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USD(AT&L)

SUBJECT: DoD Ammunition and Explosives Safety Standards: Explosives Safety Construction Criteria

References: See Enclosure 1

V2.1. PURPOSE

V2.1.1. Manual. This Manual is composed of several volumes, each containing its own purpose, and administratively reissues DoD 6055.09-STD (Reference (a)). The purpose of the overall Manual, in accordance with the authority in DoD Directives 5134.01 and 6055.9E (References (b) and (c)), is to establish explosives safety standards (hereafter referred to as "standards") for the Department of Defense.

V2.1.1.1. These standards are designed to manage risks associated with DoD-titled ammunition and explosives (AE) by providing protection criteria to minimize serious injury, loss of life, and damage to property.

V2.1.1.2. Due to the size and complexity of this Manual, alternate paragraph numbering has been approved for use throughout. The initial numeric set (V#) refers to the volume number within the Manual; the second set (E#) refers to the enclosure number; and subsequent numbers refer to the section, paragraph, and subparagraph numbers. If there is no E#, the reference is to a section above the signature of the volume.

V2.1.2. Volume. This Volume provides criteria for the construction of barricades and explosives facilities, to include criteria for facilities with reduced separation distances.

V2.2. APPLICABILITY. This Volume:

V2.2.1. Applies to:

V2.2.1.1. OSD, the Military Departments, the Office of the Chairman of the Joint Chiefs of Staff and the Joint Staff, the Combatant Commands, the Office of the Inspector General of the

Department of Defense, the Defense Agencies, the DoD Field Activities, and all other organizational entities within the Department of Defense (hereafter referred to collectively as the "DoD Components").

V2.2.1.2. DoD-titled AE wherever it is located.

V2.2.1.3. DoD personnel and property when potentially endangered by known host-nation or off-installation AE hazards.

V2.2.1.4. DoD facilities siting and construction, except as indicated in paragraph V2.2.2.

V2.2.1.5. The evaluation of non-DoD explosives siting submissions on DoD installations (see section V4.E5.21.).

V2.2.2. Provided the documentation requirements of paragraph V2.E2.3.5. are met, does not apply to:

V2.2.2.1. Existing facilities, or those approved for construction under then-current editions of these standards. This exception applies for the balance of the useful lives of such facilities provided:

V2.2.2.1.1. The facility continues to be used for its intended purpose.

V2.2.2.1.2. The explosives safety hazards are not increased.

V2.2.2.1.3. Redesign or modification is not practicable.

V2.2.2.1.4. The quantity of AE cannot be reduced for reasons of operational necessity.

V2.2.2.2. Those planned facilities that do not meet these standards, but have been certified by the Heads of the DoD Components (see section V1.E3.4.) as essential for operational or other compelling reasons.

V2.2.2.3. Other situations that, upon analysis by the Heads of the DoD Components and the Department of Defense Explosives Safety Board (DDESB), are determined to provide the required degree of safety through use of protective construction or other specialized safety features.

V2.3. DEFINITIONS

V2.3.1. Abbreviations and Acronyms. See Glossary.

V2.3.2. Terms. See Volume 8 of this Manual.

V2.4. POLICY. As established in Reference (c) and consistent with peacetime, contingency, or wartime operational requirements and corresponding DoD military munitions requirements from the broadest and most fundamental explosives safety management perspective, it is DoD policy to:

V2.4.1. Provide the maximum possible protection to people and property from the potential damaging effects of DoD military munitions (explosive and chemical). Applying the standards herein provides only the minimum protection criteria for personnel and property, and greater protection should always be provided when practicable.

V2.4.2. Minimize exposures consistent with safe and efficient operations (i.e., expose the minimum number of people for the minimum time to the minimum amount of explosives or chemical agents).

V2.5. RESPONSIBILITIES. See Enclosure 2.

V2.6. PROCEDURES. See Enclosures 3 through 5. Criteria provided in this Manual are given in English units (e.g., foot or feet (ft), pounds (lbs), pounds per square inch (psi)), with metric equivalents shown in brackets (e.g., meters (m), kilograms (kg), kilopascals (kPa)).

V2.7. RELEASABILITY. UNLIMITED. This Volume is approved for public release and is available on the Internet from the DoD Issuances Website at http://www.dtic.mil/whs/directives.

V2.8. EFFECTIVE DATE. This Volume is effective upon its publication to the DoD Issuances Website.

Enclosures
1. References
2. Responsibilities
3. Electrical Standards
4. Lightning Protection
5. Construction Criteria Permitting Reduced Separation Distances

Glossary

TABLE OF CONTENTS

TABLES

FIGURES

ENCLOSURE 1

REFERENCES

(a) DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," February 29, 2008 (cancelled by Volume 1 of this Manual)
(b) DoD Directive 5134.01, "Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L))," December 9, 2005
(c) DoD Directive 6055.9E, "Explosives Safety Management and the DoD Explosives Safety Board," August 19, 2005
(d) National Fire Protection Association 70, "National Electrical Code®," current version
(e) Under Secretary of Defense for Acquisition, Technology, and Logistics Memorandum, "Radio Frequency Identification (RFID) Policy," July 30, 2004
(f) National Fire Protection Association 780, "Standard for the Installation of Lightning Protection Systems," current version
(g) Department of Defense Explosives Safety Board, Technical Paper 15, Revision 3, "Approved Protective Construction," May 2010
(h) U.S. Army Corps of Engineers Report HNDED-CS-S-95-01, "Guide for Evaluating Blast Resistance of Nonstandard Magazines," January 1995[1]

[1] Available at www.ddesb.pentagon.mil.

ENCLOSURE 2

RESPONSIBILITIES

V2.E2.1. UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS (USD(AT&L)). The USD(AT&L) shall provide overall policy guidance for the DoD Explosives Safety Management Program.

V2.E2.2. CHAIRMAN, DDESB. The Chairman, DDESB, shall report to the Deputy Under Secretary of Defense for Installations and Environment (DUSD(I&E)) and, on behalf of the USD(AT&L) and the DUSD(I&E), shall collaborate with the Military Service-appointed voting DDESB members to maintain explosives safety standards.

V2.E2.3. HEADS OF THE DoD COMPONENTS. The Heads of the DoD Components shall:

V2.E2.3.1. Implement these DoD explosives safety standards.

V2.E2.3.2. Comply with applicable Federal and State laws and regulations. Where this Volume conflicts with such laws and regulations, ensure the safety of DoD personnel and the public while complying and notify the Chairman, DDESB, through the Component's board member, of the conflict. These standards are not intended to be so rigid as to prevent the DoD Components from accomplishing their assigned missions.

V2.E2.3.3. Issue DoD Component guidance that implements these standards and provides DoD Component unique requirements.

V2.E2.3.4. Send a copy of any implementing and supplementary guidance to these standards to the Chairman, DDESB.

V2.E2.3.5. Document the exceptions described in paragraph V2.2.2. in permanent records. These records must include:

V2.E2.3.5.1. The effective date the applicable DoD explosives safety standards were first published.

V2.E2.3.5.2. The date the deviant facility was either approved, from an explosives safety viewpoint, for use or was first used in a manner deviating from the standard.

ENCLOSURE 3

ELECTRICAL STANDARDS

V2.E3.1. GENERAL. This enclosure establishes safety standards for the design and installation of electrical equipment and wiring for explosives environments.

V2.E3.1.1. For the purposes of this Volume, the Department of Defense adopts Article 500 of the code "Hazardous (Classified) Locations" of the National Fire Protection Association (NFPA) 70 (Reference (d)), also known and hereafter referred to as the "National Electrical Code (NEC)". NEC establishes standards for the design and installation of electrical equipment and wiring for atmospheres containing combustible dusts, flammable vapors, or gasses that are comparably hazardous.

V2.E3.1.2. This enclosure does not address extraordinarily hazardous situations (e.g., nitroglycerin manufacturing) that require special consideration and design features. In these situations, the DoD Components shall develop site-specific design criteria.

V2.E3.2. HAZARDOUS LOCATIONS. NEC definitions of Class I, Division 1, and Class II, Division 1, hazardous locations are modified as follows for DoD explosives applications:

V2.E3.2.1. Areas containing explosives dusts or explosives that may, through handling, produce dust capable of being dispersed in the atmosphere shall be regarded as Class II, Division 1.

V2.E3.2.2. Areas in which explosives sublimation or condensation may occur shall be regarded as both Class I, Division 1, and Class II, Division 1.

V2.E3.3. SPECIAL OCCUPANCIES. To ensure assignment to the proper hazardous location, class, and group, it is necessary to have knowledge of the properties of explosives involved. Minimum requirements include sensitivity to heat and spark and thermal stability.

V2.E3.3.1. Acceptable Approaches for Inadequate Protection. If the properties of an explosive are such that Class I or Class II, or both, provide inadequate protection under prevailing conditions, use of any of the following approaches is acceptable:

V2.E3.3.1.1. Intrinsically safe equipment.

V2.E3.3.1.2. Purged or pressurized and suitably temperature-limited equipment.

V2.E3.3.1.3. Exclusion of electrical equipment from the hazardous atmosphere.

V2.E3.3.1.4. Isolation of equipment from the hazardous atmosphere by means of dust, vapor, or gas-free enclosures with surface temperatures positively maintained at safe levels.

V2.E3.3.2. Underground Storage Facilities. All wiring and electrical equipment in underground storage facilities shall, in addition to any other requirements of this enclosure, be of moisture and corrosion-resistant materials and construction unless a site-specific analysis indicates that such construction is not necessary. Underground facilities shall have emergency lighting systems to provide minimum illumination in the event of a power failure.

V2.E3.4. STATIC ELECTRICITY. Personnel and equipment in hazardous locations (section V2.E3.2.) and locations where static sensitive electro-explosive devices (EEDs) are exposed shall be grounded in a manner that effectively discharges static electricity and prevents static electricity accumulations that may be capable of initiating dusts, gases, vapors, or exposed EEDs. Permanent equipment in contact with conductive floors and tabletops shall not be considered grounded. Static grounds shall be bonded to the facility's grounding system. (See Enclosure 4 of this Volume.)

V2.E3.5. ELECTRIC SUPPLY SYSTEMS. There may be mutual hazards when potential explosion sites (PESs) are located near electric supply lines. To protect against these hazards, the following separation requirements apply to all new construction (public traffic route distance (PTRD) and inhabited building distance (IBD) specified in paragraphs V2.E3.5.3. and V2.E3.5.4. are based on airblast overpressure only; fragment distances do not apply):

V2.E3.5.1. Electric lines serving explosives operating facilities shall be installed underground from a point not less than 50 ft [15.3 m] away from such facilities.

