

a) When a main passageway has one exit, branch passageways should be inclined at an angle where they join the main passageway to direct the flow field towards the exit. This inclination should provide for vehicle access. Angles between 40 degrees and 70 degrees are normally appropriate.

b) The rock thickness between the chamber and the main passageway should be at least equal to or greater than the chamber interval. Otherwise, an explosion in a chamber might destroy the main passageway and prevent access to stocks of ammunition and explosives in the other chambers.

3.2.4.4. Blast Closures

a) High-pressure closures are large blocks constructed of concrete or other materials that can obstruct or greatly reduce the flow of blast effects and debris from an explosion from or into a storage chamber. For chamber loading densities of about 10 kg/m^3 or above, closure blocks will contain 40 percent or more of the explosion debris within the detonation chamber, provided the block is designed to remain intact. If a closure block fails under the blast load, it will produce a volume of debris in addition to that from the chamber itself. However, since the block's mass and inertia are sufficient to greatly reduce the velocity of the primary debris, the effectiveness of other debris-mitigating features, such as debris traps, expansion chambers and barricades is increased. Debris traps and expansion chambers intended to entrap debris must be designed to contain the full potential volume of debris, based on the maximum capacity of the largest storage chamber.

b) These debris mitigation features were investigated in the tests described in Reference [7]. These tests showed that such measures can be very effective, however, no quantitative figures for the reduction of the adit debris throw were derived. Furthermore, it was shown that a proper design of the mitigation measures is very important. Sample drawings of the features that proved to be effective for the tested configurations are in Reference [5].

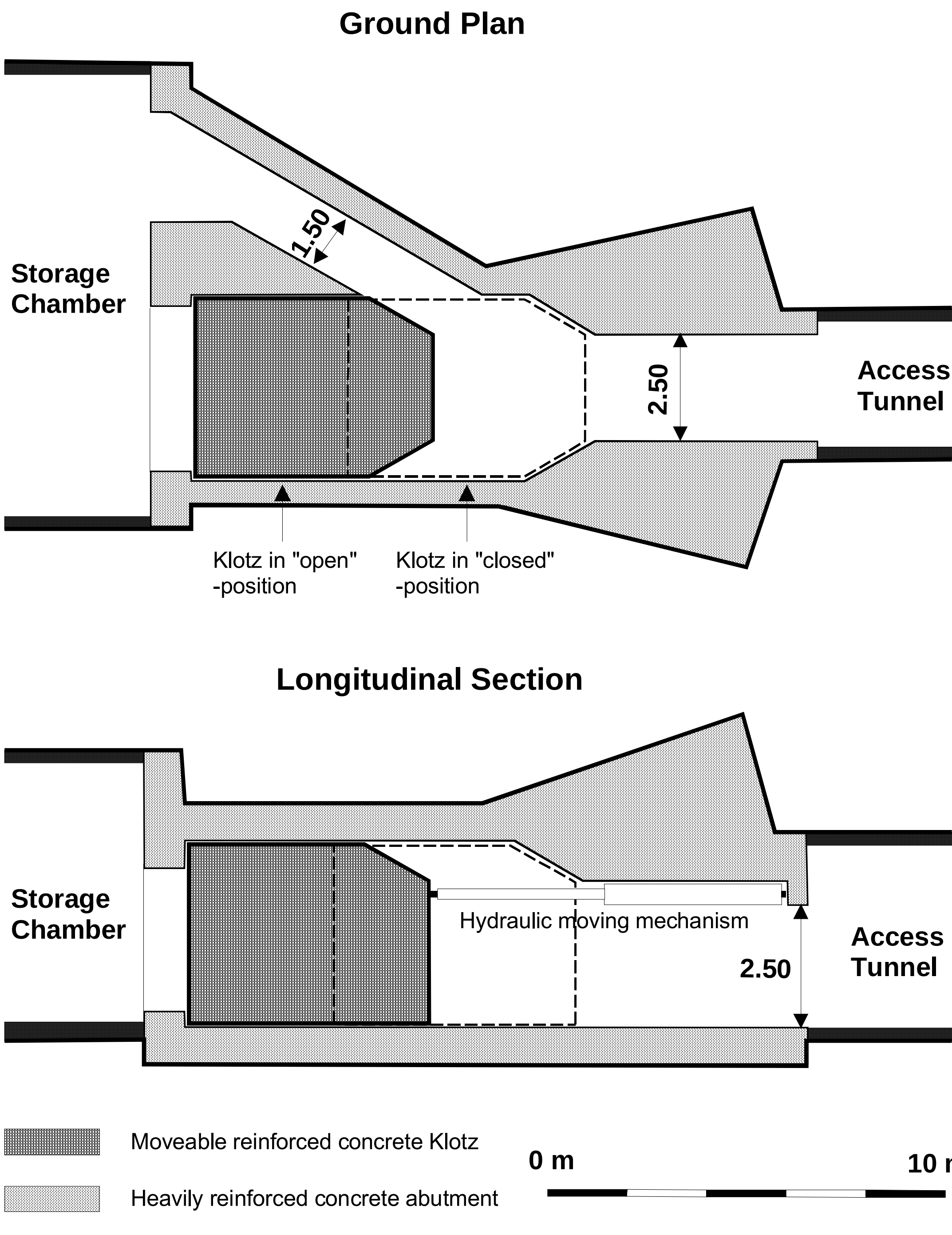
c) An alternative, full-scale tested; design for a high-pressure closure device, the Swiss-Klotz [4], is shown in Figure 2-III. This device is highly effective up to chamber loading densities of 28 kg/m^3. A special advantage of this Klotz is that it is movable and can be closed during times when access to the storage chamber is unnecessary.

d) In case of an explosion inside the storage chamber and a Klotz in closed position, practically all of the hazardous debris as well as the explosion gases will be trapped inside the storage chamber, thereby reducing these hazardous effects to virtually insignificant levels. In case the Klotz is in open position, it will be pushed into the closed position by the explosion gases within approximately 100 ms, letting pass only a small fraction of the total amount of debris and gases.

e) In any case, using a properly designed high-pressure closure device in conjunction with a portal barricade will lower the debris hazard to a level where specific debris QD considerations will not be required. Other combinations of mitigation features will also reduce adit debris throw to a great extent. The remaining adit debris hazard has to be assessed based on the actual facility layout and quantified by means of suitable tests.

f) Blast doors that are protected from primary fragments have proven effective for loading densities up to 10 kg/m^3.

Figure 2-III: The Swiss-Klotz-Layout



3.2.4.5. Expansion Chambers

a) Expansion chambers are so-named because of the volume they provide for the expansion of the detonation gasses behind the shock front as it enters the chamber from a connecting tunnel. Some additional degradation of the peak pressure at the shock front occurs as the front expands into the chamber and reflects from the walls.

b) Expansion chambers have other practical purposes. They serve as loading/unloading chambers, as weather protected areas for the transfer of munitions from trucks to storage chambers, and as turn-around areas for transport vehicles. Figures 2-IV and 2-V illustrate underground facilities with and without expansion chambers.

3.2.4.6. Constrictions

a) Constrictions, which may be used for mitigating explosives hazards, are short lengths of tunnel with reduced cross sectional area.

b) A constriction at a chamber entrance reduces the magnitude of airblast and thermal effects entering chambers near one in which an explosion might occur. A constricted chamber entrance also reduces the area, and hence the size of a blast door installed to protect the chamber contents.

c) A constriction intended to reduce airblast issuing from an exit of an underground storage facility should be located within five tunnel diameters of the exit.

d) Although constrictions located more than five tunnel diameters from exits will reduce pressures by delaying the release of energy [8, 9], their effects on pressure versus distance must be considered on a site-specific basis.

3.2.4.7. Debris Traps within the Underground Facility

a) Debris traps are excavations in the rock at or beyond the end of sections of tunnel, designed to catch debris from a storage chamber detonation. Debris traps should be at least 20 percent wider and 10 percent taller than the branch passageway from the chamber whose debris it is intended to trap, with a depth (measured along the shortest wall) of at least one tunnel diameter.

b) An expansion chamber may be effective for trapping debris. Tunnels entering or exiting the chambers must either be offset in axial alignment by at least two tunnel widths or its axis must be offset at least 45 degrees from the centerline of the tunnel associated with the chamber [5].

Figure 2-IV: Magazine with Expansion Chamber

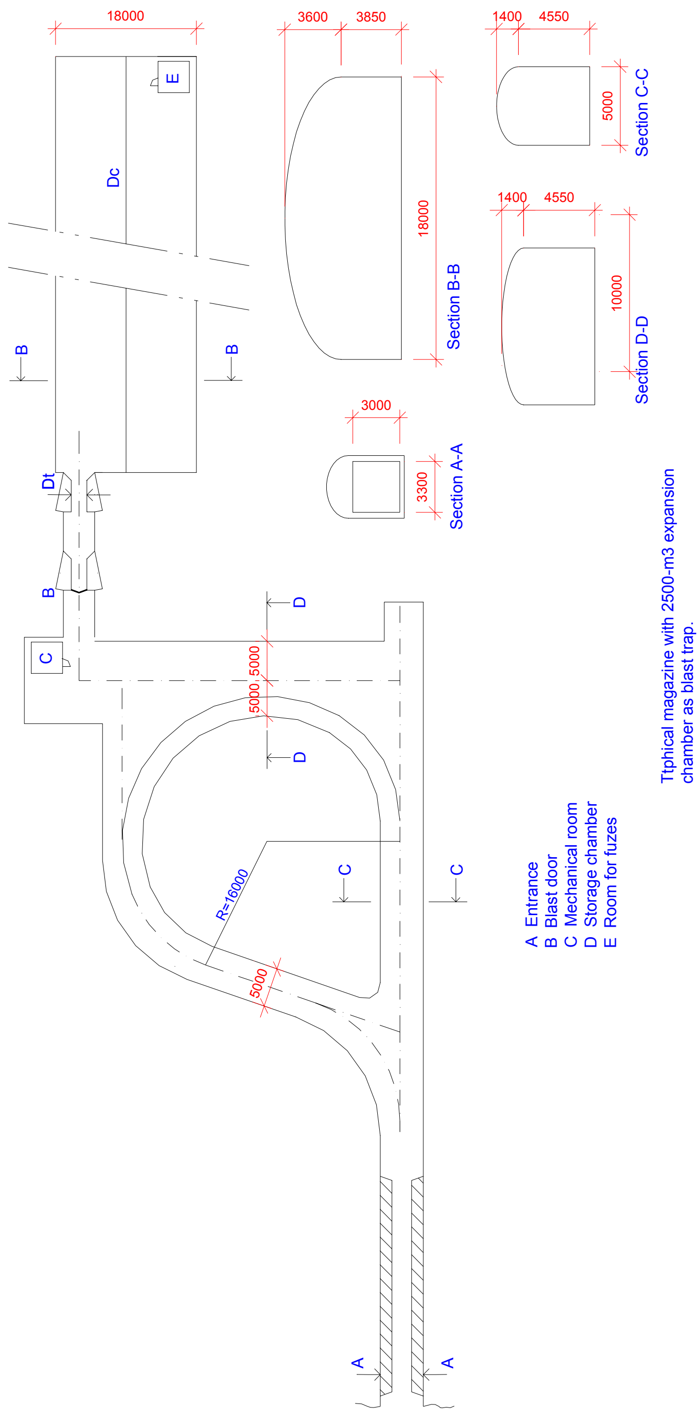
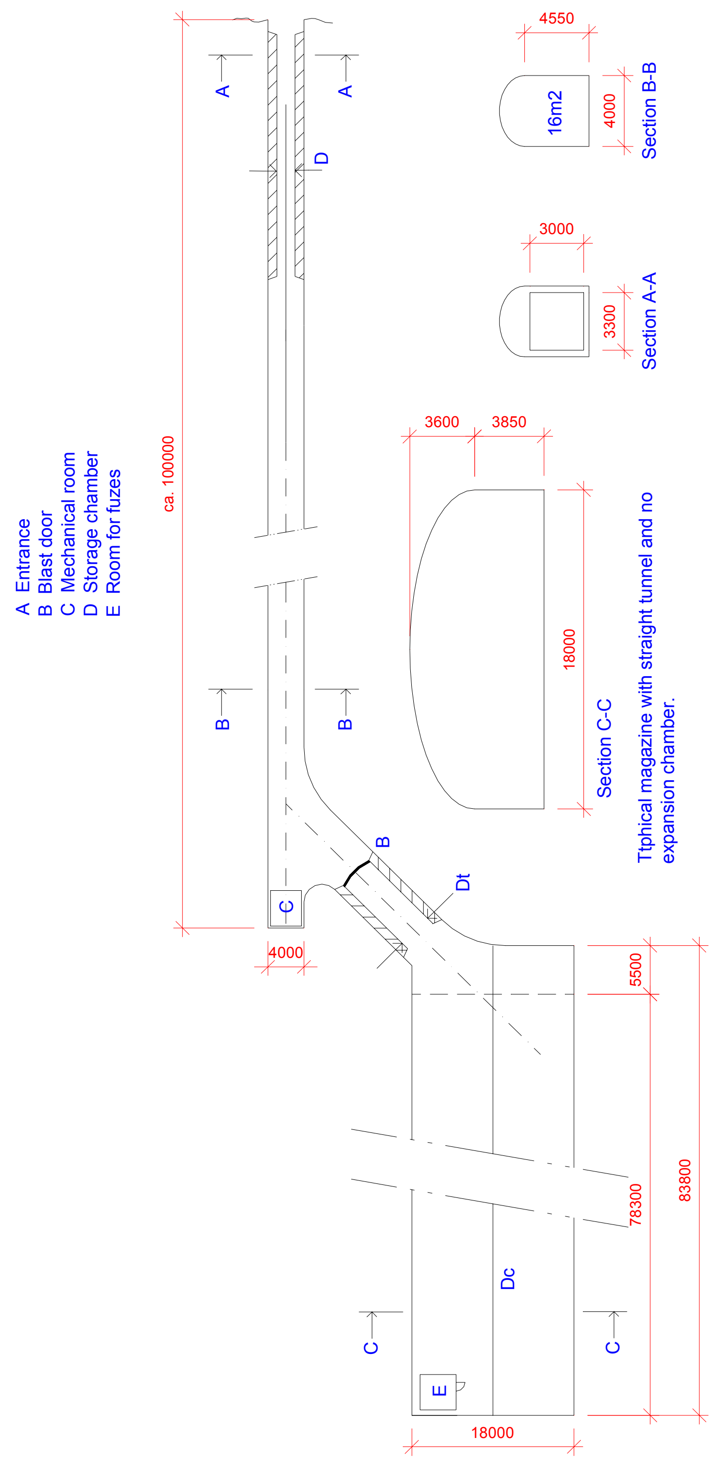


Figure 2-V: Magazine without Expansion Chamber



3.2.4.8. Blast Traps

a) Blast traps may be used to reduce the intensity of blast leaving or entering a passageway. They may be used to attenuate the blast issuing from the adit of an underground site, thus reducing hazard to people and property in the vicinity. They may also be used to reduce the blast entering an adjacent underground site, and to diminish the hazard to other ammunition. The effect of various blast traps will be a function of the geometrical design of the blast traps, and the peak side on pressure, the side on pressure impulse, the dynamic pressure and the dynamic pressure impulse of the incident blast wave. Fixed reduction figures can therefore not be given. The design of effective blast traps is a specialized subject.

b) Various types of blast traps are shown in Figure 2-VI. The relative decrease of pressure and impulse, and thereby the effect of these blast traps, is in most cases dependent upon their locations. Some of the limitations are also indicated in the figure. It is noteworthy that not all designs of blast traps are reversible.

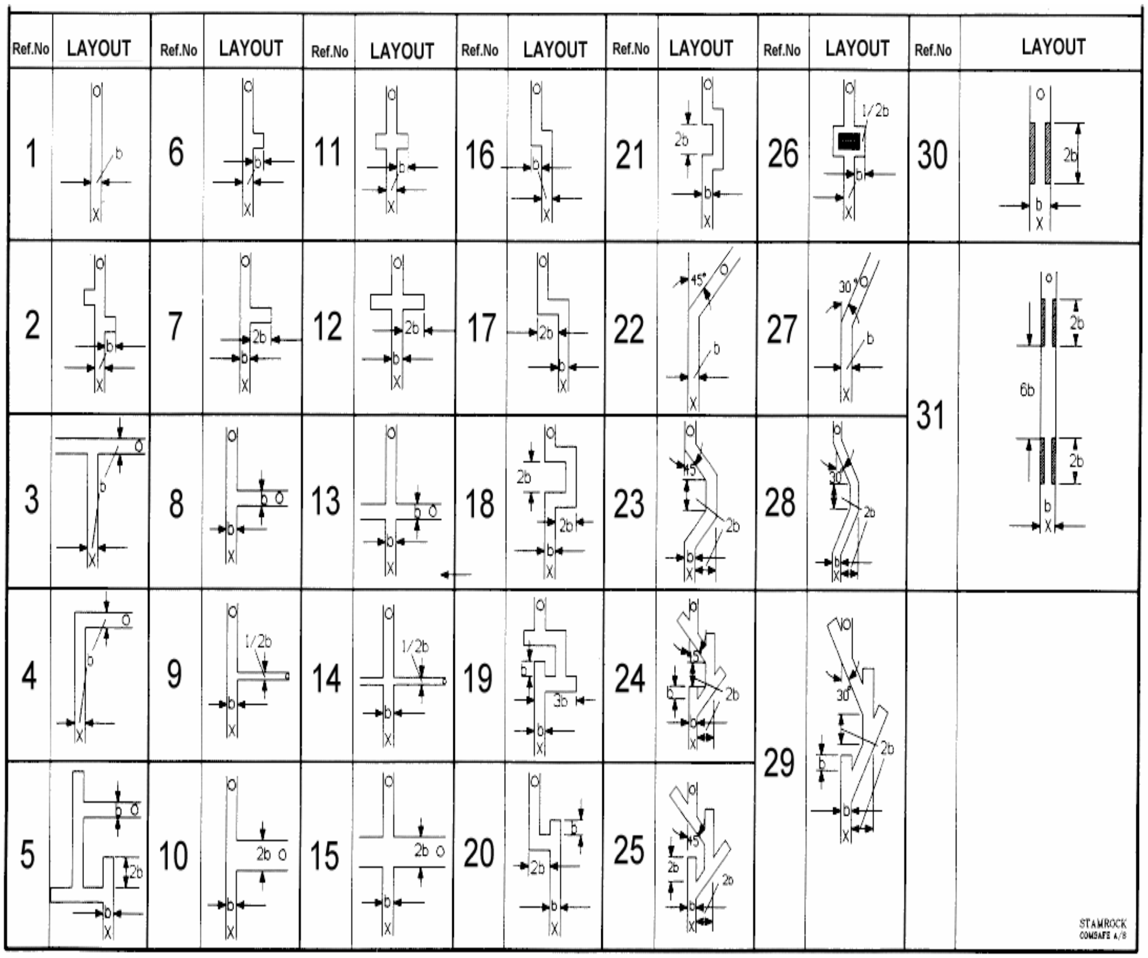
c) For maximum blast reduction, the length of blast traps built as dead end tunnels should be at least half the length of the blast wave. This may result in a considerable extension of these traps in the case of large quantities of explosives.

3.2.4.9. Portal Barricade

a) Airblast

Airblast exiting the portal of an underground facility involve directional, very intense gas flow fields along the extended centerline of the tunnel exit. Therefore, the shock wave on the extended centerline does not attenuate as rapidly as that of a surface burst. However, a barricade in front of the portal intercepts this intense flow field and directs it away from the extended centerline axis. This redirection of the flow field allows shock waves traveling beyond the portal barricade to attenuate as an above ground distributed source so that isobar contours become more circular. Figure 2-VII provides an example of a portal barricade.

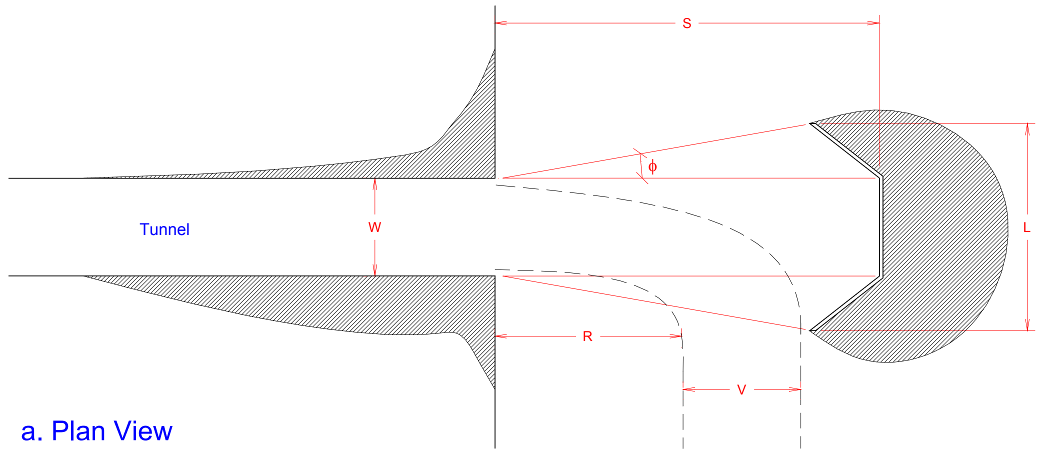
Figure 2-VI: Blast Traps



Turns, crossovers, obstacles and changes of cross section can be used to reduce the peak overpressure and positive impulse of blast in passageways. The diagrams in this figure illustrate some of the many possible designs. The Blast k assumed to travel from the point indicated by a cross to that shown by a dot. Critical dimensions are indicated as multiples of passage diameter “b”.

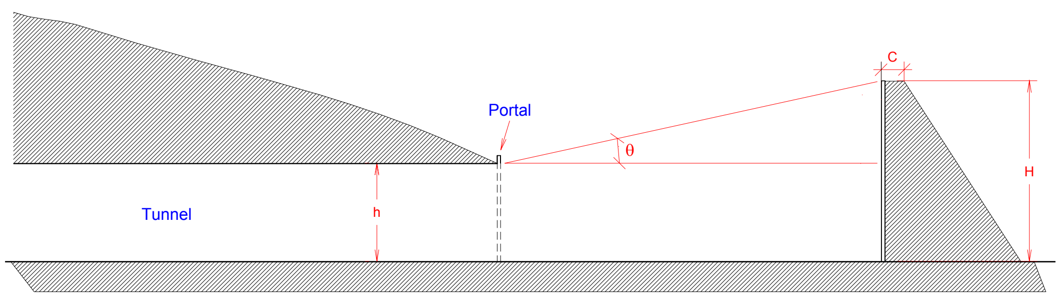
Some designs have comparatively little effect reducing the blast by only 10 % compared with the straight-through passageway in Ref. No 1, whereas others reduce the blast by as much as *80* %. It is therefore necessary to determine the actual effect of a chosen design by measurements in a model using properly scaled and located explosive charges.

Figure 2-VII: Portal Barricade Location, Height and Length



a. Plan View

S = Stand off distance from portal (1 to 3 tunnel widths)
R = Turning rasdius of munition transport vehicles
V = Width of transport vehicles
L = Length of barricade
W = Tunnel width at portal
ϕ = Single angle [10 degrees minimum]



a. Elevation View

C = Crest Width [See DEF 421-80-04]
H = Height of barricade
h = Height of tunnel
θ = Elevation angle [10 degrees minimum]

CHAPTER 3 - QUANTITY-DISTANCES

Section I - General

3.3.1.1. Types and Effects

a) Types

1. This section details how to predict QD based on criteria given in para 3.1.1.2. for the underground storage of military ammunition and explosives. Underground storage typically includes natural caverns and excavated chambers. Recommendations in this section shall only be used when the minimum distance from the perimeter of a storage area to an external surface exceeds 600 mm and $0.1 \cdot Q^{1/3}$ (m, kg). Otherwise, use aboveground siting criteria. This section addresses explosives safety criteria both with and without rupture of the cover.

2. Ground shock, debris, and air blast from an accidental explosion in an underground storage facility depend on several variables, including the local geology and site-specific parameters. These parameters vary significantly from facility to facility. Consequently, distances other than those listed below may be used provided approved experimental or analytical data indicate that the desired protection can be achieved. See below for default methods to determine QD.

   The QD for tolerable ground shock is the same in all directions for homogeneous, geological media, whereas QDs for other hazards (blast, thermal, impulse, etc.) vary markedly in different directions. Variations in QDs in different directions arise from configuration-specific features such as the locations of adits and ventilation shafts, hazards mitigating designs, and terrain. The acceptable QD in a given direction is generally taken as the maximum QD determined for the various hazards.

3. QD siting requirements of this section may be determined from the applicable equations or by interpolating between figure entries.

b) Effects

The following effects, peculiar to underground storage sites, must be taken into consideration for quantity-distance purposes:

1. Inside the Underground Installation:

The volume available to an expanding shock front is less in an underground configuration than it is in an aboveground configuration. Because of this limited space, an explosion in an underground facility typically results in long-duration, high pressures and temperatures that spread throughout the entire volume available to the shock front. Unless robust engineered designs (doors and/or other closing devices) are used to separate various parts of the facility, these long-duration blast effects spread throughout the entire underground complex. Doors or other closing devices must be properly designed and, in the case of doors, closed to provide the desired separation.

An initial event in Hazard Division 1.2 and 1.4 materials usually starts a fire, which is sustained by burning packages and components of the ammunition. This process causes additional explosions, likely at increasing frequency, until combustible materials in the site have been consumed. The results of these repeated explosions in the confined space underground will depend on the type and quantity of the substances in each unit of ammunition and the type of explosion produced.

2. Outside the Underground Installation:

Blast waves from adits exhibit highly directional flow-fields along the extended centerline of the passageway. Consequently, the blast wave effects (overpressure and impulse) do not attenuate as rapidly along the centerline axis as they do off the centerline axis.

The following effects should be considered for an external ES:

a) Blast from tunnel adits

b) Blast from craters, if the rock cover is insufficient.

c) Debris from tunnel adits

d) Debris from cratering

e) Ground Shock

f) Flame and hot gases

3.3.1.2. Quantity-Distances

a) Inside the UG Installation

QD should be determined for the following:

1. Chamber Intervals

2. Loading/Unloading Dock

3. Explosives Workshop Distance (EWD)

4. Inspection

b) Outside the UG Installation

QD should be determined for the following:

1. Inhabited Building Distance (IBD)

2. Public Traffic Route Distance (PTRD)

3. Explosives Workshop Distance (EWD)

4. Earth-covered Magazine Distance (ECMD)

5. Aboveground Magazine Distance (AGMD)

3.3.1.3. Net Explosives Quantity (NEQ)

For siting purposes, the NEQ is the total quantity of explosives material that must be included in defining a potential event. Part I, paragraph 1.4.2.5. provides guidance for finding the appropriate NEQ for sites containing materials with different Hazard Classes.

3.3.1.4. Measuring Quantity-Distances

a) Inside the Underground Installation.

The Chamber Interval is the shortest distance between the walls of two adjacent chambers. The subdivision of a cavern requires construction of massive barricades to close the gaps in the natural rock and to isolate one site or chamber from any other. The thickness of these barricades should be equal to the chamber intervals.

b) Outside the Underground Installation.

Distances to ESs outside the underground facility are normally measured as radial distances (see below) unless conditions make such a procedure clearly unreasonable:

1. Distances determined for airblast, debris, and thermal effects issuing from tunnel openings shall be the minimum distance measured from the openings to the nearest wall or point of the location to be protected. Extended centerlines of the openings should be used as reference lines for directional effects.

2. A distance determined by ground shock should be measured from the nearest wall of a chamber or a cavern containing ammunition or explosives to the nearest wall or point of the location to be protected.

3. A distance determined for air blast and debris from a breached cover shall be the minimum distance from the centre of the breach (CCB), at ground surface level, to the location to be protected (See Figures 3-XXIV and 3-XXV).

Section II - Hazard Division Material Dependence

3.3.2.1. Hazard Division 1.1, 1.3, 1.5 and 1.6 materials

a) Distances shall be determined from the total quantity of explosives, propellants, pyrotechnics, and incendiary materials in the individual chambers, unless the total quantity is subdivided to prevent rapid communication of an incident between subdivisions. All Hazard Divisions 1.1, 1.3, 1.5, and 1.6 material subject to involvement in a single incident shall be assumed to contribute to the explosion yield.

b) A connected chamber or cavern storage site containing Hazard Division 1.1 or 1.3, 1.5 and 1.6 materials shall be treated as a single chamber site, unless explosion communication is prevented by adequate subdivision or chamber separation.

c) HD 1.3 material should be treated as HD 1.1 material when it is stored underground.

3.3.2.2. Hazard Division 1.2 materials

a) The hazard to exterior ESs from primary fragments where a line-of-sight path exists from the detonation point to the ES is the only explosives safety hazard of concern for HD 1.2 materials.

b) When line-of-sight conditions exist, use distances common to aboveground situations.

c) QD requirements do not apply if the exterior ES is located outside the line-of-sight or if barricades (constructed or natural) intercept fragments issuing from an opening.

3.3.2.3. Hazard Division 1.4 materials

Exterior: Exterior explosives safety hazards are not normally significant for Hazard Division 1.4 materials. Accordingly, QD requirements do not apply for Hazard Division 1.4 materials.

Section III - Chamber Interval

References [7-10] deal with chamber intervals.

3.3.3.1. Hazard Divisions 1.1, 1.3, 1.5, and 1.6

a) Three modes by which an explosion or fire can be communicated are rock spall, propagation through cracks or fissures, and airblast or thermal effects traveling through connecting passages. Minimum storage chamber separation distances are required to prevent or control the communication of explosions or fires between donor and acceptor chambers.

The minimum chamber separation (D_{cd}) is 5 m for HD 1.1, 1.3, 1.5, and 1.6 materials.

b) Prevention of major damage by rock spall.

The chamber separation distance is the shortest distance (rock/concrete thickness) between two chambers. When an explosion occurs in a donor chamber, a shock wave propagates through the surrounding rock. The intensity of the shock decreases with distance. For small, chamber separation distances, the shock may be strong enough to spall the rock/concrete walls of acceptor chambers.

