MANUAL OF

NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

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PART III

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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
Ground Shock Particle Velocities:	
Foundation on soil	60-200 mm/s
Foundation on soft rock	115-400 mm/s
Foundation on hard rock:	230-800 mm/s

Actual particle velocity to be used at IBD should depend on the robustness of the structure under consideration.

The criteria listed above are used in Part I, Chapter 4 to obtain required distances.

[†] References are in Annex III A

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.

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 in Annex III B

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 about 60%. 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° 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° 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 which 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.

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].

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 specialised 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.

b) Adit Debris

A portal barricade reduces IBD for adit debris by obstructing the path of the debris as it exits the tunnel. However the barricade must be used in conjunction with another debris mitigating construction, such as a debris trap. QD decisions must be made by site-specific analyses and/or testing.

To be effective, a portal barricade must be properly designed and properly located.

Portal barricades for underground magazines are located immediately in front of the portal. The portal barricade should be centered on the extended axis of the tunnel that passes through the portal. For maximum effectiveness, the face of the barricade toward the portal must be vertical and concave in plan. Its central face must be oriented perpendicular to the tunnel axis, and its wingwalls should be angled about 45-degrees toward the portal. The minimum width of the central face is equal to the width of the tunnel at the portal. The wingwalls must be of sufficient width so that the entire barricade length intercepts an angle of at least ten degrees (to the right and left) of the extended width of the tunnel. Likewise, the height of the barricade along its entire width must be sufficient to intercept an angle of ten degrees above the extended height of the tunnel.

Portal barricades for underground magazines must be located a distance of not less than one and not more than three tunnel widths from the portal. The actual distance should be no greater than that required for passage of applicable transportation equipment. This distance, as shown in Fig 2-VII, is based on the turning radius and operating width of transportation equipment.

The barricade must withstand the impact of debris ejected from the tunnel and must be sufficiently robust so it does not contribute to the debris hazards.

3.2.4.10. *Interior Wall Roughness*

Although the effect of wall roughness is not fully quantified, some of the differences between measured and predicted results are likely attributable to it [8, 9]. Mitigating effects of wall roughness should be considered on a site-specific basis.

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[29] Yingxin Zhou, Hong Ho, 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

FIGURES

UNDERGROUND STORAGE

EXPLOSIVES SAFETY HAZARDS

Figure 2-I Layouts of Underground Facilities.