V2.E3.5.2. Overhead electric service lines shall be no closer to combustible PES or to an open PES than the length of the electric lines between the nearest service poles and the length of the nearest service pole. An exception is when an effective means (e.g., line spacers, weights) is provided to ensure that energized lines on breaking cannot come into contact with the facility or its appurtenances.

V2.E3.5.3. Electric distribution lines carrying less than 69 kilovolts (kV), the tower or poles supporting those lines, and unmanned electrical substations shall be no closer to PESs than PTRD. Lesser distance is permitted by Enclosure 3 of Volume 3 of this Manual for the placement of electrical substations and transformers that support explosives areas.

V2.E3.5.4. Electric transmission lines carrying 69 kV or more and the tower or poles supporting them shall be located no closer to the PES than:

V2.E3.5.4.1. IBD, if the line in question is part of a grid system serving a large off-base area.

V2.E3.5.4.2. PTRD, if loss of the line does not create serious social or economic hardships.

V2.E3.5.5. Electric transmission lines that can be interrupted without loss of power (i.e., power is rerouted through existing lines or networks) shall be separated from explosives sites in accordance with (IAW) paragraph V2.E3.5.2.

V2.E3.6. SURGE PROTECTION FOR INCOMING CONDUCTORS

V2.E3.6.1. An AE facility shall include surge protection for all incoming conductors. The surge protection must include suppression at the entrance to the facility from each wire to ground. All other metallic utility lines and pipes must be electrically connected to the structural steel of the building just before they enter the AE facility.

V2.E3.6.2. Any conductors, shielded cabling, power cabling, and communication lines shall be buried underground in metal conduit for a minimum of 50 ft [15.3 m] before entering an AE facility.

V2.E3.7. HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO). Military munitions (at times, also referred to as ordnance or AE) containing electrically initiated devices (EIDs) (e.g., exploding foil initiators, laser initiators, burn wires, fusible links, hot bridge wires, carbon bridges, and conductive compositions) shall be designed or protected such that electromagnetic radiation (EMR) does not cause an inadvertent initiation, degradation, or disablement. Both direct radio frequency (RF) induced actuation of the EID or electrical coupling to and triggering of the associated firing circuits can occur, especially in a tactical radiated electromagnetic environment (EME).

V2.E3.7.1. Certification of Military Munitions. During acquisition, HERO evaluation and certification of military munitions shall be accomplished, both for routine employment mission profiles and for any anticipated joint- or combined-operational employment to include all phases of the life-cycle EMEs identified in subparagraph V2.E3.7.1.2.

V2.E3.7.1.1. Recertification of Military Munitions. HERO certification shall be accomplished when legacy military munitions are redesigned or before military munitions are employed in an EME for which they were not previously HERO certified.

V2.E3.7.1.2. Life Cycle EME. Minimally, HERO certification shall involve evaluation without adverse effects to military munitions in an EME relevant to all life cycle configurations. This life cycle is referred to as the stockpile-to-safe-separation sequence or S4, and can consist of up to six distinct phases: transportation/storage, assembly/disassembly, handling/loading, staged, platform-loaded, and immediate post-launch.

V2.E3.7.1.3. HERO Database. All data from HERO evaluations shall be compiled in a centralized data repository to support the Joint Spectrum Center Ordnance Electromagnetic

Environmental Effects Risk Assessment Database for subsequent use in information applications supporting the DoD Components.

V2.E3.7.2. EME Controls. The DoD Components shall take measures (e.g., identifying susceptibilities, quantifying EMEs, evaluating risks associated with operating procedures, and establishing tailored emission control instructions) to ensure that HERO effects on military munitions are resolved during the planning of joint or combined operations and training exercises.

V2.E3.8. POSTING OF RF WARNING SIGNS. Areas where the levels of RF electromagnetic fields constitute a radiation hazard to military munitions or to flammable materials located in areas where radiation hazards to military munitions exist shall be clearly marked with warning signs or labels for mobile emitters.

V2.E3.8.1. HERO Warning Signs. Warning signs shall be posted at any location where radar equipment or other possible sources of EMR might create the potential for premature initiation of military munitions. Warning signs shall be placed along transportation routes approaching military munitions operations (e.g., missile assembly, ammunition pier) at designated locations. Warning signs should alert operators of mobile or portable emitter systems to a potential hazard and restrictions when using these emitters (e.g., radios, cellular telephones) past the designated point.

V2.E3.8.2. HERO Warning Labels. Warning labels may be affixed to all operated portable or mobile emitter systems to alert the user of the potential hazard if the emitter is operated closer than the prescribed safe separation distance for the military munitions-related operation of concern where appropriate.

V2.E3.8.3. Radio Frequency Identification (RFID)

V2.E3.8.3.1. USD(AT&L) Memorandum (Reference (e)) mandates the use of RFID technology. Reference (e) also mandates that Services quantify the mutual effects of the devices with respect to HERO.

V2.E3.8.3.2. Prior to using electronic equipment that intentionally generates RF energy to identify or track military munitions or for use within a military munitions storage or operating facility (e.g., assembly or disassembly, build-up areas), the using Service shall evaluate and certify such equipment for use. The certification process shall involve comparing the device's radiated emission characteristics with respect to a military munition's potential susceptibility and determining a safe separation distance.

V2.E3.8.3.2.1. If the system does not have a HERO impact that requires a safe separation distance for military munitions, the Service certifying agent shall issue a HERO certification (unrestricted) to the program manager (PM), acquisition manager (AM), or installation activity (IA) and forward a copy of the certification to the Service testing agent and proponent for publications related to the affected military munition.

V2.E3.8.3.2.2. If the system is determined to have a limited impact that will not impose operational restrictions or diminish the capability of the automatic identification technology (AIT) equipment to be used as intended and requires a safe separation distance for military munitions, the Service certifying agent shall issue a HERO certification (with restrictions) to the PM, AM, or IA and forward a copy of the certification to the Service testing agent and proponent for publications related to the affected military munition.

V2.E3.8.3.2.3. If the system can adversely affect military munitions to the extent that managing HERO will impose undue operational restrictions or the restrictions (e.g., required safe separation distances) placed on the system will diminish the capability of the equipment to be used as intended, the Service certifying agent shall issue a letter rejecting HERO certification and notifying the PM, AM, or IA of the need to either fix the equipment or, in the case of an operational requirement, request a waiver of the HERO certification requirements. Should the PM choose to fix the AIT equipment, the HERO certification request shall be reprocessed upon evaluation by the Service testing agent.

ENCLOSURE 4

LIGHTNING PROTECTION

V2.E4.1. CRITERIA. This enclosure provides the minimum explosives safety criteria for the design, installation, inspection, testing, training, and maintenance of lightning protection systems (LPSs). The Department of Defense has selected the LPS criteria of NFPA 780 (Reference (f)), as modified herein, including ~~Annex K (Protection of Structures Housing Explosive Materials),~~ Annex D (Inspection and Maintenance of Lightning Protection Systems)~~,~~ and Annex E (Ground Measurement Techniques) for AE facilities. Reference (f) shall apply regardless of any statements of nonapplicability contained within Reference (f). Annex criteria shall supersede main body criteria.~~ Properly maintained LPSs are required for AE facilities.~~

V2.E4.2. LPS DESIGN AND INSTALLATION. LPSs used to protect DoD AE must be designed and installed using the rolling sphere method with a radius of 100 ft [30.5 m] or less IAW ~~Annex K of Reference (f)~~ *Chapter 8 of Reference (f). All DoD AE facilities must be protected; section 8.1.1 of Reference (f) does not apply.*

V2.E4.2.1. Sideflash Protection. Protection from sideflash caused by lightning shall be obtained by either separation distance or bonding IAW Reference (f). In addition, fences*, gates,* and railroad tracks located within 6 ft [1.9 m] of a structure's LPS shall be bonded to the structure's LPS.

V2.E4.2.2. Earth Electrode System. Earth electrode systems dissipate the current from a lightning strike to ground. Earth electrode systems may be concrete-encased electrodes, ground loop conductors, radials, grounding rods, ground plates, a conductor immersed in nearby saltwater, chemical grounds that are installed for the purpose of providing electrical contact with the earth, or combinations of these.

V2.E4.2.3. Surge Protection. Surge protection devices shall be installed, IAW Reference (f), at all points where electrical or electronic system conductors enter or exit an AE facility.

V2.E4.2.4. Underground Storage Facilities. An underground storage site only requires protection against lightning for exposed or partially exposed parts. Lightning protection requirements shall be considered on a site-specific basis.

V2.E4.3. INSPECTION, TESTING, TRAINING, AND MAINTENANCE

V2.E4.3.1. Visual Inspection. *Sections 8.9.6 and 8.9.7 of Reference (f) do not apply.* LPSs shall be periodically inspected at a frequency determined by each DoD Component. The maximum interval between LPS visual inspections shall be 1 year or an interval determined by a continuously validating statistical model determined by the DoD Component and approved by the DDESB.

V2.E4.3.2. Electrical Tests. LPSs shall be electrically tested when placing a new facility into service and after any facility modification that may have affected the system. The maximum interval between LPS electrical testing shall be 2 years or an interval determined by a continuously validating statistical model determined by the DoD Component and approved by the DDESB. LPSs shall be tested IAW Annex D of Reference (f), and shall meet the values specified in subparagraphs V2.E4.3.2.1. and V2.E4.3.2.2.

V2.E4.3.2.1. Bonding (Resistance) Tests. A maximum resistance value of 1 ohm is permitted across each bond.

V2.E4.3.2.2. Earth Electrode Tests. The maximum resistance to earth shall not exceed 25 ohms. The DoD Components shall establish guidance for situations (e.g., lack of top soil, desert conditions) where the maximum resistance cannot be met.

V2.E4.3.2.3. Test Equipment. Test instruments shall be in good working order and calibrated IAW manufacturers' recommendations.

V2.E4.3.3. Records and Data. Records and test measurement data of resistance to earth and bonding tests shall be kept on file for the last six inspection cycles.

V2.E4.3.4. Training. Each DoD Component shall establish training requirements for personnel conducting LPS maintenance, inspection, and testing for AE facilities.