For hard rock with no specific protective construction, the minimum, chamber separation distance, D_{cd}, required to prevent major damage by spall depends on the chamber loading density (γ) as:

$$D_{cd} = 1.0 \cdot Q^{1/3} \qquad (\gamma \leq 50\, kg/m^3) \qquad \text{Eq. 3.3.3-1}$$

and

$$D_{cd} = 2.0 \cdot Q^{1/3} \qquad (\gamma > 50\, kg/m^3) \qquad \text{Eq. 3.3.3-2}$$

Example ($\gamma \leq 50\, kg/m^3$):

Q = 200,000 kg
D_{cd} = 1.0 · 58.48 = 58.5 m

For soft rock (See para 3.3.4.3.a), at all loading densities, the separation distance is:

$$D_{cd} = 1.4 \cdot Q^{1/3} \qquad \text{Eq. 3.3.3-3}$$

Example:

Q = 200,000 kg
D_{cd} = 1.4 · 58.48 = 82 m

c) Prevention of propagation by rock spall

If damage to stored munitions in the adjacent chambers is acceptable, the chamber separation distance can be reduced to the distance required to prevent propagation of the detonation by the impact of rock spall against the munitions. For smaller distances, propagation is possible. Propagation by rock spall is practically instantaneous because time separations between donor and acceptor explosions may not be sufficient to prevent coalescence of blast waves. Unless analyses or experiments indicate otherwise, explosives quantities subject to this mode must be added to other donor explosives to determine NEQ. For loading densities up to 270 kg/m³, when no protective construction is used, the separation distance, D_{cd}, to prevent explosion communication by spalled rock is:

$$D_{cd} = 0.6 \cdot Q^{1/3} \qquad \text{Eq. 3.3.3-4}$$

Example:

Q = 200,000 kg
D_{cd} = 0.6 · 58.48 = 35 m

When the acceptor chamber has protective construction to prevent spall and collapse (into the acceptor chamber) the separation distance must be determined on a site-specific basis but may be as low as:

$$D_{cd} = 0.3 \cdot Q^{1/3} \qquad \text{Eq. 3.3.3-5}$$

Example:

Q = 200,000 kg
D_{cd} = 0.3 · 58.48 = 17.5 m

d) Prevention of propagation through passageways

Blast, flame and hot gas may cause delayed propagation. Time separations between the original donor event and the potential explosions of this mode will likely be sufficient to prevent coalescence of blast waves. Consequently, for purposes of Q-D siting, only the maximum credible explosives quantity need be used to determine NEQ.

In order to protect assets, blast and fire resistant doors must be installed within multi-chambered facilities. Evaluations of design loads on doors must be made on a site-specific basis.

e) Propagation by Flame and Hot Gas through Cracks and Fissures

Consideration must be given to the long-duration action of the explosion gas. These quasi-static forces might form cracks in the rock that extend from the donor to an adjacent (acceptor) chamber, thus making it possible for hot gases to flow into this chamber and initiate an event. Significant factors for this mode of propagation include the strength of rock, the existence of cracks formed before the explosion incident, the type of barriers in cavern storage sites, the cover and the loading density in the chamber. This mode of propagation must be considered when final decisions about chamber separation distances are made.

Thus, because of these cracks and fissures, propagation may occur beyond

$$D_{cd} = 0.3 \cdot Q^{1/3} \qquad \text{Eq. 3.3.3-6}$$

Example:

Q = 200,000 kg
D_{cd} = 0.3 · 58.48 = 17.5 m

but not likely beyond;

$$D_{cd} = 2.0 \cdot Q^{1/3} \qquad \text{Eq. 3.3.3-7}$$

Example:

Q = 200,000 kg
D_{cd} = 2 · 58.48 = 117 m

Site-specific analyses, using a sound geological survey, should be made to determine proper intervals between chambers.

3.3.3.2. Hazard Division 1.2

Intervals between a chamber containing ammunition of Hazard Division 1.2 and adjacent chambers should be at least 5 m of competent rock unless structural considerations apply. This applies also to barriers used to isolate chambers in a cavern storage site.

3.3.3.3. Hazard Division 1.4

Intervals between chambers containing ammunition of Hazard Division 1.4 should be determined from structural considerations with no regard to the content of ammunition. This applies also to barriers used to isolate chambers in a cavern storage site

Section IV - Inhabited Building Distance (IBD)

IBD must be the largest of the distances for protection against airblast, debris, and ground shock [1, 7].

3.3.4.1. Airblast [8-15]

a) The side-on overpressure of 5 kPa defines IBD.

b) An explosion in an underground storage chamber may produce external airblast from two sources; the exit of blast from existing openings (tunnel entrances, ventilation shafts, etc.) and the rupture or breach of the chamber cover by the detonation. Required IBDs are independently determined for each of these airblast sources, with the maximum IBD used for siting.

1. A breaching chamber cover will produce external airblast. Use the following table to site for IBD due to airblast produced by breaching of the chamber cover. Values of IBD for airblast through the ruptured cover are:

Cover Thickness	*IBD*	*Equation*
$Cover \leq 0.1 \cdot Q^{1/3}$	$IBD\ for\ Surface Burst$	$Eq. 3.3.4-1(a)$
$0.1 \cdot Q^{1/3} < Cover \leq 0.2 \cdot Q^{1/3}$	$1/2\ IBD\ for\ Surface Burst$	$Eq. 3.3.4-1(b)$
$0.2 \cdot Q^{1/3} < Cover \leq 0.3 \cdot Q^{1/3}$	$1/4\ IBD\ for\ Surface Burst$	$Eq. 3.3.4-1(c)$
$Cover > 0.3 \cdot Q^{1/3}$	$Negligible\ Airblast\ Hazard$	$Eq. 3.3.4-1(d)$

2. This paragraph defines airblast IBDs from openings in an underground storage facility. The IBD for airblast must be considered for any opening. The method for calculation of air blast in underground storage can be divided in the following 3 steps:

   1. Calculation of air blast at the chamber exit
   2. Calculation of air blast at the tunnel adit
   3. Calculation of air blast outside the tunnel adit

a) To a first approximation, the overpressure in the storage chamber could be estimated with an algorithm of the form:

$$p_c = 1200 \cdot \left[\frac{Q}{V_C} \right]^{2/3} \qquad \text{Eq. 3.3.4-1}$$

where:

- p_c: overpressure at the chamber exit, kPa
- Q: Mass of explosives material, kg
- V_c: Volume inside the chamber that is engulfed by blast waves at the time the blast arrives at the location of interest (m^3).

b) Air blast at the tunnel adit
The reduction of peak overpressure and change of duration from the exit of a detonating chamber to the tunnel adit are calculated by using different types of tunnel elements (see figure 3-I – 3-VI) to resemble the actual configuration of the tunnel.

The following parameters and figure 3 and 4 are used to calculate the reduction of peak overpressure in a tunnel element (friction element) with a constant cross section and without junctions and turns.

$$L_R = L_S - 5 \cdot d_0 \qquad [8]$$

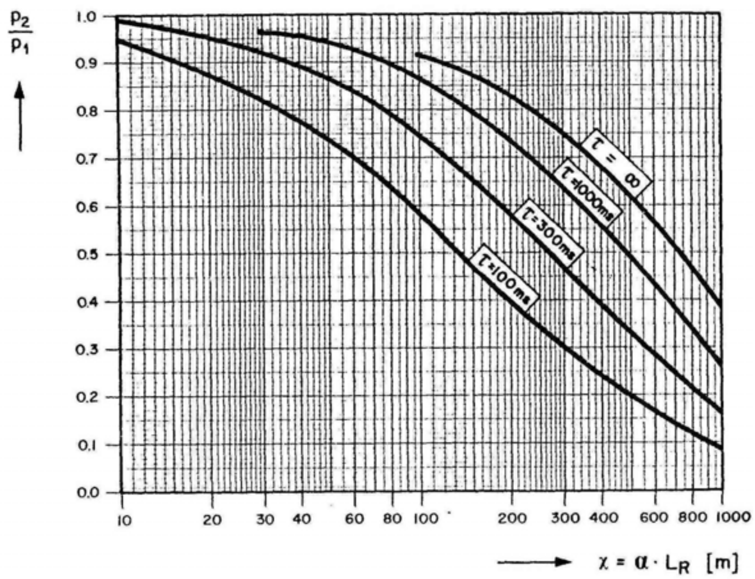
$$\chi = \alpha \cdot L_R \qquad [9]$$

$$\tau = \alpha \cdot t_1 \qquad [10]$$

$$t_1 = 20 \cdot {L_k}^{2/3} \cdot {d_0}^{1/3} \cdot \left(\frac{d_k}{d_0} \right)^2 \qquad [11]$$

L_s = Length of tunnel or tunnel element (m)
L_k =Length of chamber (m)
d_k =Average equivalent diameter of the chamber(m)
L_R =Effective length of tunnel (m)
d_0 =Average equivalent diameter of the tunnel (m)
α =Friction coefficient for concrete (α = 1), shotcrete (α = 4) and rock (α = 6)
χ =Coefficient for distance (m)
p_1, p_2 =Peak overpressure at the beginning respectively end of the tunnel element (atm).

Figure 3-I: Diagram for calculation of reduction of pressure in a tunnel



The change of duration will be calculated according to

- if the duration at the chamber exit is lower than 1000 ms, then $t_2 = \frac{p_1}{p_2} \cdot t_1$
- if the duration at the chamber exit is higher than 1000 ms, the change of duration in the tunnel is calculated according to figure 4.

Figure 3-II: Diagram for calculation of change of duration in a tunnel

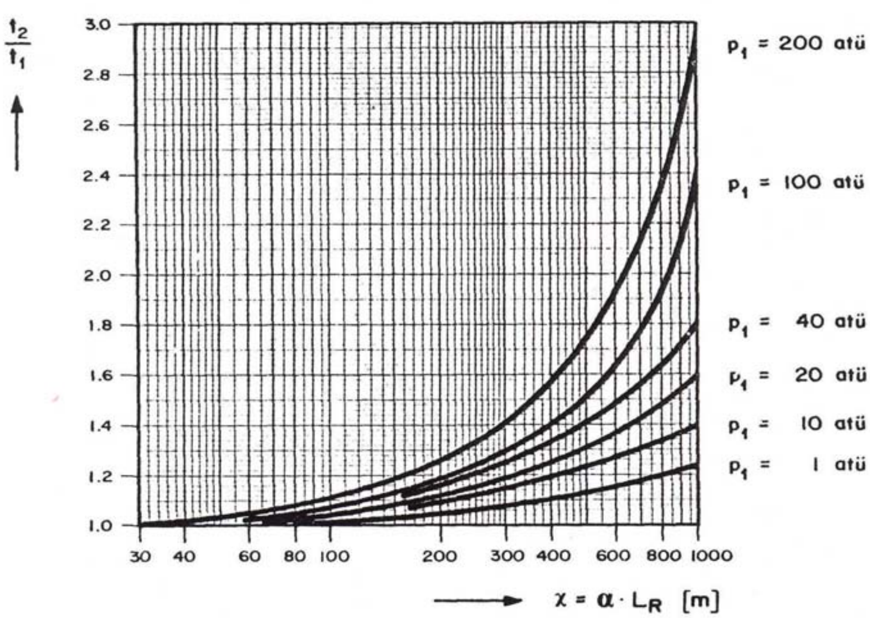


Figure 3-III: Description of tunnel elements

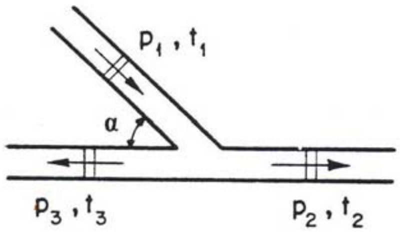
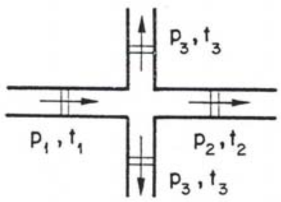
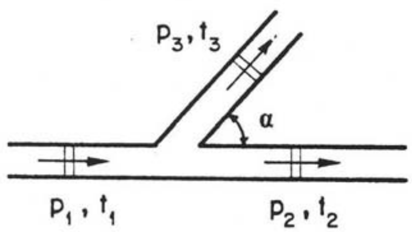
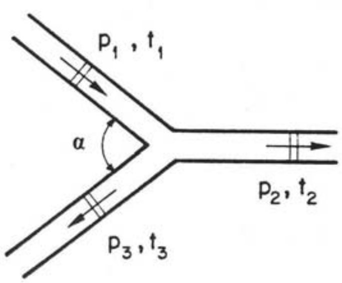
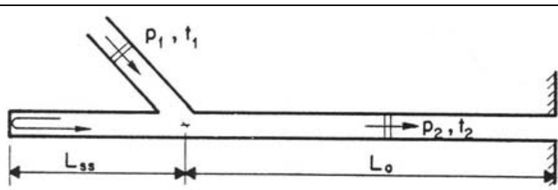
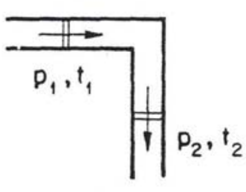
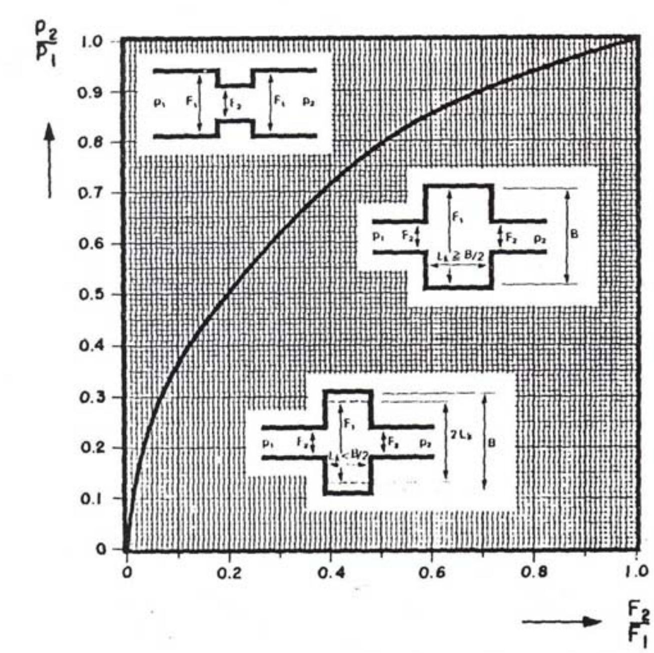
	$p_2 = \sqrt{1 - \frac{\alpha}{180^\circ}} \cdot p_1$ $p_3 = \sqrt{\frac{\alpha}{180^\circ}} \cdot p_1$ $t_2 = t_3 = 0.7 \cdot t_1$
	$p_2 = 0.8 \cdot p_1$ $p_3 = 0.25 \cdot p_1$ $t_2 = t_3 = 0.7 \cdot t_1$
	$p_2 = 0.8 \cdot p_1$ $p_3 = 0.8 \cdot \left(1 - \frac{\alpha}{180^\circ}\right) \cdot p_1$ $t_2 = t_3 = 0.7 \cdot t_1$
	$p_2 = \left(0.9 - 0.6 \cdot \left(\frac{\alpha}{180^\circ}\right)^2\right) \cdot p_1$ $p_3 = \left(0.2 + 0.6 \cdot \frac{\alpha}{180^\circ}\right) \cdot p_1$ $t_2 = t_3 = 0.7 \cdot t_1$
	$If\ L_0 \geq 2 \cdot L_{ss}$ $p_2 = 0.9 \cdot p_1$ $t_2 = t_1$ $If\ L_0 < 2 \cdot L_{ss}$ *use tunnel elements (junctions) above*
	$p_2 = 0.9 \cdot p_1$ $t_2 = t_1$

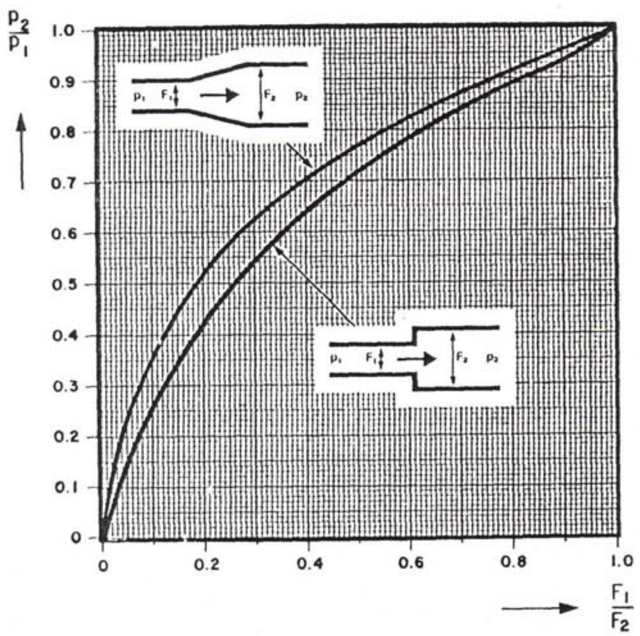
Figure 3-IV: Change of pressure and duration for constriction and expansion chambers



$t_2 = t_1$

F_1 and F_2 are tunnel crossections

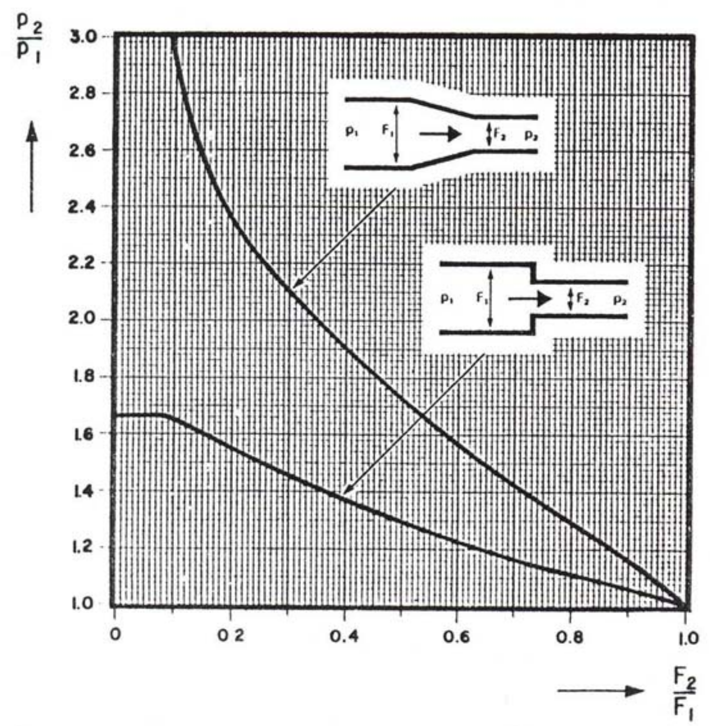
Figure 3-V: Change of pressure and duration for sudden and continuously expansion tunnel element



$$t_2 = \sqrt{\frac{F_1}{F_2}} \cdot t_1$$

F_1 and F_2 are tunnel crossections

Figure 3-VI: Change of pressure and duration for sudden and continuously constriction tunnel element



$t_2 = t_1$

F_1 and F_2 are tunnel crossections

Air blast outside tunnel adit

The resulting pressure in the tunnel adit could be expressed:

$$p_e = p_c \cdot \left[\frac{p_2}{p_1}\right] \cdot \left[\frac{p_3}{p_2}\right]\left[\frac{p_n}{p_{n-1}}\right] \quad \text{Eq. 3.3.4-3}$$

c) The required distances for inhabitant building distance, public traffic route distance and explosive workshop distance could then be calculated. The distances calculated are valid for the axis of the tunnel.

$$IBD = 1.64 \cdot d_{te} \cdot \left[\frac{p_e}{5.0}\right]^{0.74} \quad \text{Eq. 3.3.4-4}$$

$$IBD = 1.64 \cdot d_{te} \cdot \left[\frac{p_e}{9.0}\right]^{0.72} \quad \text{Eq. 3.3.4-5}$$

$$IBD = 1.64 \cdot d_{te} \cdot \left[\frac{p_e}{21.0} \right]^{0.66} \qquad \text{Eq. 3.3.4-6}$$

Where d_{te} is the equivalent diameter in the tunnel exit ($d_{te} = \sqrt{\frac{4A}{\pi}}$)

d) For a simple horizontal geometry (no barricade, a rapidly rising rock face, an extended centerline normal to the rock face) the following equation for off centerline axis can be used.

$$IBD(\theta) = IBD(\theta = 0) \cdot [1 + (\theta/56)^2]^{-0.74} \qquad \text{Eq. 3.3.4-7}$$

where:

θ: horizontal angle off centerline in degrees

Large variations in directivity have been observed (Figure 3-VII). Therefore, it is recommended that carefully constructed models and realistic exit pressures should be used to investigate directivity for an actual site.

e) High-Pressure Closure Block Designed to Remain Intact

References [4, 5] contain illustrative examples of a closure block designs (Figure 3-VIII).

Figure 3-VIII: Example of a Closing Block

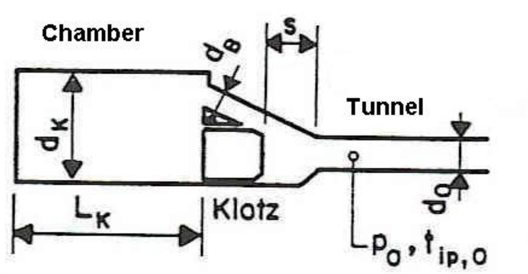
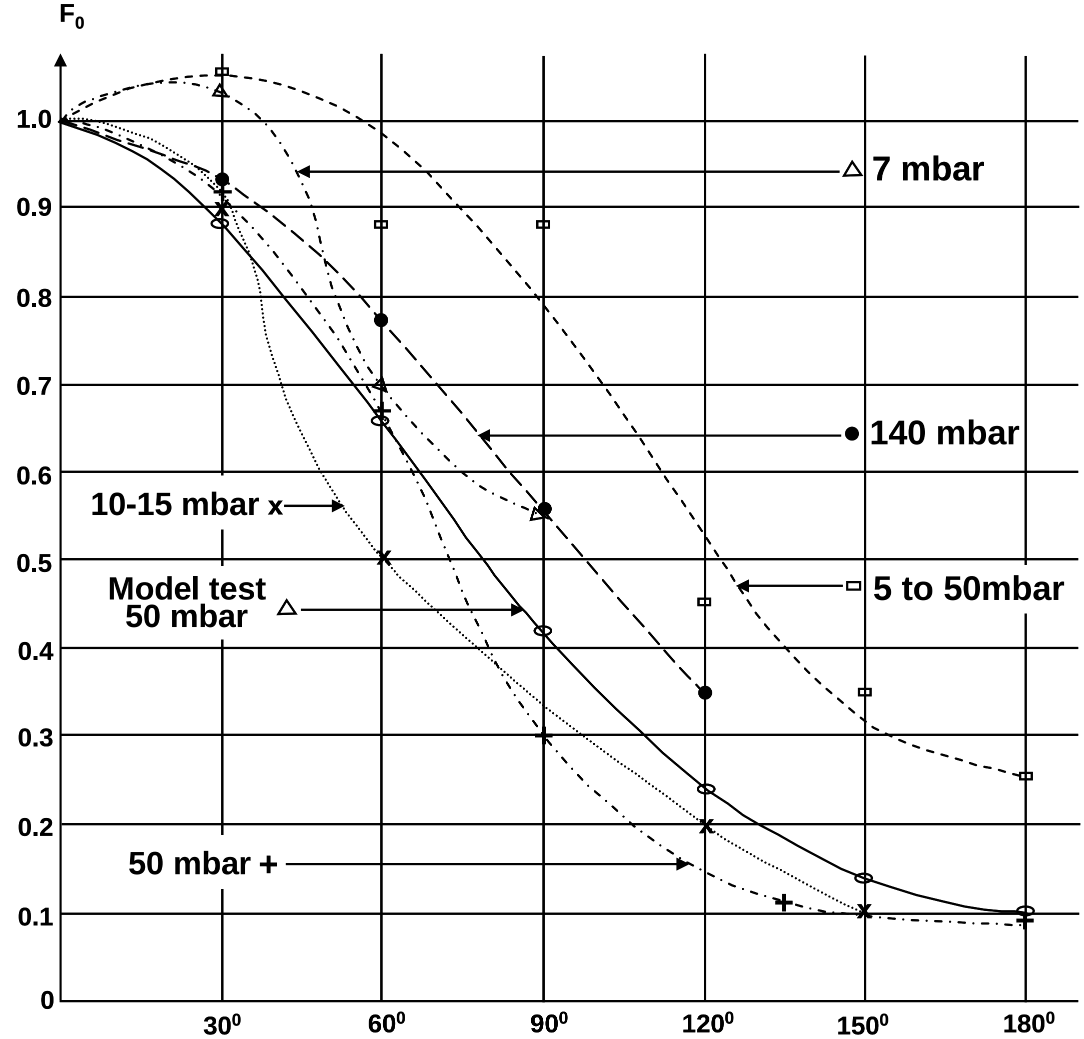


Figure 3-VII: Directivity Versus Azimuth with the Centre Line as Reference



LEGEND:

△ 1. "Free field overpressures resulting from shock waves emerging from open-ended shock tubes." Ballistic Research Lab. Mem. Report 1965.

x 2. "An investigation of the pressure wave propagated from the open end of a 30 x 18 in. Shock tube." Atomic Weapons Research Establ. AWRE Report No. 0 – 60/65.

+ 3. "Underground Explosion Trials at Raufoss 1968. Measurement of air blast outside the tunnel." Intern Report X – 124. FFI 1969.

● 4. U.S Navy Gun Blast Committee: "Survey of Research of Blast". First Interim Report, 1946.

□ 5. "Model tests to investigate external safety distances." Fortifikatorisk notat 36/67, FBT 1967.

"One-dimensional blast wave propagation." Fortifikatorisk Notat 49/69, FBT 196

For chamber loading densities greater than or equal to 10 kg/m^3, IBD may be reduced by 50% when a high-pressure closure block, designed to remain intact in case of an explosion, is used.

For chamber loading densities lower 10 kg/m3 (but greater than 1.0 kg/m3), determine the reduction by the formula:

$$y(\%) = 50 \cdot \log_{10}(\gamma) \qquad \text{Eq. 3.3.4-5}$$

where, y is the percentage reduction in IBD, and γ is loading density in kg/m3. For loading densities lower than 1.0 kg/m3, use y(%) = 0.

f) Portal Barricade

When a properly designed and located portal barricade [5, 7] is in front of the opening, IBD for airblast along the extended tunnel axis may be reduced up to 50 percent. Although the total airblast hazarded area remains almost unchanged, its shape, for explosives safety applications, becomes more circular.

3.3.4.2 Debris

Debris from an explosion in an underground facility may issue from adits or other openings; failure of nearby structures (portal, barricades, etc.); and breaching of the geological cover over the PES (crater debris).

Adit Debris

Introduction

a) Debris throw from the adit is one of the most relevant hazardous effects to be expected in case of an explosion in an underground installation in rock. Adit debris consists of parts of ammunition and its packaging, technical installations such as ventilation equipment, doors and fire fighting installations, chamber and adit lining and other reinforced concrete construction elements as well as of rock rubble produced by the explosion effects. All these pieces of debris are accelerated by the explosion gases escaping from the installation and are thrown into the surroundings in front of the adit portal.

b) Adit debris throw mainly depends on the explosives weight Q (NEQ, [kg]) stored in the installation and the geometry (ratio of length to diameter - l_a/d_a-ratio) of the adit section just behind the portal.

c) Other factors, such as the loading density (explosives weight / chamber or system volume), the centre of the explosion in the chamber, the construction of the portal area and the geometry of the whole adit may also influence adit debris throw. However, the available data from tests and accidents was insufficient to derive reliable relations.

Form of the IBD Contour Line and Influences

a) The general shape - resembling a cloverleaf - of the IBD contour line for adit debris throw is shown in Figure I. The IBD contour line is defined by points where the fragment density is one hazardous fragment (energy greater than 79 Joules) per 56 m^2 ($\cong$ 0.0179 $\#/m^2$).

b) No closed formula exists for the shape of the IBD contour line. Therefore, the line has to be constructed gradually, point per point.

c) The shape and size of the contour line is influenced by the following three parameters:

- Net explosives quantity of the stored ammunition	NEQ	[kg]
- Relevant length of the adit section behind the portal	l_a	[m]
- Average equivalent diameter of the adit (l_a)	d_a	[m]

d) The ratio l_a/d_a defines the portal parameter f_p and the standard deviation σ.

The portal parameter f_p takes into account that a long small adit leads to a more focused debris throw than a short adit with a large cross section area. Large l_a/d_a values, therefore, lead to far reaching but narrow IBD contour lines. The f_p parameter influences the maximum range of the IBD contour line.

The standard deviation σ defines the width of the IBD contour line.

Procedure to Calculate an IBD Contour Line

a) Calculate the maximum range $R_{o\,max}$ of the IBD contour line (Figure 3-IX).

$$\mathbf{R_{o\,max} = f_p \cdot \frac{-4.025 - A}{B}}$$

The parameter f_p is a function of the l_a/d_a ratio. It is to be calculated according to Figure 3-X. Typical examples on how to define the l_a/d_a ratio are given in Figure 3-XI.

The A and B values are both a function of the NEQ.

$$\mathbf{A = -5.25 + 1.0 \cdot \ln(NEQ)}$$

$$\mathbf{B = -0.0085 - \frac{0.25}{\sqrt{NEQ}}}$$

A, B and f_p values for typical amounts of NEQ and l_a/d_a ratios are also given in the tables in Figure 3-XII.

b) For a suitable number of R_o values (8 to 12, freely chosen, but $R_o < R_{o\,max}$) calculate the reference value D_o (Figure 3-IX).