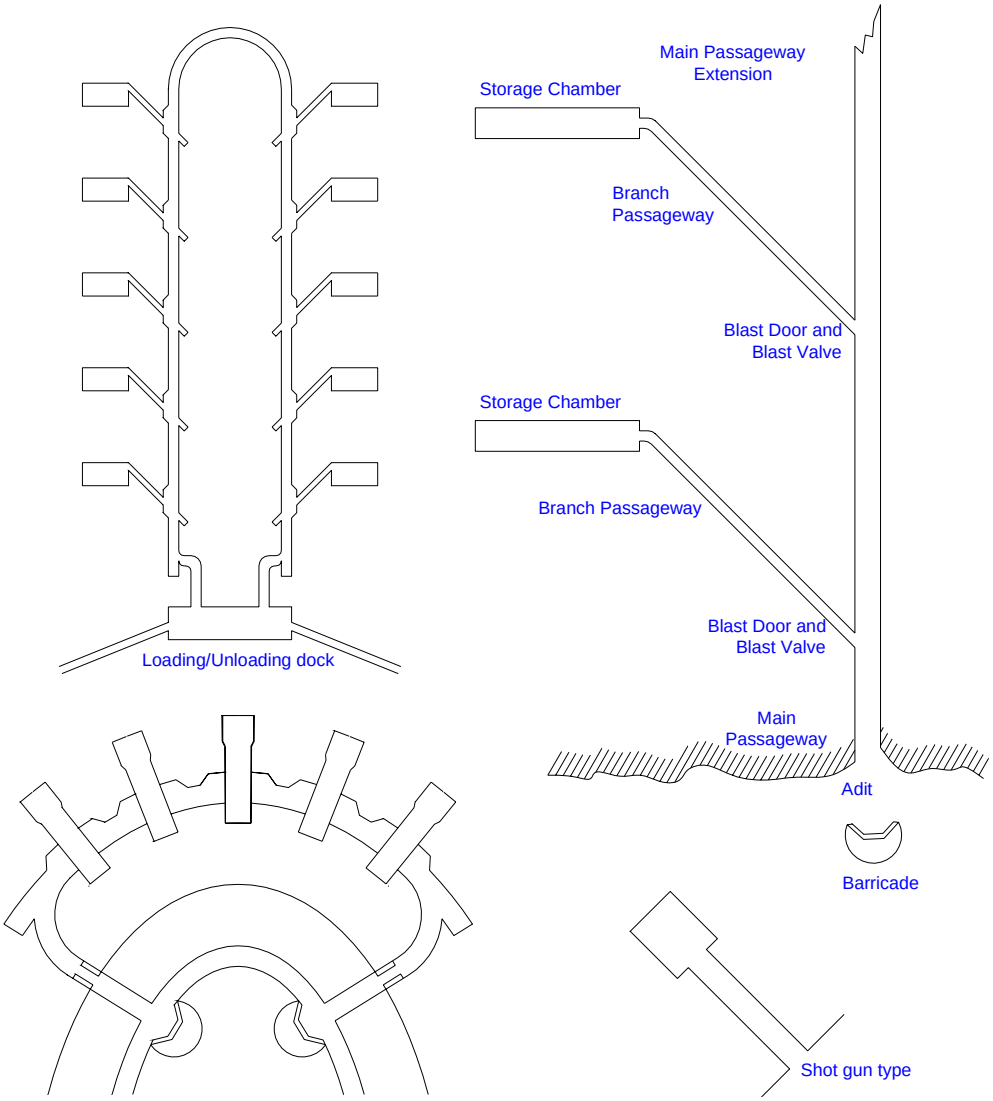


Figure 2-II Layout of an Underground Storage Site

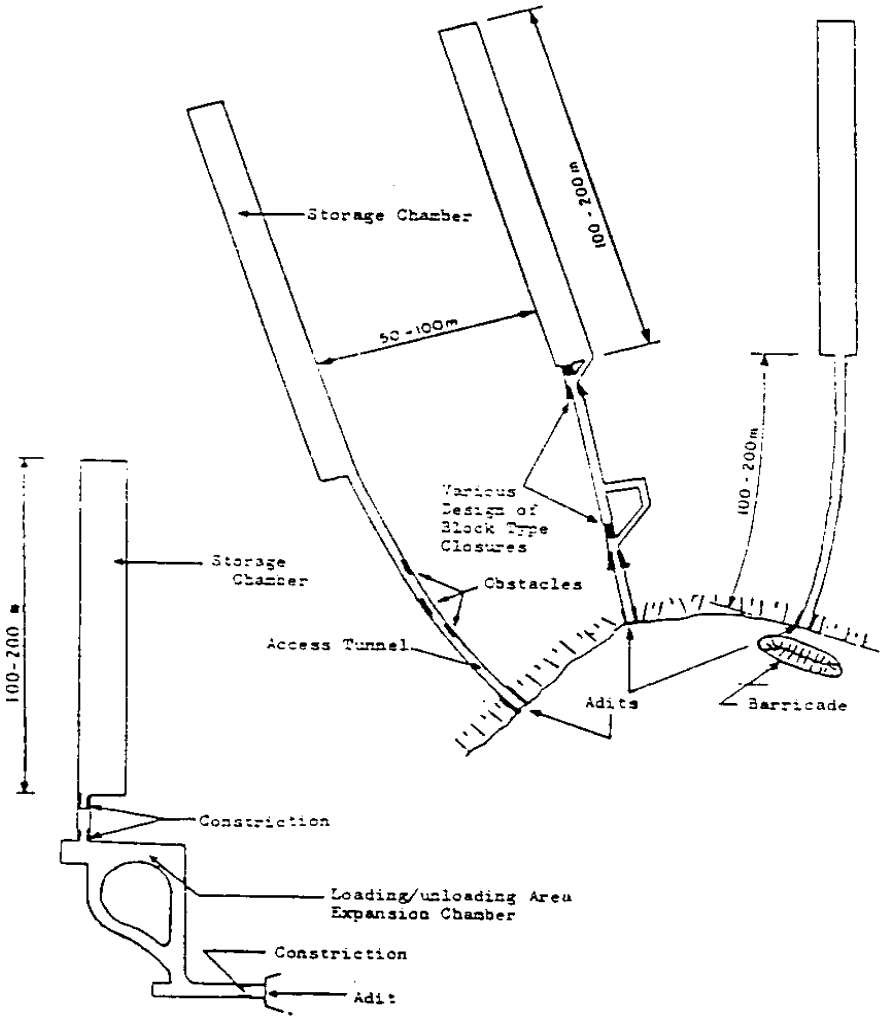


Figure 2-III: The Swiss-Klotz Layout

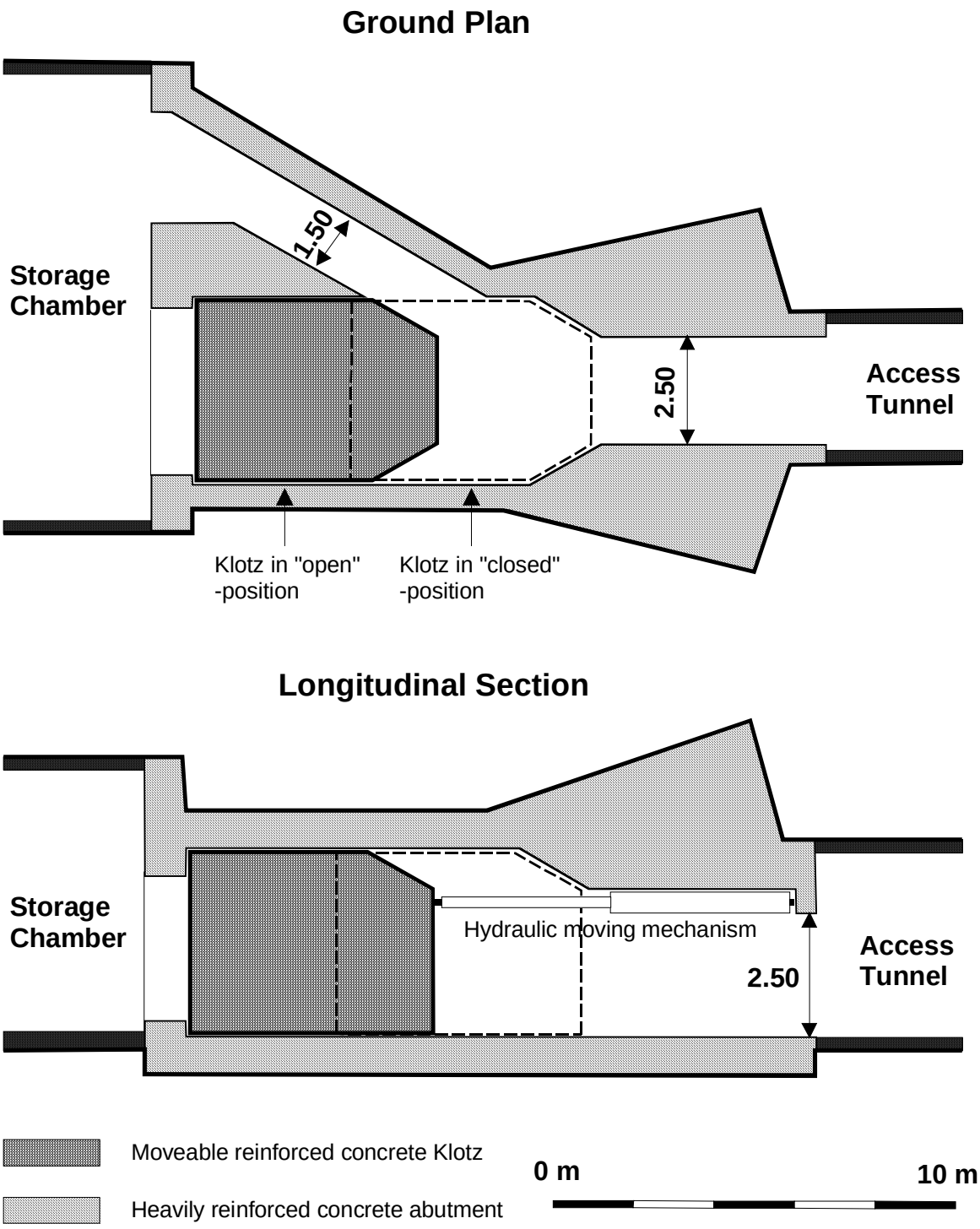


Figure 2-IV Magazine with expansion chamber

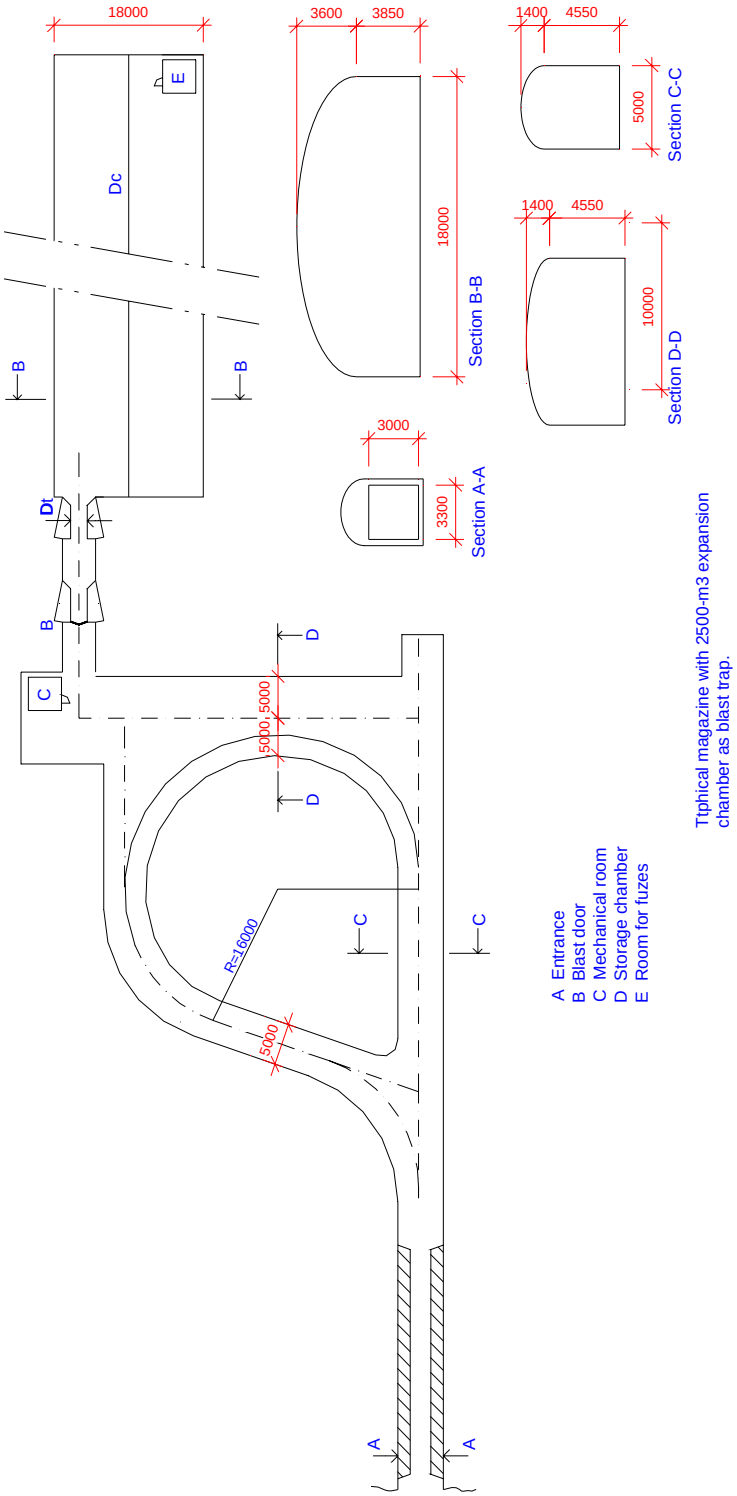


Figure 2-V Magazine without expansion chamber

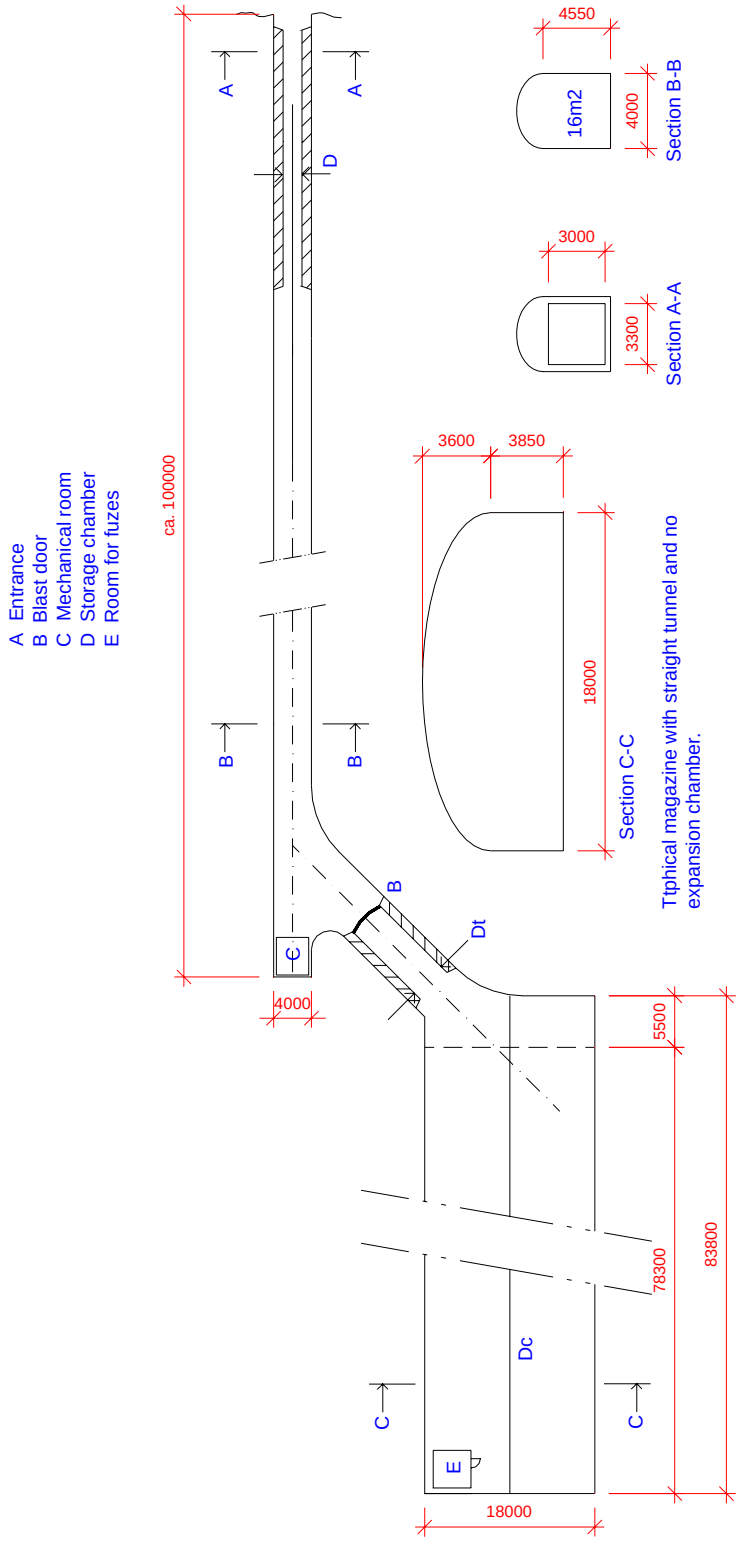
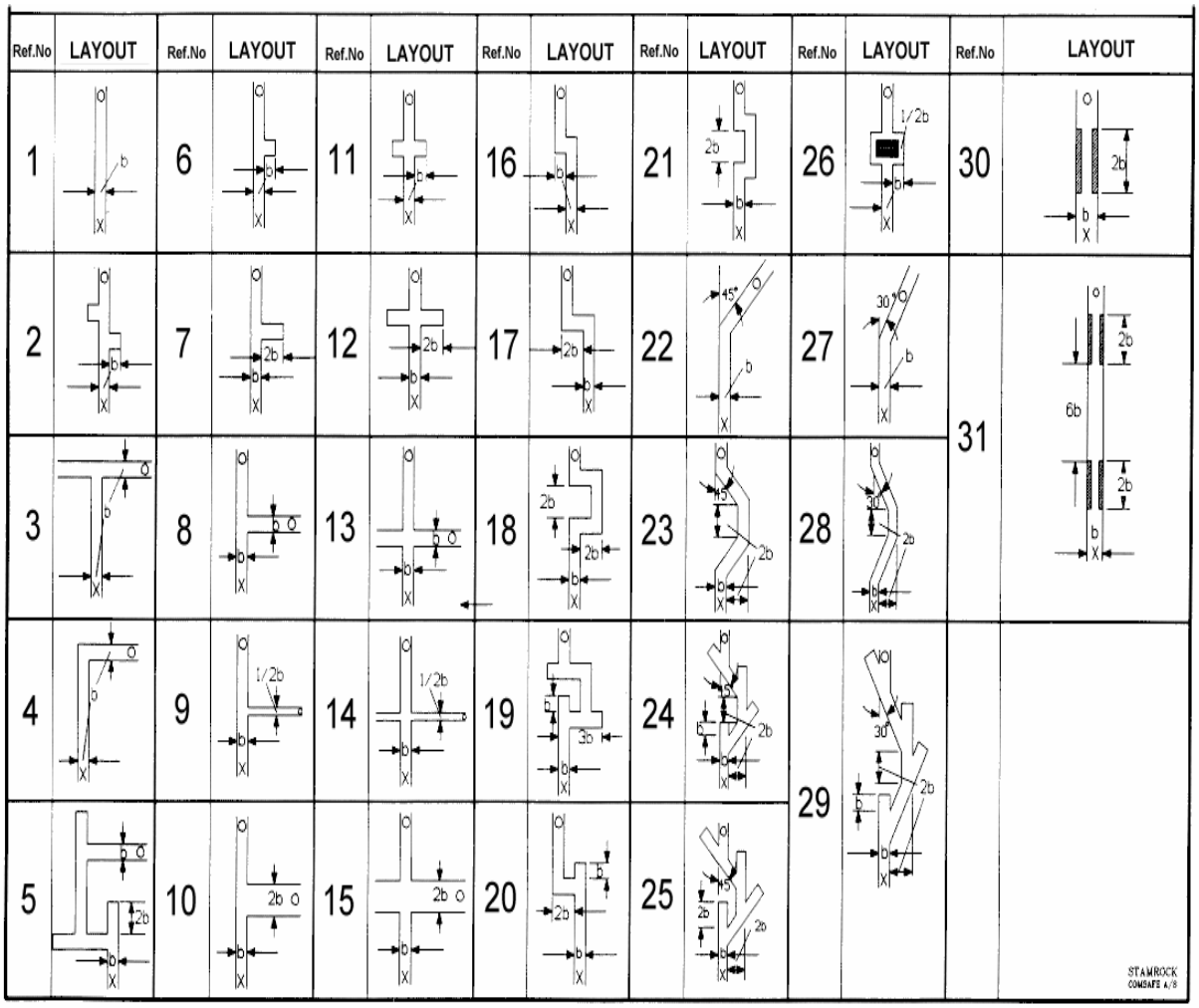