V2.E4.3.5. Maintenance. Maintenance shall be performed to ensure that the integrity of the LPS conforms with the criteria of Reference (f). *Properly maintained LPSs are required for all AE facilities.*

V2.E4.4. LIGHTNING PROTECTION EXCEPTIONS. *Paragraphs V2.E4.4.1. through V2.E4.4.6. supersede section 8.1.3 of Reference (f).* Exceptions to the LPS criteria in sections V2.E4.1. through V2.E4.3 are:

V2.E4.4.1. An LPS is not required if all of the conditions in subparagraphs V2.E4.4.1.1. through V2.E4.4.1.3. are met.:

V2.E4.4.1.1. Explosives facilities are served by an approved local lightning warning system (as determined by each DoD Component) permitting AE operations to be terminated before a thunderstorm is within 10 miles [16 kilometers] of the installation.

V2.E4.4.1.2. All personnel are evacuated to a ~~shelter~~ *location* providing protection equivalent to PTRD *based on airblast overpressure only (minimum fragment distances do not apply)*.

V2.E4.4.1.3. The resulting damage and loss from a lightning strike is acceptable to the DoD Component.

V2.E4.4.2. An LPS is not required for facilities containing only AE that cannot be initiated by lightning, and where no fire hazard exists, as determined by the DoD Component and approved by the DDESB.

V2.E4.4.3. An LPS is not required for AE facilities where personnel are not expected to sustain injury; at the same time, the resulting economic loss of the structure, its contents, and surrounding facilities is acceptable to the DoD Component.

V2.E4.4.4. The DoD Components shall establish guidance when airfield or flight-line criteria conflicts with LPS requirements.

V2.E4.4.5. Earth-covered magazines (ECMs) that constitute a metallic cage, as defined in ~~Annex K~~ *Chapter 8* of Reference (f), and do not contain any energized or unbonded metallic penetrations, do not require earth resistance testing.

V2.E4.4.6. Large catenary systems that cannot conform to the bonding distances calculated from the equations provided in Reference (f) shall be considered under the alternate LPS criteria in section V2.E4.5. Engineering analyses shall be provided to ensure that variances from Reference (f) provide equivalent protection. The DoD Components shall validate engineering analyses prior to submitting to DDESB for approval.

V2.E4.5. ALTERNATE LPS. If other LPSs for AE facilities are used, they shall offer equivalent protection. The DDESB must approve use of nonstandard lightning protection schemes or nonstandard lightning protection test methods that provide equivalent protection.

ENCLOSURE 5

CONSTRUCTION CRITERIA PERMITTING REDUCED SEPARATION DISTANCES

V2.E5.1. GENERAL

V2.E5.1.1. This enclosure contains DoD standards for construction of ECMs, barricades, barricaded open storage modules, special structures, earth-filled, steel bin-type barricades known as ARMCO, Inc. revetments, and underground storage facilities. Facilities constructed per this enclosure:

V2.E5.1.1.1. Are permitted to use reduced separation distance criteria.

V2.E5.1.1.2. Must meet the criteria of Enclosures 3 and 4 of this Volume.

V2.E5.1.2. Construction features and location are important safety considerations in planning facilities. The effects of potential explosions may be altered significantly by construction features that limit the amount of explosives involved, attenuate blast overpressure or thermal radiation, and reduce the quantity and range of hazardous fragments and debris. Proper location of exposed sites (ESs) in relation to PESs helps minimize unacceptable damage and injuries in the event of an incident. The major objectives in facility planning shall be to:

V2.E5.1.2.1. Protect against explosion propagation between adjacent bays or buildings and protect personnel against death or serious injury from incidents in adjacent bays or buildings. The construction of separate buildings to limit explosion propagation, rather than the use of either protective construction or separation of explosives within a single building, should be considered when safety would be greatly enhanced or cost would be significantly reduced.

V2.E5.1.2.2. Protect assets when warranted.

V2.E5.1.3. Protective construction, such as hardening an ES or constructing a PES to suppress explosion effects to provide an appropriate degree of protection, may allow a reduction of the separation distances required by quantity-distance (QD) tables. The rationale and supporting data that justify any such QD reduction shall be submitted to the DDESB with the site and general construction plans for approval (see section V1.E5.1.)

V2.E5.1.4. New construction of previously DDESB-approved 7-Bar and 3-Bar (structural strength designations) ECMs must meet the minimum requirements of the current revisions of the approved drawings.

V2.E5.2. SPECIAL STRUCTURES. The DDESB has approved reduced QD for structures and containers listed in Table AP1-4. of DDESB Technical Paper 15 (Reference (g)).

V2.E5.3. ABOVEGROUND MAGAZINES (AGM). There are no DDESB construction criteria for AGM. However, such structures must meet the criteria of Enclosures 3 and 4 of this Volume.

V2.E5.4. BARRICADES

V2.E5.4.1. General

V2.E5.4.1.1. Properly constructed and sited barricades and undisturbed natural earth have explosives safety applications for protecting against low-angle fragments and reducing shock overpressure loads very near the barricade. Barricades provide no protection against high-angle fragments or lobbed AE. If the barricade is destroyed in the process of providing protection, then secondary fragments from the destroyed barricade must also be considered as part of a hazards analysis.

V2.E5.4.1.2. To reduce hazards from high-velocity, low-angle fragments, the barricade must be placed between the PES and the ES so that the fragments of concern impact the barricade before the ES. The barricade must be thick enough so that it reduces fragment velocities to acceptable levels and high enough so that it intercepts the ballistic trajectories of the fragments of concern.

V2.E5.4.1.3. A barricade placed between a PES and an ES interrupts the direct line-of-sight motion of the shock wave. If the barricade has sufficient dimensions and is located close enough to the ES, there may be significant reductions in shock loading to selected areas of the ES.

V2.E5.4.2. Barricade Designs

V2.E5.4.2.1. DDESB-Approved Designs. Chapter 6 of Reference (g) lists DDESB-approved designs and construction materials for barricades. Use of these barricades satisfies barricading criteria.

V2.E5.4.2.2. Alternate Barricade Designs. Alternate barricade designs (e.g., earth-filled steel bin) may be approved by the DDESB, provided that testing or analysis demonstrates their effectiveness in stopping high-velocity, low-angle fragments.

V2.E5.4.2.3. Barricade Size and Orientation to Prevent Prompt Propagation Due to High-Velocity, Low-Angle Fragments. The location, height, and length of a barricade to prevent prompt propagation due to high-velocity, low-angle fragments shall be determined as follows:

V2.E5.4.2.3.1. Location. The barricade may be placed anywhere between the PES and the ES; however, placing it closer to either the PES or ES will provide slightly greater asset protection. For AE stacks of different height (elevation), the location shall determine the barricade's required height.

V2.E5.4.2.3.2. Height. To determine the required barricade height:

V2.E5.4.2.3.2.1. Establish a reference point at the top of the far edge of one of the two AE stacks between which the barricade is to be constructed. When both stacks are of equal height, the reference point may be established on either stack. If the tops of the two stacks are not of equal height (elevation), the reference point shall be on the top of the lower stack. To preclude building excessively high barricades between AE stacks of different height (elevation), the barricade should be located as close as possible to the lower stack. (See Figure V2.E5.F1.)

V2.E5.4.2.3.2.2. Draw a line from the reference point to the highest point of the other stack (line-of-sight).

V2.E5.4.2.3.2.3. The barricade's height shall be such that the entire width of the barricade crest is at least 1 ft [0.3 m] above the line-of-sight as established in subparagraph V2.E5.4.2.3.2.2. The barricade height shall be measured at the time of construction and at intervals throughout the life of the barricade to ensure that the specified thickness and height of the barricade are maintained. If the specified thickness and height of the barricade are not maintained, the AE stack height shall be reduced as necessary or the AE stacks shall be resited appropriately. Consideration should be given to making the barricade higher than required for safety purposes to account for accuracy of storage practices regarding AE stack heights, potential mission changes (requiring higher AE stacks), and barricade settling, erosion, etc., that could seriously degrade AE storage capability.

V2.E5.4.2.3.3. Length. The barricade's length shall be determined per Figure V2.E5.F1.

V2.E5.4.2.4. Barricade Size and Orientation for Barricaded Intraline Distance (ILD) Protection. The location, height, and length of a barricade shall be determined as follows:

V2.E5.4.2.4.1. Location. The barricade may be placed anywhere between the PES and the ES. The location shall determine the barricade's required height.

V2.E5.4.2.4.2. Height. To determine the required barricade height:

V2.E5.4.2.4.2.1. Establish a reference point at the top of the far edge of one of the two AE stacks between which the barricade is to be constructed. When both stacks are of equal height, the reference point may be established on either stack. If the tops of the two stacks are not of equal height (elevation), the reference point shall be on the top of the lower stack. To preclude building excessively high barricades, the barricade should be located as close as possible to the stack on which the reference point was established. (See Figure V2.E5.F2.)

V2.E5.4.2.4.2.2. Draw a line from the reference point to the highest point of the other stack.

V2.E5.4.2.4.2.3. Draw a second line from the reference point forming an angle of two degrees above the line.

V2.E5.4.2.4.3. Length. The barricade's length shall be determined per Figure V2.E5.F2.

V2.E5.4.2.5. Barricade Size and Orientation for Protection Against Overpressure. General procedures to predict pressure mitigation versus barricade design and location have not been developed. However, based on direct-experimental work, the overpressure loading on a surface area shielded by a barricade is reduced by approximately 50 percent when the following conditions are met:

V2.E5.4.2.5.1. Location. The barricade's standoff is within two barricade heights of the protected area.

V2.E5.4.2.5.2. Height. The top of the barricade is at least as high as the top of the protected area.