$\mathbf{D_o = \exp(A + B \cdot R_o/f_p)}$ where: $\exp(x) = e^x$ and $e = 2.718$

D_o values for typical x (= A + B · R_o/f_p) values are given in the table in Figure 3-XIV.

c) Calculate the standard deviation σ according to Figure 3-XIII. Typical values for σ as a function of the l_a/d_a ratio are given in Figure 3-XII.

d) Calculate the corresponding α and R_s values for each D_o value (Figure 3-IX).

$$\alpha = \sqrt{-2 \cdot \ln\left(\frac{0.0179}{D_0}\right) \cdot \sigma^2}$$

ln(x) values for typical x = 0.0179 / D_o values are given in the table in Figure 3-XIV.

$\mathbf{R_s = R_o \cdot \tan(\alpha)}$

tan(α) values for typical α values are given in the table in Figure 3-XIV.

e) Each related combination of R_o and R_s defines a point D on the IBD contour line were the debris density is one hazardous fragment (energy greater than 79 Joules) per 56 m^2. Therefore, drawing a line starting and ending at the adit portal and connecting all the previously calculated points D (and $R_{o\ max}$) establishes the IBD contour line.

Example

A typical example how to calculate an IBD contour line is given in Figure 3-XVa and 3-XVb.

Special Cases

Barricade in Front of the Adit Portal

a) If an artificial or natural barricade is located within 10 to 20 m from the portal, and if all of the following conditions for an effective barricade are met, the form of the IBD contour line approaches a semicircle according to Figure 3-XVI.

b) Conditions for effective barricades are:

- The front facing the portal must be more or less vertical

- The front facing the portal must be normal to the extended adit axis
- The barricade must be symmetrical to the extended adit axis
- It has to withstand the expected explosion effects
- The width of the barricade has to "cover" the IBD contour line as calculated according to Chapter 1.3 to the side of the portal (Figure 3-XVI, Ground Plan)
- The height of the barricade has to "cover" at least half of the maximum initial vertical launch angle according to Figure 3-XVII (Figure 3-XVI, Section).

c) If the conditions for an effective barricade are met, the maximum range $R_{o\ max}$ of the IBD contour line can be calculated according to Chapter 1.3. However, regardless of the l_a/d_a ratio, the portal parameter f_p is always to be set as 0.4 for installations with an effective barricade. The IBD contour line is a semicircle in front of the adit portal with the centre at the adit portal. The IBD contour line also extends a short distance backwards as indicated in Figure 3-XVI.

d) If the conditions for an effective barricade are **not** met, the debris distribution may vary considerably. Therefore, only a conservative approach for the calculation of the IBD contour line can be given in this manual.
In such cases the IBD contour lines for adits with an effective barricade and adits without a barricade in front of the portal have to be calculated and superimposed. Exposed objects must be outside of both IBD contour lines.

Further information about the effects of barricades that are only partially effective and especially barricades that are oblique to the extended adit axes is given in AASTP-4 and [2, 3, 6].

e) In addition to barricades located near the adit portal also hills and mountains farther away may limit adit debris throw. In cases where the application of the standard IBD contour line leads to major restrictions, effects of such natural obstacles may be taken into account. However, further information about the influence of the topography on adit debris throw and a relatively complicated calculation procedure are only given in AASTP-4.

Storage Chambers with Very Short Adits

a) At installations with a very short adit, the relevant length of the adit section just behind the portal (l_a) is to be measured from the portal to the first ammunition stack (Figure 3-XVIII).

b) If the ratio l_a/d_a in this case is 2 or larger, the IBD contour line can be calculated according to Chapter 1.3.

c) If the ratio l_a/d_a is smaller than 2, the following two cases have to be distinguished:

- For very short chambers and ammunition stacks reaching the portal (Figure 3-XVIII), the IBD contour line is to be calculated as for an installation with an effective barricade in front of the adit portal, according to Chapter 1.5.1 and Figure VIII.

- In all other cases, as a conservative approach, the IBD contour lines for adits with an effective barricade (according to Chapter 1.5.1 and Figure 3-XVI) and adits without a barricade in front of the portal (according to Chapter 1.3) have to be calculated and superimposed. Exposed objects must be outside of both IBD contour lines.

Further information about the effects from explosions in chambers with short adits is given in AASTP-4 and [2, 3, 6]

Installations with more than one Adit Portal

a) In certain cases storage chambers may have more than one adit or an adit may have more than one portal, e.g. as a special protection measure against enemy attacks. In addition, such adits may have different cross-section areas and the adit axis may point in different directions.

b) As a general conservative rule, for IBD purposes, the IBD contour lines as calculated above for the various cases have to be applied to each adit portal.

c) In cases where the procedure according to b) leads to major restrictions, a procedure described in AASTP-4 might be used to take into account further effects, leading - depending on the actual situation - to corresponding reductions of the IBD contour lines.

Debris Mitigation Measures

a) Debris throw from underground installations on rock is a significant threat to exposed persons outside and installation. Therefore, whenever reasonable, measures should be taken to reduce debris throw. However, if constructional measures are taken, they have to be designed appropriately to withstand the explosion effects. Be aware that failing installation parts may contribute to the debris throw and even enhance the hazard.

b) Blast closures according to Chapter 3.2.4.4 and especially the so-called Klotz-Device are very effective means to reduce not only the air blast from underground installations but also the debris throw from the adits. Information about possible reductions achievable with such devices is given in AASTP-4.

c) Apart from barricades and self-closing devices (see Chapter 3.2.4.4 and Figure 2-III), there are also other elements reducing adit debris throw such as blind tunnels and expansion chambers in the adit. In general, a combination of such elements, especially with a self-closing device, enhances the mitigation effect.

However, currently there are no models available taking such mitigation measures in the adit into account (except for the Klotz-Device). Therefore, the effectiveness of such elements has to be tested in models with an appropriate scale or with computer simulations.

Range of Validity and Background Information

a) Special caution has to be applied if this adit debris throw model is used outside the range of validity indicated below:

- explosives quantity NEQ: 100 - 500'000 kg
- chamber loading density γ_c : 1 - 100 kg/m3
- system loading density γ_s : 0.3 - 100 kg/m3

The chamber respectively system loading density (γ_c / γ_s) is defined as the ratio between the NEQ and the storage chamber volume respectively the system volume (chamber volume and adit volume).

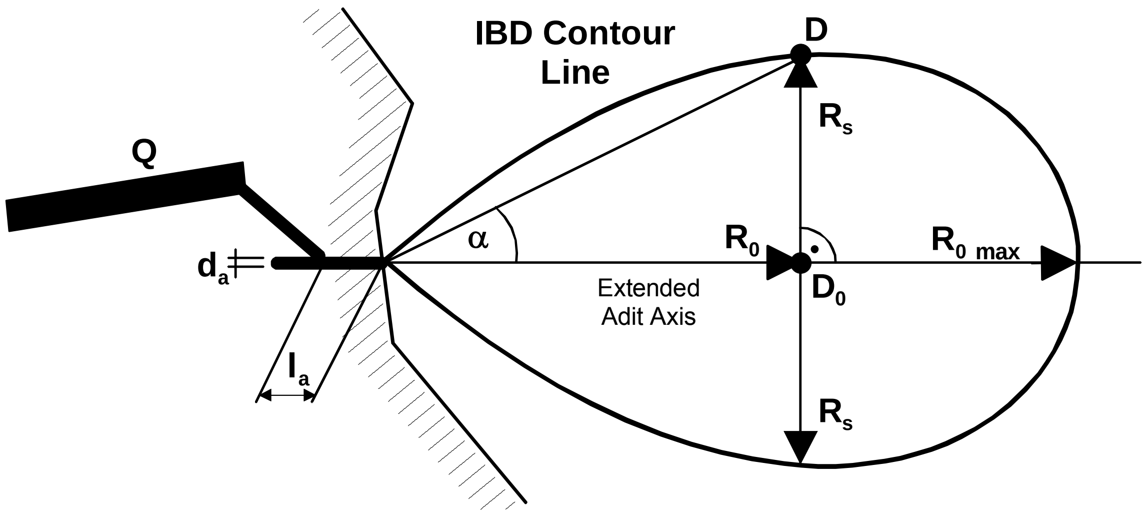
For applications below the lower limits, the model usually overestimates the debris throw (IBD is conservative). This is especially true for storage chambers with very low loading densities in combination with very long adit tunnel systems with many bends and other mitigation measures. In such cases the hazard from adit debris throw may be much lower than indicated by the model above. To establish reliable adit debris IDB for such cases appropriate model or full-scale tests are necessary.

No such statement is possible for applications above the upper limits.

b) The technical basis for the figures and formulas is mainly derived from the following report (for additional background information see [37 - 42]):

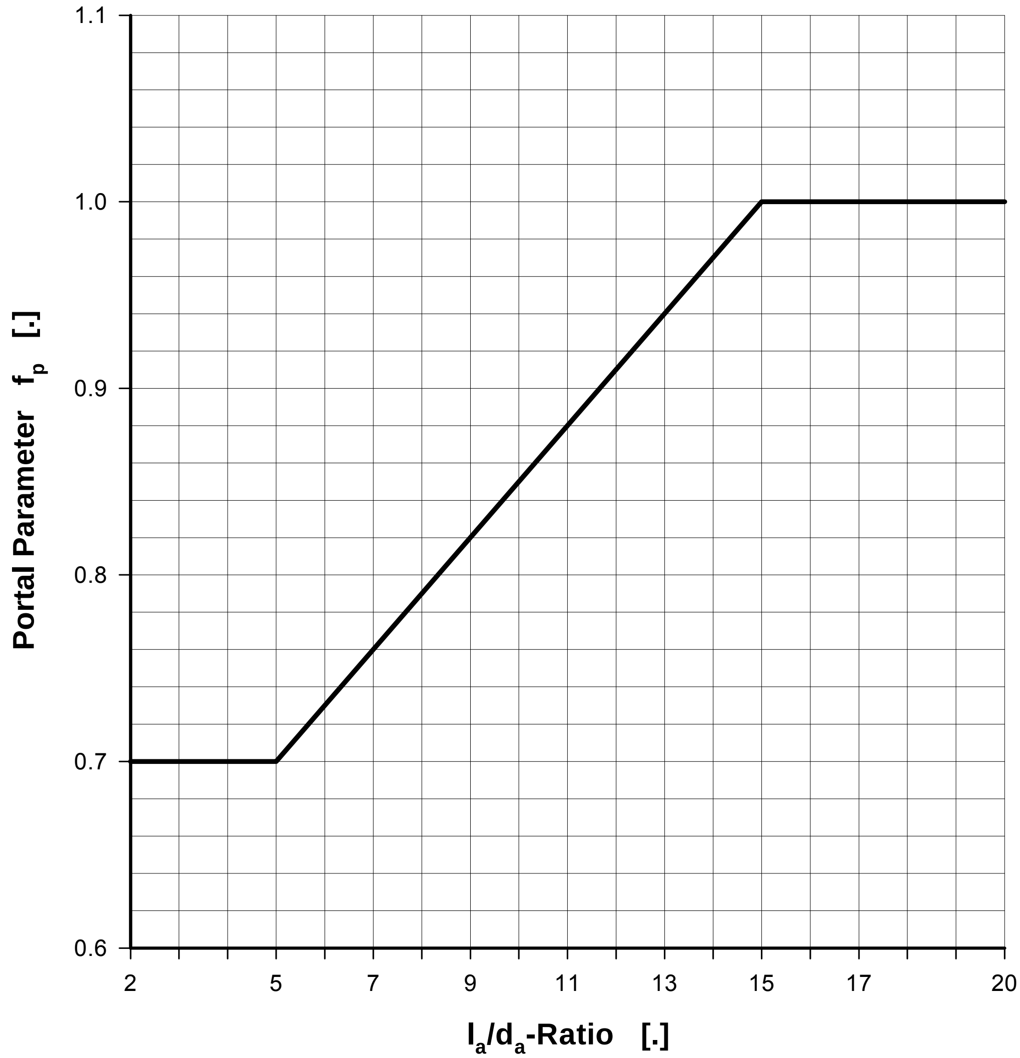
NATO - AC/258 Storage Sub-Group - UGSWG
Debris Throw from Adits of Underground Installations in Rock
Basics for Risk Analysis
Technical Background
TM 174-9 // AC/258 CH(ST) IWP 024-02, 30 March 2002

Figure 3-IX: General Shape of the Adit Debris IBD Line



Q	:	Explosives weight (NEQ)	[kg]
l_a	:	Relevant length of the adit section behind the portal	[m]
d_a	:	Average equivalent diameter of l_a	[m]
R_0	:	Distance (range) on the extended adit axis from the portal	[m]
$R_{0\ max}$	:	Maximum distance (range) of IBD	[m]
R_s	:	Distance (range) to the side of the extended adit axis at R_0	[m]
D	:	Point on IBD contour line (debris density 1 hazardous fragment per 56 m^2)	[#/m^2]
D_0	:	Reference value (debris density at R_0)	[#/m^2]
α	:	Angle showing the deviation of D from the extended adit axis α = arctan (R_s/R_0)	[°]

Figure 3-X: Portal Parameter f_p



$f_p = 0.7$	for	$l_a/d_a \leq 5$	(wide debris zones)
$f_p = 0.55 + 0.03 \cdot l_a/d_a$	for	$5 < l_a/d_a < 15$	
$f_p = 1.0$	for	$l_a/d_a \geq 15$	(narrow debris zones)

l_a:	Relevant length of the straight adit section just behind the portal	[m]
d_a:	Average equivalent adit diameter of l_a ($d_a = (4 \cdot F_a / \pi)^{0.5}$)	[m]
F_a:	Average cross-section of l_a	[m^2]

Figure 3-XI: Determination of the l_a/d_a-Ratio

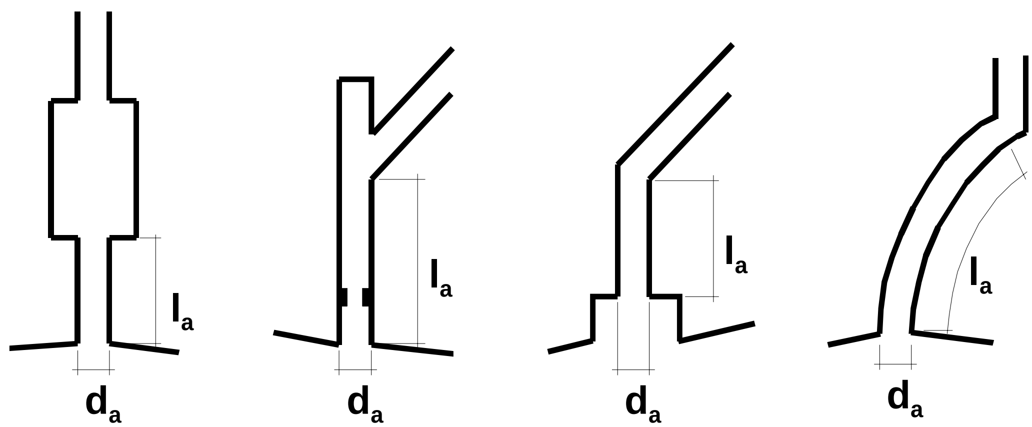


Figure 3-XII: Auxiliary Tables for the Calculation of A, B, f_p and σ

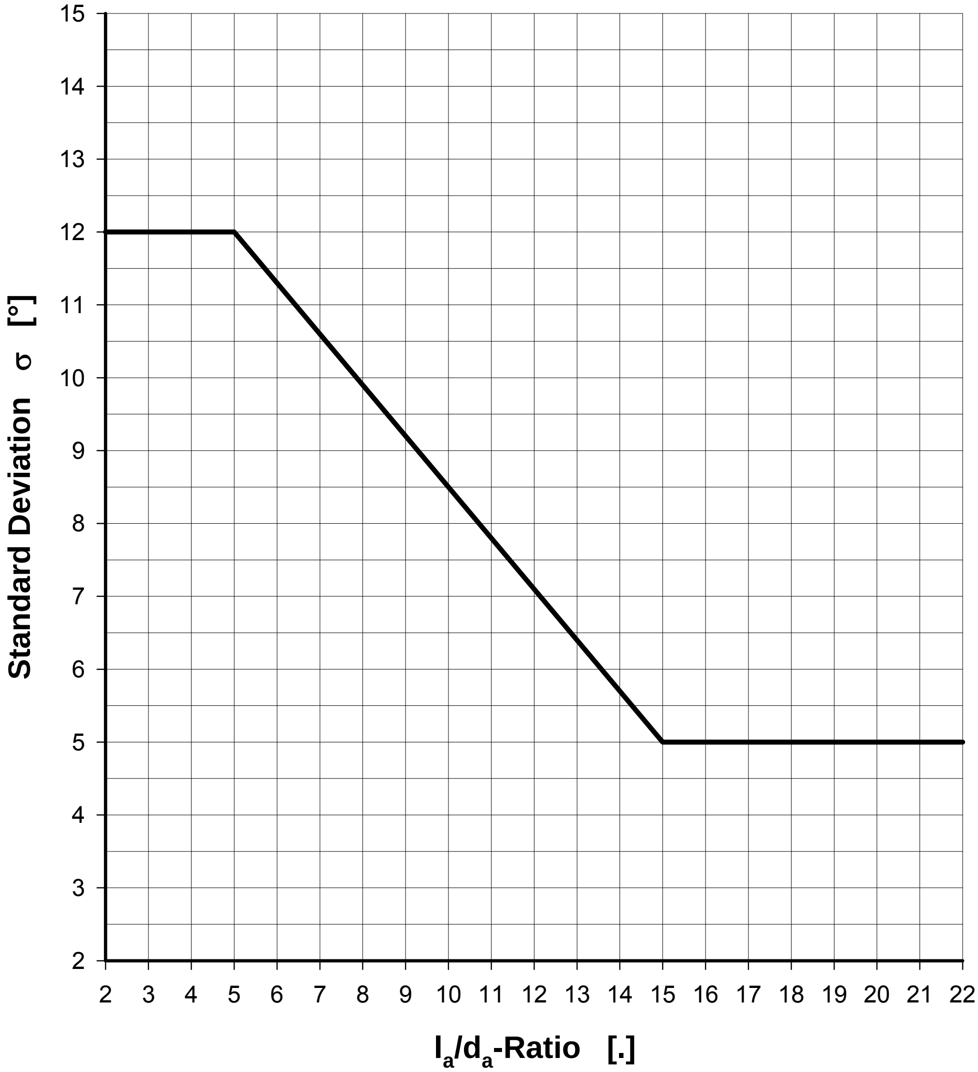
NEQ [kg]	A [.]	B [.]
100	**-0.645**	**-0.0335**
200	**0.0483**	**-0.0262**
300	**0.454**	**-0.0229**
400	**0.741**	**-0.0210**
500	**0.965**	**-0.0197**
600	**1.15**	**-0.0187**
700	**1.30**	**-0.0179**
800	**1.43**	**-0.0173**
900	**1.55**	**-0.0168**
1'000	**1.66**	**-0.0164**
2'000	**2.35**	**-0.0141**
3'000	**2.76**	**-0.0131**
4'000	**3.04**	**-0.0125**
5'000	**3.27**	**-0.0120**
6'000	**3.45**	**-0.0117**
7'000	**3.60**	**-0.0115**
8'000	**3.74**	**-0.0113**
9'000	**3.85**	**-0.0111**
10'000	**3.96**	**-0.0110**
20'000	**4.65**	**-0.0103**
30'000	**5.06**	**-0.00994**
40'000	**5.35**	**-0.00975**
50'000	**5.57**	**-0.00962**
60'000	**5.75**	**-0.00952**
70'000	**5.91**	**-0.00944**
80'000	**6.04**	**-0.00938**
90'000	**6.16**	**-0.00933**
100'000	**6.26**	**-0.00929**
200'000	**6.96**	**-0.00906**
300'000	**7.36**	**-0.00896**
400'000	**7.65**	**-0.00890**
500'000	**7.87**	**-0.00885**

l_a/d_a-Ratio [.]	f_p [.]	σ [°]
2.0	**0.700**	**12.0**
3.0	**0.700**	**12.0**
4.0	**0.700**	**12.0**
5.0	**0.700**	**12.0**
5.5	**0.715**	**11.7**
6.0	**0.730**	**11.3**
6.5	**0.745**	**11.0**
7.0	**0.760**	**10.6**
7.5	**0.775**	**10.3**
8.0	**0.790**	**9.90**
8.5	**0.805**	**9.55**
9.0	**0.820**	**9.20**
9.5	**0.835**	**8.85**
10.0	**0.850**	**8.50**
10.5	**0.865**	**8.15**
11.0	**0.880**	**7.80**
11.5	**0.895**	**7.45**
12.0	**0.910**	**7.10**
12.5	**0.925**	**6.75**
13.0	**0.940**	**6.40**
13.5	**0.955**	**6.05**
14.0	**0.970**	**5.70**
14.5	**0.985**	**5.35**
15.0	**1.00**	**5.00**
16.0	**1.00**	**5.00**
17.0	**1.00**	**5.00**
18.0	**1.00**	**5.00**
19.0	**1.00**	**5.00**
> 20.0	**1.00**	**5.00**

Linear interpolation between values is permitted; but it may lead to deviations of up to 3%, compared to the real values calculated with the corresponding formula

(for NEQ < 300 kg, the deviation of interpolation of parameter A is even larger)

Figure 3-XIII: Standard Deviation σ



$\sigma = 12$	for	$l_a/d_a \leq 5$	(wide debris zones)
$\sigma = 15.5 - 0.7 \cdot l_a/d_a$	for	$5 < l_a/d_a < 15$	
$\sigma = 5$	for	$l_a/d_a \geq 15$	(narrow debris zones)

l_a:	Relevant length of the straight adit section just behind the portal	[m]
d_a:	Average equivalent adit diameter of l_a ($d_a = (4 \cdot F_a / \pi)^{0.5}$)	[m]
F_a:	Average cross-section of l_a	[m²]

Figure 3-XIV: Auxiliary Tables for the Calculation of D_0, ln (x) and tan (α)

x = A + B x R_0 / f_p	$D_0 = e^x$ [pieces/m^2]
-6.0	**0.00248**
-5.5	**0.00409**
-5.0	**0.00674**
-4.5	**0.0111**
-4.0	**0.0183**
-3.5	**0.0302**
-3.0	**0.0498**
-2.5	**0.0821**
-2.0	**0.1353**
-1.5	**0.2231**
-1.0	**0.3679**
-0.5	**0.6065**
0.0	**1.000**
0.5	**1.649**
1.0	**2.718**
1.5	**4.482**
2.0	**7.389**
2.5	**12.18**
3.0	**20.09**
3.5	**33.12**
4.0	**54.60**
4.5	**90.02**
5.0	**148.4**
5.5	**244.7**
6.0	**403.4**
6.5	**665.1**
7.0	**1097**

x = 0.0179 / D_0	ln (x) [.]
7.5	**2.015**
5.0	**1.609**
3.0	**1.099**
2.0	**0.693**
1.0	**0.000**
0.75	**-0.288**
0.50	**-0.693**
0.30	**-1.204**
0.20	**-1.609**
0.10	**-2.303**
0.075	**-2.590**
0.050	**-2.996**
0.030	**-3.507**
0.020	**-3.912**
0.010	**-4.605**
0.0075	**-4.893**
0.0050	**-5.298**
0.0030	**-5.809**
0.0020	**-6.215**
0.0010	**-6.908**
0.00075	**-7.195**
0.00050	**-7.601**
0.00030	**-8.112**
0.00020	**-8.517**
0.00010	**-9.210**
0.000075	**-9.498**
0.000050	**-9.903**
0.000030	**-10.41**
0.000020	**-10.82**

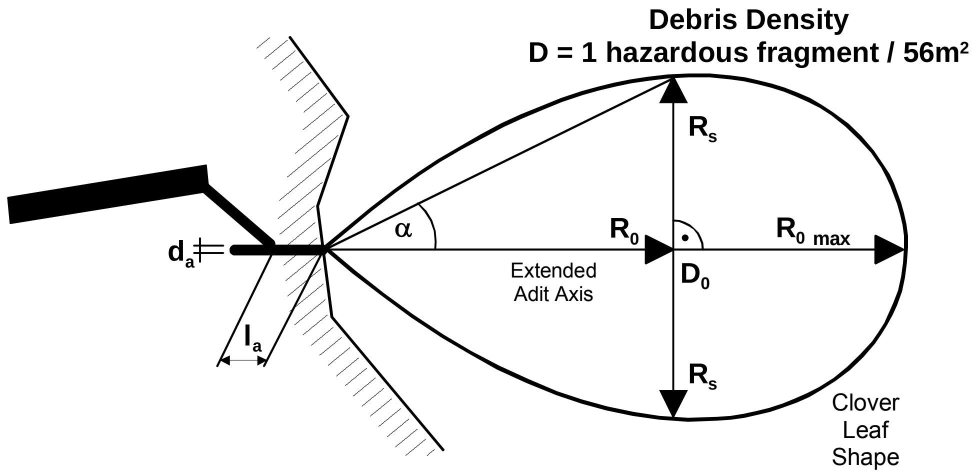
α [°]	tan (α)
0	**0.0000**
2	**0.0349**
4	**0.0699**
6	**0.1051**
8	**0.1405**
10	**0.1763**
12	**0.2126**
14	**0.2493**
16	**0.2867**
18	**0.3249**
20	**0.3640**
22	**0.4040**
24	**0.4452**
26	**0.4877**
28	**0.5317**
30	**0.5774**
32	**0.6249**
34	**0.6745**
36	**0.7265**
38	**0.7813**
40	**0.8391**
42	**0.9004**
46	**1.036**
48	**1.111**
50	**1.192**
52	**1.280**
54	**1.376**
58	**1.600**
60	**1.732**

Linear interpolation between values is permitted; but it may lead to deviations of up to 3%, compared to the real values calculated with the corresponding formulas

(for the natural logarithm close to x=1, the deviation of interpolation is even larger)

Figure 3-XVa: How to Calculate an IBD Contour Line for Adit Debris - Example

Given:



Q = 200'000 kg TNT

l_a = 32 m, d_a = 4 m => $l_a/d_a = 8$

Wanted: **IBD Contour Line (where Debris Density D = 1 Hazardous Piece per 56 m^2 [#/m^2])**

Solution: 1) $R_{0\ max}$ on the extended adit axis:

Portal Parameter (1.2 d) - Figure II or IV)	f_p	=	0.790
Parameter A (1.3 a) - Figure IV)	A	=	6.96
Parameter B (1.3 a) - Figure IV)	B	=	-0.00906

$\mathbf{R_{0\ max}} = f_p \cdot (-4.025 - A) / B =$ **958 m**

2) R_0 ($<R_{max}$) on the axis and the corresponding R_s normal to the side:

To determine the clover leaf shaped contour of the debris zone with a density of D = 1 haz-#/56m^2, R_0 and the corresponding R_s have to be calculated an appropriate number of times (starting with R_{max} and ending at the portal)

Example:	R_0 = 500 m		
Debris Density at R_0 (1.3 b) - Figure VI)	D_0	=	3.41 #/m^2
Standard Deviation (1.3 c) - Figure IV or V)	σ	=	9.90°
Deviation from the axis (1.3 d) - Figure VI)	α	=	32.09°

$\alpha = (-2 \cdot \ln(D/D_0) \cdot \sigma^2)^{0.5}$

$\mathbf{R_s} = R_0 \cdot \tan(\alpha) =$ **313 m for R_0 = 500 m**

Figure 3-XVb: How to Calculate an IBD Contour Line for Adit Debris - Example

NEQ [kg]	200'000	A [.]	6.96
		B [.]	-0.00906
l_a / d_a [.]	8	f_p [.]	0.790
		σ [°]	9.90

R_0 [m]	x = $A+BxR_0/f_p$	**$D_0 = e^x$ [#/m²]**	x = $(1/56)/D_0$	ln (x) [.]	**α [°]**	tan (α)	**R_s [m]**
900	-3.362	**0.0347**	0.515	-0.664	**11.4**	0.2018	**182**
800	-2.215	**0.109**	0.164	-1.811	**18.8**	0.3412	**273**
700	-1.068	**0.344**	0.0519	-2.958	**24.1**	0.4469	**313**
600	0.0790	**1.082**	0.0165	-4.104	**28.4**	0.5399	**324**
500	1.226	**3.407**	0.00524	-5.251	**32.1**	0.6269	**313**
400	2.373	**10.73**	0.00166	-6.398	**35.4**	0.7110	**284**
300	3.519	**33.77**	0.000529	-7.545	**38.5**	0.7942	**238**
200	4.666	**106.3**	0.000168	-8.692	**41.3**	0.8778	**176**
100	5.813	**334.7**	0.0000534	-9.839	**43.9**	0.9628	**96**

IBD Contour Line
(other side symmetrical)