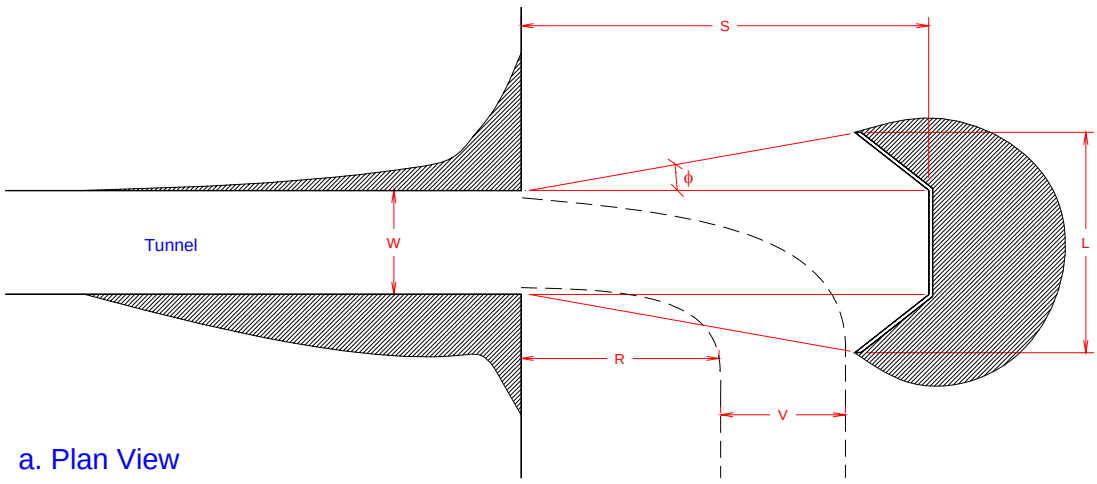
Figure 2-VI Blast Traps



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”.

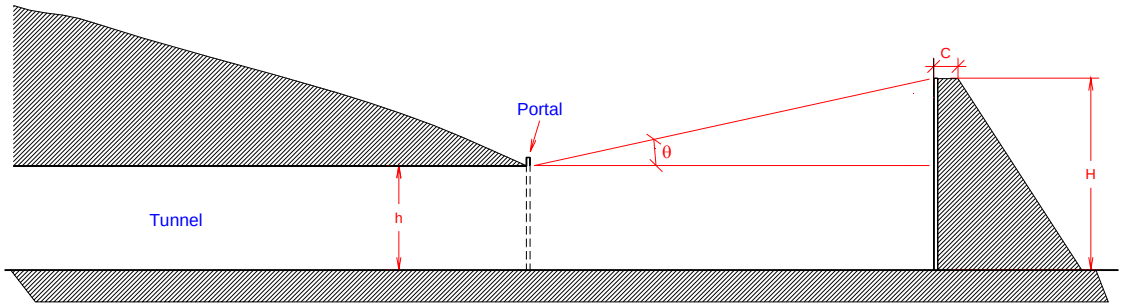
Some designs have comparatively little effect reducing the blast by only 10 % compared with the straight-through passageway in Ref. No 1, whereas others reduce the blast by as much as *80* %. It is therefore necessary to determine the actual effect of a chosen design by measurements in a model using properly scaled and located explosive charges.

Figure 2-VII: Portal Barricade Location, Height and Length.



a. Plan View

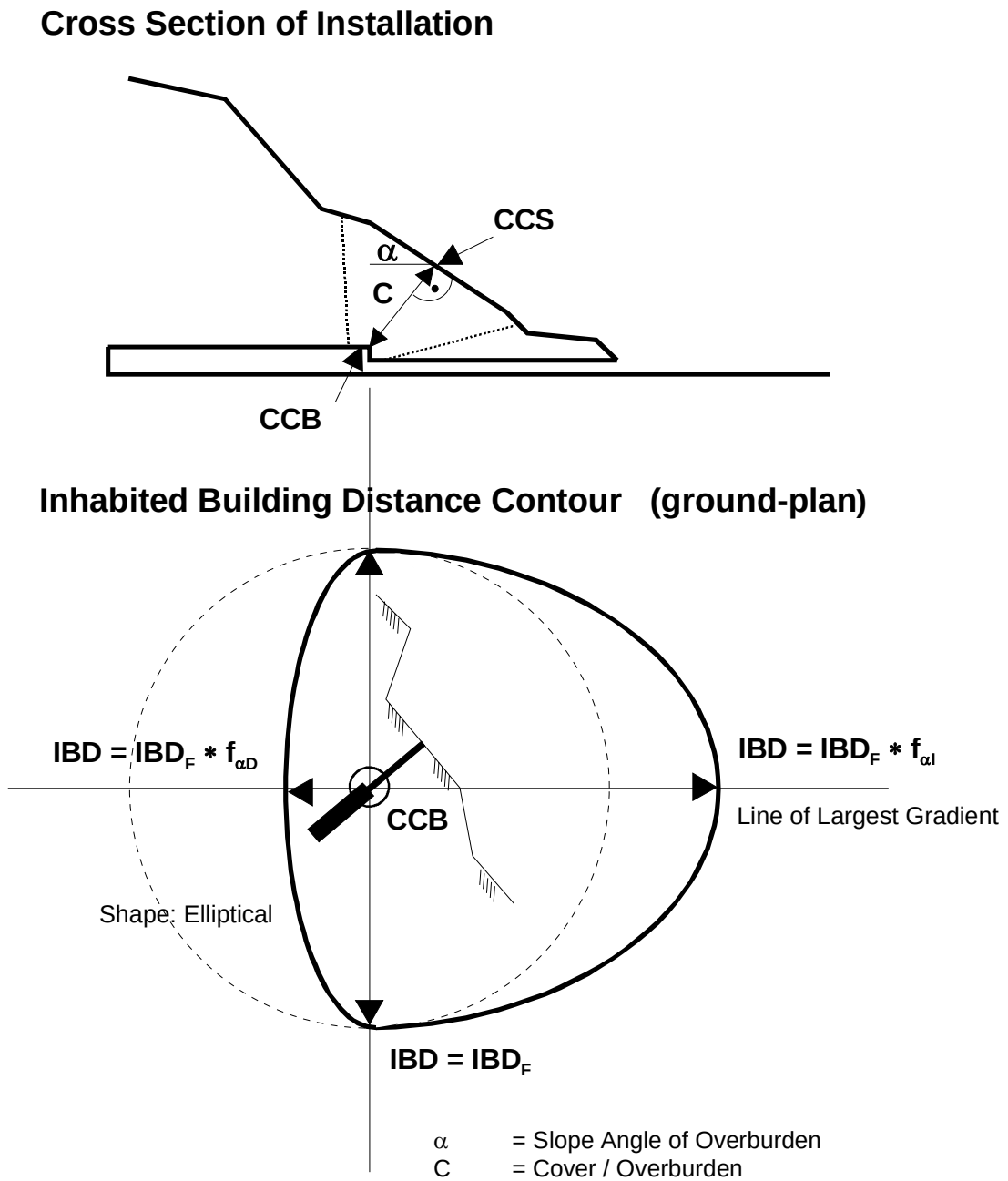
S = Stand off distance from portal (1 to 3 tunnel widths)
R = Turning rasdius of munition transport vehicles
V = Width of transport vehicles
L = Length of barricade
W = Tunnel width at portal
ϕ = Single angle [10 degrees minimum]