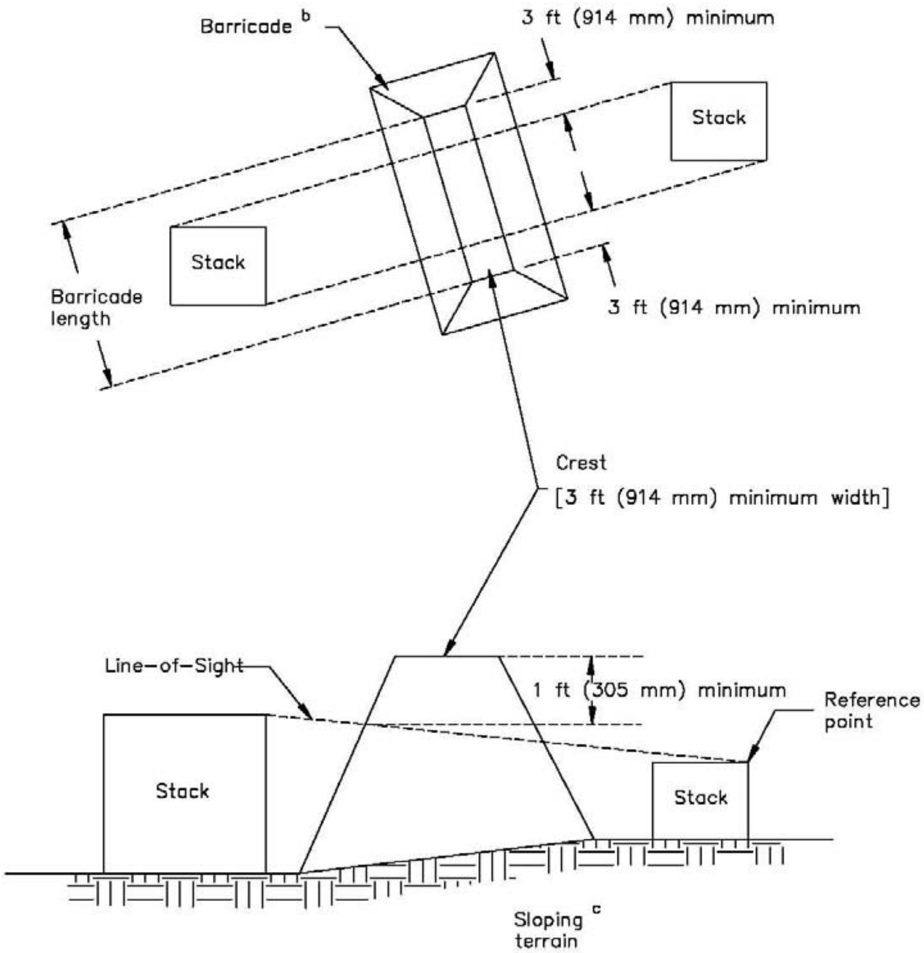
V2.E5.4.2.5.3. Length. The length of the barricade is at least two times the length of the protected area.

V2.E5.4.3. Barricade Construction Materials

V2.E5.4.3.1. Materials for earthen barricades shall be reasonably cohesive and free from harmful (toxic) matter, trash, debris, and stones heavier than 10 lbs [4.54 kg] or larger than 6 inches [152 millimeters (mm)] in diameter. The larger of acceptable stones shall be limited to the lower center of fills. Earthen material shall be compacted and prepared, as necessary, for structural integrity and erosion control. Solid or wet clay or similar types of soil shall not be used in barricades because they are too cohesive. If it is impossible to use a cohesive material (e.g., in sandy soil), the barricade shall be finished with a suitable material (e.g., geotextiles, gunnite) that shall not produce hazardous debris, but shall ensure structural integrity.

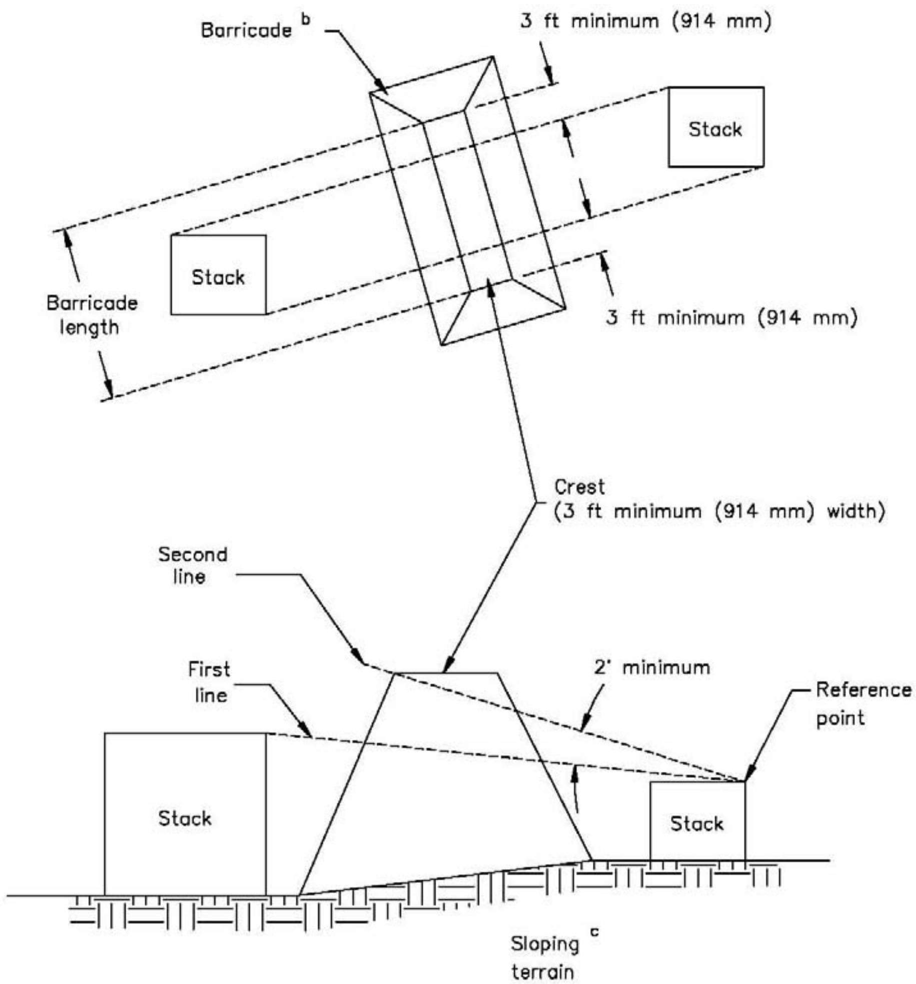
V2.E5.4.3.2. The slope of an earthen barricade must be two horizontal to one vertical, unless erosion controls are used. Earthen barricades with slopes no greater than one and one half horizontal to one vertical that were approved prior to 1976 may continue to be used. However, renovations to these facilities shall meet the two horizontal to one vertical slope criteria when feasible.

Figure V2.E5.F1. Determination of Barricade Length and Height to Prevent Prompt Propagation Due to High-Velocity, Low-Angle Fragments[a]



[a]See subparagraph V2.E5.4.2.3.
[b]Barricade must meet construction and siting criteria of section V2.E5.4.
[c]This illustration is for sloping terrain; however, a similar approach is used for level terrain.

Figure V2.E5.F2. Determination of Barricade Length and Height for Barricaded ILD Protection[a]



[a]See subparagraph V2.E5.4.2.4.
[b]Barricade must meet construction and siting criteria of section V2.E5.4.
[c]This illustration is for sloping terrain; however, a similar approach is used for level terrain.

V2.E5.4.4. Portal Barricades for Underground Storage Facilities. Portal barricades allow reduction in IBD for underground magazines. Criteria for the location and construction of portal barricades are illustrated in Figure V2.E5.F3 and include:

V2.E5.4.4.1. Location. Portal (entry or exit) barricades shall be located immediately in front of an outside entrance or exit to a tunnel leading to an explosives storage point. The portal barricade should be centered on the extended axis of the tunnel that passes through the portal and shall 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 (based on the turning radius and operating width) to allow passage of any vehicles or materials-handling equipment that may need to enter the tunnel.

V2.E5.4.4.2. Height. The height of the barricade, along its entire width, shall be sufficient to intercept an angle of 10 degrees above the extended height of the tunnel.

V2.E5.4.4.3. Width and Length

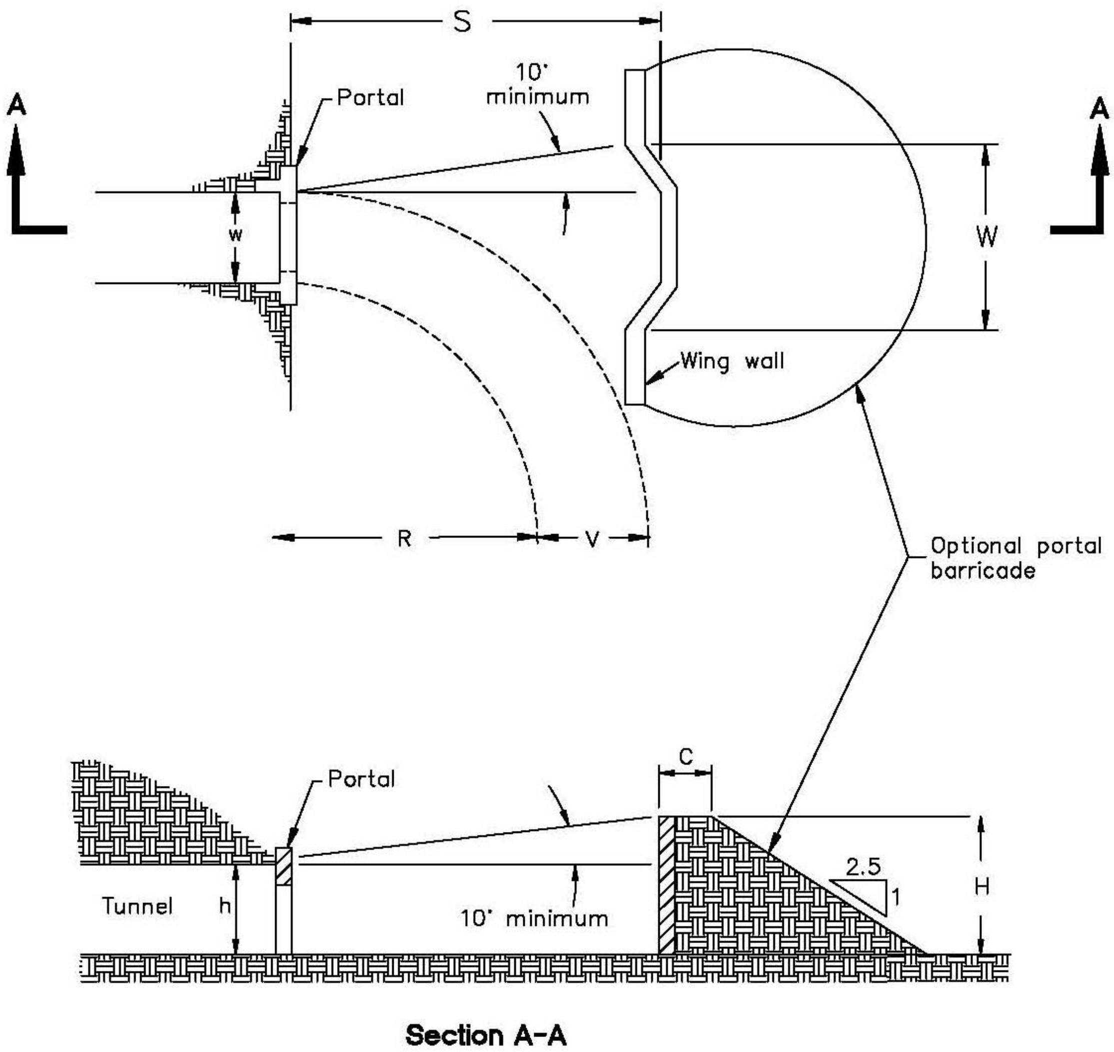
V2.E5.4.4.3.1. The width of the central face typically equals the width of the tunnel at the portal.