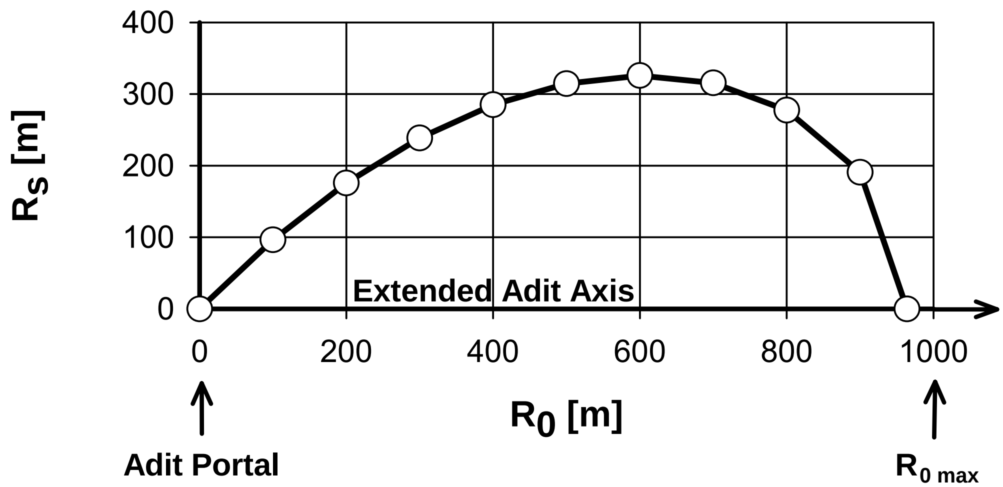


Figure 3-XVI: Influence of a Barricade

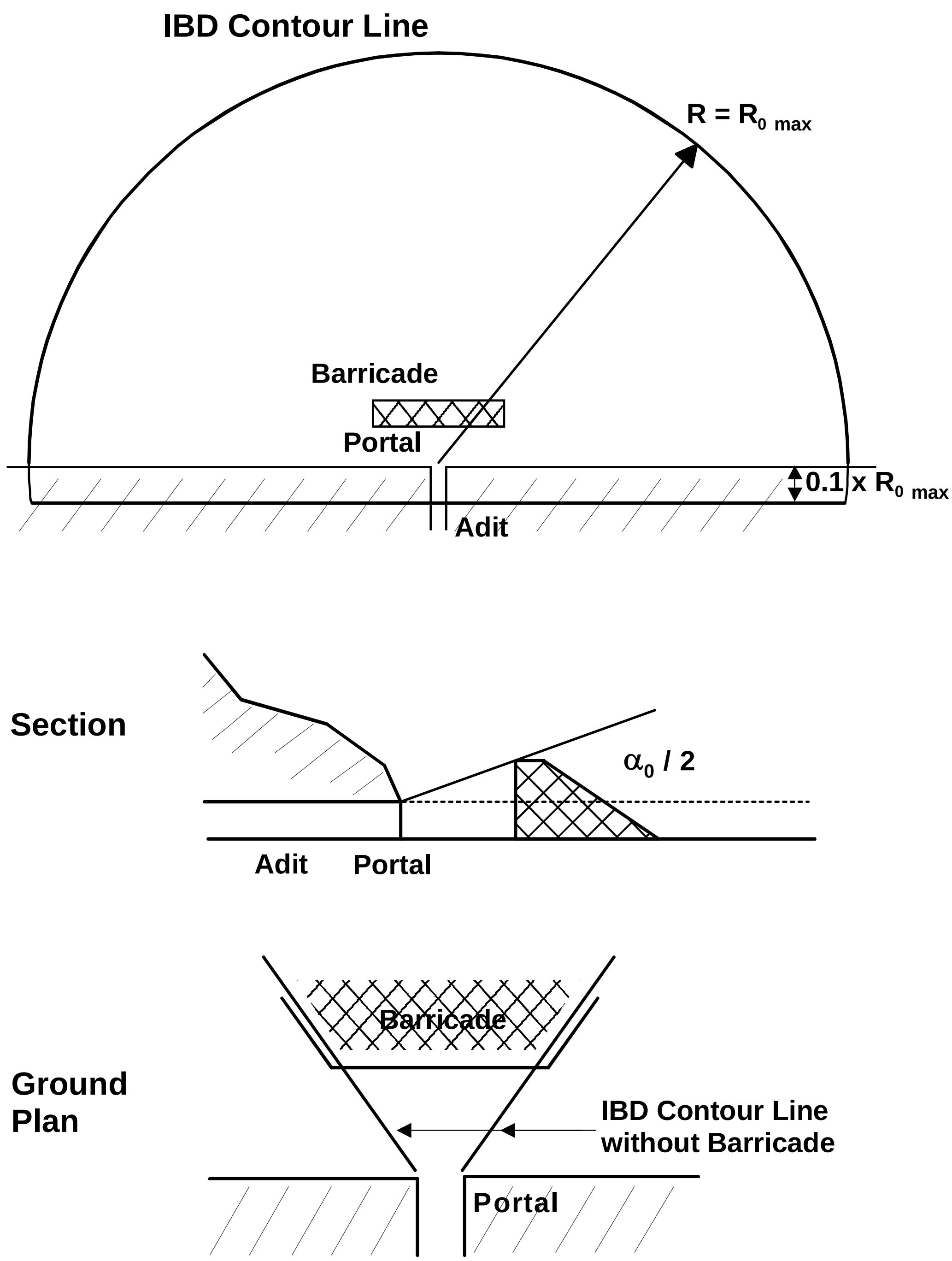
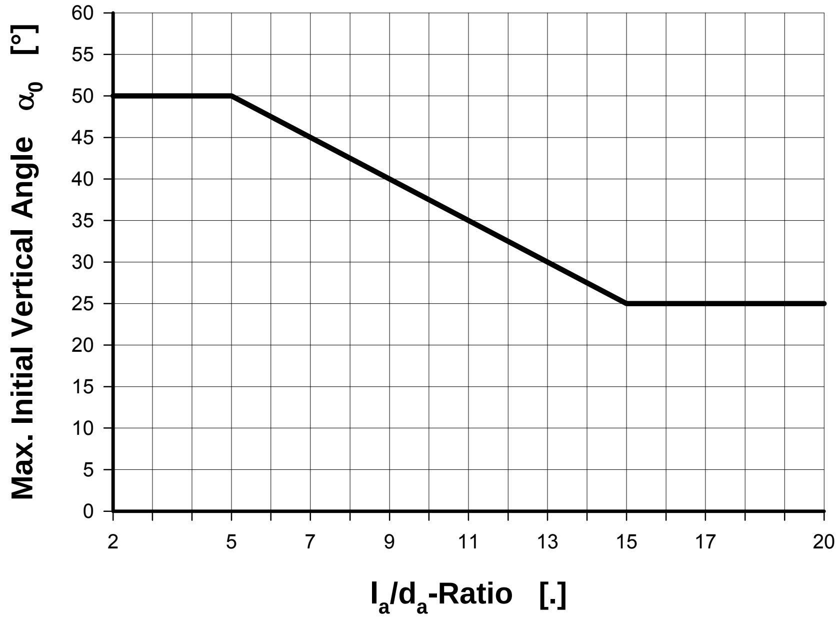


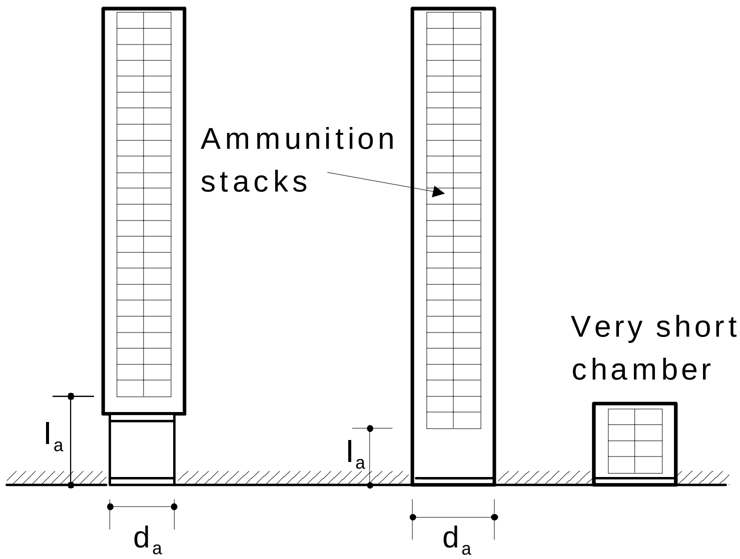
Figure 3-XVII: Maximum Initial Vertical Angle α_0



$\alpha_0 = 50°$	for	$l_a/d_a \leq 5$	(wide debris zones)
$\alpha_0 = 62.5° - 2.5° \cdot (l_a/d_a)$	for	$5 < l_a/d_a < 15$	
$\alpha_0 = 25°$	for	$l_a/d_a \geq 15$	(narrow debris zones)

l_a	:	Relevant length of the straight adit section just behind the portal	[m]
d_a	:	Average equivalent adit diameter of l_a ($d_a = (4 \cdot F_a / \pi)^{0.5}$)	[m]
F_a	:	Average cross-section of l_a	[m^2]

Figure 3-XVIII: Installations with Very Short Adits



Debris from Nearby, Failed Structures:

The dynamics of this debris will be highly dependent on site-specific parameters. Site-specific analyses should be done when this type of debris is of concern.

Debris Arising from Failure of Cover, Crater Debris [18-22, 34]

a) The chamber cover thickness is the shortest distance between the natural rock surface at the chamber ceiling (or in some cases, a chamber wall) and the ground surface. If the cover consists of part rock and part soil, the effective thickness of the cover is determined based on mass. A conservative estimate is to treat soil as having one-half the mass of rock. Therefore, 10 m of rock and 2 m of soil, with one-half the density of the rock, equals 11 m of equivalent rock cover. If the percentage of soil to rock exceeds 20% a site-specific analysis should be conducted.

   Unless the cover is adequate, an underground explosion will cause breaching of the cover. Rock, and to a lesser degree structural material, is projected as debris in all directions from the breached cover into the surroundings.

   The hazard from this type of debris depends on the quantity of explosives (Q) involved, the scaled cover depth ($C/Q^{1/3}$), the chamber loading density (γ), and the slope angle of the overburden (α) and the type of rock.

b) The rock overburden of an underground installation is sufficient for a scaled cover depth ($C/Q^{1/3}$) equal to 1.2 m/kg$^{1/3}$. For larger values, the debris throw from the overburden can be neglected. This does not mean that the surface is undisturbed after an accident. It simply means that a crater is negligible and ejecta are unlikely. For more information, see Part II, paragraph 2.5.6.2 and Figure 5-XXb. For smaller values the hazardous distance (Inhabited Building Distance) for installations in hard and moderately strong rock can be calculated with the following formula:

$$IBD = 38.7 \cdot Q^{1/3} \cdot f_y \cdot f_c \cdot f_\alpha \qquad \text{Eq. 3.3.4.6}$$

where:

IBD	=	Inhabited Building Distance	[m]
Q	=	explosives quantity (effective NEQ)	[kg]
f_γ	=	loading density parameter	[.]
f_c	=	cover depth parameter	[.]
f_α	=	overburden slope angle parameter	[.]

The loading density parameter, f_γ can be taken from the graph in Figure 3-XIX and the cover depth parameter, f_c , from Figure 3-XX. Both values can also be calculated with the corresponding formula in Figures 3-XIX and 3-XX. To simplify the calculation process Figure 3-XXI contains tables for $Q^{1/3}$, f_γ and f_c over a wide range of commonly required values.

The loading density parameter, f_α and the Inhabited Building Distance increase with an increase in loading density. The cover depth parameter (f_c) is maximum at a scaled depth of $C/Q^{1/3}$ = approx. 0.5. The biggest crater is formed and the largest amount of crater debris is thrown out into the surroundings at this scaled depth, so the largest IBD results. As the scaled overburden thickness increases above or decreases below the optimum depth of burst, both the cover depth parameter (f_c) and Inhabited Building Distance decreases.

The influence of the slope angle of the overburden on the Inhabited Building Distance is shown in Figure 3-XXII.

Figures 3-XXIV and 3-XXV show in general how the final IBD contour line has to be established and the consideration of the overburden slope angle parameter f_α

Figure 3-XXIII, which is an example, illustrates a quantitative determination of IBD for crater debris.

c) IBD should be increased by 15% for an installation built in soft rock.

d) Additional information:

The Inhabited Building Distance (IBD) has to be measured as a horizontal distance from the crater-centre at the bottom of the crater (CCB), at the level of the installation (Figure 3-XXIV).

The slope angle α shall be established in the area where the crater-centre at the surface (CCS) has to be expected.

An average value for the slope angle α over the whole crater area shall be taken in case the surface is not plain in this area.

The increase ($f_{\alpha I}$) and the decrease ($f_{\alpha D}$) factor must be applied to the IBD in direction of the line with the largest gradient intersecting the centre of the crater (CCB). This line does not necessarily coincide with the axis of the adit tunnel.

No increase or decrease factors need applied to the side of the crater.

The shape of the IBD contour is elliptical.

In cases where more than one crater-centre is possible (e.g. in cases of a flat rock overburden surface), the IBD has to be applied from each possible crater-centre. The IBD contour shall be the outer connection of the single lines (Figure 3-XXV).

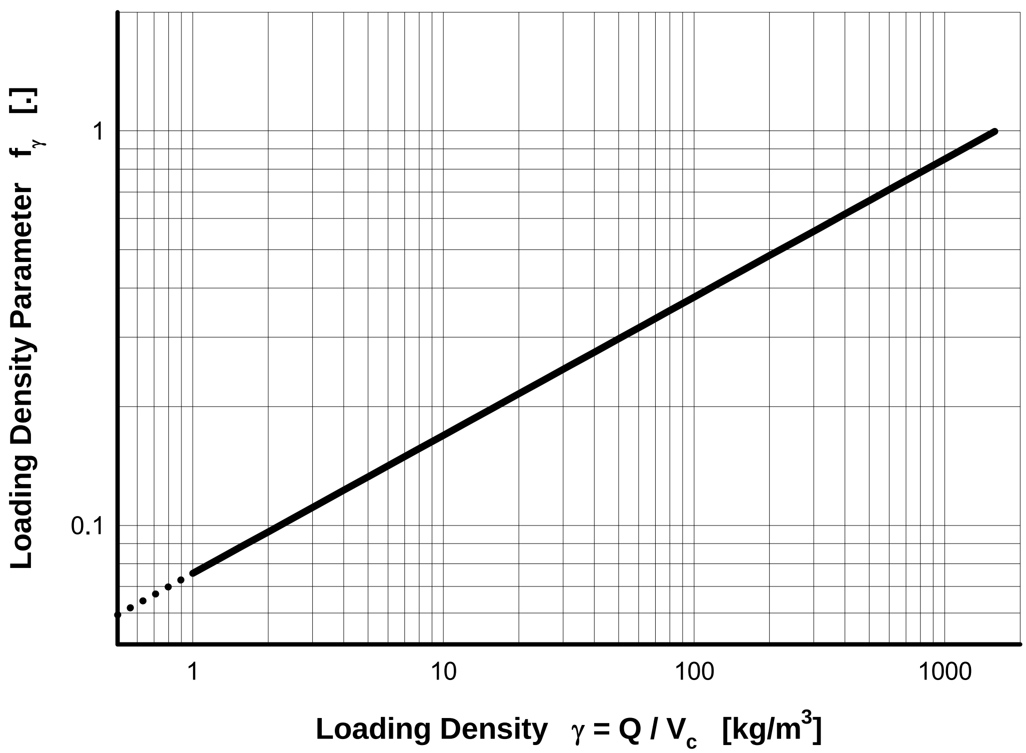
e) Limitations:

This crater debris throw model is based on an empirical evaluation of the available data and engineering judgment of a comparatively small number of tests and accidents. The overall accuracy is therefore limited to the range of the investigated cases. Thus, the crater debris throw model may be used only within the following boundaries:

quantity of explosives	NEQ	=	1 t - 2000 t
chamber loading density	γ	=	1 kg/m^3 - 300 kg/m^3
scaled cover depth	$C/Q^{1/3}$	>	0.1 $m/kg^{1/3}$

In case of parameters exceeding these values it is appropriate to take special care when applying the model.

Figure 3-XIX: Loading Density Parameter f_γ

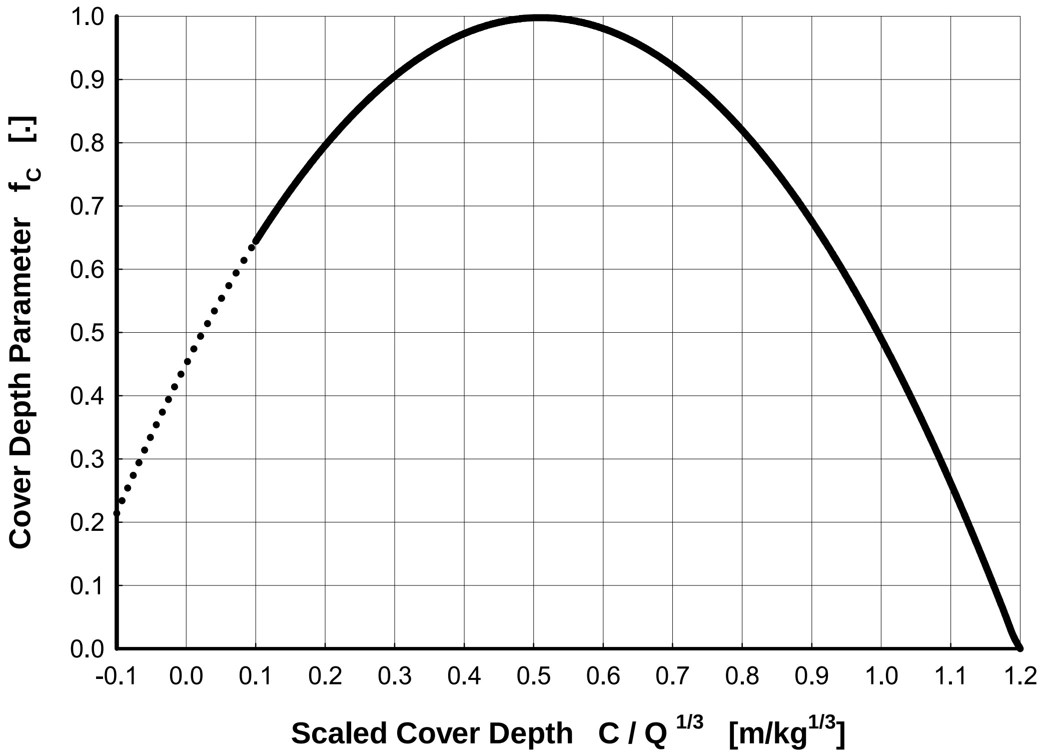


$$f_\gamma = (\gamma / 1600)^{0.35}$$

Q = Weight of Explosives, NEQ [kg]

V_C = Storage Chamber Volume [m^3]

Figure 3-XX: Cover Depth Parameter f_c



$$f_C = 0.45 + 2.15 * x - 2.11 * x^2 \quad ; \quad x = C / Q^{1/3}$$

C = Overburden, Cover [m]

Q = Weight of Explosives, NEQ [kg]

Figure 3-XXI : Auxilliary Tables for the Calculation of $Q^{1/3}$, F_C and f_γ

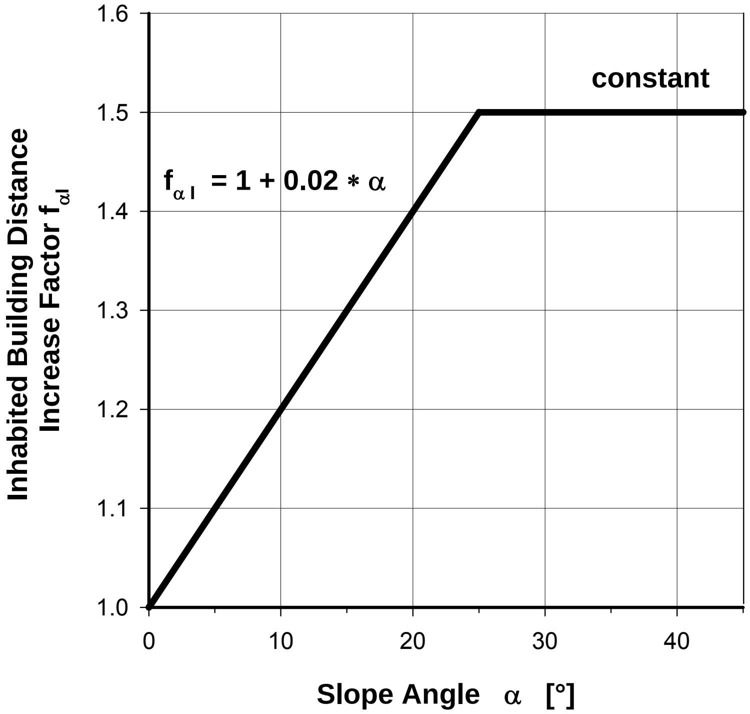
Q [kg]	$Q^{1/3}$ [$kg^{1/3}$]
1'000	**10.0**
1'500	**11.4**
2'000	**12.6**
2'500	**13.6**
3'000	**14.4**
4'000	**15.9**
5'000	**17.1**
6'000	**18.2**
7'000	**19.1**
8'000	**20.0**
10'000	**21.5**
15'000	**24.7**
20'000	**27.1**
25'000	**29.2**
30'000	**31.1**
40'000	**34.2**
50'000	**36.8**
60'000	**39.1**
70'000	**41.2**
80'000	**43.1**
100'000	**46.4**
150'000	**53.1**
200'000	**58.5**
250'000	**63.0**
300'000	**66.9**
400'000	**73.7**
500'000	**79.4**
600'000	**84.3**
700'000	**88.8**
800'000	**92.8**
1'000'000	**100.0**
1'500'000	**114.5**
2'000'000	**126.0**

Scaled Cover Depth [$m/kg^{1/3}$]	f_C [.]
0.10	**0.64**
0.15	**0.73**
0.20	**0.80**
0.25	**0.86**
0.30	**0.91**
0.35	**0.94**
0.40	**0.97**
0.45	**0.99**
0.50	**1.00**
0.55	**0.99**
0.60	**0.98**
0.65	**0.96**
0.70	**0.92**
0.75	**0.88**
0.80	**0.82**
0.85	**0.75**
0.90	**0.68**
0.95	**0.59**
1.00	**0.49**
1.05	**0.38**
1.10	**0.26**
1.15	**0.13**
1.20	**0.00**

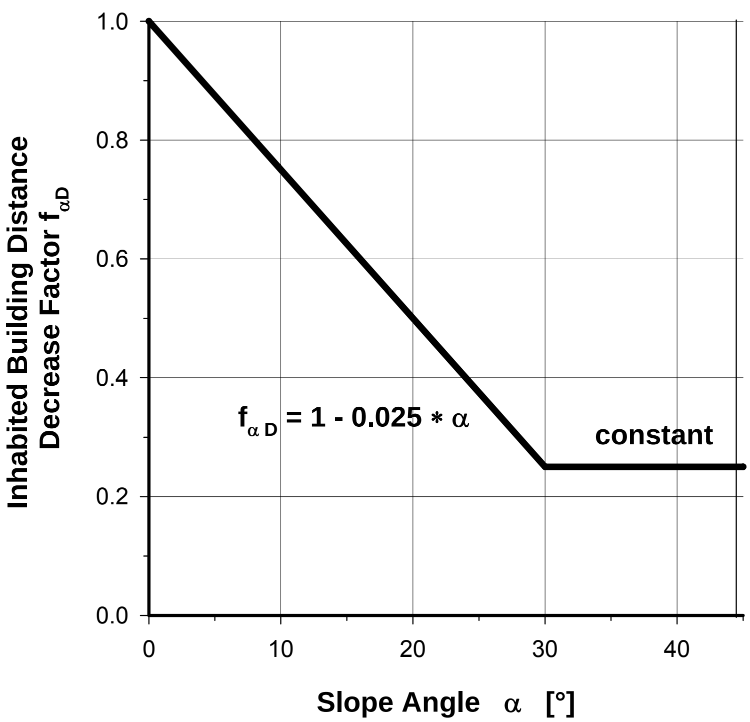
Loading Density [kg/m^3]	f_γ [.]
1	**0.08**
3	**0.11**
5	**0.13**
10	**0.17**
15	**0.20**
20	**0.22**
25	**0.23**
30	**0.25**
40	**0.27**
50	**0.30**
60	**0.32**
70	**0.33**
80	**0.35**
90	**0.37**
100	**0.38**
120	**0.40**
140	**0.43**
160	**0.45**
180	**0.47**
200	**0.48**
220	**0.50**
250	**0.52**
300	**0.56**

Q = Weight of Explosives, NEQ

Figure 3-XXII: Overburden Slope Angle Parameter fα



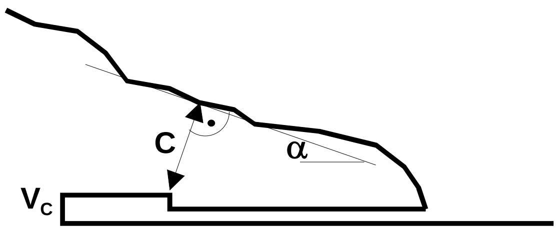
α	$f_{\alpha I}$
0.0	1.00
2.5	1.05
5.0	1.10
7.5	1.15
10.0	1.20
12.5	1.25
15.0	1.30
17.5	1.35
20.0	1.40
22.5	1.45
> 25	1.50



α	$f_{\alpha D}$
0.0	1.00
2.5	0.94
5.0	0.88
7.5	0.81
10.0	0.75
12.5	0.69
15.0	0.63
17.5	0.56
20.0	0.50
22.5	0.44
25.0	0.38
27.5	0.31
> 30	0.25

Figure 3-XXIII: How to Calculate IBD's for Crater Debris Throw - Example

Given:



VC = 5000 m^3
NEQ = 200'000 kg = Q
C = 50 m
a = 20 °

Solution: $Q^{1/3}$ (from Figure XII) = 58.5 $kg^{1/3}$
Loading Density = Q / V_C = 200'000 / 5000 = 40 kg/m^3
Scaled Cover Depth = $C / Q^{1/3}$ = 50 / 58.5 = 0.85 $m/kg^{1/3}$

Loading Density Parameter (from Figure X or XII) f_γ = 0.27
Cover Depth Parameter (from Figure XI or XII) f_C = 0.75

$IBD_F = 38.7 * Q^{1/3} * f_\gamma * f_C$
$= 38.7 * 58.5 * 0.27 * 0.75$ = 458 m

IBD Increase Factor (from Figure XIII) $f_{\alpha I}$ = 1.4
IBD Decrease Factor (from Figure XIII) $f_{\alpha D}$ = 0.5

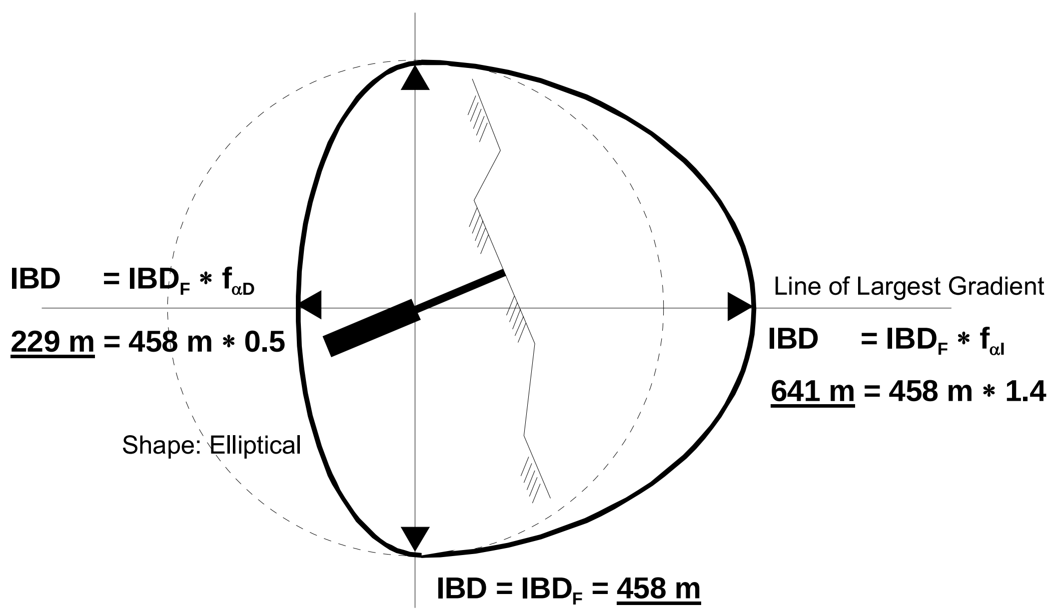
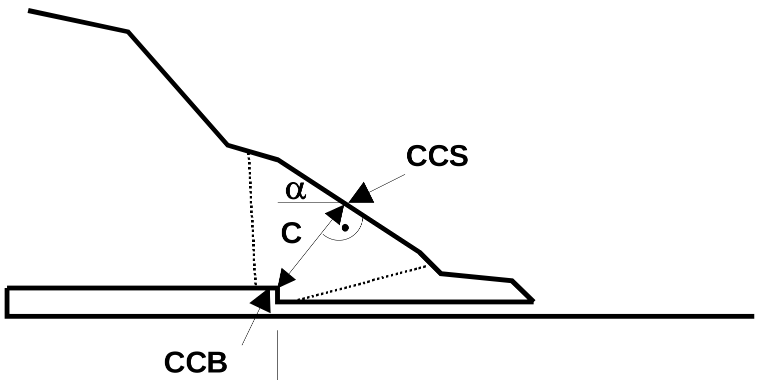
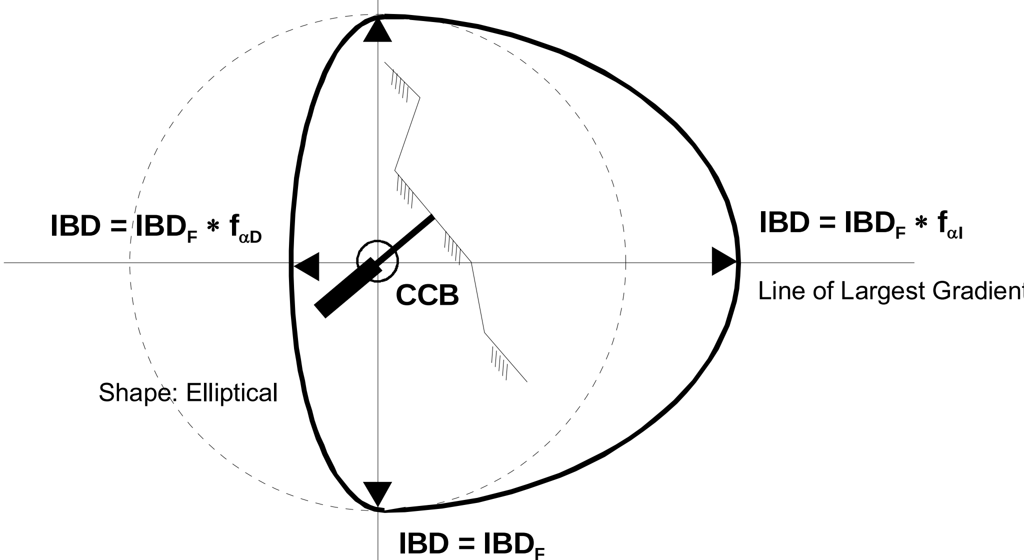


Figure 3-XXIV: How to Establish Inhabited Building Distance Contrours

Cross Section of Installation



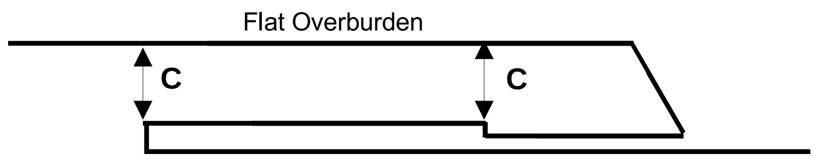
Inhabited Building Distance Contour (ground-plan)



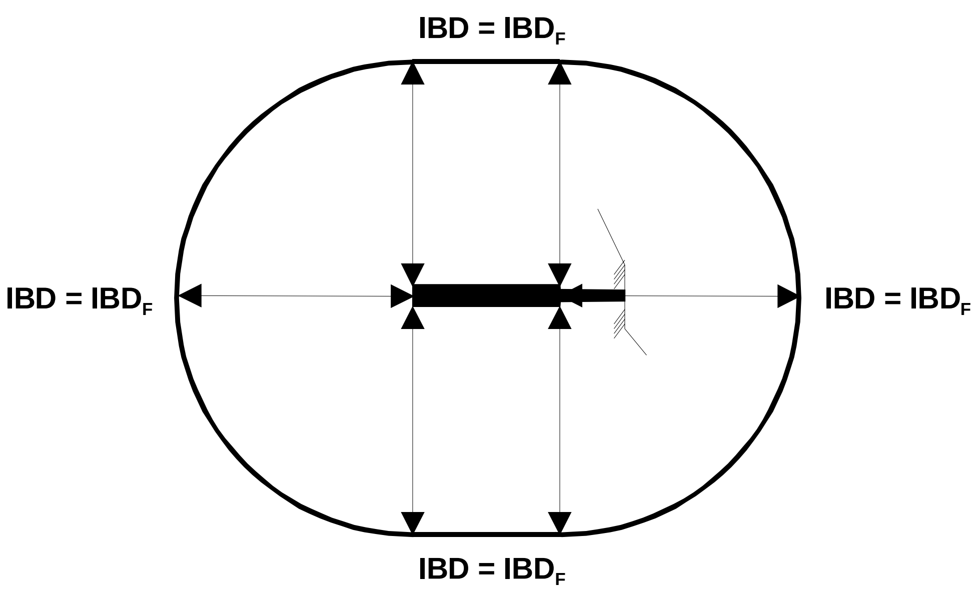
α	= Slope Angle of Overburden
C	= Cover / Overburden
CCS	= Crater-Center-Surface
CCB	= Crater-Center-Bottom
IBD_F	= Inhabited Building Distance for Flat Terrain / Overburden
$f_{\alpha I}$	= Inhabited Building Distance Increase Factor
$f_{\alpha D}$	= Inhabited Building Distance Decrease Factor

Figure 3-XXV: How to Establish Inhabited Building Distance Contrours

Cross Section of Installation



Inhabited Building Distance Contour (ground-plan)



C = Cover / Overburden
IBD_F = Inhabited Building Distance for Flat Terrain / Overburden

3.3.4.3 Ground Shock

1 Introduction

The prediction of ground shock and the derivation of its quantity-distances require careful consideration of the all factors affecting ground shock propagation and the ground shock parameters.