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]

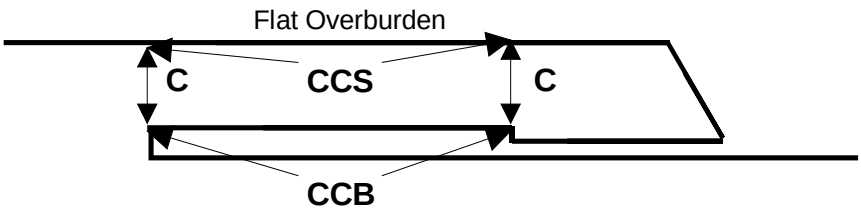
Figure 3-Ia: How to Establish Inhabited Building Distance Contours



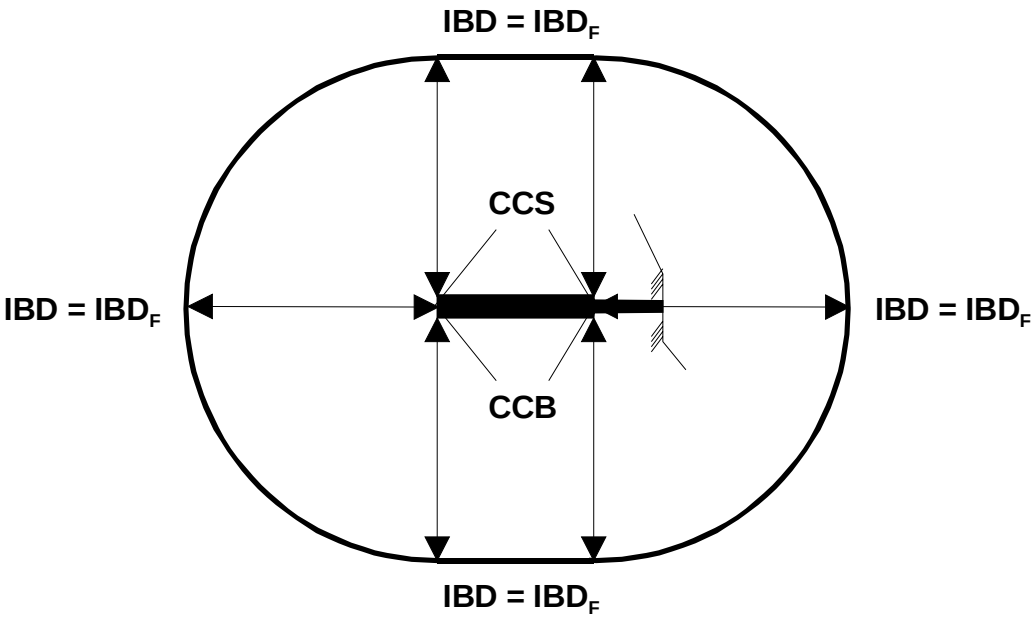
α	= Slope Angle of Overburden
C	= Cover / Overburden
CCS	= Crater-Center-Surface
CCB	= Crater-Center-Bottom
IBD_F	= Inhabited Building Distance for Flat Terrain / Overburden
$f_{\alpha I}$	= Inhabited Building Distance Increase Factor
$f_{\alpha D}$	= Inhabited Building Distance Decrease Factor

Figure 3-Ib: How to Establish IBD Distance Contours

Cross Section of Installation

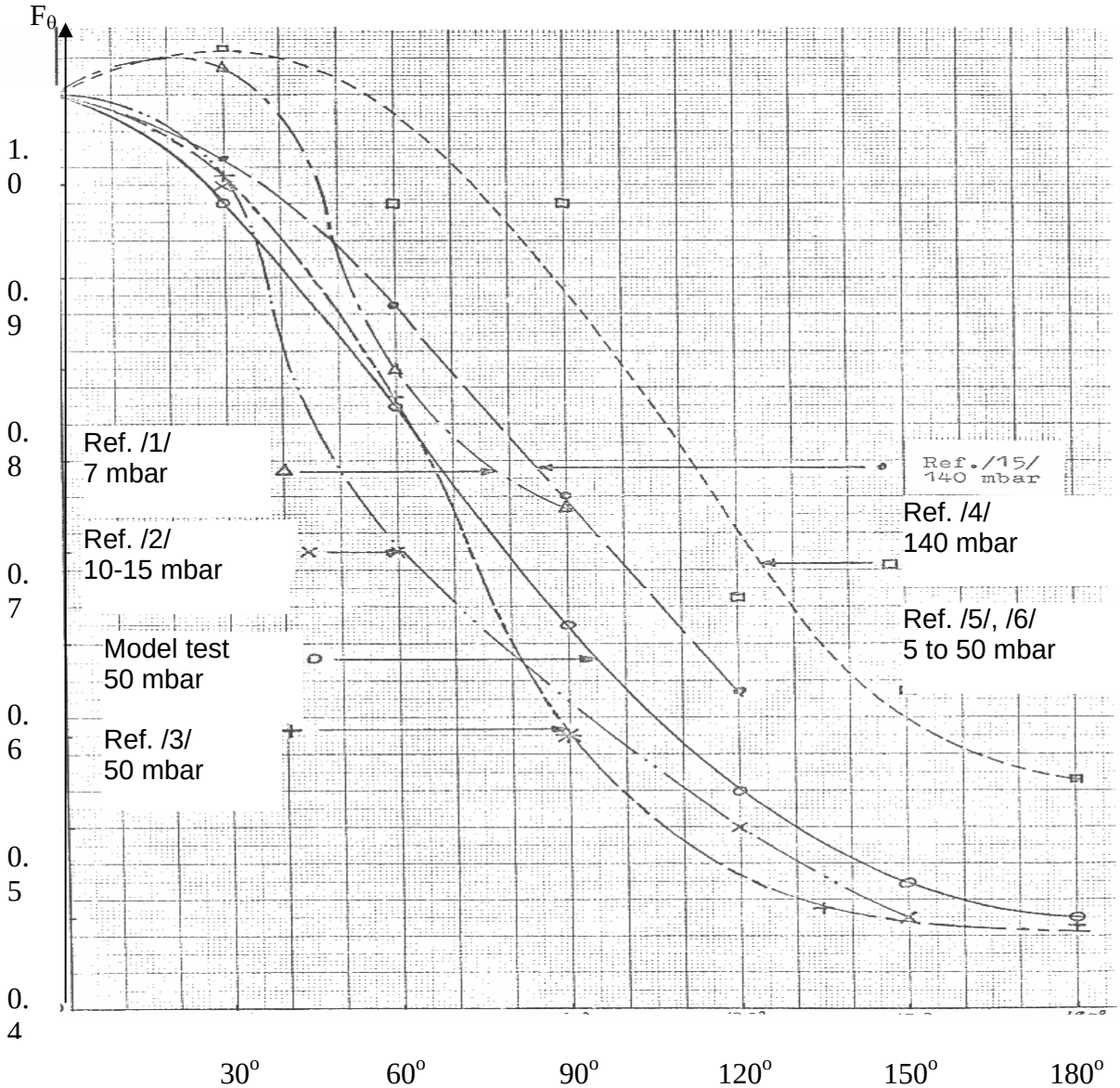


Inhabited Building Distance Contour (ground-plan)



C = Cover / Overburden
IBD_F = Inhabited Building Distance for Flat Terrain / Overburden
CCB = Crater-Center-Bottom
CCS = Crater-Center-Surface

Figure 3-II Directivity versus azimuth with the centre line as reference:



/1/ “Free field overpressures resulting from shock waves emerging from open-ended shock tubes.” Ballistic Research Lab. Mem. Report 1965.

/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.

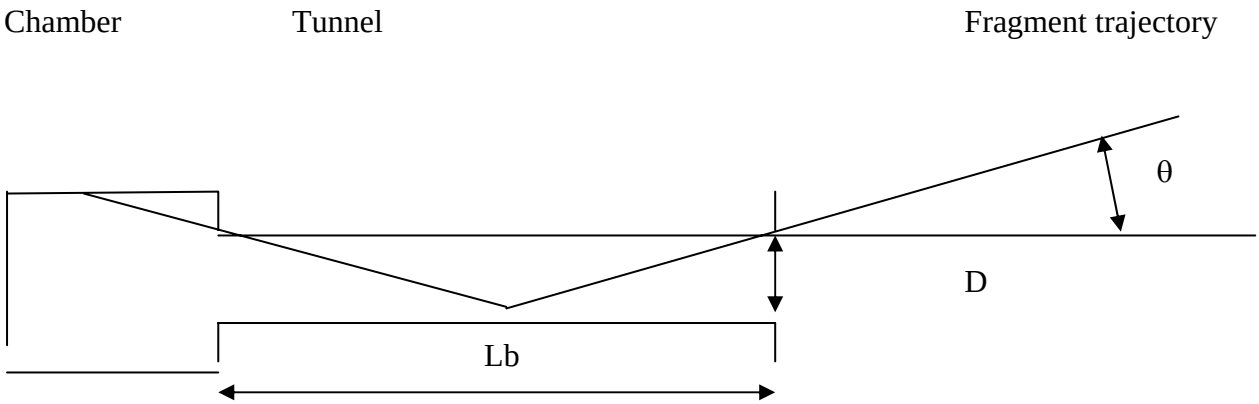
/4/ U.S Navy Gun Blast Committee: “Survey of Research of Blast”. First Interim Report, 1946.

/5/ “Model tests to investigate external safety distances.” Fortifikatorisk notat 36/67, FBT 1967.

/6/ “One-dimensional blast wave propagation.” Fortifikatorisk Notat 49/69, FBT 1969 .