V2.E5.4.4.3.2. The front face (i.e., the face toward the entry or exit) shall be vertical and concave in plan view, consisting of a central face oriented perpendicular to the tunnel axis and wing walls.

V2.E5.4.4.3.3. The wing walls shall be of sufficient width so that the entire barricade length intercepts an angle of 10 degrees (minimum) to the right and left of the extended tunnel width.

V2.E5.4.4.4. Construction. To withstand the impact of debris ejected from the tunnel, the front face (including wing walls) shall be constructed of reinforced concrete, with a minimum thickness equal to 10 percent of the barricade height, but in no case less than 12 inches [30.5 centimeter (cm)]. The concrete wall shall have a spread footing of sufficient width to prevent significant settlement. In addition, the central wall, wing walls, and footing shall be structurally tied together to provide stability. The backfill behind the concrete wall may be composed of any fill material, to include rock rubble from the tunnel excavation, with a maximum particle size of 6 inches [15.2 cm] within the area extending out to 3 ft [0.9 m] from the rear face of the wall.

Figure V2.E5.F3. Portal Barricade Location, Height, and Width[a]



[a]See paragraph V2.E5.4.4.

S = Barricade standoff distance from portal
W = Width of barricade (excluding wing walls)
H = Height of barricade
V = Width of munitions transport vehicles
R = Turning radius of munitions transport vehicles
C = Crest width
w = Tunnel width at portal
h = Height of tunnel

V2.E5.4.5. Earth-Filled, Steel Bin-Type Barricades (ARMCO, Inc. Revetments or Equivalent) for Outside Storage

V2.E5.4.5.1. These barricades are earth-filled steel bins used to separate AE awaiting scheduled processing (e.g., AE on a flight line associated with aircraft parking or loading operations or the temporary positioning of AE awaiting transfer to preferred, long-term storage). These barricades, which are also used to separate explosive-loaded aircraft, are normally used to form a series of cells. They are designed to limit the maximum credible event (MCE), for QD siting purposes, of AE properly positioned in separate cells by preventing prompt detonation transfer to adjacent cells.

V2.E5.4.5.2. There are limitations of ARMCO, Inc. revetment cells (see paragraph C6.2.7.3. of Reference (g)).

V2.E5.4.5.2.1. ARMCO, Inc. revetments cells are approved for storage of any hazard division (HD) 1.1 and HD 1.2 AE assigned to sensitivity groups 1 through 4, as discussed in paragraph V1.E6.2.3 of Volume 1 of this Manual. In addition, storage of HD 1.3, HD 1.4, or HD 1.6 items is approved.

V2.E5.4.5.2.2. When properly sited, these cells prevent prompt detonation transfer; however, all assets in the series of cells are at risk of loss. Although a revetment is effective in limiting the blast loading of an adjacent ES to that produced by the largest contents of a single cell, there is a significant probability that the contents of many of the cells will be damaged or destroyed by the initial and subsequent fire and explosion events. The extent of such losses increases with the amount of explosives present.

V2.E5.4.5.3. There are two types of ARMCO, Inc. revetments.

V2.E5.4.5.3.1. Type A revetments, which must be a minimum of 7 ft [2.1 m] thick, can be used to limit the MCE in a series of cells to the largest quantity in a single cell, provided the quantity in the single cell does not exceed 30,000 lbs net explosive weight (NEW) [13,608 kg net explosive quantity (NEQ)].

V2.E5.4.5.3.2. Type B revetments, which must be a minimum of 5.25 ft [1.6 m] thick, can be similarly used to limit the MCE, provided no cell contains more than 5,000 lbs NEW [2,268 kg NEQ].

V2.E5.4.5.4. For ARMCO, Inc. revetments to be used effectively, the following conditions must be met:

V2.E5.4.5.4.1. The criteria shown in Figure V2.E5.F1. shall be applied.

V2.E5.4.5.4.2. AE shall be positioned no closer than 10 ft [3.1 m] from cell walls, no closer than 3 ft [0.9 m] from the end of the wing walls, and no higher than 2 ft [0.6 m] below the top of cell walls.

V2.E5.4.5.4.3. AE shall be distributed over the available area within the cell, rather than being concentrated in a small area.

V2.E5.4.5.4.4. AE stored in a cell in quantities near the maximum NEW limit shall not be configured into a single row of pallets, stacks, or trailers.

V2.E5.4.5.4.5. The storage of AE in flammable outer-pack configurations shall be minimized.

V2.E5.5. ECM. An ECM's primary purpose is to protect AE. To qualify for the default intermagazine distance (IMD) in Table V3.E3.T6 of Volume 3 of this Manual, an ECM, acting as an ES, must not collapse. Although substantial permanent deformation of the ECM may occur, sufficient space should be provided to prevent the deformed structure or its doors from striking the contents.

V2.E5.5.1. ECMs may be approved for storage of up to 500,000 lbs NEW [226,795 kg NEQ] of HD 1.1 IAW Table V3.E3.T5 of Volume 3 of this Manual. Reference (g) provides listings of the various types of ECMs that have been constructed. These magazines are identified by their structural strength designator (i.e., 7-Bar, 3-Bar, or undefined). Table AP1-1. of Reference (g) lists the 7-Bar and 3-Bar ECM designs that are currently approved for new construction.

V2.E5.5.1.1. If an ECM's drawing number(s) are not listed in Reference (g), it shall be treated as an undefined ECM until a structural analysis is performed to show that the ECM qualifies for another structural strength designation, or support documentation is provided to prove the ECM had been approved by the DDESB with a different structural strength designation.

V2.E5.5.1.2. For existing, arch-shaped undefined ECMs, U.S. Army Corps of Engineers (USACE) Report HNDED-CS-S-95-01 (Reference (h)) may be used to determine if an undefined ECM could qualify as a 7-Bar or a 3-Bar ECM.

V2.E5.5.1.3. DDESB approval is required prior to any change in an ECM's structural strength designator.

V2.E5.5.1.4. Certain ECMs, above ground storage magazines, and containers have been approved with reduced NEWs or reduced QDs, and these are listed in Table AP1-4. of Reference (g). Use of these structures or containers requires that their use and siting meet all conditions and restrictions specified in the design and approval documentation, as described in Reference (g).

V2.E5.5.2. ECMs must be designed to withstand the following:

V2.E5.5.2.1. Conventional (e.g., live, dead, snow) loads for the barrel of an arch-shaped ECM.

V2.E5.5.2.2. Conventional (e.g., live, dead, snow) and blast-induced loads for the roof of a flat-roofed ECM.

V2.E5.5.2.3. Conventional (e.g., live, dead, snow) loads for the rear wall of an arch-shaped ECM and the rear and side walls of a flat-roofed ECM.

V2.E5.5.2.4. Expected blast loads, as applicable, follow:

V2.E5.5.2.4.1. On the head wall and door of 3-Bar ES ECMs is a triangular pulse with peak overpressure of 43.5 psi [3 bars, 300 kPa] and impulse of $11.3W^{1/3}$ psi-milliseconds (psi-ms) [100 NEQ in kilograms $(Q)^{1/3}$ Pascal-seconds (Pa-s)].

V2.E5.5.2.4.2. On the head wall and door of 7-Bar ES ECMs is a triangular pulse with peak overpressure of 101.5 psi [7 bars, 700 kPa] and impulse of $13.9W^{1/3}$ psi-ms [$123Q^{1/3}$ Pa-s].

V2.E5.5.2.4.3. On the roof of a flat-roofed undefined, 3-Bar, or 7-Bar ES ECM is a triangular pulse with peak overpressure of 108 psi [7.5 bars, 745 kPa] and impulse of $19W^{1/3}$ psi-ms [$170Q^{1/3}$ Pa-s].

V2.E5.5.3. Earth-cover for ECMs shall meet the following requirements:

V2.E5.5.3.1. Earth cover shall be reasonably cohesive and free from harmful (toxic) matter, trash, debris, and stones heavier than 10 lbs [4.54 kg] or larger than 6 inches [152 mm] in diameter. Solid or wet clay or similar types of soil shall not be used as earth cover because they are too cohesive. The larger of acceptable stones shall be limited to the lower center of fills and shall not be used for earth cover over magazines. The earthen material shall be compacted and prepared, as necessary, for structural integrity and erosion control. If it is impossible to use a cohesive material (e.g., in sandy soil), the earth cover over ECMs shall be finished with a suitable material (e.g., geotextiles, gunnite) that will ensure structural integrity.

V2.E5.5.3.2. The earth fill or earth cover between ECMs may be either solid or sloped. A minimum of 2 ft [0.61 m] of earth cover shall be maintained over the top of each ECM. If the specified thickness and slope of earth on the ECM is not maintained, the ECM shall be sited as an AGM.

V2.E5.6. BARRICADED OPEN STORAGE MODULES

V2.E5.6.1. As depicted in Figure V2.E5.F4, a module is a barricaded area composed of a series of connected cells with hard surface (e.g., concrete, packed earth, engineered materials) storage pads separated from each other by barricades. Although a light metal shed or other lightweight fire retardant cover may be used for weather protection for individual cells, heavy structures (e.g., reinforced concrete, dense masonry units) or flammable material shall not be used.

V2.E5.6.2. The maximum NEW [NEQ] permitted to be stored within each cell is 250,000 lbs [113,398 kg].

V2.E5.6.3. Module storage is considered a temporary expedient and may be used as the DoD Component concerned determines necessary. However, from an explosives safety and reliability standpoint, priority shall be given to the use of ECMs for items requiring protection from the elements, long-term storage, or high-security protection.