1.1 Factors Affecting Ground Shock Effects

Ground shock is highly site-dependent and is affected by the following factors:

a. Geological structure and rock mass properties
b. Explosives charge weight and scaled range
c. Chamber loading density
d. Charge distribution and chamber volume

1.2 Geological Classification

The geological classification presented in Table 1-I should be used for the prediction of the ground shock parameters. If the rock type is not clear, the classification should be based on wave propagation properties rather than on strength. Important rock mass properties affecting wave propagation include bulk density, seismic wave velocity, and joints and their orientation.

1.3 Geology of Site

The geology of a site is further classified into the following categories:

Single medium – where the Potential Explosion Site (PES) and Exposed Site (ES) are in the same rock mass.
Mixed media – where the bedrock is overlain by a soil layer of a significant thickness (typically with a soil-to-rock thickness ratio of 0.2), which affects ground shock propagation and the frequency content of the ground shock wave reaching the structure, and PES is in rock where the storage chambers are sited and ES in a soil overburden on which buildings are found.

For cases where the soil cover is less than 0.05 of the transmission distance or less than 5 m, the site geology may be classified as single medium.

1.4 Ground Shock Parameters

The prediction of ground shock must be done with a view for the assessment of structural response. A complete definition of the ground shock wave is the response spectra, which can be generated either empirically or numerically.

For assessment of structural response, the most important parameters for ground shock are the magnitude and the frequency content. The magnitude is often expressed by the Peak Particle Velocity (PPV) while the frequency content can be represented by the Principal Frequency (PF). If possible, calculations should be made for both the vertical and horizontal components of the ground shock wave.

2 Prediction Equations for PPV and PF

The Peak Particle Velocity (PPV) and Principal Frequency (PF) equations can generally be described as follows, respectively:

$$PPV = A\left(\frac{R}{Q^{1/3}}\right)^{-m}$$

$$PF = B\left(\frac{R}{Q^{1/3}}\right)^{-n}$$

where

PPV	= Peak Particle Velocity	[m/s]
PF	= Principal Frequency	[Hz]
R	= Radial distance measured from the chamber wall along a line drawn from the chamber centre to the point of interest on the ground surface [m]	
Q	= Net Explosives Quantity	[kg]

A and B are initial values at scaled range, $R/Q^{1/3}$ = 1.0 m/kg$^{1/3}$; and
m and n are the attenuation coefficients.

Summary tables of the initial values and attenuation coefficients for the Peak Particle Velocity (PPV) and Principal Frequency (PF) prediction equations are presented in Table 1-II and Table 1-III respectively.

The results cover charge weights up to 500 tonnes, chambers of length ranging from 45 to 120 m with maximum volume of 50,000 m^3, and span to length ratio between 1:2 and 1:4. The loading densities considered range up to 50 kg/m^3 with rock cover or equivalent cover of about 1.0Q$^{1/3}$ m.

3 Frequency-based Ground Shock IBD for Reinforced Concrete (RC) Structures

3.1 Response of Structures due to Ground Shock

The damage of a building due to ground shock can be characterised by the reduction in natural frequency of the structural system. This can be represented by a building damage index (DI), which can be calculated using the following equation:

$$BDI = 1 - \frac{f_i^2}{f_p^2}$$

where

f_i	=	Initial natural frequency	[Hz]
f_p	=	Post-event natural frequency of structure	[Hz]

3.2 Classification of Building Damage

Building damage due to ground shock can be classified into the following categories given in Table 2-I.

3.3 Prediction of Building Damage Index

The building damage index (DI) of a typical reinforced concrete structure up to ten storeys, with span up to 5 m and inter-storey height up to 3m, can be obtained for a given Peak Particle Velocity (PPV) and Principle Frequency (PF).

The equations for the prediction of PPV and PF can be found in Section 2. If other methods are used to predict the PPV in the horizontal and vertical directions, the resultant PPV should be used, and can be calculated from the following equation:

$$PPV = \sqrt{PPV_x^2 + PPV_y^2}$$

where

PPV_x	=	maximum peak particle velocity in the horizontal direction	[m/s]
PPV_y	=	maximum peak particle velocity in the vertical direction	[m/s]

3.4 Criteria for Ground Shock IBD

The recommended building damage index (DI) to adopt is 0.4. At this value, the building is expected to suffer only repairable minor damage, where small cracks occur in the concrete, but the reinforcement will remain in the elastic range. The overall stiffness will be reduced by 20 – 40%. Collapse of buildings is not expected and fatality is unlikely. If a higher damage index were to be adopted, the ground shock IBD equations in Section 3.5 would have to be adjusted accordingly. Studies related lethality rates and the associated damage index could be used to guide the selection of the acceptable damage index.

3.5 Ground Shock IBD for Reinforced Concrete (RC) Structures

The response and damage of buildings are primarily governed by the magnitude (PPV) and frequency content (PF) of the ground shock. Based on an acceptable building damage index of 0.4 as given in the previous section, the allowable PPV for reinforced concrete structures will be given as:

$PPV \leq 0.4$ m/s	for $10\ Hz \leq PF \leq 30\ Hz$
$PPV \leq 0.0825\ PF^{0.46}$ m/s	for $30\ Hz < PF \leq 100\ Hz$
$PPV \leq 0.7$ m/s	for $100\ Hz < PF$

The IBD for the siting of reinforced concrete structures is:

$IBD = (\frac{0.4}{A})^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$	for $10\ Hz \leq PF \leq 30\ Hz$
$IBD = (\frac{0.0825 B^{0.46}}{A})^{\frac{1}{(-m+0.46n)}} * (Q^{\frac{1}{3}})$	for $30\ Hz < PF \leq 100\ Hz$
$IBD = \left(\frac{0.7}{A}\right)^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$	for $100\ Hz < PF$

Where IBD is in metres, measured directly from the chamber wall, and A, B, m and n are constants given in Table 1-II and 1-III.

Since the PF is also a function of the distance, the user should check the PF and ensure that the correct IBD equation from the above is used. Iterative calculations may be required to solve for the ground shock IBD.

Example #1:

Given: Q = 125,000kg Loading density = 20kg/m^3 Span-length ratio = 1:2
Geology: Single Medium, Good Rock
Equivalent cover thickness = 1.0 Q$^{1/3}$

Solution: From Table 1-II and 1-III, A = 1.35, m = 1.23, B = 72, n = 0.84

$IBD = (\frac{0.4}{A})^{-\frac{1}{m}} * (Q^{\frac{1}{3}}) = (\frac{0.4}{1.35})^{-\frac{1}{1.23}} * (125{,}000^{\frac{1}{3}})$ = 134 metres

Check PF = $B(\frac{R}{Q^{1/3}})^{-n} = 72(\frac{134}{125{,}000^{1/3}})^{-0.84}$ = 31 Hz > 30 Hz => Not OK!

$IBD = (\frac{0.0825 B^{0.46}}{A})^{\frac{1}{(-m+0.46n)}} * (Q^{\frac{1}{3}}) = (\frac{0.0825 * 72^{0.46}}{1.35})^{\frac{1}{(-1.23+0.46*0.84)}} * (125{,}000^{\frac{1}{3}})$ = 133 metres

Check PF = $B(\frac{R}{Q^{1/3}})^{-n} = 72(\frac{133}{125{,}000^{1/3}})^{-0.84}$ = 32 Hz > 30 Hz and < 100Hz => Ok!

Example #2:

Given: Q = 125,000kg Loading density = 20kg/m^3 Span-length ratio = 1:2
Geology: Mixed media with Good Rock Soil to rock cover ratio = 0.2

Equivalent cover thickness = 1.0 $Q^{1/3}$

Solution: From Table 1-II and 1-III, A = 1.54, m = 1.71, B = 51, n = 0.67

IBD = $(\frac{0.4}{A})^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$ = $(\frac{0.4}{1.54})^{-\frac{1}{1.71}} * (125{,}000^{\frac{1}{3}})$ = 110 metres
Check PF = B $(\frac{R}{Q^{1/3}})^{-n}$ = 51 $(\frac{110}{125{,}000^{1/3}})^{-0.67}$ = 31 Hz > 30 Hz => Ok!

4 Ground Shock IBD for non-RC Structures

For non-RC structures, the allowable ground shock peak particle velocity PPV_a criteria are given according to their foundation geology as follows:

Foundation on Soil : PPV = 60 – 200 mm/s
(Sand, gravel, clay)

Foundation on Soft Rock : PPV = 115 – 400 mm/s
(Firm moraine slate, shale stone, soft limestone)

Foundation on Hard Rock : PPV = 230 – 800 mm/s
(Granite, gneiss, diabase, quartzite sandstone, hard limestone)

Based on the selected allowable PPV_a value, the ground shock IBD for non-RC structures can be calculated as follows.

$$\text{IBD} = (\frac{PPV_a}{A})^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$$

Where IBD = Inhabited Building Distance in metres, measured directly from the chamber wall. The ground shock parameters, A and m, can be referred from Table 1-II based on the geological classification in Table 1-I, and the cavern design parameters.

Example #1:

Given: Q = 125,000 kg Loading density = 10 kg/m^3 Span-length ratio = 1:4
Foundation on Hard Rock
Geology: Good Rock
Equivalent cover thickness = 1.0 $Q^{1/3}$

Solution: From Table 1-II, A = 0.75, m = 1.23
Chosen PPV_a at IBD = 0.23 m/s

IBD = $(\frac{PPV_a}{A})^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$ = $(\frac{0.23}{0.75})^{-\frac{1}{1.23}} * (125{,}000^{\frac{1}{3}})$ = <u>131 metres</u>

Example #2:

Given: Q = 125,000 kg Loading density = 10kg/m^3 Span-length ratio = 1:4
Foundation on Soil
Geology: Mixed media with Good Rock
Equivalent cover thickness = 1.0 Q1/3

Solution: From Table 1-II,
A = 1.29, m = 1.71
Chosen PPV_a at IBD = 0.06 m/s

IBD = $\left(\frac{PPV_a}{A}\right)^{-\frac{1}{m}} * (Q^{\frac{1}{3}})$ = $\left(\frac{0.06}{1.29}\right)^{-\frac{1}{1.71}} * (125{,}000^{\frac{1}{3}})$ = <u>301 metres</u>

5 Validity of Range

The range of validity for the IBD equations proposed in the following cover charge weights up to 500 tonnes, chambers of length ranging from 45 to 120 m with maximum volume of 50,000 m^3, and span to length ratio between 1:2 and 1:4. The loading densities considered range up to 50 kg/m^3 with rock cover or equivalent cover about 1.0Q$^{1/3}$ m. Interpolations can be carried out between the recommended values for different storage conditions.

The ground shock IBD given in this chapter is for a typical reinforced concrete structure up to ten storeys, with span up to 5 m and inter-height up to 3 m. Little work has been done to quantify the damage criteria for other structure types of masonry, wooden and steel. A specific analysis should be conducted and siting decisions should be based on the foundation type and robustness of these structures to withstand the ground shock.

For storage sites where the rock cover or equivalent cover is less than 1.0Q$^{1/3}$, the equations given by Table 1-II and Table 1-III should not be used to predict the ground shock parameters for scaled range less than 1 m/kg$^{1/3}$. For cases where the rock cover or equivalent cover is significantly more than 1.0Q$^{1/3}$, Table 1-II may under-predict the peak particle velocities on the ground surface.

For storage sites that deviate very much from the conditions specified, further study and analysis is recommended and detailed site specific characterisations should be used to support the final construction and explosives safety siting decisions.

Other Hazard Divisions

For HD 1.2, a single item (or that explosives weight for the maximum number of items to react simultaneously) can be treated as HD 1.1 for the purpose of ground shock prediction. Otherwise, ground shock effects from HD 1.2 in bulk storage are negligible.

For HD 1.3 stored in underground caverns, it should be treated as HD 1.1 for the purpose of ground shock prediction.

The ground shock effects resulting from HD 1.4 items can be neglected.

For HD 1.2, 1.3, and 1.4 items or storage where various HD’s are mixed, it is safe and conservative to treat all items as HD 1.1 for the purpose of ground shock prediction.

Table 1-I: Classification of Site Geology for Ground Shock Analysis

Typical Rock Type / Rock Mass Quality	Gabbro, Gneiss, Granite, Norite, Andesite, Dolerite, Diabase, Rhyolite, Quartzite, Dolomite, Marble, Limestone*, Sandstone*	Mudstone, Siltstone, Shale, Slate, Limestone*, Sandstone*	Tuff, Chalk, Rock Salt, Coal, Limestone*, Sandstone*
Good to Very good quality rock mass with few sets of unweathered or slightly weathered discontinuity sets Q > 10 RMR > 65 RQD > 75% V_p > 4500 m/s	Good	Fair	Poor
Fair to good quality rock mass with several sets of moderately weathered discontinuities 1 < Q < 10 50 < RMR < 65 50% < RQD < 75% 3500 < V_p < 4500 m/s	Fair	Fair	Poor
Poor quality rock mass with numerous weathered joints Q < 1 RMR < 50 RQD < 50% V_p < 3500 m/s	Poor	Poor	Poor

where
RMR = Rock Mass Rating
RQD = Rock Quality Designation
Q = Rock Quality Index

Table 1-II: Summary of Initial Value, A and attenuation coefficient, m for Peak Particle Velocity (PPV) Prediction Equation

A. For PPV in Single Medium Geology

A.1 Chamber with width-to-length ratio of 1:2

Geology	Loading Density, kg/m^3				
	5	10	20	50	
	A				m
Good Rock	0.79	1.08	1.35	1.52	1.23
Fair Rock	1.00	1.19	1.40	1.62	1.56
Poor Rock	1.00	1.30	1.55	1.82	1.90

A.2 Chamber with width-to-length ratio of 1:4

Geology	Loading Density, kg/m^3				
	5	10	20	50	
	A				m
Good Rock	0.56	0.75	1.08	1.20	1.23
Fair Rock	0.78	1.00	1.23	1.49	1.56
Poor Rock	0.78	1.01	1.39	1.64	1.90

B. For PPV in Mixed-Media Geology

B.1 Chamber with width-to-length ratio of 1:2

Geology	Loading Density, kg/m^3				
	5	10	20	50	
	A				m
Good Rock	1.14	1.38	1.54	1.77	1.71
Fair Rock	1.41	1.69	2.01	2.37	2.01
Poor Rock	1.89	2.32	2.60	2.96	2.34

B.2 Chamber with width-to-length ratio of 1:4

Geology	Loading Density, kg/m^3				
	5	10	20	50	
	A				m
Good Rock	1.08	1.29	1.45	1.70	1.71
Fair Rock	1.20	1.62	1.85	2.13	2.01
Poor Rock	1.78	2.10	2.47	2.77	2.34

Note:
Peak Particle Velocity, PPV = $A\,(R/Q^{1/3})^{-m}$

Table 1-III: Summary of initial value, B and attenuation coefficient, n for Principal Frequency (PF) Prediction Equation

Geology and Chamber Geometry	Loading Density, kg/m^3				
	5	10	20	50	
	B, Hz				n
Single Medium Geology					
Chamber with width-to-length ratio of 1:2	85	76	72	65	0.84
Chamber with width-to-length ratio of 1:4	96	86	79	73	
Mixed Media Geology					
	Loading Density, kg/m^3				
	5	10	20	50	
	B, Hz				n
Chamber with width-to-length ratio between 1:2 and 1:4	64	61	51	45	0.67

Note:
Principal Frequency, PF = B $(R/Q^{1/3})^{-n}$

Table 2-I: Classification of Building Damage

Damage	Damage Index	Description of Damage – High Frequency Response	State of Building
Minor	< 0.4	Small cracks in concrete. Reinforcement still in elastic state. Overall stiffness reduction by about 20-40%.	Easily repairable
Moderate	0.4 – 0.6	Many small cracks occur along structural members. Overall stiffness reduction by about 40-60%	Repairable
Severe	0.6 – 0.9	Many large cracks, some areas with plastic hinge formation, reinforcement yields. Overall stiffness reduction by 60-100%.	Non-repairable
Collapse	> 0.9	Collapse. Complete loss of stiffness.	Loss of building

Section V - Public Traffic Route Distances (PTRD)

Public traffic route distance (PTRD) (For all Hazard divisions)

1. Ground Shock QD is 2/3 of IBD for ground shock.

2. Debris QD is 2/3 of IBD for debris.

3. The calculated distance according to equation 3.3.4-5 should be used, alternatively the more conservative 2/3 of IBD could be used..

4. For heavy traffic use the maximum IBD determined in the previous three paragraphs.

5. Because of the hazards arising from the strong on-axis jetting, special considerations should be given when ES is on the extended centreline of the main passageway.

Section VI - Explosives Workshop Distance (EWD)

An Explosives Workshop (EW) may be either an aboveground structure or an underground chamber with its own entrance tunnel. Except for HD 1.4 ammunition, an underground EW should not be connected (air ducts, passageways, etc.) to other underground storage chambers. Otherwise, an underground ES should be sited as a storage chamber. Distances between PES and EW are intended to provide a reasonable degree of personnel protection within the EW from the effects of a nearby explosion (blast, flame, debris, and ground shock).

An explosion in an underground facility produces a directional impulsive load along the extended centerline axis of an adit. This impulsive load is considerably more intense at a given distance than that from a comparable above ground detonation. Little work has been done to quantify the on-axis impulsive load as a function of distance.

3.3.6.1. Potential Crater

An Aboveground EW should be sited so it is at least outside the potential crater of an underground explosion.

3.3.6.2. Aboveground EW Located within the Maximum Dispersal Angle

An unhardened EW should be sited at the corresponding IBD found above.

3.3.6.3. Aboveground EW Located Outside the Maximum Angle of Dispersal

An EW may be sited at 1/3 of the corresponding IBD found above. Required distance from the tunnel adit because of airblast could be determined from Eq. 3.3.4-6.

Section VII – Aboveground Earth-Covered Magazine (ECM)

A site-specific analysis should be conducted and siting decisions should be based on the protection the ECM provides.

Section VIII - Aboveground Magazine Distance (AGMD)

An unbarricaded AGM should be sited at 2/3 of the corresponding IBD found above.

A barricaded AGM should be sited at 1/3 of the corresponding IBD found above.

REFERENCES

UNDERGROUND STORAGE

EXPLOSIVES SAFETY HAZARDS

[1] AASTP-1, “Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives” (May 1992)

[2] Wilfred E. Baker, Peter S. Westine, and Franklin P. Dodge, “Similarity Methods in Engineering Dynamics, Theory and Practice of Scale Modeling”, Published by Elsevier (1991)

[3] LLNL Explosives Handbook, “Properties of Chemical Explosives and Explosive Simulants, Change 2, “Lawrence Livermore National Lab., CA.; Department of Energy, Washington, DC. (NTIS Order Number: DE91006884INZ)

[4] Swiss Federal Buildings Office/Engineering Division - Swiss-Klotz Design, Drawing Nos. 1036.SP.2.020/025/027

[5] US Army Corps of Engineers Drawings, "Definitive Drawings Underground Storage Facility" (DEF 421-80-04)

[6] Royal Swedish Fortifications Administration - Klotz-Test Operation Block, Report No. 119:5, 01.05.1974

[7] L. K. Davis and So-Young Song, “Technical Managers Final Report,” Joint U.S./ROK R&D Program for New Underground Ammunition Storage Technologies TR SL-97-10 and UAST-TR-97-002 (September 1997)

[8] NO(ST)(UGS/AHWP)IWP 6-98 dated 24 November 1998 One-dimensional Blast Wave Propagation

[9] NO(ST)(UGS/AHWP) IWP 8-98 dated 24 November 1998 Model Tests of Accidental Explosions in Underground Ammunition Storage, II: Blast Wave Propagation in Tunnel Systems

[10] NO(ST)(UGS/AHWP) IWP 7-98 dated 24 November 1998 Model Test of Accidental Explosions in Underground Ammunition Storage, I: Chamber Pressure

[11] NO(ST)(UGS/AHWP) IWP 9-98 dated 24 November 1998 Blast Propagation outside a Typical Underground Storage Site

[12] NO(ST)(UGS/AHWP) IWP 10-98 dated 24 November 1998 Underground Ammunition Storage Magazines, Blast Effects from Accidental Explosions. (Norwegian Magazines Standard)

[13] NO(ST)(UGS/AHWP) IWP 11-98 dated 24 November 1998 Calculation of Airblast from Underground Ammunition Storage Magazines. (Norwegian Magazines Standard)

[14] NO(ST)(UGS/AHWP) IWP 12-98 dated 24 November 1998 Air Blast from Tubes Meeting 27-28 October 1987

[15] NO(ST)(UGS/AHWP) IWP 13-98 dated 24 November 1998 Underground Ammunition Storage. Blast Effects from Accidental Explosions

[16] UK(ST)IWP 311 dated 3 March 1998 - AASTP- I Advice on Adit Debris Projections from Underground Storage Sites

[17] CH(ST)UGS/AHWP IWP 007 dated 30 October 1998 - Debris Throw from Adit Tunnels. Proposed Changes to the NATO Safety Manual AASTP- 1, Part III Technical Background for Throw Distances

[18] CH(ST)UGS/AHWP IWP 005 dated 30 May 1998 – Debris Throw from Craters - Proposed Changes to the NATO Safety Manual AASTP-1, Part III - Technical Background

[19] CH(ST) UGS/AHWP IWP 006 dated 30 October 1998 – Debris Throw from Craters - Proposal Changes to the NATO Safety Manual AASTP-1, Part III - Proposed Wording

[20] CH(ST)UGS/AHWP IWP 008 dated 4 November 1998 - Proposed Changes to the NATO Safety Manual AASTP- 1, Part III - Proposed Wording - Swiss Contribution

[21] CH(ST)UG/AHWP IWP 002 dated 24 September 1997 - Debris Throw from Craters. – Pertinent Technical Reports

[22] CH(ST)UG/AHWP IWP 003 dated I October 1997. - Debris Throw from Craters.

[23] US MEMO, dated 30 July 1997 - Recommendations for Ground Shock Criteria in NATO Documents

[24] US(ST)(UGS/AHWP) IWP 1-98 dated 30 September 1998 - US proposal for Ground Shock from an Underground Storage Facility

[25] US MEMO, dated 31 December 1997 - Proposal for Ground Shock Explosives Safety Principles

[26] NO(ST)UGS/AHWP IWP 1/98 dated 11 February 1998 - AASTP- I Part II, Inhabited Building Distance, Ground Shock

[27] Fook-Hou Lee, Wee-Beng Koh, and Thiam-Soon Tan, "Numerical Back Analysis of Field Measurements of Ground Vibration from Underground Explosions," 28th DOD Explosives Safety Seminar 18-20 August 1998, Orlando, Florida

[28] Yingxin Zhou, Karen O Y Chong, and Yaokun Wu, "Small-Scale Testing on Ground Shock Propagation in Mixed Geological Media," 28th DOD Explosives Safety Seminar 18-20 August 1998, Orlando, Florida

[29] Yingxin Zhou, Hong Hao, and Guowei Ma, "Ground Shock Damage Criteria for Inhabited Buildings," 28th DOD Explosives Safety Seminar 18-20 August 1998, Orlando, Florida

[30] US(ST)(UGS/AHWP) IWP 1-98 dated 30 September 1998 - US proposal for Ground Shock from an Underground Storage Facility

[31] NO(ST)(UGS/AHWP) IWP 14-98 dated 15 December 1998 - Ground Shock in Rock-Full scale Tests in Norway

[32] US MEMO, dated 16 December 1998, Minutes of Special UGS/AHWP meeting 15-16 October 1998

[33] Peter Westine, "Ground Shock from the Detonation of Buried Explosives, "Journal of Terramechanics, Vol 15, No 2, pp 69-79 (1978)

[34] CH(ST) UG/AHWP IWP 4 dated 6 March 1998 – Debris Throw from Craters – CH Status Report as of 6 March 1998

[35] PFP(AC_326-SG_5)(CUSTODIAN-UGAS)(NO)IWP(2006)0001

[36] PFP(AC_326-SG_5)(CUSTODIAN-UGAS)(NO)IWP(2006)0002.

[37] NATO - Allied Ammunition Storage and Transport Publication (AASTP)
AASTP-4, "Explosives Safety Risk Analysis"
NATO AC/258 Risk Analysis Working Group (RAWG)
AC/258(ST)WP/214 / 27.02.2001 / NATO PFP unclassified

[38] Debris Throw from Adits of Underground Installations in Rock
Basics for Risk Analysis - Technical Background
Contribution to NATO - AC/258 Storage Sub Group - UGSWG
Defence Procurement Agency - General Staff, Switzerland
Bienz, Kummer & Partner AG
Kummer, P.; Willi, W.; Nussbaumer, P.
TM 174-9 // AC/258 CH(ST)IWP 024-02 / 30.03.2002

[39] Trümmerwurf aus Zugangsstollen von Felsanlagen
TLM 75/Teil 2 - Revision technische Anhänge
Grundlagen
Generalstab - Sektion SUR
Bienz, Kummer & Partner AG
Kummer, P.; Willi, W.; Nussbaumer, P.
B 150-12 / 30.11.2001

[40] Debris Throw from Adit Tunnels
Proposed Changes to the NATO Safety Manual AASTP-1, Part III
Technical Background for Throw Distances
Contribution to NATO - AC/258 Underground Storage Ad hoc Working Party
Defence Procurement Agency, Switzerland
Bienz, Kummer & Partner AG
Kummer, P.
TM 158-9 // CH(ST)UGS/AHWP IWP 007 / 30.10.1998

[41] Debris Throw from Adit Tunnels
Proposed Changes to the NATO Safety Manual AASTP-1, Part III
Proposed Wording
Contribution to NATO - AC/258 Underground Storage Ad hoc Working Party
Defence Procurement Agency, Switzerland
Bienz, Kummer & Partner AG
Kummer, Peter
TM 158-10 // CH(ST)UGS/AHWP IWP 008 / 04.11.1998

[42] Debris Throw from Adits
Basics for Risk Analysis
Proposed Wording for AASTP-4
CH Contribution to the NATO AC/258 Storage Sub-Group - UGSWG
Defence Procurement Agency / General Staff - Switzerland
Bienz, Kummer & Partner AG
Nussbaumer, P.; Kummer, P.
AC/258 CH(ST)IWP 030-02 // TM 174-15 / 28.02.2002 / NATO PFP unclassified

ALLIED AMMUNITION STORAGE AND TRANSPORT PUBLICATION 1
(AASTP-1)

MANUAL OF NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

PART IV

SPECIAL SITUATIONS

May 2010

TABLE OF CONTENTS

CHAPTER 1 - GENERAL

4.1.0.1. *Purpose and Scope*

a) This part of the Manual provides safety principles for use in special situations. This has previously been defined as those cases where it is not possible, without seriously prejudicing operational effectiveness, to apply the normal peacetime principles detailed in Parts I-III of the Manual. With the production of AASTP-5, under the purview of SG6, that intent has been overtaken. What remains in this Part are special situations that have yet not been moved to AASTP-5 and where there may be a reduced level of protection due to operational requirements.

b) Where a reduced level of protection, below that detailed in Parts I-III of the Manual, has been used in this part, consequences as detailed in Part I, Chapter 3, Section VII have been accepted. This must be borne in mind by all those using the recommendations contained in Part IV.