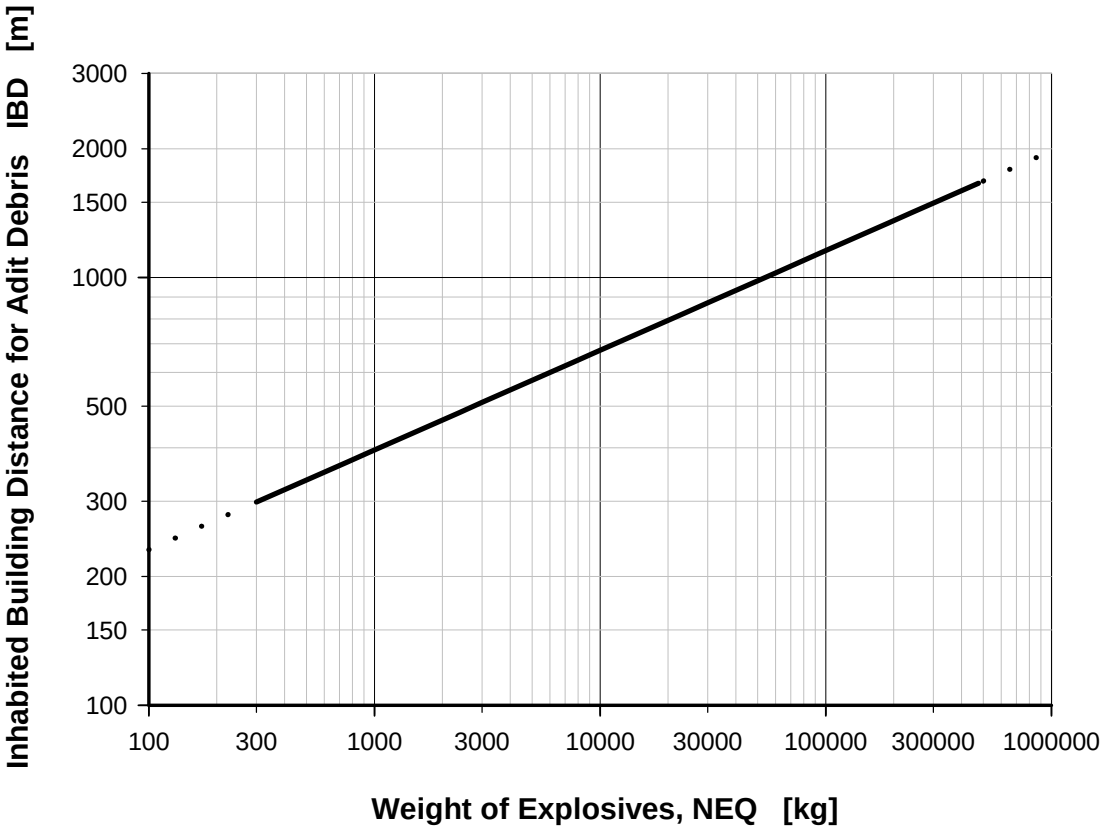
Figure 3-III: Inhabited Building Distance for Adit Debris

ADIT DEBRIS



Maximum dispersion angle (θ) = 10° for L/D ≥ 11 else θ = 20°
Lb = Length of straight tunnel section from portal

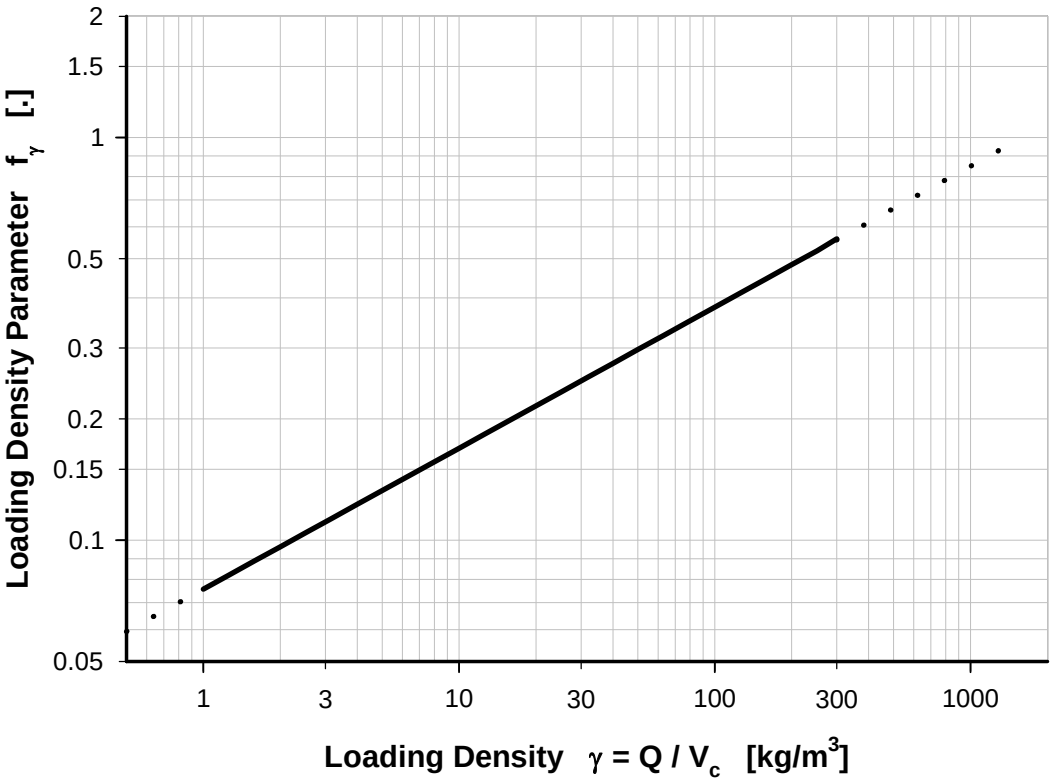
Figure 3-IV: Inhabited Building Distance for Adit Debris



$$IBD = 79 * Q^{0.233}$$

Q = Weight of Explosives, NEQ [kg]

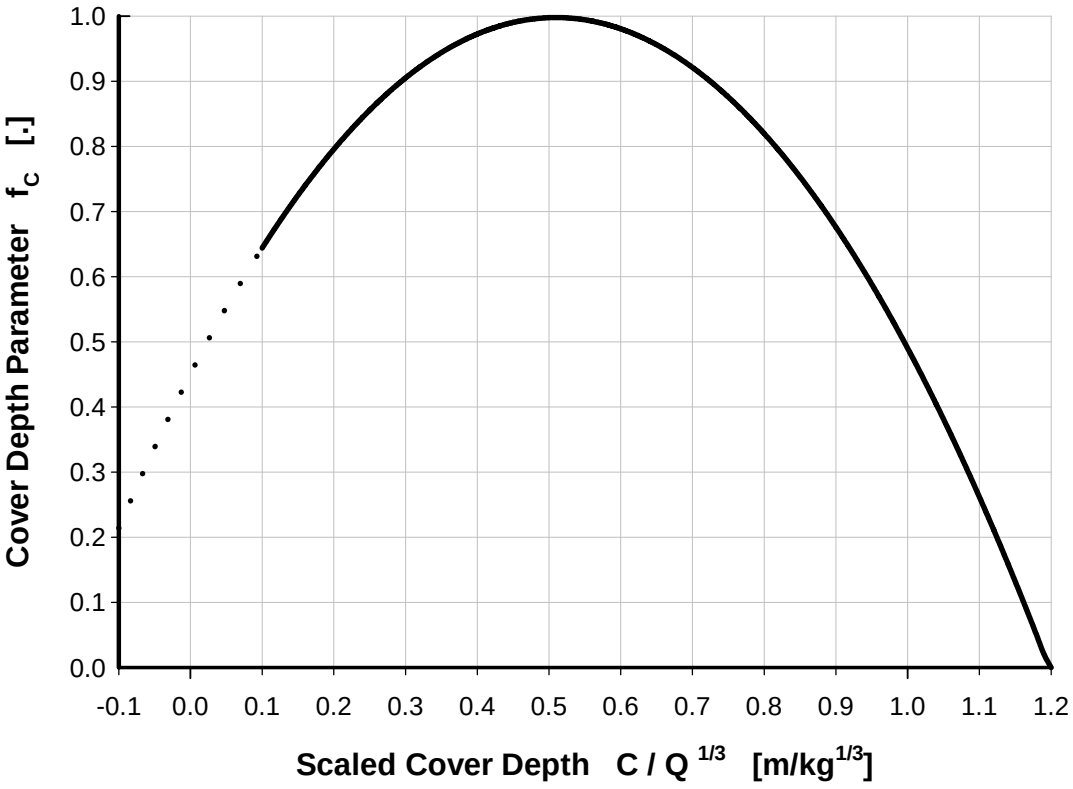
Figure 3-V: Loading Density Parameter fγ



$$f_\gamma = (\gamma / 1600)^{0.35}$$

Q = Weight of Explosives, NEQ [kg]
V_C = Storage Chamber Volume [m^3]

Figure 3-VI Cover Depth Parameter fc



$$f_C = 0.45 + 2.15 * x - 2.11 * x^2 \quad ; \quad x = C / Q^{1/3}$$

C = Overburden, Cover [m]

Q = Weight of Explosives, NEQ [kg]

Figure 3-VII Auxiliary Tables for the Calculation of $Q^{1/3}$, fc and fγ

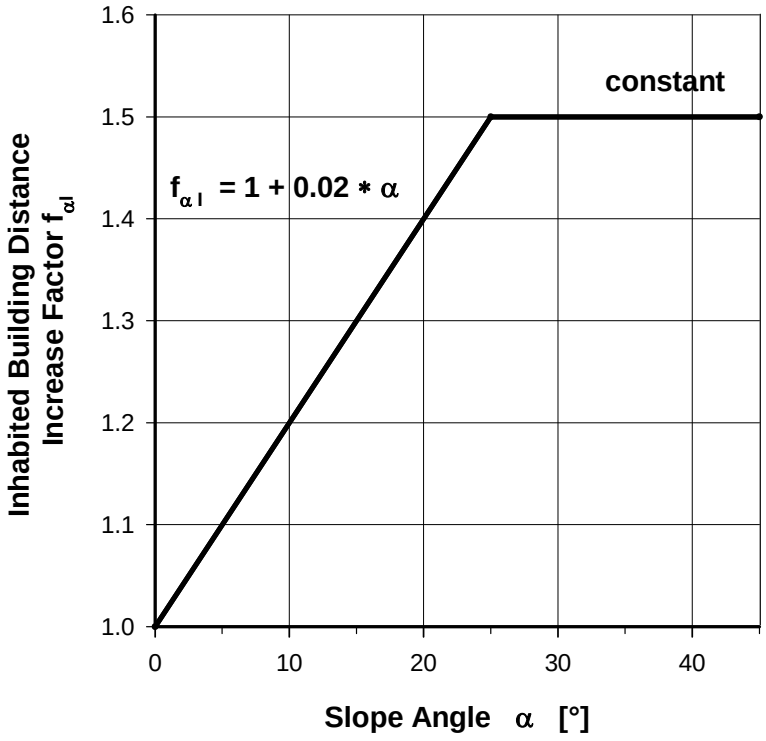
Q [kg]	$Q^{1/3}$ [$kg^{1/3}$]
1'000	**10.0**
1'500	**11.4**
2'000	**12.6**
2'500	**13.6**
3'000	**14.4**
4'000	**15.9**
5'000	**17.1**
6'000	**18.2**
7'000	**19.1**
8'000	**20.0**
10'000	**21.5**
15'000	**24.7**
20'000	**27.1**
25'000	**29.2**
30'000	**31.1**
40'000	**34.2**
50'000	**36.8**
60'000	**39.1**
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**