V2.E5.6.4. Storage shall be limited to AE that will not promptly propagate explosions or mass fire between modules, and that are not susceptible to firebrands and fireballs. These restrictions allow storage at K-factor (English system) (K)1.1 [K-factor (metric system) $(K)_m$ 0.44] separation.

V2.E5.6.4.1. Only the following AE are approved for modular storage:

V2.E5.6.4.1.1. High-explosive bombs (fuzed or unfuzed, with or without fins) and similarly cased HD 1.1 AE when stored on nonflammable pallets.

V2.E5.6.4.1.2. The following items when contained in nonflammable shipping containers:

V2.E5.6.4.1.2.1. 30 mm and smaller AE.

V2.E5.6.4.1.2.2. Cluster bomb units.

V2.E5.6.4.1.2.3. Inert AE components.

V2.E5.6.4.1.2.4. HD 1.4 AE.

V2.E5.6.4.2. Module storage of AE items in flammable outer-packaging configurations shall be minimized. AE items in flammable outer-packaging configurations must be covered with fire retardant material. Combustible dunnage or other flammable material shall not be stored either in, or within, 100 ft [30.5 m] of modules.

V2.E5.6.4.3. When fire retardant materials are used to cover AE items stored in modules, ventilation shall be provided between the covers and the stored AE items to minimize the effects of solar heating upon the stored AE.

V2.E5.6.4.4. AE stored in each module shall normally be limited to one type of item, unless the DoD Component concerned authorizes mixed storage.

V2.E5.6.5. Barricade requirements:

V2.E5.6.5.1. All barricades used in forming the module shall meet the requirements in section V2.E5.4. The width or length of the stack of AE (controlled by the pad size of the cell) and the distances between the stack and the top of the barricade influences the minimum barricade height requirement. The heights listed in Table V2.E5.F4 are the minimum requirements for barricade locations. These minimum heights are based upon the storage pad sizes and the separations shown. When feasible, barricade heights should be increased.

V2.E5.6.5.2. The centerlines of barricades between cells of the module shall be located at a point halfway between adjacent AE storage pads. Back and end (outside) barricades shall be located at the same distance from the pads as those between the cells.

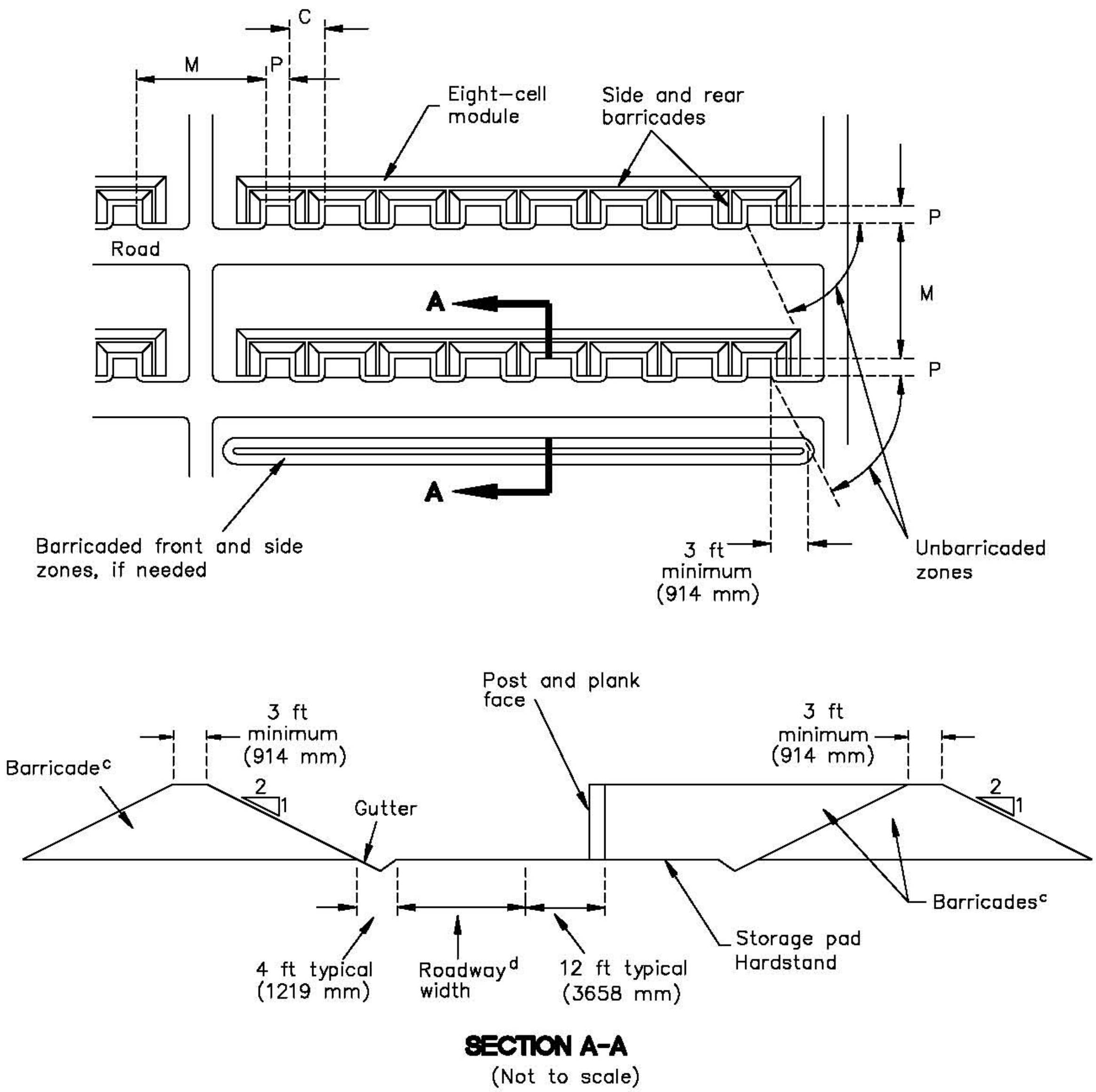
V2.E5.6.5.3. When selecting a site for a module, maximum advantage should be taken of natural topographical barriers. When used, natural barriers shall provide the same level of protection as the barricade shown in Figure V2.E5.F4.

V2.E5.6.6. Table V2.E5.T1 provides the minimum pad sizes necessary to store the net explosive weight for quantity-distance (NEWQD) indicated. The pad's size may need to be adjusted to accommodate specific AE. This adjustment will impact the required barricade height (see footnote b of Table V2.E5.T1).

V2.E5.6.7. The only restriction on the arrangement of cells within a module and of groups of modules is that cell openings may not face each other, unless they are either barricaded or meet QD criteria for an unbarricaded AGM (see Table V3.E3.T6 of Volume 3 of this Manual).

V2.E5.7. HIGH-PERFORMANCE MAGAZINES (HPMs). HPMs allow a reduction in encumbered land by limiting the MCE to a quantity considerably less than that stored in the HPM. HPMs are to be constructed per Naval Facilities Engineering Command guidance, as outlined in Table AP1-1. of Reference (g), and are to be sited at the IMD provided by Table V3.E3.T6. HPM separation walls protect against fire propagation between internal storage areas. Although IMD provides nearly complete asset protection between HPMs (MCE = 60,000 lbs [27,216 kg] maximum), AE damage may occur to about K9 [K_m 3.57] from a donor NEW > 350,000 lbs [158,757 kg].

Figure V2.E5.F4. Typical Eight-Cell Open Storage Module[a,b]



[a]See section V2.E5.6.
[b]Number of cells, cells' NEWQD, pad size (P), distance between cells (C) and modules (M), and minimum barricade heights can vary. (See Table V2.E5.T1.)
[c]Refer to section V2.E5.4. for barricade design criteria and alternate barricade designs.
[d]Roadway width determined by the DoD Components.

Table V2.E5.T1. HD 1.1 IMD for Barricaded Open Storage Module

NEWQD	Minimum Pad-to-Pad Separation Distance ("C" and "M" in V2.E5.F4)[a, b]	Maximum Pad Dimension ("P" in V2.E5.F4) Width or Depth	Minimum Height Above Top of Stack[c]
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
50,000	41	30	2
22,680	*12.5*	*9.1*	*0.6*
70,000	45	30	2
31,751	*13.9*	*9.1*	*0.6*
100,000	51	30	2
45,359	*15.7*	*9.1*	*0.6*
150,000	58	30	2
68,039	*18.0*	*9.1*	*0.6*
200,000	64	30	2
90,718	*19.8*	*9.1*	*0.6*
200,000	64	40	2.5
90,718	*19.8*	*12.2*	*0.8*
250,000	69	40	2.5
113,398	*21.3*	*12.2*	*0.8*
250,000	69	50	3
113,398	*21.3*	*15.2*	*0.9*

a	English equations (EQNs) (W in lbs, D in ft) $D = 1.1W^{1/3}$ EQN V2.E5.T1-1 $W = D^3/1.33$ EQN V2.E5.T1-2 *Metric EQNs (Q in kg, D in m)* *$D = 0.44Q^{1/3}$ where D is in m and Q is in kg* *EQN V2.E5.T1-3* *$Q = D^3/0.083$ where Q is in kg and D is in m* *EQN V2.E5.T1-4*
b	AE shall not be stored beyond the boundaries of the storage pad.
c	Barricade height is based upon storage pad size. When "P" exceeds 50 ft [15.2 m], then the barricade height shall be increased by 6 inches [152 mm] for each 10 ft [3.05 m] increase of "P."