4.1.0.2. *Basis for this Part of the Manual*

In preparing this part of the Manual the following principles have been followed:

1. In peacetime the recommendations in Part IV must not reduce the normal level of protection afforded to the general public as detailed in Parts I-III.

2. The recommendations in Part IV may reduce the normal peacetime level of protection afforded to the personnel responsible for military operations, where this is essential in the interests of operational effectiveness, bearing in mind the nature of the operation, and the consequences (see subparagraph 4.1.0.1.b)).

4.1.0.3. *Use of Principles*

The decision whether to use the principles contained in this part or to use those in Parts I-III must be made by National Authorities.

4.1.0.4. *Updating*

The Group of Experts that forms the CNAD Ammunition Safety Group (AC/326) and specifically Sub-group 6, as custodian of this Manual, intends to maintain its value by publishing corrigenda from time to time.

4.1.0.5 *Conditions of Release :*

The NATO Manual on Safety Principles for Storage of Military Ammunition and Explosives (AASTP-1) is a NATO Document involving NATO property rights. The understanding and conditions agreed for the release of the Manual are that it is released for technical defence purposes and for the use by the defence services only of the country concerned. This understanding requires that the release of the whole, or any part, of the Manual must not be undertaken without reference to, and written approval of, NATO.

4.1.0.6. *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.

CHAPTER 2 - FIELD STORAGE

Section I - Introduction

4.2.1.1. *Scope*

a) The principles in this chapter apply to the storage of ammunition in the theatre of operations (communications zone and combat zone) in Field Storage Areas where the principles for storage in permanent depots cannot be applied and greater risks must be accepted. The principles are most important with respect to safety and protection of ammunition when stored under field conditions. The principles apply also to the parking of vehicles loaded with ammunition in the theatre of operations. Each vehicle or container is treated as a Field Stack Module.

b) In Field Storage, all potentialities must be used to

1. keep the ammunition serviceable

2. avoid ammunition losses.

Protection of personnel, material, installations, and buildings should be considered

4.2.1.2. *Exclusions*

a) The following factors must also be considered but are outside the scope of this Manual and are left to the discretion of the National Authorities.

1. Dispersion against attack.
2. Ground pattern.
3. Camouflage.
4. Isolation.
5. Communications.
6. Expansion.
7. Improvement.
8. Security.
9. Sabotage.

b) The principles do not deal with ammunition depots established in peacetime to meet the need for holding war reserves, even though the depot may be under field conditions. The normal principles for storage apply to such situations.

c) The principles do not apply to the holding of ammunition in battery positions or in readiness areas.

4.2.1.3. *Selection of Sites*

Sites should be carefully selected taking account of the following requirements:

1. The ground must be firm to carry the heavy weight of ammunition stacks and laden vehicles.

2. The ground should be level, dry and pervious to water.

3. The site should be easily accessible, preferably on both sides of by-roads. Loading and unloading of vehicles should be capable of being accomplished away from main roads so that traffic is not hindered.

4. The site should be located sufficiently far from trees, telegraph poles, pylons etc. so that a lightning strike to a tree etc. would not cause damage to the ammunition.

5. A water supply should be available for fire-fighting.

6. Variations in terrain or a dense forest should be exploited to provide natural barricades.

7. Firebreaks of sufficient width should be planned and maintained to prevent a potential spread of fire. Roads of corresponding width are considered as fire-breaks.

Section II - Field Storage History

4.2.2.1. *Introduction*

Since the acquaintance of UN Logistics Directive 312 “Ammunition and Explosives” (dated 1992) there have been a lot of discussion in NATO AC/258 AHTWP if NATO could provide better advice for storage of ammunition and explosives during operations out-of-area. This discussion led to a NATO AC/258 STSG Field Storage Workshop held on 4th November 1997 where national methodologies, procedures and experiences regarding field storage were presented. The Storage Sub-Group noted the following conclusions from this first workshop:

a) Field Commanders needed tools as well as, but not instead of, rules;
b) tools/rules users needed to be educated in concepts;
c) overall risk strategy and its consequences needed to be determined;
d) guidance developed by AC/258 should be set at a level suitable for people who understand the concepts and not for the completely uninitiated.

4.2.2.2.

The workshop was succeeded with the establishment of the NATO Expert Working Group on Field Storage (EWG/FS), which had its first meeting in Alexandria, VA, USA on 23-24 March 1998. The objective of the EWG/FS is to develop changes to be made to the field storage advice in the NATO publication AASTP-1 based on the information already available to AC/258.

4.2.2.3.

The NL MOD and UK MOD tasked TNO Prins Maurits Laboratory to write a Draft IWP with a proposal of NATO advice on this subject on the basis of the following IWPs:

a) NL(ST)IWP/2-97;
b) US(ST)IWP/103-98;
c) GE(ST)(EWG/FS)IWP1-98;
d) GE(ST)(EWG/FS)IWP2-98;
e) GE(ST)(EWG/FS)IWP3-98.

This task resulted in a first draft version with guidelines [11]. This original version was discussed by UK-, GE- and NL-MOD delegates during an interim meeting on January 12th, 1999 at TNO. Comments of UK-, GE-, NL- and DK-MOD [12] were included in a second draft version [13] which was discussed during the 3rd NATO AC/258 FSWG meeting on June 7th, 1999 in Brussels. Comments on this second draft version [13] are implemented in this final IWP.

The report starts giving short abstracts of the IWPs mentioned above. Topics of these IWPs are then selected and combined into common NATO advice. The proposed guidelines for field storage are presented in Annex A of the report. Annex B presents a proposal for the re-division of the current Part IV of NATO publication AASTP-1.

4.2.2.4. Abstract of IWPs

a) NL approach

On behalf of the RNLA and RNLAF, TNO-PML proposed guidelines for field storage of ammunition and explosives which are based on a modular storage concept by analogy with Part IV of the NATO publication AASTP-1. While the AASTP-1 gives Q-Ds for relatively large storage sites (maximum 200 t gross weight) and storage areas (maximum 5000 t gross weight), the proposed field storage concept is based on much smaller quantities of ammunition and explosives specifically for battalion or company size.
In this concept a ***basic module*** is defined as 5000 kg NEQ of ammunition and explosives stored in any storage facility or open stack. In general, this NEQ matches the amount of ammunition and explosives in a vehicle or 20 ft container during transport. A *storage module* consists of one to five basic modules. Therefore, the maximum credible event is determined by the number of basic modules in a storage module (5 t, 10 t, 15 t, 20 t or 25 t NEQ). Several storage modules together are defined as a *storage site*.
Internal safety refers to explosion safety precautions inside a storage site. *Intermodule Q-Ds* are defined to prevent sympathetic reactions of adjacent basic modules or storage modules. External safety is related to exterior exposed sites which are subdivided into military exposed sites inside a military compound and civil exposed sites. Military exposed sites are redefined, e.g. unprotected, semi-protected, and protected personnel.

In practice, situations may arise in which the standard minimum quantity-distances cannot be observed. Therefore, for some well-documented exposed sites, like unprotected people and people in buildings, the resulting consequences are assessed and presented in Hazard Diagrams. Although these hazard diagrams give no absolute figures, they have the objective of making field commanders aware of the increased level of risk when the standard Q-Ds cannot be observed.
The Hazard Diagrams include all (primary, secondary and tertiary) detonation effects in one graph and are drawn up with the TNO-PML computer program RISKANAL [7].

b) US approach

The U.S. established a Working Group of DDESB members. This working group was tasked to propose an update of Chapter 10 of the U.S. manual DoD6055.9-STD entitled "Theater of Operations". This resulted in the document US(ST)IWP/103-98 which is a draft version of Chapter 10.
The U.S. IWP is complete and detailed and written from the U.S. point of view and requirements. U.S. makes distinction between Field Storage and Handling Areas (large amounts of NEQ: > 500 kg) and BLAHAs (small amounts of NEQ: 5 up to 4000 kg). The corresponding Q-Ds are based approximately upon the same damage/injury criteria (low consequences).

It is proposed to replace the current Chapter IV of Part IV of AASTP-1 entitled "Q-Ds for BLAHAs" by the updated section on BLAHAs of Chapter 10 of the U.S. manual DoD6055.9-STD.

The draft Chapter 10 cites Risk Analysis as a tool to underpin waivers and exemptions to standard Q-D criteria. The steps of a risk analysis procedure are mentioned but not discussed in detail in this report. However, the developments of the risk-analysis concept of U.S. MoD is and will be extensively presented and discussed in the NATO AC/258 RAWG. Any proposed risk assessment technique needs to be simple enough for field commanders to understand.

c) GE approach

The GE MOD formulated a draft directive on field storage of ammunition during out-of-area missions for the German Forces. The directive includes preliminary protective and safety regulations for field storage of ammunition and explosives. Q-Ds are given for three categories of exposed sites within a field camp. These categories are more or less compatible with the categories as proposed by NL MOD, e.g. unprotected-, semi-protected-, and protected personnel. Q-Ds are given for NEQs ranging from 500 kg to 20,000 kg.

The German Ernst Mach Institute was tasked to develop field storage advice for waivers and exemptions to standard Q-D criteria. They came up with:

1. *Risk Score Diagrams* (give a qualitative description of risk).
2. *Hazard Diagrams* (lethality/injury as a function of stand-off distance and NEQ for people endangered by blast, projections and building collapse).
3. *Hazard Formula* (gives hazard potential and shows what parameters have an influence on the level of risk).
4. *Tolerable activities* (distance vs. acceptable activity for MCE of a detonation of 4,000 kg ammunition in a container enclosed by barricades).

4.2.2.5. Synthesis of IWPs

a) Twofold approach

During the first Field Storage Workshop [9] it was concluded that NATO advice in the form of standard Q-Ds only, based on peace time acceptance criteria, is not enough to cope with all peace keeping, peace enforcing and combat situations. Although standard Q-Ds are not easily observed in out-of-area conditions, they still form a good basis for explosives safety.

From this starting point, a twofold approach is suggested for implementation in Part IV of the NATO publication AASTP-1:

1. give advice in the form of standard Q-Ds;
2. give advice with the help of consequence analysis tools.

In the following sections both approaches are further defined using the information given in the considered IWPs of the NL-, US- and GE MOD. The proposed changes to AASTP-1 are presented in Annex A and Annex B of this report.

b) Standard Q-Ds for field storage

It is proposed to adopt the Modular Storage Concept by NL MOD. The NEQ per module is variable to cover differing field situations. However, it is strongly recommended to limit the NEQ of a module to 1000 kg. The proposed amendments to NATO manual AASTP-1 regarding HD1.2 items are included [10].

Besides this basic information, it is proposed to include the German example of acceptable activities in the case of field storage of 4,000 kg NEQ in the NATO advice [3]. This amount of NEQ is the exact turning point between both concepts.

c) Advice based on consequence-analysis tools

The Hazard Formula as proposed by the German Ernst Mach Institute can be an ideal tool for Field Commanders. With the Hazard Formula in- and outputs, a Field Commander can see if the risk of a specific established field storage is acceptable or not and what parameters affect this risk. In the first draft version of this report [11], some Hazard Diagrams of NL MOD were included to make Field Commanders

aware to what extent the risk increases when the advised minimum quantity-distances cannot be observed. In this second draft report these diagrams are reduced to one general 'risk' curve which is produced by the TNO-PML risk model RISKANAL [7].
The general Hazard Diagram in combination with the Hazard Formula should give a Field Commander enough basic information to make well considered decisions. For detailed information on risk assessment and -analysis methodologies the proposed guidelines refer to the upcoming NATO 'Risk manual' AASTP-4.

4.2.2.6. Conclusions

A dual approach for NATO advice has been proposed:

a) implementation of standard Q-Ds which are adapted for field storage conditions;
b) implementation of consequence-analysis tools to quantify and control risk when standard QDs can not be observed.

Ad 1. The modular storage concept of NL MOD is adopted in which the NEQ per module is variable. It is strongly recommended to limit the NEQ per basic module to 1,000 kg. However, a list with acceptable activities for basic modules with 4,000 kg NEQ (on the basis of GE IWP) is included.

Ad 2. Two types of information are proposed for implementation in AASTP-1:

a) presentation of the so-called Hazard Formula (proposal of GE). This qualitative tool shows a user what parameters have a major influence.
b) Presentation of a general Hazard Diagram which give information about the increase of risk (expressed as probability of lethality) when standard Q-Ds cannot be observed.

REFERENCES

[1] TNO-PML fax 98D2/1158F, dated 23 June 1998, with proposed topics for draft IWP on field storage of ammunition and explosives.

[2] AC/258 GE(ST)(EWG/FS)IWP/1-98, dated 2 March 1998.
"Draft" Directive on Field storage of ammunition during out-of-area missions for the German Armed Forces.

[3] AC/258 GE(ST)(EWG/FS)IWP/2-98, dated 3 March 1998.
Hazards arising with field storage of ammunition. Charts and Hazard Formula. Report E 20/97 by G. Gürke (Ernst Mach Institute).

[4] AC/258 GE(ST)(EWG/FS)IWP/3-98, dated 4 March 1998.
Field storage of ammunition. Risk score analysis and tolerable activities. Report W/98 by G. Gürke (Ernst Mach Institute).

[5] US(ST)IWP/103-98, dated 2 March 1998.
Draft Chapter 10 of U.S. DoD 6055.9-STD manual.

[6] AC/258-NL(ST)IWP/2-97, dated 4 February 1997.
Guidelines for field storage of ammunition and explosives.

[7] R.J.M. van Amelsfort
Risk calculations involved in storing explosives.
TNO-report PML 1992-123, dated November 1992.

[8] AASTP-1
Manual of NATO safety principles for the storage of military ammunition and explosives. May 1992.

[9] Decision sheet AC/258(ST)DS/59, dated 11 December 1997.

[10] UK(ST)IWP 312 (Revised) D/ESTC/6/3/2
Proposed amendments to NATO manual AASTP-1 for the inclusion of revised Hazard Division 1.2 Quantity Distance rules.

[11] AC/258-NL(ST)IWP/2-98
Proposed NATO advice for field storage of ammunition and explosives.
TNO draft report, July 1998.

[12] AC/258 DA(ST)(FSWG) IWP 1/98
Comments on the concept for field storage. 30 December 1998.

[13] AC/258-NL(ST)IWP/4-99, dated May 1999.
Proposed NATO advice for field storage of ammunition and explosives.
TNO report 1999-C20.

Section III-Definitions

4.2.3.1. *Definitions*

The following definitions are used in connection with field storage:

4.2.3.2. *Basic Module*

A Basic Module Consists of 5,000 kg NEQ of ammunition and explosives stored in any storage facility or open stack.

4.2.3.3. *Storage Module*

A Storage Module consists of from one to five Basic Modules.

4.2.3.4. *Storage Site*

A Storage Site consists of several Storage Modules.

4.2.3.5. *Intermodule Q-Ds*

Intermodule Q-Ds prevent Sympathetic reactions of adjacent Basic or Storage Modules.

Section IV-Guidelines for Field Storage

4.2.4.1. Standard Q-Ds

a) Site planning principles

The function of a proper layout of an ammunition and explosives storage site is dual:

1. Internal safety must be guaranteed. The basic modules should be positioned in such a way that the probability of a sympathetic reaction of adjacent modules is minimised. Barricades around modules should always be used, since they considerably reduce minimum intermodule quantity-distances necessary to prevent sympathetic detonations. Barricades function by stopping ammunition fragments and to protect the stored ammunition against external threats, like enemy fire.
   If barricades are not available, the corresponding larger minimum intermodule quantity-distance should be observed. If the prescribed minimum intermodule distances can not be observed, the net explosive quantity to calculate interior- and exterior quantity-distances is the sum of all net explosive quantities of the Potential Explosion Sites (PESs). As a result, interior- and exterior quantity-distances will be considerably larger. If these interior and exterior minimum quantity-distances can not be observed, the safety of the troops and civilians inside these distances is compromised (see section 2: Consequence-analysis tools).

2. External safety must be optimal. Complying with the advised minimum quantity-distances to military- and civil exposed sites results in an acceptable level of risk for military personnel and civilians. The exterior quantity-distances for military and civil exposed sites result in a layout of the total compound in which the most vulnerable Exposed Sites (ESs), like unprotected lodging or administrative accommodations, are positioned further away from the PES than less vulnerable exposed sites, for instance protective shelters.

b) General principles

1. The amount of ammunition and explosives in the field camp must be limited to the minimum consistent with safe and efficient operations. "No ammunition in the field camp that does not support the mission".
2. Store the main amount of ammunition and explosives in a field storage site separated from the field camp. Transfer only the minimum ammunition and explosives to the field camp.
3. Modular storage of ammunition and explosives is mandatory in the field camp to limit the MCE (Maximum Credible Event) to one basic module. Modular storage refers to a barricaded area comprised of a series of cells separated from each other by barricades.
4. The NEQ per module should be kept as low as practically possible, consistent with the mission and the available separation distances.

c) Mixing of HDs and CGs

The UN international system of hazard classification with definitions of hazard divisions and storage compatibility groups is effective. Normally, a storage module should contain ammunition of one hazard division only. When this is not possible, the following principles should apply:

1. When ammunition of HD1.2 and HD1.3 are stored together in the same storage module, the quantity-distances for each hazard division is assessed independently and the larger distance must be observed.

2. When ammunition of HD1.2 and/or HD1.3 is stored in the same module as ammunition of HD1.1, then the whole storage module must be regarded as HD1.1 with regard of quantity-distances.

Different compatibility groups should be stored in a separate storage module as well, except that:

1. Items of compatibility groups C, D and E may occupy the same storage module.
2. Items of compatibility group S may occupy the same module as any other items except those in compatibility group L.
3. Fuzes may be stored in the same module as the projectiles to which they belong.

The following types of ammunition must be stored in separated storage modules:

1. Ammunition in compatibility group B.
2. Ammunition in compatibility group F.
3. Ammunition in compatibility group G.
4. Ammunition in compatibility group H.
5. Ammunition in compatibility group K.
6. Ammunition in compatibility group L (within this group, different types of ammunition should be stored separately).

This indicates that in general several storage modules are necessary.

d) Storage conditioning

In order to keep the ammunition and explosives operational, the storage modules should give adequate protection against all weather conditions including lightning. A variety of equipment to achieve internal conditioning of the facility is available. The use of pallets to stack the ammunition and explosives is strongly advised to keep the stored goods free from the floor and thus dirt and mud and to obtain maximum air circulation and ventilation.

4.2.4.2 Q-Ds

a) Intermodule Quantity-Distances

Minimum intermodule quantity-distances for ammunition and explosives of HD1.1, HD1.2 and HD1.3 necessary to prevent adjacent modules sympathetically detonating are given in the following tables as a function of Hazard Division and Maximum Credible Event. These distances do not cover assets preservation.

The use of effective barricades is highly recommended, because they:

1. protect the ammunition from external threats, like enemy fire;
2. minimise explosion effects in case of an accidental explosion (barricades stop ammunition fragments);
3. prevent sympathetic detonation of adjacent modules.

As a result, the application of effective barricades around storage modules will reduce the required surface area for a storage site considerably. Effective barricade designs are described in Part II, Chapter III, Section III.
Instead of conventional earth embankments which have certain slopes and which are therefore space consuming, 'big bags' or concertainers can be used (e.g. Hesco Bastion Concertainers). These concertainers must be filled with a material (like sand) that stops ammunition fragments and that does not contribute to debris throw.

Figure 1.2.1.a Example of field barricades (ref. AC/258 DA(ST)IWP1-99).

In case of storage of HD1.2 and HD1.3 articles it is recommended that an effective roof constructions be applied. The roof will protect the stored ammunition for external threats and minimise explosion effects (like ammunition fragments, lobbed ammunition, heat radiation), especially during the first minutes after alarm when evacuation of personnel will take place. Proposed effective roof constructions for out-of-area circumstances are, for instance, earth covered plates of steel or concrete prefab slabs.

Table 1.2.1.a Minimum intermodule Q-Ds (in meters) for ammunition of HD1.1 stored in ISO containers or equivalent.

		Quantity-Distances for HD1.1						
		500 kg NEQ	1 ton NEQ	5 tons NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unbarricaded	$D= 4.8\ Q^{1/3}$	39	48	83	105	120	135	145
Barricaded	$D= 0.8\ Q^{1/3}$	7	8	14	18	20	22	24

Table 12.1.b Minimum intermodule Q-Ds (in meters) for ammunition of HD1.2(.1 and .2) stored in ISO containers or equivalent.

	Quantity-Distances for HD1.2						
	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unbarricaded	10	10	10	10	10	10	10
Barricaded	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Barricaded and protective roof	No QD	No QD	No QD	No QD	No QD	No QD	No QD

Table 1.2.1.c Minimum intermodule Q-Ds (in meters) for ammunition of HD1.3C stored in ISO containers or equivalent.

		Quantity-Distances for HD1.3C						
		500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unbarricaded	$D= 0.44\ Q^{1/2}$	10	14	32	44	56	64	70
Barricaded	$D= 0.22\ Q^{1/2}$	5	7	16	22	28	32	35
Barricaded and protective roof	-	No QD	No QD	No QD	No QD	No QD	No QD	No QD

Table 1.2.1.d Minimum intermodule Q-Ds (in meters) for ammunition of HD1.3G stored in ISO containers or equivalent.

	Quantity-Distances for HD1.3G						
	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unbarricaded	10	10	10	10	10	10	10
Barricaded	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Barricaded and protective roof	No QD	No QD	No QD	No QD	No QD	No QD	No QD

b) Exterior Quantity-Distances

Specific types of exposed sites as they appear in the theatre of operations are redefined and classified into their vulnerability to explosion effects. They are subdivided into military and civil ones (see table 1.2.2.a).

Table 1.2.2.a Definitions of exposed sites in the exterior military and civil zone.

Exposed site		Examples
	Unprotected personnel	Personnel in: the open, standard vehicles, tents, light structures, field hospitals, etc.
	Semi-protected personnel	Personnel in strengthened structures
	Protected personnel	Personnel in: protective shelter, armoured vehicles (like YPR-765), etc.
	Unprotected POL-installation	-
	Protected POL-installation	POL-installation with protective measures, e.g. Hesco Bastions <u>and</u> protective roof construction
	Unprotected civilians	People in: the open, houses, cars, etc.
	Chemical industry	-

"Semi-protected personnel" refers to personnel in strengthened structures. Examples are:

1. accommodations in which the normal glazing is replaced by air blast- and bullet resistant glazing;
2. accommodations which are equipped with bullet (SAA) resistant panels;
3. strengthened roof constructions (e.g. earth covered 20 ft flatracks).

"Protected personnel" refer to personnel in bunkers and armoured vehicles. This type of structures must be able to resist explosion effects like ammunition fragments and air blast with a peak incident overpressure of 21 kPa (corresponding with a protection level of 8.0 $Q^{1/3}$).

An example of a field protective shelter is shown in figure 1.2.2.a. Protection is given by walls of Hesco Bastion Concertainers and a protective roof which is made of small Hesco Bastion Concertainers filled with sand with on top of that a burster layer. Inside this heavy structure, a 20 ft iso-container is placed to offer personnel some comfort.

Figure 1.2.2.a Example of protective shelter.

Minimum exterior Q-Ds for ammunition and explosives of HD1.1, HD1.2(.1 and .2) and HD1.3 are given in the following tables.

Table 1.2.2.b Minimum exterior distances (in meters) from a PES with ammunition of HD1.1.

Exposed Site	Quantity-Distances for HD1.1							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	$D= 22.2\ Q^{1/3}$	180	225	380	480	550	610	650
Semi-protected personnel	$D= 14.8\ Q^{1/3}$	120	150	255	320	365	405	435
Protected personnel	$D= 8.0\ Q^{1/3}$	64	80	140	175	200	220	235
Unprotected POL-installation	$D= 22.2\ Q^{1/3}$	180	225	380	480	550	610	650
Protected POL-installation	$D= 1.2\ Q^{1/3}$	10	12	21	26	30	33	36
Unprotected civilian	$D= 22.2\ Q^{1/3}$	180	225	380	480	550	610	650
Chemical industry	$D= 22.2\ Q^{1/3}$	180	225	380	480	550	610	650

Table 1.2.2.c Minimum exterior distances (in meters)from an unbarricaded open stack or light structure (e.g. ISO container) PES with ammunition of HD1.2.1.

Exposed Site	Quantity-Distances for HD1.2.1							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	D2*	220	257	337	370	389	402	412
Semi-protected personnel	D6*	148	173	226	248	261	270	277
Protected personnel	N/A	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected POL-installation	D2*	220	257	337	370	389	402	412
Protected POL-installation	N/A	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected civilian	D2*	220	257	337	370	389	402	412
Chemical industry	D2*	220	257	337	370	389	402	412

* Ref. [10].

Table 1.2.2.d Minimum exterior distances (in meters) from an unbarricaded open stack or light structure (e.g. ISO container) PES with ammunition of HD1.2.2.

Exposed Site	Quantity-Distances for HD1.2.2							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	D1*	75	88	123	141	152	160	166
Semi-protected personnel	D5*	60	60	83	95	103	108	112
Protected personnel	N/A	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected POL-installation	D1*	75	88	123	141	152	160	166
Protected POL-installation	N/A	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected civilian	D1*	75	88	123	141	152	160	166
Chemical industry	D1*	75	88	123	141	152	160	166

* Ref. [10].

Table 1.2.2.e Minimum exterior distances (in meters) from the side- and rear walls of earth covered PES with ammunition of HD1.2(.1 and .2).

Exposed Site	Quantity-Distances for HD1.2(.1 and .2)							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	IBD*	60	60	60	60	60	60	60
Semi-protected personnel	PTRD*	60	60	60	60	60	60	60
Protected personnel	EWD*	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected POL-installation	IBD*	60	60	60	60	60	60	60
Protected POL-installation	N/A	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected civilian	IBD*	60	60	60	60	60	60	60
Chemical industry	IBD*	60	60	60	60	60	60	60

* Ref. [10].

Table 1.2.2.f Minimum exterior distances (in meters) from a PES with ammunition of HD1.3C.

Exposed Site	Quantity-Distances for HD1.3C							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	$D= 6.4\ Q^{1/3}$	51	64	110	140	160	175	190
Semi-protected personnel	$D= 4.3\ Q^{1/3}$	35	43	73	92	110	120	125
Protected personnel	$D= 3.2\ Q^{1/3}$	26	32	55	68	80	87	94
Unprotected POL-installation	$D= 6.4\ Q^{1/3}$	51	64	110	140	160	175	190
Protected POL-installation	$D= 3.2\ Q^{1/3}$	26	32	55	68	80	87	94
Unprotected civilian	$D= 6.4\ Q^{1/3}$	51	64	110	140	160	175	190
Chemical industry	$D= 6.4\ Q^{1/3}$	51	64	110	140	160	175	190

Table 1.2.2.g Minimum exterior distances (in meters) from a PES with ammunition of HD1.3G.

Exposed Site	Quantity-Distances for HD1.3G							
	Protection level	500 kg NEQ	1 ton NEQ	5 ton NEQ	10 ton NEQ	15 ton NEQ	20 ton NEQ	25 ton NEQ
Unprotected personnel	N/A*	51	64	110	140	160	175	190
Semi-protected personnel	N/A*	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Protected personnel	N/A*	No QD	No QD	No QD	No QD	No QD	No QD	No QD
Unprotected POL-installation	$D = 6.4\ Q^{1/3}$	51	64	110	140	160	175	190
Protected POL-installation	$D = 3.2\ Q^{1/3}$	26	32	55	68	80	87	94
Unprotected civilian	$D = 6.4\ Q^{1/3}$	51	64	110	140	160	175	190
Chemical industry	$D = 6.4\ Q^{1/3}$	51	64	110	140	160	175	190

*It is here assumed that there are opportunities to evacuate personnel after alarm.

4.2.4.3 Acceptable activities for 4,000 kg NEQ HD1.1

The statements in Table 1.3a apply under the precondition that by means of protective measures it has been ensured that in the worst case a NEQ of 4,000 kg of HD1.1 may detonate at once in an ammunition container. It is assumed that temporary structural protective measures, barricades or other barriers exist at the PES. The exposed sites must be protected by protective roofs especially against fragments and projections. The distances in Table 1.3a are laid down in such a way that the direct and indirect consequences of an occurrence of damage will not lead to a catastrophe.

Table 1.3.a Tolerable activities in case there is a small probability of an accidental explosion of 4,000 kg NEQ of HD1.1.

Minimum range (m)	Tolerable activities	Risk level and expected consequences in case of an explosion
350	a) Built-up area	b) Minor risk c) Projections and breaking glass
250	d) Billets if structural protection is available e) Scattered buildings f) Public roads	g) Medium risk h) Injuries caused by projections, collapse and breaking glass
150	i) Billets if structural protection against projections, breaking glass, and collapse is available j) Unprotected personnel in the open: 50 maximum, temporarily k) Public roads: low density	l) Significant risk m) Injuries caused by fragments and projections n) Fatalities
100	o) Personnel in the open with individual protective equipment: 20 maximum, for a short time p) Continuous parking of armoured vehicles, temporary parking of vehicles q) Storage of materiel r) Maintenance work if structural protection is available	s) Significant risk t) Injuries caused by fragments and projections u) Fatalities
50	v) Guard personnel: 10 maximum, continuously w) Structural protection against projections and collapse x) Parking of armoured vehicles for a short time	y) Significant risk z) Injuries caused by blast, fragments and projections aa) Fatalities
< 50	bb) Ammunition handling: 2 to 6 persons and vehicles for a short time	cc) Significant risk dd) Fatalities

4.2.4.4. Consequence-analysis tools

a) Hazard Diagrams

In practise, situations may arise in which the standard minimum quantity-distances can not be observed. For some well-documented exposed sites, like unprotected humans and humans in buildings, the resulting consequences are known. Figure 2.1.a shows a general hazard diagram in which the increase in risk as a function of the actual distance between PES and ES is presented. The example curve represents the risk for personnel in the open subjected to explosion effects of HD1.1 articles with a NEQ of about 5 tons.