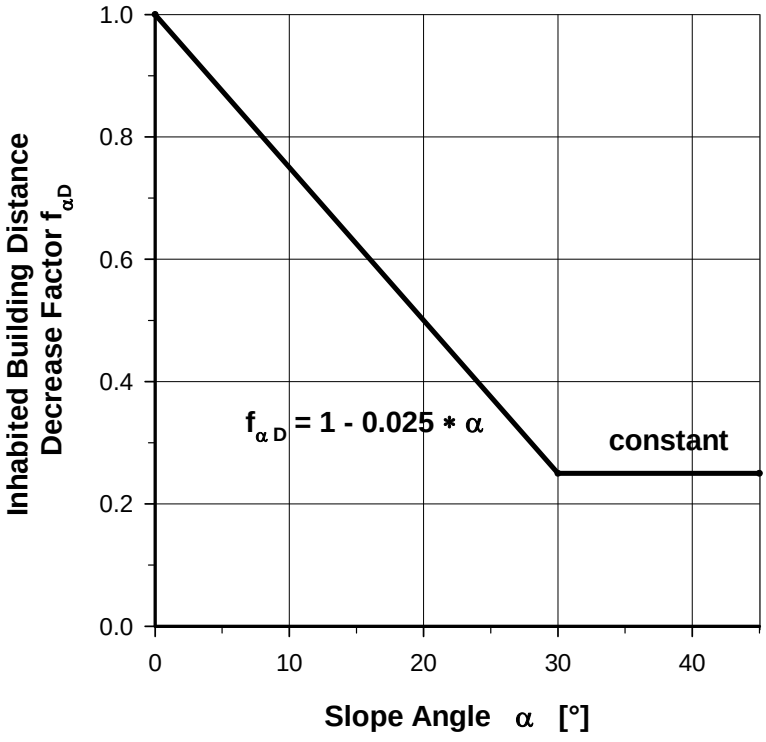
Loading Density [kg/m^3]	f_γ [.]
1	**0.08**
3	**0.11**
5	**0.13**
10	**0.17**
15	**0.20**
20	**0.22**
25	**0.23**
30	**0.25**
40	**0.27**
50	**0.30**
60	**0.32**
70	**0.33**
80	**0.35**
90	**0.37**
100	**0.38**
120	**0.40**
140	**0.43**
160	**0.45**
180	**0.47**
200	**0.48**
220	**0.50**
250	**0.52**
300	**0.56**

Q = Weight of Explosives, NEQ

Figure 3-VIII: Overburden Slope Angle Parameter



α	$f_{\alpha I}$
0.0	1.0
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

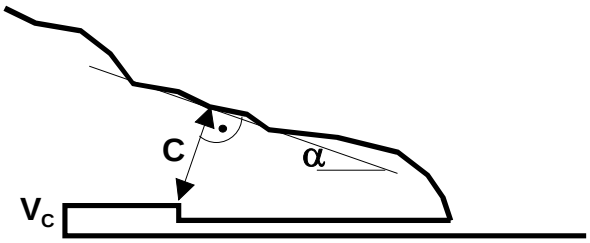


α	$f_{\alpha D}$
0.0	1.0
2.5	0.94
5.0	0.88
7.5	0.81
10.0	0.75
12.5	0.69
15.0	0.63
17.5	0.56
20.0	0.50
22.5	0.44
25.0	0.38
27.5	0.31
>30	0.25

fα

Figure 3-IX: 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 VII) = 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 V or VII) f_γ = 0.27
Cover Depth Parameter (from Figure VI or VII) 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 VIII) $f_{\alpha I}$ = 1.4
IBD Decrease Factor (from Figure VIII) $f_{\alpha D}$=0.5

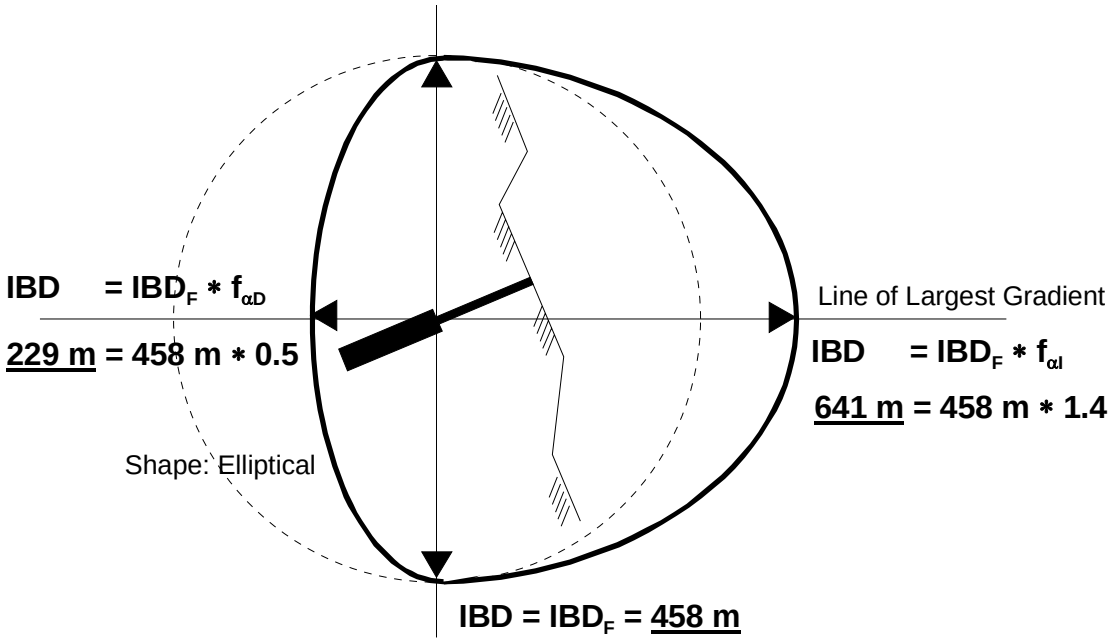
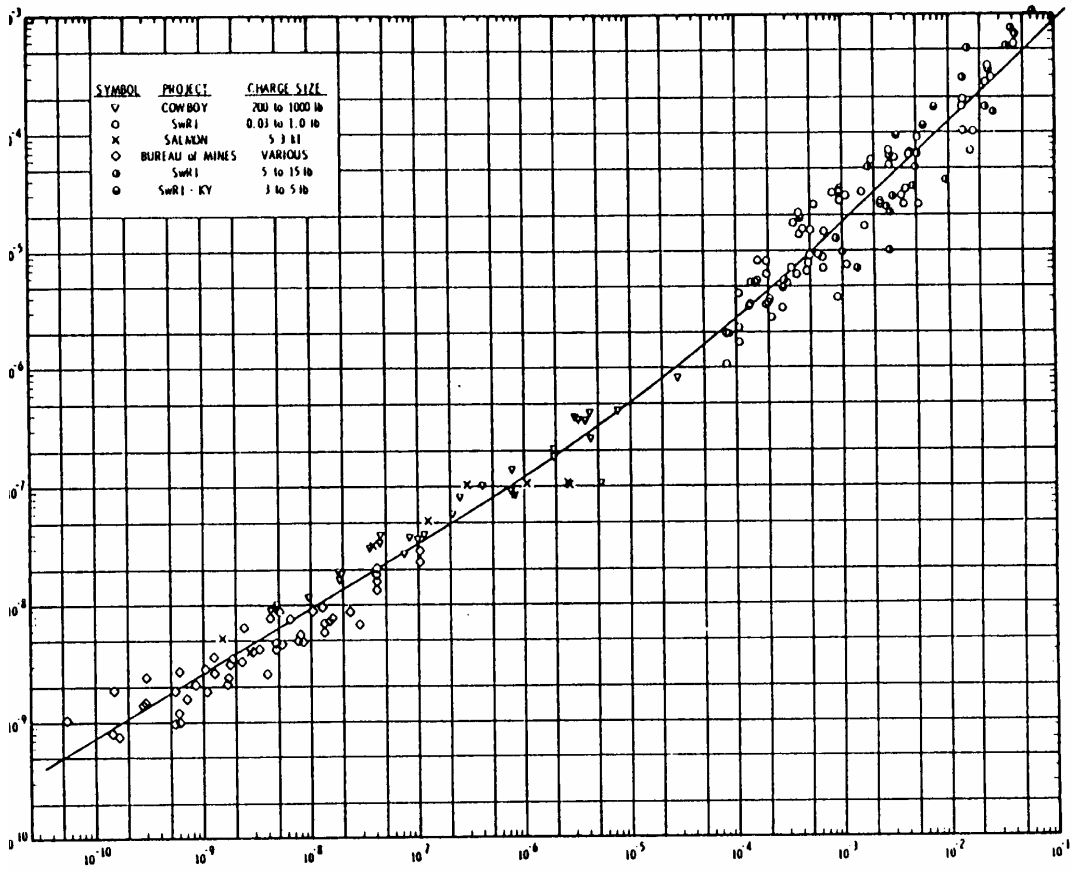


Figure 3-X: Radial Particle Velocity Versus Scaled Energy Release in Rock and Soil

$$\left(\frac{U}{c_p}\right) \cdot \left(\frac{P_o}{\rho_s c_p^2}\right)^{1/2}$$



$$\frac{E_Q \cdot Q}{\rho \cdot c_p^2 \cdot R^3}$$

u_p(tamped) =	peak particle velocity, (m/s)
r =	radial distance (m)
E_Q =	effective energy/mass [3] for explosives material (J/kg)
Q =	net explosives quantity (kg)
ρ_s =	mass density of soil or rock (kg/m^3)
c_p =	seismic velocity of p-wave (m/s)
P_0 =	atmospheric pressure (N/m^2)

MANUAL OF

NATO SAFETY PRINCIPLES

FOR THE STORAGE OF MILITARY

AMMUNITION AND EXPLOSIVES

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.

PART IV

MAY 2006

CHAPTER 1 - GENERAL

4.1.0.1. *Purpose and Scope*

a) This part of the Manual provides safety principles for use in 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.

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 4, 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 on the Safety Aspects of Transportation and Storage of Military

Ammunition and Explosives (AC/258)", 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

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[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 and 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.

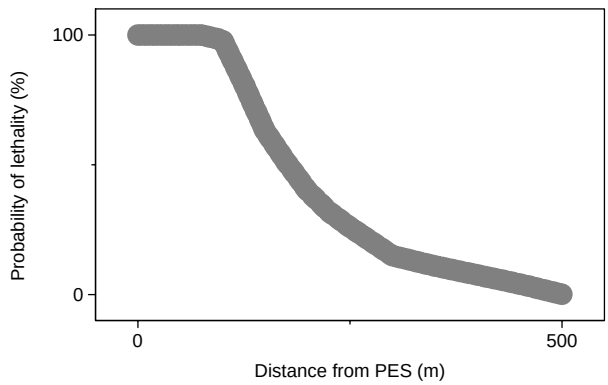


Figure 2.1.a The increase of risk when advised minimum quantity-distances can not be met [7].

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 / (F1çF2çF3...)

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 - QUANTITY-DISTANCE PRINCIPLES FOR BASIC LOAD AMMUNITION HOLDING AREAS

4.4.0.1. *General*

a) Provisions of this chapter apply only to essential basic load ammunition holding areas, which are permitted by host nation laws and/or status of Forces Agreements, case by case.

b) Certain units must keep their basic load ammunition in readiness within the boundaries of their barracks or in the immediate vicinity thereof. This requires deviations from the quantity-distance standards in Part I, Chapter 3. A high level of risk must be accepted in relation to Interior Quantity-Distances, otherwise the units cannot fulfil their mission. The Exterior Quantity-Distances, however, are not reduced.

c) The following quantity-distance standards apply to locations where combat units hold their basic load ammunition in armoured vehicles, trucks, trailers, structures or on pads. Such locations are described in this Manual as basic load ammunition holding areas.

d) It is emphasized that the quantity-distances given in this chapter are the minima and that greater quantity-distances should be observed wherever practicable in order to provide a higher degree of safety.

4.4.0.2. *Mixing of Basic Load Ammunition of Different Hazard Divisions and Compatibility Groups*

Ammunition in Hazard Divisions 1.1 and 1.2 in a basic load ammunition holding area is regarded as Hazard Division 1.1 ammunition for administrative convenience and Table 4-I applies. All components necessary for complete rounds of artillery, mortar and rocket ammunition may be stored together without regard to compatibility. Complete rounds of ammunition of all compatibility groups may be stored together within heavy armoured vehicles.

4.4.0.3. *Net Explosives Quantity*

a) Normally the total NEQ of ammunition in a single site is used for the computation of quantity-distances. For exclusion of propelling charges from the computation, see Part I, paragraph 1.3.2.6. In the case of basic load ammunition holding areas, it is also permitted to exclude from the computation the NEQ of ammunition in Hazard Division 1.3 unless this is the only ammunition at a site in which case Table 3 of Part I, Annex A applies. The maximum NEQ at any site in a basic load ammunition holding area must not exceed 4 000 kg.

b) Armoured Vehicles

The total NEQ of ammunition in each single vehicle (heavy or light) is used for the computation of quantity-distances.

c) Trucks and Trailers

1) The total NEQ of ammunition in each truck or trailer is used for the computation of quantity-distances, provided that each truck or trailer is separated from every other one by at least the BD1-distances in Table 4-I, if barricaded, or BD3-distances, if unbarricaded.

2) The total NEQ of ammunition in all trucks or trailers within a truck park or a trailer park is used for the computation of quantity-distances, if the trucks or trailers within a park are not separated from each other by quantity-distances specified in 1) above.

4.4.0.4. *Separation of Vehicle Parks*

Figure 4-I shows a schematic layout of vehicle parks. The BD-distances refer to the columns in Table 4-I. It is permissible to park both trucks and trailers in a single park.

4.4.0.5. *Separation of Armoured Vehicles*

Armoured vehicles containing basic load ammunition are separated from each other by a minimum distance of 2 m in all directions regardless of the quantity of ammunition within the vehicle. This separation distance is required for manoeuvering of the vehicles and it is not based on explosive safety considerations.

4.4.0.6. *Separation of Trucks and Trailers*

Trucks and trailers containing basic load ammunition are separated from each other by BD3-distances in Table 4-I.

4.4.0.7. *Storage in Earth-Covered Structures*

Sometimes it may be possible to place basic load ammunition in earth-covered structures in unit load configurations which permit rapid loading of vehicles. When standard igloos are used, separation distances given for Hazard Division 1.1 ammunition apply (see Part I, Annex A, Table 1). When earth-covered shelters of light construction are used, the BD1-distances in Table 4-I apply to the side-to-side configuration provided that the earth-cover complies with Part I, paragraph 1.3.6.7. and the explosives are stored at least 1 m from the end of the shelter. If end-to-end exposures are involved the BD2-distances in Table 4-I apply provided that there is a barricade (Part I, paragraph 1.3.6.1.).

4.4.0.8. *Exterior Quantity-Distances*

a) Exterior Quantity-Distances from Vehicles with Heavy Armour

The BD6-distances in Table 4-I are used both as Public Traffic Route Distances and as Inhabited Building Distances. It can be assumed that heavy armour can contain fragments and is therefore an effective barricade. The BD6-distances are based on blast impulse only.

b) Exterior Quantity-Distances from Vehicles with Light Armour

The BD4- and BD5-distances in Table 4-I are used as Public Traffic Route Distances and

Inhabited Building Distances, respectively. Barracks, headquarters and maintenance facilities within a military installation should be separated in all cases from trucks and trailers by BD5-distances. If this is not possible owing to operational requirements and limitations of real estate, the user nation may observe lesser distances provided these have been properly authorized by that user nation.

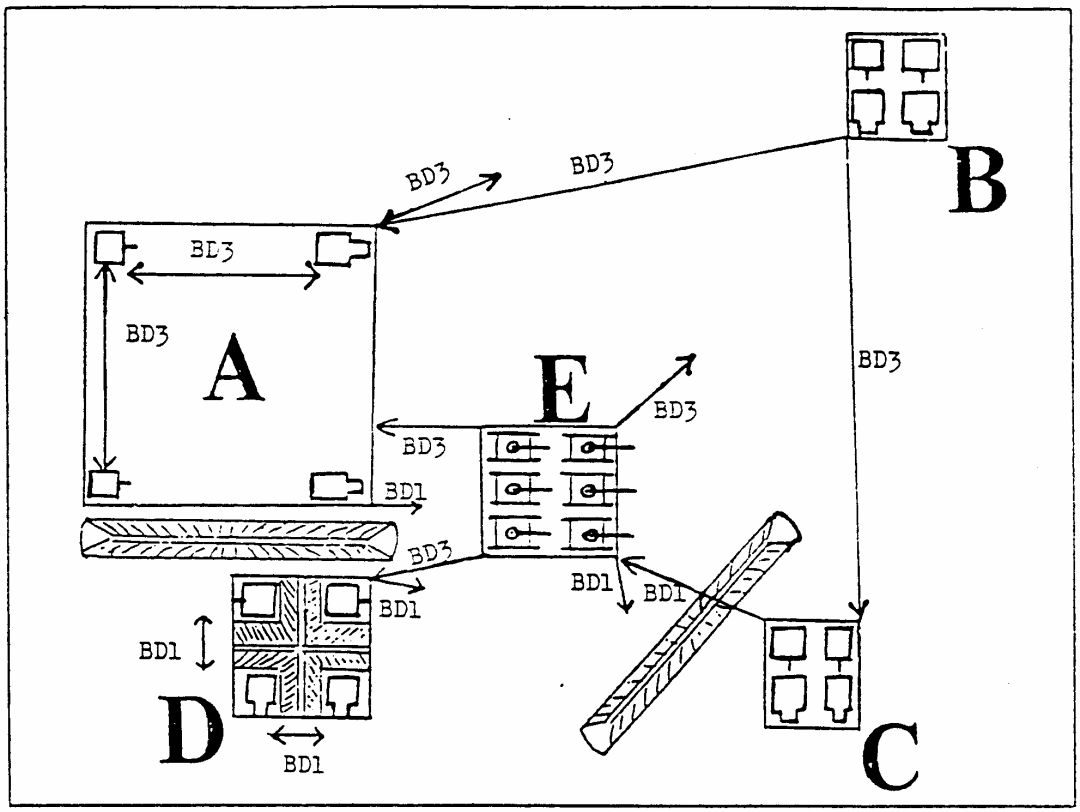
4.4.0.9. *Location of Basic Load Vehicles within Ammunition Facilities*

Proper location of basic load ammunition within ammunition storage points, pre-stock points and depots is essential in order to preclude the possible loss of large stocks of ammunition. Therefore the user nation must assess carefully such a proposal before granting a special authorization.

4.4.0.10. *Miscellaneous Installations*

Basic load ammunition holding areas are separated from other important facilities by BD5-distances in Table 4-I unless special operational requirements demand other distances.

Figure 4-I - Separation of Basic Load Vehicle Parks



1. A, B, C and D are parks for trucks and trailers, each vehicle containing Q_1 kg NEQ.
   E is a park for light or heavy armoured vehicles, each vehicle containing Q_2 kg NEQ.
   Every vehicle and park is considered in turn as, a PES.

2. In Park A the vehicles are unbarricaded but are separated by BD3-distances in Table 4-I. Hence the Interior and Exterior Quantity-Distances from this park are based on Q_1 only.

3. In Park B the vehicles are unbanicaded and closer together than BD3-distances in Table 4-I. Hence the Interior and Exterior Quantity-Distances from this park are based on 4 Q_1.

4. In Park C the effective NEQ is $4Q_1$. Be barricade between Park C and Parks D and E permits BDI-distances in Table 4-1 to be used from this park in the direction of Park D and Park E.

5. In Park D the individual trucks and trailers are barricaded and separated by BDI-distances in Table 4-1. Hence the Interior and Exterior Quantity-Distances from this park are based on Q_1 only.

6. In Park E the vehicles ire separated by at least 2 m. The Interior Quantity-Distance from this park is BDl or BD3 based on Q_2 only. Park E is deemed to be a barricaded PES when the armour is heavy; light armour, however, cannot contain all fragments.

7. When Park E is considered as an ES, it is always deemed to be barricaded since the light or heavy armour is capable of excluding fragments.

8. The relative sizes of the Interior Quantity-Distances depend on the values of Q_1 and Q_2 and the number of trucks and trailers which are aggregated. The optimum layout balances the numbers of vehicles and parks against the availability of land and earth for barricades.

Q-D TABLE FOR BASIC LOAD AMMUNITION HOLDING AREAS

NEQ Q (kg)	Quantity-Distances m					
	BD1	BD2	BD3	BD4	BD5	BD6
50	3.0	7	18	180	270	20
75	3.5	8	21	|	|	26
100	4.0	9	23	|	|	32
125	4.0	9	24	|	|	38
150	4.5	10	26	|	|	42
175	4.5	11	27	|	|	
200	5.0	11	28	|	|	
				|	|	
250	6.0	12	31	|	|	
300	6.0	13	33	|	|	
350	6.0	13	34	|	|	
400	6.0	14	36	|	|	
450	7.0	14	37	|	|	
				|	|	
500	7.0	15	39	|	|	
600	7.0	16	41	|	|	
700	8.0	16	43	|	|	
800	8.0	17	45	|	|	
900	8.0	18	47	|	|	
				|	|	
1 000	8.0	18	48	|	|	
1 200	9.0	20	52	|	|	
1 400	9.0	21	54	|	|	
1 600	10.0	22	57	|	|	
1 800	10.0	22	59	|	|	
				|	|	
2 000	11.0	23	61	180	270	
2 500	11.0	25	66	185	275	
3 000	12.0	26	70	205	305	
3 500	13.0	28	73	220	330	
4 000	13.0	29	77	235	350	
Distance Functions	BD1 = $0.8\ Q^{1/3}$	BD2 = $1.8\ Q^{1/3}$	BD3 = $4.8\ Q^{1/3}$	BD4 = $3.6...Q^{1/2}$	BD5 = $5.5\ Q^{1/2}$	BD6= $1.5Q^{2/3}$

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.

[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 (7.2$Q^{1/3}$) 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.

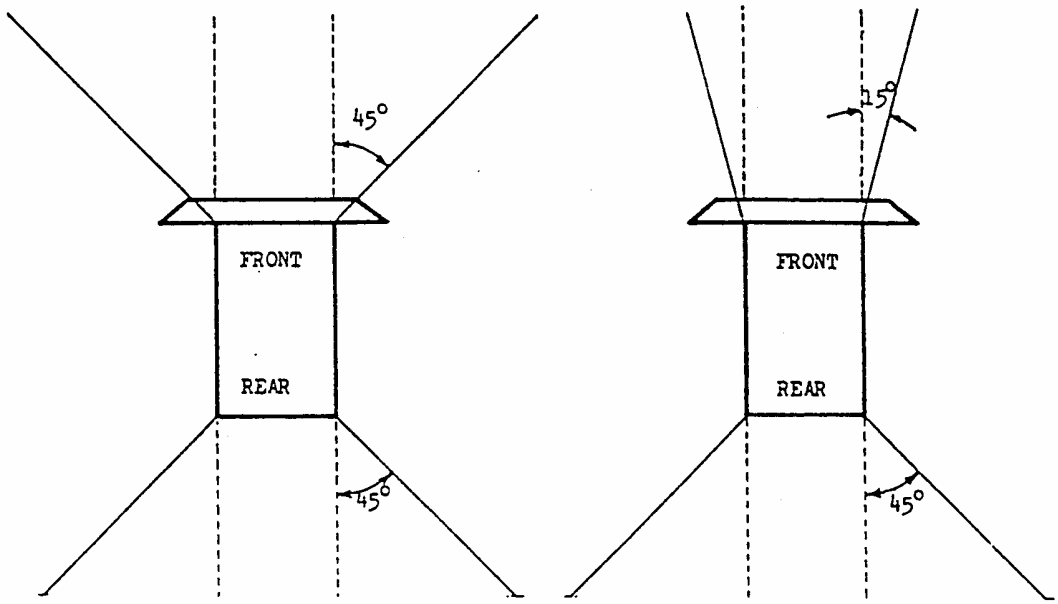
4.5.0.5. *Operational Considerations*

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.

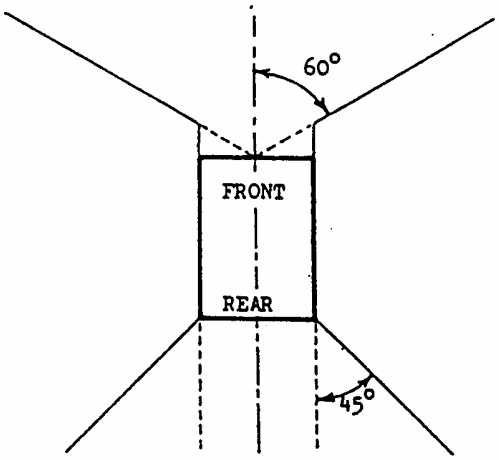
c) Safety is enhanced by towing aircraft, after loading, to aircraft being loaded or unloaded.

Figure 5-I



HAS AS EXPOSED SITE (ES)

HAS AS POTENTIAL EXPLOSION SITE (PES)



IGLOO AS ES OR PES

FIGURE 5-II

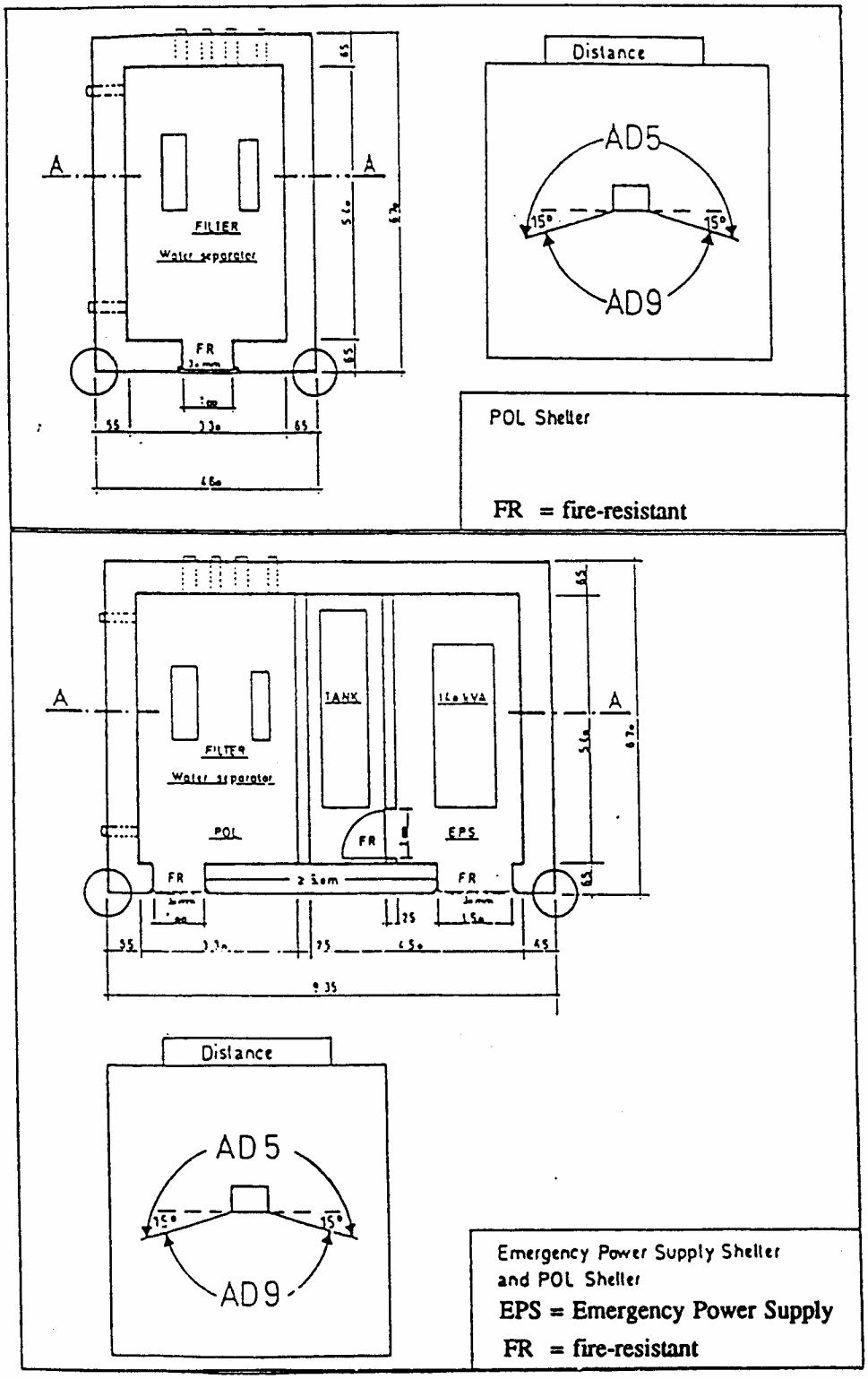

Distance
AD5
AD9
15°
15°
A
A
FILTER
Water separator
FR
POL Shelter
FR = fire-resistant
TANK
EPS
POL
FR
Emergency Power Supply Shelter
and POL Shelter
EPS = Emergency Power Supply
FR = fire-resistant

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	AD12	AD13	AD14	AD15	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 Generation 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 Rear Front Barr. Front Unbarr.	Use PART I Distances					
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

FROM (PES) / TO (ES)		Igloo				Magazine	
		Side	Rear	Front Barr.	Front Unbarr.	Barr.	Unbarr.
1st Generation Aircraft Shelter	Side Rear Front	See TABLE 5-II					
2nd or 3rd Generation Aircraft Shelter	Side Rear Front						
Ready Service Igloo	Side Rear Front Barr. Front Unbarr.	Use PART I Distances					
Ready Service Magazine	Barr. Unbarr.						

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 ESs.

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.

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