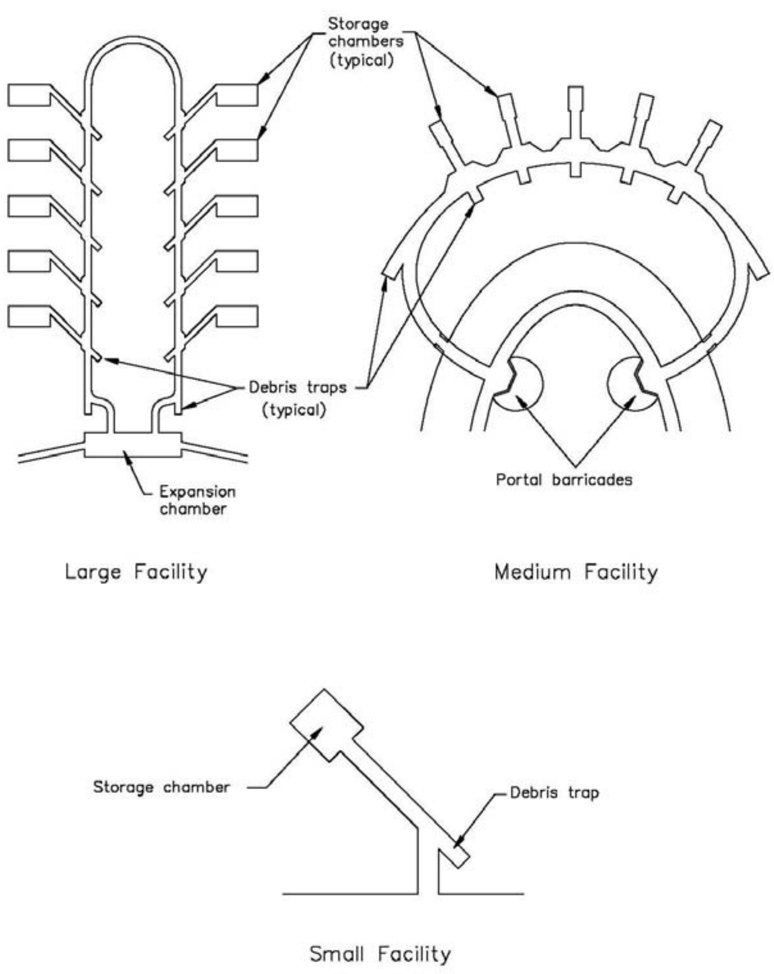
V2.E5.8. UNDERGROUND STORAGE FACILITIES

V2.E5.8.1. General Design Considerations

V2.E5.8.1.1. Underground storage facilities may consist of a single chamber or a series of connected chambers and other protective construction features. The chambers may be either excavated or natural geological cavities. Figure V2.E5.F5 shows the layout of several typical underground facilities. To qualify as an underground facility, the minimum distance from the perimeter of a storage area to an exterior surface shall be greater than $0.25\ W^{1/3}$ [$0.10\ Q^{1/3}$]. This minimum distance normally, but not always, equals the thickness of the earth cover. If this criterion cannot be met, the facility must be sited as an AGM.

V2.E5.8.1.2. Design of new underground storage facilities must take into account site conditions, storage requirements, and operational needs. Once these are established, a design may be developed based on the USACE definitive drawing, DEF 421-80-04, discussed in Chapter 5 of Reference (g). Special features (e.g., debris traps, expansion chambers, closure blocks, portal barricades, and constrictions) may be incorporated in the design of underground storage facilities to reduce the IBD for debris and airblast. The specifications for these special features are also given in USACE definitive drawing, DEF 421-80-04, and their effects are discussed in paragraphs V2.E5.8.2. through V2.E5.8.5.

Figure V2.E5.F5. Typical Underground Storage Facilities[a]



[a]See section V2.E5.8.

V2.E5.8.2. Debris Mitigation. Debris IBD may be reduced through the use of debris traps, expansion chambers, high-pressure closures, and portal barricades. Use of barricades with any of the features addressed in subparagraphs V2.E5.8.2.1 through V2.E5.8.2.4. will lower the debris hazard to a level where QD considerations for debris are not required.

V2.E5.8.2.1. Debris Traps. Debris traps are pockets excavated in the rock at or beyond the end of sections of tunnel that are designed to catch debris from a storage chamber detonation. Debris traps should be at least 20 percent wider and 10 percent taller than the tunnel leading to the trap, with a depth (measured along the shortest wall) of at least one tunnel diameter. To be effective, debris traps must be designed to contain the full potential volume of debris, based on the maximum capacity of the largest storage chamber.

V2.E5.8.2.2. Expansion Chambers. Expansion chambers are very effective in entrapping debris, as long as the tunnels entering and exiting the chambers are either offset in axial alignment by at least two tunnel widths, or enter and exit the chambers in directions that differ by at least 45 degrees. To be effective, expansion chambers that are 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.

V2.E5.8.2.3. Portal Barricades. Portal barricades provide a means of reducing IBD from debris by obstructing the path of the debris as it exits the tunnel.

V2.E5.8.2.4. High-Pressure Closures. 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 density (w) of about 0.625 lb/cubic feet (ft^3) [10 kg/cubic meter (m^3)] or above, closure blocks will contain 40 percent or more of the explosion debris within the detonation chamber, provided that 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, because the block’s mass and inertia are sufficient to greatly reduce the velocity of the primary debris, the effectiveness of other debris-mitigating features (e.g., debris traps, expansion chambers, and barricades) is increased.

V2.E5.8.3. Airblast Mitigation. Special features that may be used in underground storage facilities to reduce airblast IBD include:

V2.E5.8.3.1. Facility Layouts. A facility’s layout and its volume control the external airblast effects.

V2.E5.8.3.1.1. In a single-chamber facility with a straight access tunnel leading from the chamber to the portal, which is commonly called a “shotgun” magazine, the blast and debris are channeled to the external area as if fired from a long-barreled gun. In this type of facility design, airblast mitigation, given a fixed NEWQD, can be provided by increased chamber and tunnel dimensions.

V2.E5.8.3.1.2. In more complex facility layouts, reflections of the explosive shock against the various tunnel walls may reduce the exit pressures. The cumulative effects of these reflections may reduce the overpressure at the shock front to that of the expanding gas pressure. In addition, the detonation gas pressure decreases as the volume it occupies increases. Therefore, larger, more complex facilities will produce greater reductions in the effective overpressure at the opening, which will reduce the IBD.

V2.E5.8.3.1.3. In a more complex facility with two or more openings, the IBD will be reduced by about 10 percent.

V2.E5.8.3.2. Expansion-Chambers. Expansion-chambers provide additional volume for the expansion of the detonation gasses behind the shock front as it enters the chamber from a connecting tunnel. Some additional reduction of the peak pressure at the shock front occurs as the front expands into the expansion-chamber and reflects from the walls. Although expansion-chambers may be used as loading areas or as turn-around areas for transport vehicles servicing facilities through a single entry passage, they shall not be used for storage.

V2.E5.8.3.3. Constrictions. Constrictions are short lengths of tunnel whose cross-sectional areas are reduced to one-half or less of the normal tunnel cross-section. Constrictions reduce the airblast effects passing through them. To be effective, constrictions should be placed within five tunnel diameters of the tunnel exit or to the entrances of storage chambers. As an added benefit, constrictions at chamber entrances also reduce the total loading on blast doors that may be installed to protect a chamber's contents.

V2.E5.8.3.4. Portal Barricades. A barricade in front of the portal (entrance into tunnel) will reflect that portion of the shock wave moving directly outward from the portal, thereby reducing the pressures along the extended tunnel axis and increasing the pressures in the opposite direction. The result is a more circular IBD area centered at the portal. A portal barricade meeting the construction criteria of the USACE definitive drawing discussed in subparagraph V2.E5.8.1.2. will reduce the IBD along the extended tunnel axis by 50 percent. The total IBD area is only slightly reduced, but will change to a circular area, half of which is behind the portal.

V2.E5.8.3.5. High-Pressure Closures. High-pressure closures are large blocks constructed of concrete or other materials that obstruct or greatly reduce the flow of blast effects and debris from an explosion from or into a storage chamber.

V2.E5.8.3.5.1. When used to reduce QD by restricting the blast outflow from a chamber, the block must be designed to be rapidly driven from an open to a closed position by the detonation pressures in the chamber. While this type of block will provide some protection of chamber contents from an explosion in another chamber, blast doors must also be used to provide complete protection. Tests have shown that a closure block, with sufficient mass, can obstruct the initial outflow of airblast from an explosion in a chamber to reduce pressures in the connecting tunnels by a factor of two or more, even when the block is destroyed. Blocks with sufficient strength to remain structurally intact can provide greater reductions. Because many variables influence the performance of a closing device, their design details must be developed on a site-specific basis.

V2.E5.8.3.5.1.1. For loading densities (w) of 0.625 lb/ft^3 [10 kg/m^3] or higher, a 50-percent reduction in IBD may be applied to the use of a high-pressure closure block provided it is designed to remain intact in the event of an explosion.

V2.E5.8.3.5.1.2. For loading densities (w) less than 0.625 lb/ft^3 [10 kg/m^3], use the following reductions:

V2.E5.8.3.5.1.2.1. For $0.0625 < w < 0.625$ lb/ft^3 [$1.0 < w < 10$ kg/m^3], reductions may be calculated by the equations shown in Figure V2.E5.F6.

Figure V2.E5.F6. Subparagraph V2.E5.8.3.5.1.2.1. Equations

$y(\%) = 50\log_{10}(16.02w)$	English EQN V2.E5.8-1
$y(\%) = 50\log_{10}(1.0w)$	*Metric EQN V2.E5.8-2*
where y is the percent reduction in IBD and w is loading density in lb/ft^3 [kg/m^3]	

V2.E5.8.3.5.1.2.2. For $w < 0.0625$ lb/ft^3 [$w < 1$ kg/m^3]: $y(\%) = 0$.

V2.E5.8.3.5.2. When used to protect the contents of a chamber from an explosion in another chamber, the block must be designed to move from a normally closed position to an open position when entry is required. Blast doors are not required for this type of closure block.

V2.E5.8.4. Chamber Separation Requirements. Minimum storage chamber separation distances are required to prevent or control the communication of explosions or fires between chambers. There are three modes by which an explosion or fire can be communicated: rock spall, propagation through cracks or fissures, and airblast or thermal effects traveling through connecting passages. Spalled rock of sufficient mass that is traveling at a sufficient velocity may damage or sympathetically detonate impacted AE in the acceptor chambers.

V2.E5.8.4.1. Prevention of Damage by Rock Spall (HD 1.1 and HD 1.3). The chamber separation distance is the shortest distance (rock thickness) between two chambers. When an explosion occurs in a donor chamber (a PES), a shock wave is transmitted through the surrounding rock. The intensity of the shock decreases with distance. For small chamber separation distances, the shock may be strong enough to produce spalling of the rock walls of adjacent ES chambers. See Table V2.E5.T2 for the minimum chamber separation distance required to prevent hazardous spall effects (D_{cd}) when no specific protective construction is used.