The (upcoming) NATO publication AASTP-4 (Risk Manual) includes detailed information on risk assessment and –analysis methodologies and tools. In the absence of AASTP-4, a useful methodology is described in the following section.

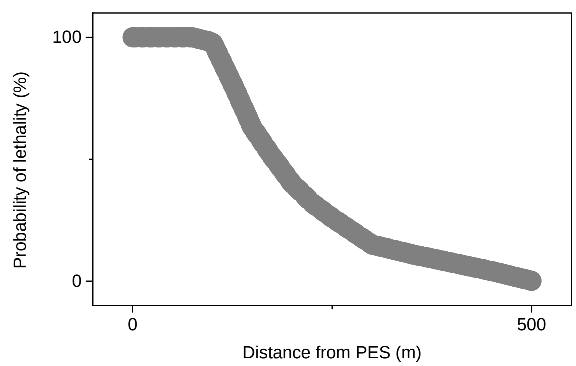


Figure 2.1.a The increase of risk when advised minimum quantity-distances can not be met [7].

b) Hazard Formula

In the following the concept of the hazard formula is shown by means of an example. It uses quantities, which on the one hand are closely related to the hazardousness of an accidental detonation and on the other hand can be analysed with a relatively high degree of exactness. The proposed procedure leads to a clear result: It thus enables the responsible officer to take his stand against risky storage situations.

The scenario: an ammunition container containing a load quantity with an NEQ of 4,000 kilograms is to be stored. The numerical data regarding the hazard potential and the reduction factors are to be taken as examples. Should the proposed approach be taken into consideration, it will be the responsibility of ammunition safety experts to determine the parameters of the hazard formula.

The hazard formula: For the "hazard G" for persons staying in the environment of a field storage site, a "hazard potential P" is determined. The "reduction factors F" reduce the hazard potential.

G = P / (F1ςF2ςF3...)

The hazard formula is structured in such a way that for a positive decision a value G equal to or smaller than 1 is required.

The hazard potential: In order to obtain numerical values for the hazard potential P of an ammunition container it is proposed that the hazard divisions and the compatibility groups available for all types of ammunition be used. In accordance with the six hazard divisions, an exponential rise of hazard potential P is allocated to the ammunition container. That means:

Hazard Division 1.6	Hazard Potential P = 2
Hazard Division 1.5	Hazard Potential P = 4
Hazard Division 1.4	Hazard Potential P = 8
Hazard Division 1.3	Hazard Potential P = 16
Hazard Division 1.2	Hazard Potential P = 32
Hazard Division 1.1	Hazard Potential P = 64

The reduction factors: In order to reduce the hazard G to the value 1 or smaller, reduction factors F are used. For that purpose physical and organizational reduction factors are taken into consideration.

Physical reduction factors F_m:
As examples for physical reduction factors F_m for the ammunition container with NEQ = 4000 kilograms the following factors are suggested:

- Barricade in due form: $F_{m1} = 4$
- Simple barrier: $F_{m2} = 2$
- Making use of the terrain (under certain circumstances): $F_{m3} = 2$ through 4
- Explosive quantity distance 500 m: $F_{m4} = 16$
- Explosive quantity distance 350 m: $F_{m5} = 8$;
- Explosive quantity distance 250 m: $F_{m6} = 4$
- Explosive quantity distance 150 m: $F_{m7} = 2$;
- Reduction of load quantity by 50 %: $F_{m8} = 2$
- Demonstrated measures to avoid detonation transmission: $F_{m9} = 2$ through 16.

Organizational reduction factors F_o:
Hazard G can also be reduced by organizational measures. Periods in the endangered area can be limited in regard to number of people present as well as to location and time. Examples:

1. The distance range R < 150 meters must be crossed. By means of organizational measures it is ensured that only one vehicle at a time stays in the area for a few seconds. $F_{o1} = 2$.
2. In the distance range R = 150 meters to R = 250 meters unprotected people stay for no longer than a few hours for physical exercises. $F_{o2} = 4$.
3. The rooms of a building on the side facing the storage site are not occupied. $F_{o3} = 2$.

Under certain conditions a strict guard, an alarm system, or video monitoring may contribute to reduce the hazard.

There may be cases in which the decision must be made that only one or two of the organizational reduction factors may be used.

Renunciation: Application of the hazard formula may mean renunciation. If it is impossible to achieve risk value 1 by means of physical and organizational measures there remains the possibility to reduce the quantity of ammunition stored or to do without certain ammunition types.

Step-by-step approach: The procedure is completed by a step-by-step approach:

1. **Operational planning:** Storage of ammunition and explosives should be taken into consideration when planning out-of-area missions. That planning is done at home by means of ammunition catalogs, plane-table sheets, layout plan and so on. The result of the operational planning is a hazard potential P and references to potential reduction factors. Operational planning has to come to the result that it is possible to obtain the value G = 1 by means of the hazard formula.

2. **Local planning:** At the operational location the first task will be to define the reduction factors F. Can the reduction factors proposed within the scope of operational planning be implemented? Local planning directs the measures which enable achievement of the value G = 1 by means of the hazard formula.

3. **Measures taken on-site:** The last decision level concerns the current situation on-site which may constantly change during out-of-area missions. Does the hazard potential ascertained during operational planning and local planning still apply? Are the reduction factors still valid? How much ammunition has been added or taken away? Which changes have occurred in the environment? Is equipment and materiel available by now to erect a larger barricade? Have there been terrorist attacks? Has the situation changed in regard to sabotage? On site the measures have to be taken which make it possible to obtain the value G = 1 by means of the hazard formula.

Example: An ammunition container holds Q = 4000 kilograms of engineer demolitions of Hazard Division 1.1. According to operational planning it has a hazard potential with the value P = 64. At the operational location a minimum explosive quantity distance of R = 350 meters can be observed - corresponding to reduction factor $F_{m5} = 8$. A barrier in due form reduces the hazard potential by a reduction factor $F_{m1} = 4$. In order to achieve the hazard value G = 1, an organisational measure must be taken. The rooms of the barracks facing the storage site must not be occupied: $F_{o3} = 2$. The hazard formula leads to the result:

$$G = P / (F_{m5} \varsigma F_{m1} \varsigma F_{o3}) = 64 / (8 \varsigma 4 \varsigma 2) = 1.$$

With the value G = 1 relative safety is achieved. In the case of an accident serious injuries and especially fatalities should be avoided. A commander who gets the value G = 1 or lower three times - in other words: who has come to a positive decision three times, may assume that he has done all that is humanly possible. The remaining risk will be justifiable.

Section V - Fire-Fighting

4.2.5.1. *General*

Fire-fighting principles and procedures are the same as those given for permanent depots in Part I, Chapter 7 and Part II, Chapter 4 respectively. However, ammunition in field storage is more vulnerable to fire than when in permanent depots, therefore more importance should be placed on fire precautions and fire-fighting in field storage.

4.2.5.2. *Symbols*

Fire-fighting symbols must be displayed at each Field Storage Site. Symbols are fixed to posts, clear of the ammunition and placed where they are easily seen by anyone approaching the site. To take into account the need for camouflage as the situation may require, the colour of the fire symbols should be left to the discretion of the National Authorities.

CHAPTER 3 - QUANTITY-DISTANCE PRINCIPLES FOR MISSILE INSTALLATIONS

4.3.0.1. *General*

The quantity-distance principles missile installations are essentially the same as those given in Part I, Chapter 4 for aboveground storage of ammunition. These distances do not cater for the inadvertent release of a missile. Each missile installation is treated as a PES requiring Interior and Exterior Quantity-Distances as given in Part I, Annex A, Section II. Judgement should be used to associate the missile installation with an appropriate pictograph for a PES taking account of the particular design. Reference to Part III, Chapter 2 may also be necessary. Interior Quantity-Distances required for system-determined technical and/or operational reasons are not taken into consideration in this chapter. They are part of the weapons system regulations.

4.3.0.2. *Potential Explosion Sites*

a) Launching platforms, warheading buildings, ready-round storage areas and other facilities where the missile with warhead is serviced or stored are considered to be PES containing ammunition of Hazard Division 1.1.

b) The "Definitive Drawings" for a missile installation should include the separation distances necessary to prevent propagation of explosion. Where operational requirements for the missile system necessitate smaller distances, the PES are aggregated and considered to be one PES as regards Exterior Quantity-Distances.

4.3.0.3. *Exposed Sites*

a) Military sites such as operation centres, readiness structures, radar and communication installations, fuel stations, parking areas and guard shelters may be considered to be ES which are protected by appropriate Interior Quantity-Distances. These ES may be inside the missile installation under consideration or inside another military installation.

b) The "Definitive Drawings" for a missile installation are based on operational requirements which may override the Interior Quantity-Distances and which must be taken into account by additional infrastructure measures (site safety plans).

c) An Exposed Site outside a missile installation, not being inside another military installation, must be protected by the Exterior Quantity-Distances given in Part I.

4.3.0.4. *Measuring of Quantity-Distances*

Quantity-Distances at launcher platforms are measured from the extremities of the missile(s) when in normal position on the platform. As regards assembly buildings and storage sites at a missile installation the normal procedure in Part I, paragraph 1.3.2.3. applies.

4.3.0.5. *Net Explosives Quantity*

The normal procedure for computing the NEQ applies, see Part I, subparagraphs 1.3.2.3.a) and 1.3.2.3.b). Information, which may be classified, on the effective NEQ of a particular type of missile should be obtained from the design authority. Otherwise the actual NEQ must be calculated in accordance with the definition as follows: The NEQ is the total explosives content of ammunition unless it has been determined that the effective quantity is significantly different from the actual quantity. It does not include such substances as white phosphorus, war gases or smoke and incendiary compositions unless these substances contribute significantly to the dominant hazard of the hazard division concerned.

CHAPTER 4

reserved

(Formerly "Quantity-Distance Principles For
Basic Load Ammunition Holding Areas". This Chapter has been moved to AASTP-5.)

CHAPTER 5 - QUANTITY-DISTANCE PRINCIPLES FOR AIRFIELDS USED ONLY BY MILITARY AIRCRAFT

4.5.0.1. *General*

a) This chapter recommends principles and safety requirements for airfields used only by military aircraft.

b) Air forces generally operate in war from the same locations that they occupy in peacetime. It may therefore be necessary to store or hold weapons and ammunition as close to the aircraft as possible without exposing personnel or facilities to unacceptable risk from an accidental explosion or the detonation of weapons or ammunition as a result of enemy action in war. The following advice is intended to provide the minimum levels of protection deemed necessary.

c) The quantity-distances specified in this chapter apply essentially to PES which exist in peacetime. It follows that Hardened Aircraft Shelters (HAS) which contain armed aircraft and/or stocks of ammunition in peacetime should be treated as PES. Commanders will need to decide the quantity-distances to be applied to sites which only become PES in emergencies or wartime and such distances will need to be catered for in the airfields' peacetime layout. In reaching his decision the Commander should bear in mind that a reduction in recommended quantity-distances to non-operationally essential facilities may result, in the event of an explosion at the PES in increased damage and casualties, whilst a similar reduction to operationally essential facilities could result in the facility ceasing to function and the prejudicing of operational plans.

d) Operational Commanders are advised that the more essential military resources may require additional protection.

4.5.0.2. *Aircraft Parking - Designated Areas*

a) Aircraft carrying explosives must be armed, loaded, unloaded or parked in a Designated Area. Where possible such a Designated Area should be separated from other such areas and from ES by the quantity-distances given in paragraph 4.5.0.4.

b) A loading, unloading or parking area specifically designated for continual use presents a recurring hazard as opposed to an occasional one and should be formally authorised for the purpose.

c) Exception

This requirement does not apply to aircraft containing only installed explosives and safety devices such as authorised signals in survival kits, egress systems components, engine starter cartridges, fire extinguisher cartridges and other such items necessary to flight operations.

4.5.0.3. *Aircraft Parking - Principles for Selecting Designated Areas*

a) The following principles should be followed in selecting Designated Areas:

1. The safest possible area compatible with quantity-distances prescribed in this chapter and operational requirements must be used.

2. The loading, unloading or parking area must be located outside runway clear zones. Aircraft arm/disarm pads are exempted from the restriction[1]

3. Whenever possible, the quantity-distances recommended in paragraph 4.5.0.4. should be observed between adjacent loaded aircraft which are in the open. Where this is not possible consideration should be given to grouping several aircraft together and separating the groups by greater distances than can be provided between individual aircraft. If an explosion should occur, aircraft in adjacent groups may be damaged by fragments; however, the explosion is unlikely to propagate simultaneously. Subsequent explosions may be caused by fragments, debris or secondary fires.

[1] In general, the applicable runway clearance is the 150 m lateral safety zone each side from the runway centreline. Further details are given in the 6th or latest Edition of NATO Airfield Criteria.

4. Ideally, aircraft should face the direction involving least exposure of personnel, equipment and facilities to the line of fire of forward-firing armament. For practical purposes, aircraft should be pointed so that no centre of population exists for 3 000 m within 5° on either side of the line of fire unless this is intercepted by a suitable barricade.

b) Exceptions

Aircraft carrying their operational loads of gun ammunition, practice bombs and small rockets (e.g. 2.75" HE rockets or others with equivalent characteristics) do not require the quantity-distances specified in paragraph 4.5.0.4.

4.5.0.4. *Quantity-Distances*

a) The following quantity-distances, which assume Hazard Division 1.1 loads, may be used for all hazard divisions. Where Part I of the Manual permits, lesser distances may be used for hazard divisions other than Hazard Division 1.1.

b) Quantity-Distances between Aircraft Loaded with Explosives

1. Unbarricaded individual aircraft, or groups of aircraft at Designated Areas, loaded with explosives should be separated from one another by AD13-distances (12.0 $Q^{1/3}$) unless space limitations or operational considerations dictate otherwise. At this distance, adjacent unsheltered aircraft may sustain damage due to fragments but should, in most cases, remain operable. Where nearly complete protection against fragments is deemed necessary, a distance of 270 m between aircraft should be provided. Individual or groups of aircraft should be separated by AD10-distances (7.2 $Q^{1/3}$) to protect against propagation of detonation. If the aircraft carry ammunition of comparable resistance to propagation as robust shells, AD9-distances (4.4 $Q^{1/3}$) may be used to protect against simultaneous detonation. Lesser distances may be used for specific weapons where trials have shown that such distances are adequate to minimize the probability of propagation.

2. Barricades between adjacent aircraft will prevent simultaneous propagation due to high velocity, low angle fragments. It should be noted, however, that a barricade does not necessarily prevent subsequent propagation or damage caused by blast, lobbed items, debris or secondary fires.

c) Exterior Quantity-Distances from Designated Areas

Where possible, the appropriate Exterior Quantity-Distances in Part I should apply between parked aircraft loaded with explosives at Designated Areas and ES not related to the servicing and support of those aircraft. Safety is enhanced by towing aircraft, after loading, to a safer area rather than close to other aircraft being loaded or unloaded.

d) Quantity-Distances between HAS and Associated Storage Facilities

1. HAS[2] and associated storage facilities spaced according to Table 5-II will prevent propagation between such facilities. An explosion in one shelter or ready storage facility may destroy it and its contents, but aircraft within adjacent shelters will be undamaged, provided the doors are closed. Those aircraft may not be immediately removable due to debris.

2. HAS and associated storage facilities spaced according to Table 5-III may be damaged; however, there will be a high degree of protection against propagation. These distances should be used only in wartime or during periods of increased operational readiness.

3. Areas of hazard to front, side or rear of HAS or igloos as PES or ES lie in the arcs shown in Figure 5-I. A particular face of an ES is deemed to be threatened by a PES face when both these faces lie within the arc of threat or hazard of the other. In those cases where an ES lies on the line separating rear/side etc. of a PES, the appropriate larger quantity-distance should be observed.

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[2] The tables in this chapter do not apply to Norwegian designs of third generation HAS for which tables will be published in due course.

e) Quantity-Distances to Runways and Taxiways

If the transient risk to military aircraft movements is accepted, it is recommended that the separation of the PES from runways and taxiways which are considered to be operationally essential should ideally be such as to prevent the runways or taxiways being rendered unoperational by ground shock as a result of an explosion in the PES. The use of a distance equivalent to about three times the crater radius is recommended. In normal soil AD4-distances (1.8 $Q^{1/3}$) should be used; in saturated soils or clay greater distances may be advisable because of the increased crater radius. If the transient risk is not accepted, AD13-distances (12.0 $Q^{1/3}$) should be used to provide protection to the aircraft.

f) Quantity-Distances to Explosives Workshops

Explosives workshops should be separated from other PES by AD11-distances (8.0 $Q^{1/3}$). Suitably hardened explosives workshops may be sited at reduced distances.

g) Quantity-Distances to Facilities and Activities in Both Direct and Indirect Support of Flightline and Aircraft Servicing

Use AD10-distances (7.2Q $^{1/3}$) for separation of any PES where explosives are present on a long-term basis from squadron operations buildings, flightline maintenance functions, flightline fire and rescue stations, and other activities in direct support of flightline and aircraft servicing (e.g. alert crew, POL and LOX facilities) unless the facilities are hardened to NATO criteria, when reduced distances may be used. At this distance, damage to unstrengthened buildings may be of a serious nature with resulting casualties. Where greater protection is required, AD12-Distances (9.6 $Q^{1/3}$) should be used, except where subparagraph 4.5.0.4.k) permits smaller distances. Use AD14-distances (16.0 $Q^{1/3}$) for similar unhardened facilities in indirect support of flightline operations, with reductions for facilities hardened to NATO criteria. In transition to war (TTW) and war, all facilities may be considered to be directly supporting and the lesser distances used.

h) Quantity-Distances for Emergency Power Supply Shelter and POL Shelter for the Support of Hardened Aircraft Shelters

If the quantity-distances prescribed in subparagraph 4.5.0.4.g) cannot be maintained, lesser quantity-distances are permissible for the construction of Emergency Power Supply Shelter and POL Shelter for the support of a nearby HAS under the following conditions:

1. Power Supply and POL Shelters must be hardened
   - Wall and roof thickness : at least 65 cm reinforced concrete
   - Gate thickness : at least 30 mm steel plate

2. The POL tank for this structure must be buried (minimum earth-cover 1 m).

3. The following quantity-distances to PES have to be maintained (see Figure -II):

   - Minimum distance between the walls and PES : AD5-distances
   - Minimum distance between the gates and PES : AD9-distances, at least 25 m
   - At least 25 m for the buried POL tank.

i) Quantity-Distances to Military Aircraft not Loaded with Explosives

Use AD13-distances (12.0 $Q^{1/3}$) for separation of PES from military aircraft in exposed parking (tankers, transports), but damage may be sustained due to fragments (see sub-subparagraph 4.5.0.4.b).1.). Where operational requirements outweigh consideration of asset preservation, distances may be reduced to that dictated by operational necessity but minimum distances corresponding to the distance function 9.6 $Q^{1/3}$ for embarking/disembarking military personnel for transport and distances corresponding to the distance function 7.2 $Q^{1/3}$ for tanker aircraft should be considered.

j) Quantity-Distances to Open Stacks of Ammunition

Open storage of ammunition, barricaded effectively, is permitted at not less than AD13-distances (12.0 $Q^{1/3}$) from parked aircraft outside shelters.

k) Quantity-Distances to General Public and Central Airfield Administrative Support Facilities

1. Use AD16-distances (14.0 $Q^{1/3}$) from the rear and AD17-distances (18.0 $Q^{1/3}$) from the sides and front of ready service igloos containing up to 10 000 kg NEQ at loading density of up to 20 kg/m^3. Apply a minimum distance of 270 m to central airfield administrative support facilities and low density public traffic routes.

2. When the PES is a US third-generation or similar hardened aircraft shelter containing up to 5 000 kg NEQ, the AD18-distances (20.0 $Q^{1/3}$) from the front, the AD19-distances (25.0 $Q^{1/3}$) from the side and AD14-distances (16.0 $Q^{1/3}$) from the rear may be used to protect an unhardened ES against debris and blast. With NEQ of 50 kg or less in a HAS, a minimum distance of 80 m to the front of the HAS and nil to the side and rear need only to be applied.

3. Use AD15-distances (22.2 $Q^{1/3}$) for other PES where explosives are present on a long-term basis, and apply minimum distances of 270 or 400 m depending on the nature of the PES (open vs igloo) and the ES (density of population).

4. Where ES have been hardened, lesser distances may be used depending on the degree of hardening provided.

4.5.0.5. *Operational Considerations*

a) When operational requirements necessitate the use of Table 5-III or distances less than those prescribed above, particularly in the case of explosives of Hazard Division 1.1, the operational Commander should be advised of any potentially serious risks in accordance with Part I, Chapter 3, Section VII, so that measures can be taken to eliminate or at least reduce the consequences.

b) The aim should be to maintain the maximum practicable separation between unbarricaded aircraft loaded with explosives of Hazard Division 1.1. The use of distances less than 270 m involves a progressively increasing risk of propagation by blast, flame, radiant heat and projections.

c) Safety is enhanced by towing aircraft, after loading, to aircraft being loaded or unloaded.

Figure 5-I

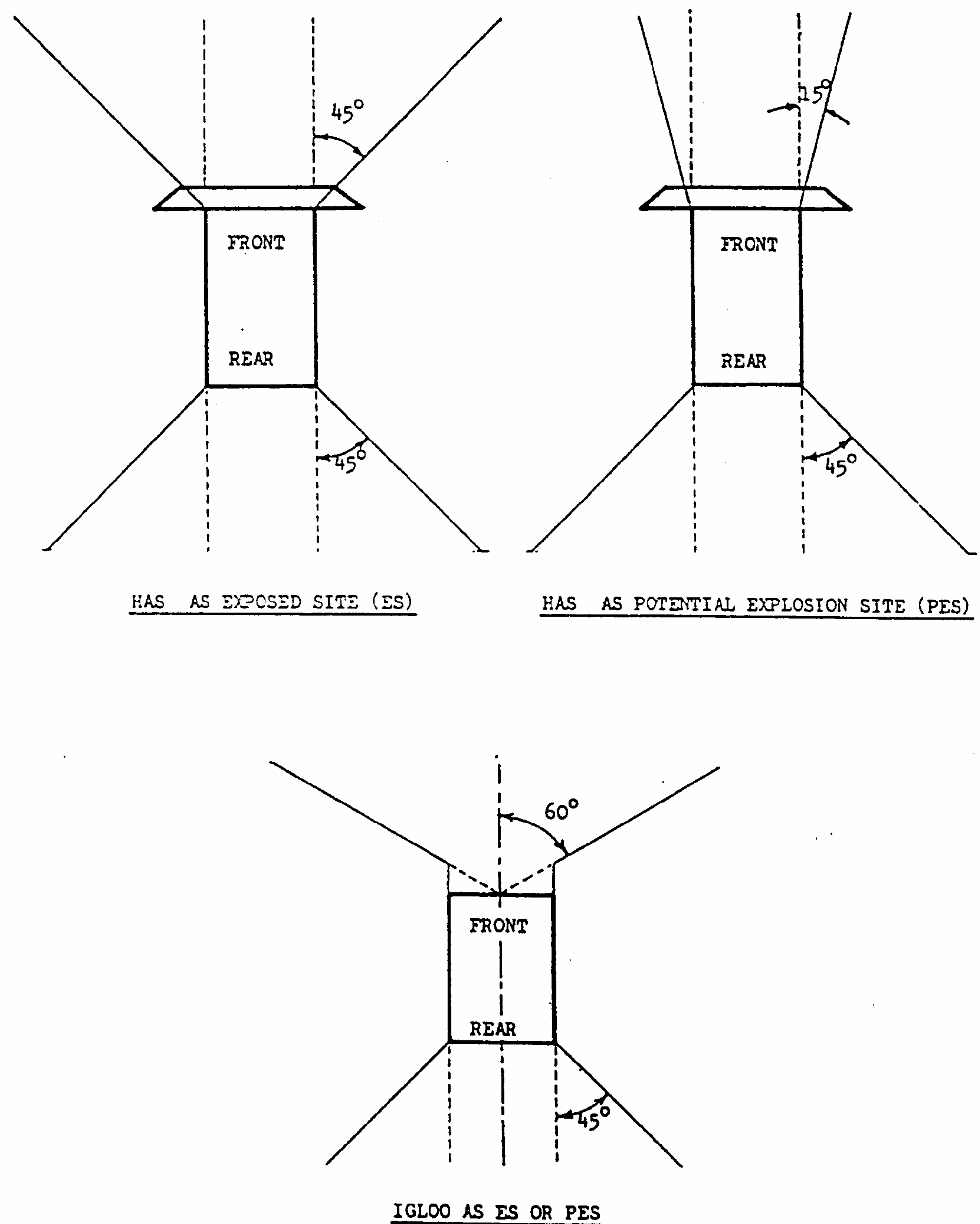
45°
FRONT
REAR
45°
HAS AS EXPOSED SITE (ES)
15°
FRONT
REAR
45°
HAS AS POTENTIAL EXPLOSION SITE (PES)
60°
FRONT
REAR
45°
IGLOO AS ES OR PES

FIGURE 5-II

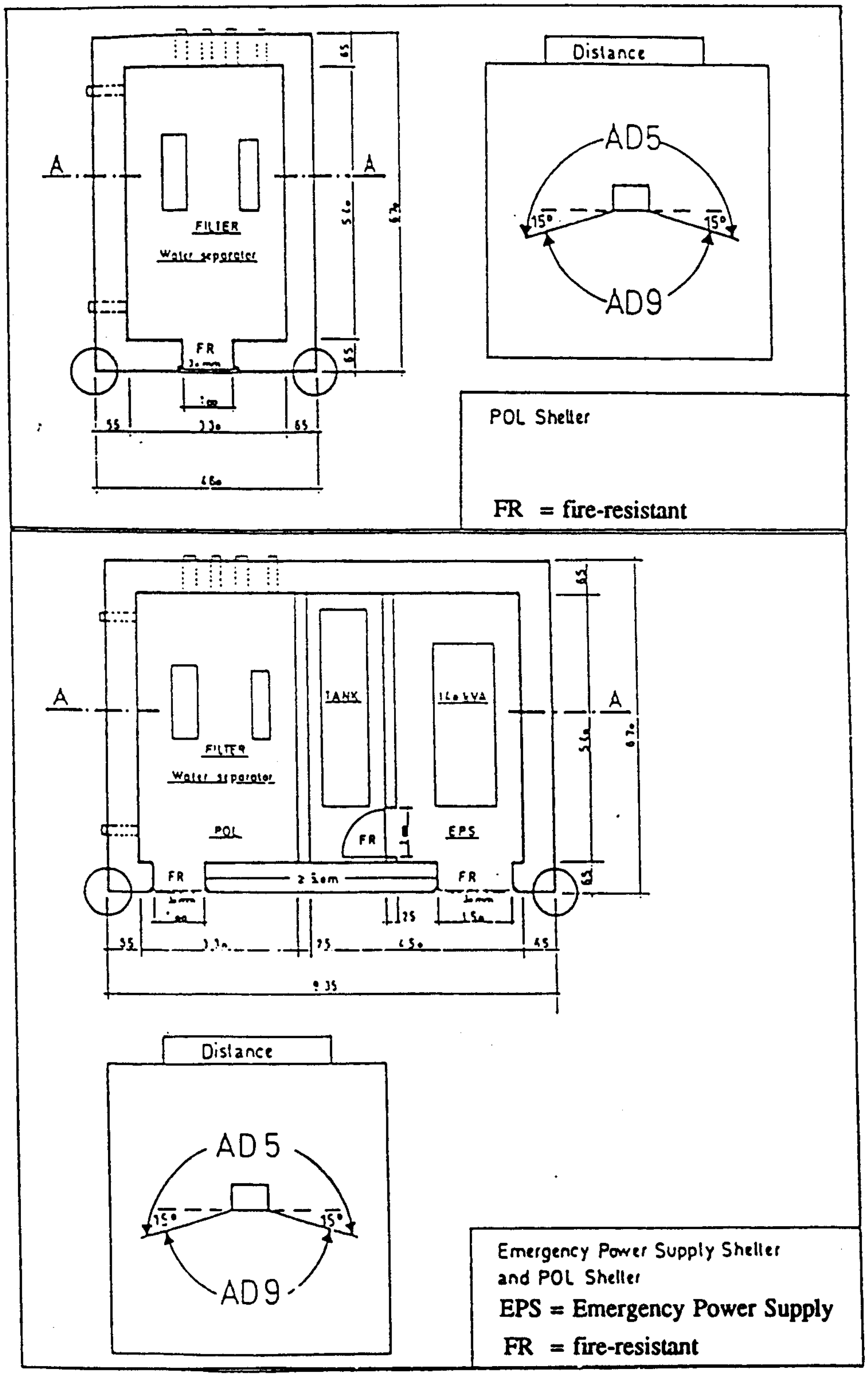
A
A
FILTER
Water separator
FR
Distance
AD5
15°
15°
AD9
POL Shelter
FR = fire-resistant
A
A
TANK
FILTER
Water separator
POL
FR
EPS
FR
FR
Distance
AD 5
15°
15°
AD 9
Emergency Power Supply Shelter
and POL Shelter
EPS = Emergency Power Supply
FR = fire-resistant

TABLE 5-I (PAGE 1)

Q-D TABLE FOR AIRFIELDS HAZARD DIVISION 1.1

NEQ Q kg	Quantity-Distances m									
	AD1	AD2	AD3	AD4	AD5	AD6	AD7	AD8	AD9	AD10
500	4	6	9	15	16	20	25	29	35	58
600	5	7	10	16	17	21	27	31	38	61
700	5	7	10	16	18	22	28	32	40	64
800	5	7	11	17	19	23	30	34	41	67
900	5	8	11	18	19	24	31	35	43	70
1 000	5	8	11	18	20	24	32	36	44	72
1 200	6	9	12	20	21	26	34	39	47	77
1 400	6	9	13	21	22	27	36	41	50	81
1 600	6	9	13	22	23	29	37	43	52	85
1 800	7	10	14	22	24	30	39	44	54	88
2 000	7	10	14	23	25	31	40	46	56	91
2 200	7	10	14	24	26	31	42	47	57	94
2 500	7	11	15	25	27	33	43	49	60	98
3 000	8	12	16	26	29	35	46	52	64	105
3 500	8	12	17	28	30	37	49	55	67	110
4 000	8	13	18	29	32	39	51	58	70	115
4 400	8	13	18	30	33	39	52	59	72	120
5 000	9	14	19	31	34	42	55	62	76	125
6 000	10	15	20	33	36	44	58	66	80	135
7 000	10	15	22	35	38	46	61	69	85	140
8 000	10	16	22	36	40	48	64	72	88	145
8 800	10	17	23	37	41	50	66	74	91	150
9 000	11	17	23	38	42	50	67	75	92	150
10 000	11	17	24	39	43	52	69	78	95	160
Distance Functions	AD1 = 0.5 $Q^{1/3}$	AD2 = 0.8 $Q^{1/3}$	AD3 = 1.1 $Q^{1/3}$	AD4 = 1.8 $Q^{1/3}$	AD5 = 2.0 $Q^{1/3}$	AD6 = 2.4 $Q^{1/3}$	AD7 = 3.2 $Q^{1/3}$	AD8 = 3.6 $Q^{1/3}$	AD9 = 4.4 $Q^{1/3}$	AD10 = 7.2 $Q^{1/3}$

TABLE 5-I (PAGE 2)

Q-D TABLE FOR AIRFIELDS HAZARD DIVISION 1.1

NEQ Q kg	Quantity-Distances m								
	AD 11	AD1 2	AD1 3	AD1 4	AD1 5	AD15 a)	AD17 a)	AD18 a)	AD19 a)
500	64	77	95	130	270	270	270	160	200
600	68	81	100	135	|	|	|	170	215
700	72	86	105	145	|	|	|	180	225
800	75	90	110	150	|	|	|	190	235
900	78	93	115	155	|	|	|	195	245
1 000	80	96	120	160	|	|	|	200	250
1 200	86	105	130	175	|	|	|	215	270
1 400	90	110	135	180	|	|	|	225	280
1 600	94	115	140	190	|	|	|	235	295
1 800	99	120	145	195	|	|	|	245	305
2 000	105	125	150	205	|	|	|	255	315
2 200	105	125	155	210	270	|	|	265	330
2 500	110	135	165	220	275	|	|	275	340
3 000	120	140	175	235	305	|	270	290	365
3 500	125	150	180	245	330	|	275	305	380
4 000	130	155	190	255	350	|	290	320	400
4 400	135	160	200	260	365	|	295	330	410
5 000	140	165	205	275	380	|	310	345	430
6 000	150	175	220	295	405	|	330	--------	---------
7 000	155	185	230	310	425	270	345		
8 000	160	195	240	320	445	280	360		
8 800	170	200	250	330	460	290	375		
9 000	170	200	250	335	465	295	380		
10 000	175	210	260	345	480	305	390		
Distance Functions	AD11 = 8.0 $Q^{1/3}$	AD12 = 9.6 $Q^{1/3}$	AD13 = 12.0 $Q^{1/3}$	AD14 = 16.0 $Q^{1/3}$	*) **)	AD16 = 14.0 $Q^{1/3}$	AD17 = 18.0 $Q^{1/3}$	AD18 = 20.0 $Q^{1/3}$	AD19 = 25.0 $Q^{1/3}$

*) AD15 = 5.5 $Q^{1/2}$ for Q < 4 500 kg

**) AD15 = 22.2 $Q^{1/3}$ for Q   4 500 kg

NOTE: a) see subparagraph 4.5.0.4.k)

TABLE 5-II (PAGE 1)

ASSET PRESERVATION

FROM (PES) / TO (ES)		1st Generation Aircraft Shelter [a)]			2nd and 3rd Generation Aircraft Shelter [a)]		
		Side	Rear	Front	Side	Rear	Front
1st Generation Aircraft Shelter	Side	AD8	AD6	AD8	AD8	AD6	AD8
	Rear	AD7	AD5	AD7	AD7	AD5	AD7
	Front	AD10	AD10	AD10	AD10	AD10	AD10
2nd or 3rd Generation Aircraft Shelter	Side	AD8	AD6	AD8	AD8	AD6	AD8
	Rear	AD7	AD5	AD7	AD7	AD5	AD7
	Front	AD9	AD8	AD10	AD9	AD8	AD10

Distance Functions: see TABLE 5-I

NOTE: a) Limited to a maximum of 5 000 kg per shelter.

TABLE 5-II (PAGE 2)

ASSET PRESERVATION

FROM (PES) / TO (ES)		Ready Service Igloo [b)]				Ready Service Magazine [c)]	
		Side	Rear	Front Barr.	Front Unbarr.	Barr.	Unbarr.
1st Generation Aircraft Shelter	Side	AD3	AD3	AD7	AD7	AD7	AD7
	Rear	AD3	AD3	AD7	AD7	AD7	AD7
	Front	AD9	AD8	AD10	AD10	AD10	AD10
2nd or 3rd Generation Aircraft Shelter	Side	AD3	AD3	AD7	AD7	AD7	AD7
	Rear	AD3	AD3	AD7	AD7	AD7	AD7
	Front	AD3	AD3	AD7	AD7	AD7	AD7

Distance Functions: see TABLE 5-I

NOTES:

b) Ready Service Igloo - An earth-covered explosives storage location, often utilizing an arch-type interior shell, used to store built-up ammunition for combat aircraft loading. Storage is limited to not more than 10 000 kg NEQ and a loading density of not more than 20 kg $m^{-1/3}$.

c) Ready Service Magazine - Any aboveground explosives storage facility, other than an igloo, used to store built-up ammunition for combat aircraft loading. Storage is limited to not more than 10 000 kg.

TABLE 5-II (PAGE 3)

ASSET PRESERVATION

FROM (PES) TO (ES)		Igloo				Magazine	
		Side	Rear	Front Barr.	Front Unbarr.	Barr.	Unbarr.
1st Generation Aircraft Shelter	Side	AD5	AD5	AD7	AD7	AD7	AD7
	Rear	AD5	AD5	AD7	AD7	AD7	AD7
	Front	AD10	AD10	AD10	AD10	AD10	AD10
2nd or 3rd Generation Aircraft Shelter	Side	AD5	AD5	AD7	AD7	AD7	AD7
	Rear	AD5	AD5	AD7	AD7	AD7	AD7
	Front	AD5	AD5	AD7	AD7	AD7	AD7

Distance Functions: see TABLE 5-I

TABLE 5-III (PAGE 1)

PROPAGATION PREVENTION

FROM (PES) / TO (ES)		1st Generation Aircraft Shelter			2nd or 3rd Generation Aircraft Shelter [a]		
		Side	Rear	Front	Side	Rear	Front
1st Generation Aircraft Shelter	Side	AD2	AD2	AD3	AD2	AD2	AD3
	Rear	AD2	AD2	AD3	AD2	AD2	AD3
	Front	AD6	AD4	AD7	AD6	AD4	AD8
2nd or 3rd Generation Aircraft Shelter	Side	AD2	AD2	AD3	AD2	AD2	AD3
	Rear	AD2	AD2	AD3	AD2	AD2	AD3
	Front	AD4	AD3	AD5	AD4	AD4	AD6
Ready Service Igloo	Side	AD2	AD2	AD3	AD2	AD2	AD3
	Rear	AD2	AD2	AD3	AD2	AD2	AD3
	Front Barr.	AD3	AD3	AD5	AD3	AD3	AD6
	Front Unbarr.	AD6	AD4	AD7	AD6	AD4	AD8
Ready Service Magazine	Barr.	AD6[b]	AD6[b]	AD6	AD6[b]	AD6[b]	AD6
	Unbarr.	AD9	AD9	AD9	AD9	AD9	AD9

Distance Functions: see TABLE 5-I

NOTES:

a) Limited to a maximum of 5 000 kg per shelter.

b) This separation provides a high degree of protection (see Part I, subpara. 1.3.1.9.b)2)). AD3-distances may be used for robust stores or in wartime or emergency situations and would provide a moderate degree of protection (see Part I, subpara. 1.3.1.9.b)3)).

TABLE 5-III (PAGE 2)

PROPAGATION PREVENTION

FROM (PES)		Ready Service Igloo [c]				Ready Service Magazine [d]	
TO (ES)		Side	Rear	Front Barr.	Front Unbarr.	Barr.	Unbarr.
1st Generation Aircraft Shelter	Side	AD1[e]	AD1[e]	AD3[f]	AD3[f]	AD3	AD3
	Rear	AD1[e]	AD1[3]	AD3[f]	AD3[f]	AD3	AD3
	Front	AD3[f]	AD3[f]	AD6[f]	AD8[f]	AD6	AD8
2nd or 3rd Gene-ration Aircraft Shelter	Side	AD1[e]	AD1[e]	AD3[f]	AD3[f]	AD3	AD3
	Rear	AD1[e]	AD1[e]	AD3[f]	AD3[f]	AD3	AD3
	Front	AD1[e]	AD1[e]	AD3[f]	AD3[f]	AD3	AD3
Ready Service Igloo	Side	Use PART I Distances					
	Rear						
	Front Barr.						
	Front Unbarr.						
Ready Service Magazine	Barr.						
	Unbarr.						

NOTES:

c) Ready Service Igloo - An earth-covered explosives storage location, often utilizing an arch-type interior shell, and often used to store built-up ammunition for combat aircraft loading. Storage is limited to not more than 10 000 kg NEQ and a loading density of not more than 20 kg $m^{-1/3}$, except as noted below.

d) Ready Service Magazine - any aboveground storage facility, other than an igloo, used to store built-up ammunition for combat aircraft loading. Storage is limited to not more than 10 000 kg.

e) Use AD2-distances where the loading density exceeds 20 kg $m^{-1/3}$.

f) The loading density limitation of 20 kg $m^{-1/3}$ not to be applied.

TABLE 5-III (PAGE 3)

PROPAGATION PREVENTION

<table>
<tr><td colspan="2" rowspan="2">FROM (PES)

TO (ES)</td><td colspan="4">Igloo</td><td colspan="2">Magazine</td></tr>
<tr><td>Side</td><td>Rear</td><td>Front Barr.</td><td>Front Unbarr.</td><td>Barr.</td><td>Unbarr.</td></tr>
<tr><td>1st Generation Aircraft Shelter</td><td>Side
Rear
Front</td><td colspan="6" rowspan="2">See TABLE 5-II</td></tr>
<tr><td>2nd or 3rd Generation Aircraft Shelter</td><td>Side
Rear
Front</td></tr>
<tr><td>Ready Service Igloo</td><td>Side
Rear
Front Barr.
Front Unbarr.</td><td colspan="6" rowspan="2">Use PART I Distances</td></tr>
<tr><td>Ready Service Magazine</td><td>Barr.
Unbarr.</td></tr>
</table>

CHAPTER 6 - SAFETY PRINCIPLES FOR THE TRANSFER OF MILITARY AMMUNITION AND EXPLOSIVES IN NAVAL OR MILITARY PORTS

Section I-Introduction

4.6.1.1.

The principles detailed in this chapter leaflet are designed to give the levels of protection to other vessels, facilities and to personnel working in the immediate environment as well as to the general public when vessels are anchored, moored or berthed in naval or military ports, and are in general based on the advice used in AASTP-1 for above-ground storage.

4.6.1.2.

This leaflet recommends a desired level of protection, with related quantity-distances but because it may not always be practical to obtain this desired level, also details, wherever possible, alternative lower levels of protection and their related quantity-distances. It is the responsibility of the National Authorities to decide which level of protection to use after conducting a proper assessment of the often conflicting requirements of safety and operational effectiveness.

4.6.1.3.

In general warships are ignored for the purposes of this document provided that the following conditions are met:

(1) all ammunition is stowed in the designated magazines and/or explosives lockers

(2) all explosive storage areas are secure

(3) no movement of explosives takes place on board the warship.

4.6.1.4.

In general the guiding principle is to consider a vessel being loaded at a berth as equivalent to a storage site for quantity distance purposes, particularly if the berth is in constant or almost constant use.

4.6.1.5.

However where the berth is not in constant use or a higher explosives limit is required for only short periods of operation then the assessment of HD 1.1 limits should be made initially using the quantity distance guidelines laid down in this leaflet and the results confirmed by a consequence analysis. Having assessed the HD 1.1 limits, limits for explosives of HD 1.2 and 1.3 are generally derived using a comparison technique.

4.6.1.6.

Appropriate models, which may be used to conduct the consequence analysis, are detailed in the modelling section of AASTP-4.

4.6.1.7.

It must be emphasised that probability of propagation, damage and casualties are all directly related to separation distance. Any increase above quantity-distances recommended in this leaflet will result therefore in improved levels of protection. In addition good working practices can do much to reduce the probability of propagation, for example mooring ships in tandem and closing hatches.

4.6.1.8.

As the aim of this leaflet is to produce a practical and applicable technique for the assessment of explosive limits in ports, albeit naval or military ones, the advice given in the leaflet could also be useful to the regulatory authorities, port users and the ports authorities themselves.

Section II- General

4.6.2.1.

This prescription details safety principles for the transfer of military explosives when vessels are anchored, moored or berthed in naval or military ports, i.e. areas where the basin, cargo handling facilities, and inland support facilities are under the jurisdiction of the military. Each vessel is considered either as a Potential Explosion Site (PES) or as an Exposed Site (ES), if it is at risk from a PES. For definitions of other ES see AASTP-1.

4.6.2.2.

These principles apply to the separation distances to be observed by vessels loaded with military explosives. Examples of such vessels are Lighters, Barges, Small Coastal Craft, Cargo Ships, Transports, Auxiliary Vessels and Warships although this list is not intended to be exhaustive.

4.6.2.3.

Circumstances where these Principles may not apply. These principles are not applicable to military explosives stored in ships' magazines, which are intended for the service of the shipboard armament or aircraft, provided that these magazines are not opened or worked upon when the vessel is at the berth. They do, however, apply to the loading, off-loading, or handling of such military explosives. Special procedures are applied to those circumstances where ammunition "topping-up" operations are required.

4.6.2.4.

Traversed/Untraversed Vessels. The military explosives in a vessel are considered to be traversed when they are all stored at least 0.5 m below the waterline. Conversely, if any are stored less than 0.5m below the waterline, the total quantity of explosives embarked is to be considered as untraversed.

Section III - Calculation of Net Explosives Quantity

4.6.3.1.

In view of the close proximity of ships' compartments and holds, and adjacent ship to shore transfer area, it is possible that an explosion could involve the whole cargo. For this reason all the military explosives on board a vessel are to be aggregated in accordance with the principles of AASTP-1. The NEQ to be taken into account must therefore include:

1) all military explosives on jetties or in vehicles or vessels alongside the ship; and

2) all military explosives being handled and fitted on the deck of the ship; and

3) all military explosives in the magazine or hold being worked plus those in adjacent magazines or hold being worked plus those present in any other adjacent magazines unless the risk of simultaneous propagation has been assessed as being negligible. (See paragraph 4.6.3.2 below)

4.6.3.2.

It may be possible to arrange for a vessel's explosive cargo to be stowed in such a way that the simultaneous propagation of an explosion from one stowage location to another would not occur. Such stowage must include both a separation distance and traversing to intercept and prevent high-speed fragments initiating a simultaneous explosion. The distance must be at least 0.8 $Q^{1/3}$ and the traversing must be at least equivalent to the traverse (2.4 metres of earth) normally provided for storage ashore. Care should be taken to ensure that there are no 'windows' in the traversing particularly where stowage on different deck levels is envisaged. The traverse can be composed of inert material such as provisions, water ballast, ship's machinery, 1.4 ammunition, etc. During loading and unloading operations only one hold may be worked at any one time and care must be taken to ensure that the inert material remains in place to provide the necessary traverse. In case of doubt as to the equivalence or effectiveness of the traverse advice may be sought through normal explosives safety channels.

4.6.3.3. Quantity-Distances

Quantity-distances to be observed by vessels when carrying, loading or unloading military explosives at piers, jetties, wharves or anchorages are given in Table A at Annex A and are to be applied as detailed below for the NEQ concerned to ensure adequate protection of ES.

4.6.3.4.

Measurements are made from the nearest point of compartments in which military explosives are stowed in a berthed or anchored vessel to the nearest point of the ES.

4.6.3.5.

When quantity-distances are calculated due allowance is to be made for movement of ships due to tides when anchored or berthed at a single buoy. The radius of the swinging circle is to be taken into account in the overall distance and the position of the aftermost compartment in which military explosives are stored taken as the point from which the quantity-distances should be measured.

4.6.3.6.

If it is necessary to berth 2 or more vessels containing military explosives at less than the appropriate separation distance that is required by considering each vessel as a separate PES, the total NEQ of the cargo of both vessels is to be used as one unit PES to determine quantity-distances to any other ES.

4.6.3.7.

If berthing of 2 vessels together is necessary they should preferably be moored in tandem (i.e. one behind the other) as the bows and sterns will afford additional protection to each of the vessels by reducing their exposed areas. Provided that the conditions detailed in paragraph 3.2 above have been met this should allow the vessels to be treated as being effectively traversed. Vessels so berthed should be secured by the bows and sterns to prevent swinging in order to maintain the effectiveness of the traversing arrangement.

4.6.3.8.

Table B is a summary of quantity-distances to be observed for vessels loaded with or loading or unloading military explosives of Hazard Division (HD) 1.1 in naval ports.

4.6.3.9.

The application of greater minimum separation distances may be appropriate where nuclear powered vessels are considered as ES's.

Section IV - Levels of Protection Against Propagation for HD 1.1

4.6.4.1. *General*

There is only one level of protection against propagation, viz protection level B, allowed for, in accordance with the principles laid down in AASTP-1. It is considered that protection level A is inappropriate since no vessel is capable of providing complete protection against protection equivalent to that afforded by an earth covered structure. In addition since, under protection level C, the loss of stocks, and therefore in all likliehood the vessels containing them, at the ES is almost guaranteed in the event of an accidental explosion at the Potential Explosion Site this level of protection is not considered as a normally acceptable option.

4.6.4.2. *Protection Level B*

There is a high degree of protection against practically instantaneous propagation of explosion by ground shock, blast, flame and high velocity projections. There are occasional fires or subsequent explosions caused by these effects or by lobbed ammunition. Heavy cased ammunition is likely to be serviceable although covered by debris. However the probability is significant that stocks of other types of explosives are likely to be lost through subsequent propagation from lobbed ammunition or the spread of burning debris.

Section V - Protection Between Vessels Each Loaded with Military Explosives

4.6.5.1. *General*

Such vessels must be separated from other vessels loaded with military explosives by quantity-distances selected according to the HD of the military explosives concerned and the type of vessel at the ES. If the vessel at the ES is a warship this may be discounted from consideration provided the conditions of paragraph 1.3 have been met. The distances in this section are to be observed between vessels at anchorages, explosives piers or jetties. No specific separation distances are advised to vessels which are underway.

4.6.5.2. *HD 1.1.*

For HD 1.1 Protection Level B should be applied wherever practicable. Different separation distances are recommended for warships and other explosives carrying vessels because of the rational given at 6.1. Smaller separation distances are also quoted which may be acceptable when it is unlikely that significant numbers of personnel will be exposed to blast and debris hazards. Berthing of vessels in tandem at the same pier or at an anchorage will help to decrease the fragment hazard to the explosive cargo because of the additional protection afforded by the bow and stern. The quantity-distances, which should be used, are given below and the distance functions quoted relate to those given in Table A at Annex A.

4.6.5.3.

Normal Protection Level (B) for explosives carrying vessels :

a. Untraversed : SD3.

b. Traversed : SD2.

HD 1.2. For HD 1.2 fixed separation distances are applied as follows :

c. 60 m for military explosives of HD 1.2*

d. 90 m for military explosives of HD 1.2

4.6.5.4. Flooding

An incident involving military explosives belonging only to HD 1.2 may be reduced significantly in severity if means are available to rapidly flood the vessel. In such a case, a lesser distance of 60 m may be acceptable.

4.6.5.5. *HD 1.3*

A minimum separation distance of 60 m is to be used whether the PES is traversed or untraversed and for any quantity of explosives regardless of the vessel at the ES.

4.6.5.6. HD 1.4

When the cargo comprises only military ammunition and explosives of HD 1.4, vessels are to be separated by a minimum distance of at least 25 m for any quantity of explosives whether the vessel is traversed or untraversed. This is primarily to allow effective fire fighting access.

4.6.5.7. Piers and Jetties

The distances quoted above for other explosives carrying vessels should also be used for protection of untraversed military explosives on piers and jetties from vessels (both traversed and untraversed) loaded with military explosives.

Section VI - Protection from Vessels Loading or Unloading Military Explosives

4.6.6.1.

The distances in this section are also to be observed from a vessel loading or unloading at an anchorage, explosives pier or jetty. No specific separation distances are advised to vessels which are underway.

4.6.6.2.

To vessels carrying military explosives, untraversed.

HD 1.1 : SD4

HD 1.2 : Fixed separation distance of 90 m.

HD 1.2* : Fixed separation distance of 60 m.

HD 1.3 : Fixed separation distance of 60 m.

HD 1.4 : Fixed separation distance of 25 m.

4.6.6.3.

To vessels carrying military explosives, effectively traversed.

HD 1.1 : SD3

HD 1.2 : Fixed separation distance of 90 m.

HD 1.2* : Fixed separation distance of 60 m.

HD 1.3 : Fixed separation distance of 60 m.

HD 1.4 : Fixed separation distance.

4.6.6.4. Protection of Explosives Workshops

The separation distances from all vessels loaded or vessels loading or unloading military explosives to an explosives workshop are to be based on the aggregated NEQ within the vessel and on the adjacent transfer area. These distances are the minimum permissible distances between PES and explosives workshops as given in AASTP-1. The distances are intended to provide a reasonable degree of immunity for personnel within the explosives workshops from the effects of a nearby explosion, such as blast, flame, radiant heat and projections. Light structures are likely to be severely damaged. These distances also provide a high degree of protection against immediate or subsequent propagation of explosion.

4.6.6.5. Protection of Marshalling Areas

Separation from loaded vessels or vessels loading or unloading military explosives to marshalling areas containing road or rail trucks and wagons of military explosives are SD3-distances given in Table A for traversed and untraversed vessels, based on the NEQ within the vessel and on the adjacent transfer area.

4.6.6.6. Protection of the General Public and Other Non Explosive Exposed Sites

1) Schools, Hospitals and Similar Institutions must not be sited at less than the full inhabited building distance (22.2 $Q^{1/3}$) when occupied.

2) Buildings of Vulnerable Construction must not be sited at less than 33 $Q^{1/3}$ but these will require individual assessments. Buildings of Vulnerable Construction are defined in AASTP-1.

3) Ordinary Property of Conventional Design should in general not be sited at less than 16.7 $Q^{1/3}$ separation distances. However a few isolated buildings may be acceptable between SD3 and 16.7 $Q^{1/3}$ distances provided that no unacceptable fatality levels are generated as a result. It may also be necessary for such property beyond 22.2 $Q^{1/3}$ to be taken into account if there are areas of high density development. Any property of unconventional design will have to be assessed separately. The following types of facilities are included in this overall grouping:

(a) one or two storey housing of conventional brick wall design

(b) public houses

(c) dock offices, customs offices, etc

(d) factories, offices and manned facilities not in any way associated with the explosives handling.

(e) Personnel working in the open and not involved with the explosives shipment should not be exposed at separations less than 11.1 $Q^{1/3}$.

(f) Bulk above ground Petroleum, Oil and Lubricant Storage Installations should not be sited at less than 11.1 $Q^{1/3}$, provided that the tanks are effectively bunded. Special attention should be paid to Petroleum Spirit, LNG and LPG tanks which should not generally be sited at less than 16.7 $Q^{1/3}$ distances.

(g) Canteens should in general not be sited at less than 11.1 $Q^{1/3}$ provided they are occupied by less than 50 people. If they are occupied by more than 50 people they should in general not be sited at less than 16.7 $Q^{1/3}$ distances. They may be ignored if they are likely to be unoccupied during the actual explosives handling operations.

(h) Passenger terminals and passenger ships when embarking or disembarking should not be sited at less than 22.2 $Q^{1/3}$ when explosives are being handled and 16.7 $Q^{1/3}$ from ships loaded with explosives where explosives are not being handled. Any open areas over which passengers are likely to pass should not in general be sited at less than 11.1 $Q^{1/3}$.

(i) Tankers used for carrying petroleum spirit, LNG or LPG, unless empty and inerted, should not be sited at less than 16.7 $Q^{1/3}$, provided that neither the explosives are being handled or the tanker is being loaded or unloaded. If concurrent operations are essential then the separation should not be less than 22.2 $Q^{1/3}$. A separation of 16.7 $Q^{1/3}$ should be used from an explosives ship if the explosives are being handled but no loading or unloading of the tanker is taking place, or vice-versa.

(j) Bulk carriers carrying significant quantities of other dangerous goods should not be berthed at less than 11.1 $Q^{1/3}$. Consideration may need to be given to special loads.

(k) Lock gates or other facilities, if vital to the operation of the port and manned should be assessed specifically but in general should not be sited at less than 11.1 $Q^{1/3}$.

(l) Transit Sheds and other installations used for the storage of significant quantities of highly flammable materials should not be sited at less than 16.7 $Q^{1/3}$. Such facilities containing other dangerous goods should not be sited at less than 11.1 $Q^{1/3}$. If the facility is used for the storage of inert materials and is unmanned it may be ignored. If the facility is manned it should not in general be sited at less than 16.7 $Q^{1/3}$. However lesser distances may be acceptable if the facility is of substantial construction or the numbers employed in the facility are very low.

(m) Roads giving access to the berth may be ignored but the density of traffic on all other roads should be assessed. If the density of traffic is very high then they should not be sited at less than 16.7 $Q^{1/3}$. If the density is relatively low the road should not be sited in general at less than 11.1 $Q^{1/3}$. All other roads should not in general be sited at less than 8.0 $Q^{1/3}$.

(n) Railways used for goods traffic in the dock area may be ignored. Main line or busy suburban passenger train routes should not be sited at less than 16.7 $Q^{1/3}$. All other passenger routes should not in general be sited at less than 11.1 $Q^{1/3}$.

(o) Other ships, not loaded or with non-dangerous cargoes and having resident personnel on board, should be sited at not less than 11.1 $Q^{1/3}$.

Section VII - Scuttling Areas

6.6.7.1.

Safe areas should be designated at ports used for handling military explosives to which vessels carrying military explosives should, if possible, be directed or towed in the event of circumstances leading to a decision to scuttle. Scuttling areas should be selected at the appropriate quantity-distances from ES, and in sufficient depth of water to ensure complete swamping of military explosives holds at all states of the tides. Calculation should be based on the largest NEQ likely to be in a single vessel handled at the port and the quantity-distance should be measured from the boundaries of the designated scuttling area. The scuttling area will normally be one of the approved licensed berths or buoys.

Table A. *Q-D Table for Vessels*

Net Explosives Quantity	Quantity-Distances			
Q	SD1	SD2	SD3	SD4
kg	m	M	m	m
500	60	39	135	130
600	60	41	135	135
700	60	43	135	145
800	60	45	135	150
900	60	47	135	155
1 000	60	48	135	160
1 200	60	52	135	175
1 400	60	54	135	180
1 600	60	57	135	190
1 800	60	59	135	195
2 000	60	61	135	205
2 500	60	66	135	220
3 000	60	70	135	235
3 500	60	73	135	245
4 000	60	77	135	255
5 000	60	83	140	275
6 000	60	88	150	295
7 000	62	92	155	310
8 000	64	96	160	320
9 000	67	100	170	335
10 000	69	105	175	345
12 000	74	110	185	370
14 000	78	120	195	390
16 000	81	125	203	405
18 000	84	130	210	420
20 000	87	135	218	435
25 000	94	145	235	470
30 000	100	150	250	500
35 000	105	160	265	530
40 000	110	165	275	550
50 000	120	180	295	590
60 000	130	190	315	630
70 000	135	200	330	660
80 000	140	210	345	690
90 000	145	220	360	720
100 000	150	225	375	750
130 000	160	245	395	790
140 000	170	250	420	840
160 000	175	265	435	870
180 000	185	275	455	910
200 000	190	285	470	940
250 000	205	305	510	1 020
300 000	215	325	540	1 080
350 000	230	340	570	1 140
400 000	240	355	590	1 180
500 000	255	380	640	1 280
1 000 000	320	480	800	1 600
Distance functions	$SD1=3.2Q^{1/3}$	$SD2=4.8Q^{1/3}$	$SD3=8.0Q^{1/3}$	$SD4=16.0Q^{1/3}$

Table B. *Summary of Quantity-Distances to be Observed for Seagoing Vessels Loaded with or Loading or Unloading Military Explosives HD 1.1 in Naval Ports*

Exposed site	Potential explosion site			
	Vessels loaded with explosives		Vessels loading or unloading explosives	
	Traversed	Untraversed	Traversed	Untraversed
Vessels loaded with explosives	SD3	SD3 (135 m minimum)	SD4[b]	SD4[b]
Vessels loading or unloading explosives	SD4[b]	SD4[b]	SD4[ab]	SD4[ab]
Other cargo vessels	SD4[b]	SD4[b] (180 m minimum)	SD4[b]	SD4[b] (180 m minimum)
Port facilities	c	C	c	c
Inhabited buildings	c	C	c	c
Public traffic routes and main shipping routes	c	C	c	c
Explosives workshops	c	C	c	c
Holding areas	SD3	SD3	SD3	SD3
POL jetties	SD4[b]	SD4[b]	SD4[b]	SD4[b]

Notes

a. Ships moored in tandem may use SD2-distances.

b. May be reduced to SD3 provided the exposed vessels are under military control and the controlling authority determines the exposure to be operationally necessary.

c. Quantity-distances in AASTP-1 Inhabited Building Distances and Public Traffic Routes.