V2.E5.8.4.2. Prevention of Propagation by Rock Spall (HD 1.1 and HD 1.3). Because rock spall is considered an immediate mode of propagation, time separations between donor and acceptor explosions may not be sufficient to prevent coalescence of blast waves. If damage to AE stored in adjacent chambers is acceptable, chamber separation distances from those determined to prevent damage (see subparagraph V2.E5.8.4.1.) can be reduced to prevent propagation by rock spall. See Table V2.E5.T2 for the minimum chamber separation distance required to prevent propagation by rock spall (D_{cp}). If the required D_{cp} in Table V2.E5.T2 cannot be met, explosives weights in all chambers must be added together to determine W, unless analyses or experiments demonstrate otherwise.

V2.E5.8.4.3. Prevention of Propagation Through Cracks and Fissures (HD 1.1 and HD 1.3). Propagation between a donor and an acceptor chamber has been observed to occur when natural, near-horizontal jointing planes, cracks, or fissures in the rock between the chambers are opened by the lifting force of the detonation pressure. Prior to construction of a multi-chamber magazine, a careful site investigation must be made to ensure that such joints or fissures do not extend from one chamber location to an adjacent one. Should such defects be encountered during facility excavation, a reevaluation of the intended siting is required.

V2.E5.8.4.4. Prevention of Propagation through Passageways (HD 1.1 and HD 1.3). Flame and hot gas may provide a delayed mode of propagation. Time separations between the events in the donor chamber and the acceptor chamber by this mode will likely be sufficient to prevent coalescence of blast waves. Consequently, siting is based on each chamber's NEWQD. To protect assets, blast and fire resistant doors may be installed within multi-chambered facilities. Evaluations for required chamber separations due to this propagation mode should be made on a site-specific basis using procedures outlined in USACE definitive drawing DEF 421-80-04. For HD 1.1 and HD 1.3 materials:

V2.E5.8.4.4.1. Chamber entrances at the ground surface, or entrances to branch tunnels off the same side of a main passageway, shall be separated by at least 15 ft [4.6 m].

V2.E5.8.4.4.2. Entrances to branch tunnels off opposite sides of a main passageway shall be separated by at least twice the width of the main passageway.

V2.E5.8.5. Chamber Cover Thickness. The chamber cover thickness is the shortest distance between the ground surface and the natural rock surface at the chamber's ceiling or, in some cases, a chamber's wall. For all types of rock, the critical cover thickness required to prevent breaching of the chamber cover by a detonation (C_c) is shown in Figure V2.E5.F7.

Figure V2.E5.F7. Paragraph V2.E5.8.5. Equations

$C_c = 2.5W^{1/3}$	English EQN V2.E5.8-3
$C_c = 0.99Q^{1/3}$	*Metric EQN V2.E5.8-4*
where C_c is in ft and W is in lbs [C_c is in m and Q is in kg]	

Table V2.E5.T2. Chamber Separation Distances Required to Prevent Damage and Propagation by Rock Spall

NEWQD	Chamber Separation to Prevent Damage by Rock Spall, D_{cd}[a]			Chamber Separation to Prevent Propagation by Rock Spall, D_{cp}[b]	
	Moderate-to-Strong Rock		Weak Rock (all loading densities)	No Protective Construction	With Protective Construction
	w ≤ 3 lbs/ft^3 *w ≤ 48.1 kg/m^3*	w > 3 lbs/ft^3 *w > 48.1 kg/m^3*			
	Footnote c	Footnote d	Footnote e	Footnote f	Footnote g
(lbs)	(ft)	(ft)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*	*[m]*	*[m]*
1,000	25	50	35	15.0	7.5
454	*7.6*	*15.2*	*10.7*	*4.6*	*2.3*
2,000	31	63	44	18.9	9.4
907	*9.6*	*19.2*	*13.5*	*5.8*	*2.9*
3,000	36	72	50	22	10.8
1,361	*11.0*	*21.9*	*15.4*	*6.6*	*3.3*
4,000	40	79	56	24	11.9
1,814	*12.1*	*24.1*	*17.0*	*7.3*	*3.7*
5,000	43	85	60	26	12.8
2,268	*13.0*	*26.0*	*18.3*	*7.9*	*3.9*
7,000	48	96	67	29	14.3
3,175	*14.6*	*29.1*	*20.4*	*8.8*	*4.4*
10,000	54	108	75	32	16.2
4,536	*16.4*	*32.8*	*23.0*	*9.9*	*5.0*
20,000	68	136	95	41	20.4
9,072	*20.6*	*41.3*	*29.0*	*12.5*	*6.3*
30,000	78	155	109	47	23.3
13,608	*23.6*	*47.3*	*33.2*	*14.3*	*7.2*
50,000	92	184	129	55	27.6
22,680	*28.0*	*56.0*	*39.3*	*17.0*	*8.5*
70,000	103	206	144	62	30.9
31,751	*31.3*	*62.7*	*44.0*	*19.0*	*9.5*
100,000	116	232	162	70	34.8
45,359	*35.3*	*70.6*	*49.6*	*21.4*	*10.7*
200,000	146	292	205	88	43.9
90,718	*44.5*	*89.0*	*62.5*	*27.0*	*13.5*
300,000	167	335	234	100	50.2
136,077	*50.9*	*101.8*	*71.5*	*30.9*	*15.4*
500,000	198	397	278	119	59.5
226,795	*60.4*	*120.7*	*84.8*	*36.6*	*18.3*

Table V2.E5.T2. Chamber Separation Distances Required to Prevent Damage and Propagation by Rock Spall, Continued

NEWQD	Chamber Separation to Prevent Damage by Rock Spall, D_{cd} [a]			Chamber Separation to Prevent Propagation by Rock Spall, D_{cp} [b]	
	Moderate-to-Strong Rock		Weak rock (all loading densities)	No Protective Construction	With Protective Construction
	w ≤ 3 lbs/ft³ *w ≤ 48.1 kg/m³*	w > 3 lbs/ft³ *w > 48.1 kg/m³*			
	Footnote c	Footnote d	Footnote e	Footnote f	Footnote g
(lbs) *[kg]*	(ft) *[m]*	(ft) *[m]*	(ft) *[m]*	(ft) *[m]*	(ft) *[m]*
700,000	222	444	311	133	66.6
317,513	*67.5*	*135.1*	*94.8*	*40.9*	*20.5*
1,000,000	250	500	350	150	75.0
453,590	*76.1*	*152.1*	*106.8*	*46.1*	*23.1*

a	D_{cd} has a minimum distance of 15 ft [4.6 m].
b	The D_{cp} distances in this table are based on an explosive loading density of 17 lbs/ft³ [272.3 kg/m³] and will likely be safety conservative for lower loading densities.
c	English EQNs (W in lbs, D_{cd} in ft) $D_{cd} = 2.5W^{1/3}$ EQN V2.E5.T2-1 $W = D_{cd}^3/15.625$ EQN V2.E5.T2-2 *Metric EQNs (Q in kg, D_{cd} in m)* $D_{cd} = 0.99Q^{1/3}$ *EQN V2.E5.T2-3* $Q = D_{cd}^3/0.97$ *EQN V2.E5.T2-4*
d	English EQNs (W in lbs, D_{cd} in ft) $D_{cd} = 5W^{1/3}$ EQN V2.E5.T2-5 $W = D_{cd}^3/125$ EQN V2.E5.T2-6 *Metric EQNs (Q in kg, D_{cd} in m)* $D_{cd} = 1.98Q^{1/3}$ *EQN V2.E5.T2-7* $Q = D_{cd}^3/7.762$ *EQN V2.E5.T2-8*
e	English EQNs (W in lbs, D_{cd} in ft) $D_{cd} = 3.5W^{1/3}$ EQN V2.E5.T2-9 $W = D_{cd}^3/42.875$ EQN V2.E5.T2-10 *Metric EQNs (Q in kg, D_{cd} in m)* $D_{cd} = 1.39Q^{1/3}$ *EQN V2.E5.T2-11* $Q = D_{cd}^3/2.686$ *EQN V2.E5.T2-12*
f	English EQNs (W in lbs, D_{cp} in ft) $D_{cp} = 1.5W^{1/3}$ EQN V2.E5.T2-13 $W = D_{cp}^3/3.375$ EQN V2.E5.T2-14 *Metric EQNs (Q in kg, D_{cp} in m)* $D_{cp} = 0.60Q^{1/3}$ *EQN V2.E5.T2-15* $Q = D_{cp}^3/0.216$ *EQN V2.E5.T2-16*
g	English EQNs (W in lbs, D_{cp} in ft) $D_{cp} = 0.75W^{1/3}$ EQN V2.E5.T2-17 $W = D_{cp}^3/0.422$ EQN V2.E5.T2-18 *Metric EQNs (Q in kg, D_{cp} in m)* $D_{cp} = 0.30Q^{1/3}$ *EQN V2.E5.T2-19* $Q = D_{cp}^3/0.027$ *EQN V2.E5.T2-20*

GLOSSARY

ABBREVIATIONS AND ACRONYMS

AE	ammunition and explosives
AGM	aboveground magazine
AIT	automatic identification technology
AM	acquisition manager
C	distance between cells
cm	centimeter
DDESB	Department of Defense Explosives Safety Board
DUSD(I&E)	Deputy Under Secretary of Defense for Installations and Environment
ECM	earth-covered magazine
EED	electro-explosive device
EID	electrically initiated device
EME	electromagnetic environment
EMR	electromagnetic radiation
EQN	equation
ES	exposed site
ft	foot or feet
ft^3	cubic feet
HD	hazard division
HERO	hazards of electromagnetic radiation to ordnance
HPM	high-performance magazine
IA	installation activity
IAW	in accordance with
IBD	inhabited building distance
ILD	intraline distance
IMD	intermagazine distance
K	K-factor (English system)
kg	kilogram
K_m	K-factor (metric system)
kPa	kilopascal
kV	kilovolt
lbs	pounds

LPS	lightning protection system
m	meter
M	distance between modules
m^3	cubic meter
MCE	maximum credible event
mm	millimeter
ms	millisecond
NEC	National Electrical Code
NEQ	net explosive quantity
NEW	net explosive weight
NEWQD	net explosive weight for quantity-distance
NFPA	National Fire Protection Association
P	pad size
Pa-s	Pascal-second
PES	potential explosion site
PM	program manager
psi	pounds per square inch
psi-ms	pounds per square inch-milliseconds
PTRD	public traffic route distance
Q	NEQ in kilograms
QD	quantity-distance
RF	radio frequency
RFID	radio frequency identification
USACE	U.S. Army Corps of Engineers
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics