

**APPROVED PROTECTIVE CONSTRUCTION
(Version 2.0)**



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**Department of Defense Explosives Safety Board
Alexandria, VA
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FOREWORD

Technical Paper (TP) 15 is a record of historically significant information about the origin and evolution of protective construction designs (e.g., earth-covered magazines (ECM), other magazines with reduced quantity-distance (QD) criteria, underground storage facilities (tunnel magazines), barricades, barricaded module storage, hardened aircraft shelters, missile test cells, etc.) and the explosives safety criteria associated with them. The Department of Defense Explosives Safety Board's (DDESB) intent is to keep this document current, and it will be improved and updated as new protective construction facilities and features are designed and approved and as additional information is received. Version 2 expands on Version 1, which was published in February 2001. Significant changes associated with Version 2 are:

- Chapter 2: * Expansion of ESKIMO VII testing and conclusions related to box type magazine designs.
- * Expansion of High Performance Magazine (HPM) related testing information pertaining to non-propagating wall (NPW) technology and sympathetic detonation (SD) criteria.
- Chapter 3: * Typical ECM feature descriptions of have been expanded to clarify questions that have been raised and to address the flow-through ECM design.
- Chapter 6: * Addition of sand-filled walls, missile test cell, and substantial dividing wall (SDW) protective construction to Chapter 6 as a means to reduce a maximum credible event (MCE).
- * Inclusion of work accomplished to develop a better understanding of QD associated with ammunition stored within International Organization for Standardization (ISO) containers.
- * Expansion of Donovan T-10 information to include new DDESB approvals for the disposal of munitions.

-Significant upgrade of the TP 15 magazine tables, which identify, at this publication of TP 15 (Version 2), 261 separate magazine design entries and provide design specific information for them.

- Relocation of the above magazine tables to a new Appendix, AP1. These tables will be kept current by the DDESB and will be republished on the DDESB's webpage <http://www.ddesb.pentagon.mil>, as required.

- Addition of a new Appendix, AP2, to specifically address ammunition and explosives (AE) operational storage in the field. The intent with this appendix is to provide assistance to users in a field storage scenario regarding the methods and techniques available to them, for reducing MCE and QD. This appendix will be kept current by the DDESB and will be republished on the DDESB's webpage <http://www.ddesb.pentagon.mil>, as required.

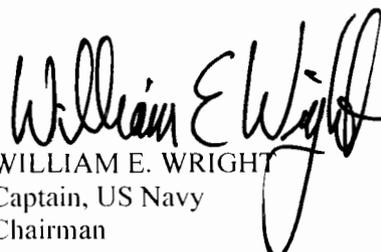

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ABBREVIATIONS AND ACRONYMS

AAP	Army Ammunition Plant
AE	Ammunition and Explosives
AEC	U.S. Army Engineer Corps (preceded Corps of Engineers)
AF or USAF	United States Air Force
AFB	Air Force Base
AF-NGB	Air Force, National Guard Bureau
AFSC	Air Force Safety Center
AFSSG	Air Force Special Study Group
AFWL	Air Force Weapons Laboratory
AG	Aboveground
ALCM	Air Launched Cruise Missile
ANESB	Army Navy Explosives Safety Board (NOTE : JANASB renamed to ANESB on 2 May 1945)
ANFO	Ammonium Nitrate and Fuel Oil
ANG	Air National Guard
APCN	Air Pollution Control Unit
ARL	Army Research Laboratory
ASET	Aircraft Shelter Explosive Test
ASP	AGAN Steel Panel
ASESB	Armed Services Explosives Safety Board (NOTE : ANESB was renamed to ASESB on 16 September 1948)
ATD	American Table of Distances, published by The Institute of Makers of Explosives (IME)
BEM	Buried Explosion Module
BFR	Blast and Fragment Resistant
BOD	Basis of Design
BRL	Ballistics Research Laboratory (NOTE : Now the Army Research Laboratory (ARL))
CBU	Cluster Bomb Unit
CINCPACAF	Commander-in-Chief, Pacific Air Force
COE	U.S. Army Corps of Engineers
CONEX	Container Express
DA	Department of the Army
DAC	U.S. Army Defense Ammunition Center
DASA	Defense Atomic Support Agency
DBC	Donovan Blast Chamber
DDESB	Department of Defense Explosives Safety Board (NOTE : ASESB renamed to DDESB on 23 October 1971)
DLA	Defense Logistics Agency
DNA	Defense Nuclear Agency
DoD	Department of Defense

DDESTSG DOT-E	DoD Explosives Safety Testing Steering Group Department of Transportation - Exemption
EB	Enclosed Barricade
ECD	Explosive Containment Device
ECM	Earth-Covered Magazine
EOD	Explosive Ordnance Disposal
EOD RSL	EOD Ready Service Locker
ES	Exposed Site
ESKIMO	Explosive Safety Knowledge Improvement Operation
ESQD	Explosives Safety Quantity Distance
ESS	Explosives Safety Submission
ESTC	Explosives Storage and Transportation Committee
EUR	Europe
FAA	Federal Aviation Administration
FM	Factory Mutual
FRELOC	Unknown acronym. (NOTE: This was the designation given by U.S. Army Engineer Command, Europe to a specific ECM design of the mid-1970s, 33-15-13, a modified Stradley design)
FSTS	Forward Storage Site
HAS	Hardened Aircraft Shelter
HAZMAT	Hazardous Material
HD	Hazard Division
HEST	High Explosive Simulation Test
HPM	High Performance Magazine
HSILS	High Security Integrated Locking System
IAW	In Accordance With
IBD	Inhabited Building Distance
ILMF	Intermediate Level Maintenance Facility
IMD	Intermagazine Distance
IME	Institute of Makers of Explosives
ISO	International Organization for Standardization
JBA	Joint Board on Ammunition (NOTE: Established 2 July 1928. This was the Board assigned to review storage conditions within the military, following the Lake Denmark accident in 1926).
JANMB	Joint Army Navy Munitions Board (NOTE: Established 6 August 1928. This was the name of the first Board established by the Secretaries of the War and Navy to advise them).
JANBAS	Joint Army and Navy Board on Ammunition Storage (NOTE: JANMB was renamed to JANBAS on 20 August 1930. On 22 January 1942, the Board was renamed to Joint Army and Navy Board of Ammunition Storage).

JANASB	Joint Army Navy Ammunition Storage Board (NOTE : The JANBAS was renamed to JANASB on 24 March 1943).
JHCS	Joint Hazard Classification System
MCAS	Marine Corps Air Station
MCE	Maximum Credible Event
MCLB	Marine Corps Logistics Base
MIL-BUL	Military Bulletin
MILCON	Military Construction
MILVAN	Military-Owned Demountable Containers
MK	Mark
MLH	Munitionslagerhaus (NOTE : German word for munitions storage magazine)
MOD	Ministry of Defence
MOFB	Miniature Open Front Barricade
MPB	Missile Processing Building
MRM	Modular Ready Magazine
MSD	Minimum Separation Distance
MSM	Modular Storage Magazine
MTC	Missile Test Cell
MWB	Mineral Water Bottle
N/A	Not Applicable
NAS	Naval Air Station
NASA	National Aeronautical and Space Administration
NATO	North Atlantic Treaty Organization
NAVFAC or NAVFACENGCOM	Naval Facilities Engineering Command
NAVSEASYSKOM	Naval Sea Systems Command
NAWS	Naval Air Warfare Station
NAWC	Naval Air Warfare Center
NCEL	Naval Civil Engineering Laboratory (NOTE : Now known as Naval Facilities Engineering Service Center)
NEW	Net Explosive Weight
NFESC	Naval Facilities Engineering Service Center
NGB	National Guard Base
NMERI	New Mexico Engineering Research Institute
NOTS	Navy Ordnance Test Station (NOTE : Now known as Naval Air Warfare Center, China Lake, CA)
NPW	Non-Propagation Wall
NRL	Naval Research Laboratory
NSWC	Naval Surface Warfare Center
OCE	Office Chief of Engineers (U.S. Army)
OCO	Office of the Chief of Ordnance
ODC	On-site Demolition Container

OE	Ordnance Explosive
OFB	Open Front Barricade
OQMG	Office of the QuarterMaster General
PACAF	Pacific Air Force
PES	Potential Explosion Site
PTRD	Public Traffic Route Distance
QD	Quantity Distance
QRS	Quick Reaction Site
RC	Reinforced Concrete
RSL	Ready Service Locker
SD	Sympathetic Detonation
SDW	Substantial Dividing Wall
SG	Sensitivity Group
SNL	Sandia National Laboratory
STD	Standard
SUBASE	Submarine Base
TDP	Technical Data Package
TM	Technical Manual
TNT	Trinitrotoluene
TOW	Tube-Launched, Optically-Tracked, Wire-Guided
TP	Technical Paper
TRANSCOM	Transportation Command
UL	Underwriters' Laboratory
UNK	Unknown
USADACS	United States Army Defense Ammunition Center and School (NOTE: Now known as Defense Ammunition Center (DAC), located at McAlester, OK.)
US	United States
USAESCH	U.S. Army Engineering and Support Center, Huntsville
USATCES	U.S. Army Technical Center for Explosives Safety (NOTE: Part of DAC)
USAF or AF	United States Air Force
USAFE	United States Air Forces, Europe
USAREUR	U.S. Army, Europe
UXO	Unexploded Ordnance
VSS	Vented Suppressive Shield
WPNSTA	Weapon Station
WSA	Weapon Storage Area

WW

World War

Y & D

Bureau of Yards and Docks (NOTE: Former name of NAVFAC)

C1. CHAPTER 1

INTRODUCTION

C1.1. GENERAL.

C1.1.1. DDESB Technical Paper (TP) 15 provides a comprehensive listing of ammunition and explosives (AE) storage facilities and protective construction facilities and features that have been designed and built over the past 70 years. Its purposes are to: (1) educate and enhance from an historical perspective, an understanding of how criteria developed and were influenced; and (2) to document approved protective construction designs to provide the explosives safety community common information for their use and benefit. It accomplishes this by documenting:

(a) Significant testing that has been performed, and that has impacted the development and evolution of explosives safety criteria found in reference 1-1,

(b) Past and present protective construction design information.

(c) Relevant siting information associated with each protective construction facility and feature.

C1.1.2. Throughout TP 15, safety distance is calculated primarily by means of the formula $D = K \cdot W^{1/3}$, where "D" is the distance in feet, "K" is a factor depending upon the risk assumed or permitted, and "W" is the NEW in pounds. This is further described in Chapter 2 of Reference 1-1. Distance requirements determined by the above formula are sometimes expressed by the value of "K", using the terminology K9, K11, K18, to mean K = 9, K = 11, and K = 18. In certain cases, safety distances have been determined by means of testing, such as with a full or partial containment of explosion effects (e.g., blast, thermal, primary fragments, structural debris). When this is the case, a description of the test and the results of testing will be provided.

C1.1.3. TP 15 will be updated periodically by adding information on existing items contained therein and to expand it to address new protective construction areas, as deemed necessary.

C1.1.4. Appendices AP1 and AP2 will be maintained and kept current without re-issuing TP15. The updates will be re-published at the DDESB's webpage <http://www.ddesb.pentagon.mil>.

C1.1.5. Where additional information or explanation is considered important or relevant, an editor's note is provided. This information is identified as follows: [**Note:**].

C1.2. SUMMARY OF DDESB TP 15 CONTENT. The following descriptions provide a brief summary of the content of each chapter.

C1.2.1. Chapter 2 provides a history of the evolution of magazine design since the early 1990s and the significant testing that has been conducted as part of this evolution that has impacted magazine design and magazine siting criteria.

C1.2.2. Chapter 3 addresses the major differences between 7-Bar, 3-Bar, and Undefined ECM and describes the typical features and structural components associated with each type. Chapter 3 also includes a discussion of storage magazines and transportation containers that have been specifically approved with reduced net explosive weight (NEW) and/or reduced QD.

C1.2.3. Chapter 4 provides information associated with the four magazine tables found in Appendix AP1. Those tables list ECM, as well as those magazines and transportation containers that have reduced QD or reduced MCE, identified to date and relevant information for each design.

C1.2.4. Chapter 5 pertains specifically to underground (tunnel) AE storage facilities. The information contained within this chapter is minimal at this time.

C1.2.5. Chapter 6 provides a comprehensive discussion of available barricade designs, fragment distance-limiting barrier designs, test cells, suppressive shields, and other similar protective construction, that have been approved for use by the DDESB and pertinent testing and information related to each item.

C1.2.6. Chapter 7 describes the history and testing associated with barricaded module development and their use for AE storage.

C1.2.7. Chapter 8 documents the history and testing of hardened aircraft shelters (HAS).

C1.2.8. Appendix AP1 contains Tables AP1-1 through AP1-4, which are discussed in Chapter 4. Supporting information, as appropriate, are included in the tables.

C1.2.8.1. Table AP1-1 identifies 7- and 3-Bar ECM designs approved for new construction. These are designs that are being maintained by DoD Components and that are kept current with explosives safety criteria (e.g., explosives safety, construction, specifications).

C1.2.8.2. Table AP1-2 lists existing 7- or 3-Bar ECM designs that users may find in the field. These designs are no longer maintained and will more than likely not reflect current criteria. **[NOTE:** These designs can be considered for new construction, as approved on a case-by-case basis by the DoD Component, provided the designs have been thoroughly reviewed and the design drawings updated to reflect current criteria.]

C1.2.8.3. Table AP1-3 is a listing of ECM designs determined to be Undefined structures. A design is placed in this category when it is either known to be structurally weaker than a 7- or 3-Bar ECM design (through a structural assessment, analysis or test), or if insufficient information is available to indicate its strength. When testing is being considered, it should be coordinated through the DDESB to ensure the proper testing is being conducted. **[NOTE:** These

designs can be considered for new construction, as approved on a case-by-case basis by the DoD Component, provided they have been thoroughly reviewed and updated to reflect current criteria.]

C1.2.8.4. Table AP1-4 lists magazine (both ECM and aboveground) designs and transportation containers that have reduced QD and/or reduced MCE.

C1.2.9. Appendix AP2, Operation Field Storage, has been added to assist those users who have a need to establish AE storage sites in the field, typically with significant real estate constraints. AP2 addresses the use of protective construction for the reduction of a MCE. This is important because personnel in the field typically have insufficient real estate available to them to apply default explosives safety quantity distance criteria of reference 1-1. The information contained in AP2 was extracted and consolidated from TP15 and other sources, as necessary. [**NOTE:** A reduced MCE will generally, but not always, result in reduced QD.]

C1.3. **TP 15 SUPPORT DOCUMENTATION.**

C1.3.1. A great deal of supporting documentation (e.g., construction drawings, approval memorandums, DoD Component letters, messages, technical reports, analyses) has been accumulated in the process of developing TP15. Work is continuing by the DDESB to convert this information into an electronic format to be stored within a DDESB repository that is available to authorized outside users. In addition, the Naval Facilities Engineering Command (NAVFAC) is establishing a web site that will make specific information (e.g., drawings, approval memorandum, specifications) related to magazine designs shown in Tables AP1-1 through AP1-4 more easily accessible to authorized users. NAVFAC is working closely with the DDESB to ensure their web site content is consistent with TP15.

C1.3.2. Finding drawings for older magazines is not an easy process, and in many cases the drawings may no longer be available. Users of this document need to be aware that the organizations referred to as "Designer" reflect the original designer; therefore, in some cases, the listed design organization may no longer be in existence. In such cases, the location of their drawings may not be known. Drawings for newer magazines, or information pertaining to design drawings, may be obtained from the design and explosives safety agencies shown below:

Army

U.S. Army Corps of Engineers
Engineering and Support Center, Huntsville (USAESCH)
Attn: CEHNC-ED-CS-S
P.O. Box 1600
Huntsville, AL 35807-4301

Defense Ammunition Center
Attn: SJMAC-EST
1 C Tree Road
McAlester, OK 74501-9053

Navy Naval Facilities Engineering Command (NAVFACENGCOM)
Attn: NAVFAC Criteria Office (Code 15C)
1510 Gilbert Street
Norfolk, VA 23511-2699

Naval Ordnance and Security Activity (NOSSA)
Attn: N71
23 Strauss Avenue, Bldg D323
Indian Head, MD 20640-5035

Naval Facilities Engineering Service Center (NFESC)
Attn: ESC62
1100 23rd Avenue, Building 1100
Port Hueneme, CA 93043-4370

Marine Corps Commander, Marine Corps Systems Command
Attn: AM-EES
Barnett Avenue, Suite 315
Quantico, VA 22134-5010

Air Force Air Force Safety Center (AFSC)
Attn: AFSC/SEW
9750 Avenue G, Suite 264
Kirtland AFB, NM 87117-5670

DDESB Department of Defense Explosives Safety Board
Room 856C, Hoffman Building I
Attn: KT
2461 Eisenhower Avenue
Alexandria, VA 22331-0600

C1.4. **KEEPING TP 15 CURRENT**. For TP15 to be of continuing value to all users, it is important that it be kept current and accurate. The DDESB will maintain this document on its Web site [<http://www.ddesb.pentagon.mil>] and will update it as new protective construction designs are approved and as information is received/evaluated. The explosives safety community is asked to provide the DDESB (Attn: Mr. Eric Deschambault, Code DDESB-KT2) with copies of any documentation that can be used to correct, update, or enhance this document. In particular, it is requested that copies of old drawings and electronic photographs be provided for those structures and barricades listed herein (or not listed so that they can be added), for inclusion into the documentation database. Upon receipt, all information will be reviewed, and if warranted, added to TP 15. As new designs are approved or modified, they will be added to the documentation database. In order to improve the timeliness of the magazine listings in TP15, the four tables containing the magazine listings were re-located (as part of TP15 Version 2.0) from Chapter 4 (TP 15, Version 1.0) to Appendix AP1 so that they can be updated periodically without the re-issuance of TP15.

C1.5. REFERENCES.

- 1-1. DoD 6055.9-STD, "DoD Ammunition and Explosives Safety Standards," Under Secretary of Defense for Acquisition, Technology, and Logistics (current edition).

C2. CHAPTER 2

MAGAZINE HISTORY

C2.1. EARLY HISTORY OF EXPLOSIVES SAFETY DISTANCES. Throughout this document, reference is made to the American Table of Distances (ATD). The following provides a brief history of the ATD, its origins, and how it was initially used by the military services. The historical information contained in this section was extracted from references 2-1 and 2-2 and various Board records between 1928 and 1956. Reference 2-3 provides a listing and summary discussion for the meetings that were held during this time period.

C2.1.1. Prior to 1910, there was no recognized rule or table that specified safe distances from AE storage sites in the United States. Because of this, large quantities of AE could be and were stored in close proximity to population centers, often leading to disastrous results when accidents occurred. In 1910, a group associated with the explosives industry developed the ATD, with an objective of establishing distances between stores of explosives and its surroundings. The goal was to minimize hazards to the public and to public property. The ATD distances were based on experiences from over 100 notable explosions involving up to 800,000 pounds net explosive weight (NEW). Following development of the ATD, a number of states incorporated it into their laws. The ATD was adopted for use by the military services in 1928. The circumstances leading to military adoption of the ATD are described in C2.1.3 below.

C2.1.2. There were two elements of the ATD that eventually led to its demise as the continued basis for military safe distances for the storage of high explosives. The first was that it was based on late nineteenth and early twentieth century accidents and did not include more “recent” (in 1945) accidents involving more energetic or powerful military explosives. The second was that the primary basis for the ATD was the assumption the explosion took place in the open, behind a shield or barricade. On this basis, the ATD permitted the use of reduced distances, if the explosion site was barricaded. However, by 1945, it was generally recognized that, except in very special circumstances, barricades around explosives had no effect in reducing the maximum distance at which structural damage occurred. This recognition was based on a further assessment of post-1910 accidents involving military explosives and the results of testing that proved that the distances prescribed in the ATD were inadequate in providing an acceptable level of protection to the public involving military explosives.

C2.1.3. The following chronology describes the origin and use of explosives safety distances by the U.S. military, up to 1956, when DoD criteria were first published for the storage and handling of mass-detonating materials:

10 July 1926 - A catastrophic explosion, ignited by a lightning strike to an explosives storage site, occurred at Lake Denmark Naval Ammunition Depot, NJ (located adjacent to Picatinny Arsenal and approximately 3-1/2 miles from Dover, N.J). The initial event propagated to additional explosives storage sites. This accident virtually destroyed the depot, causing heavy damage to adjacent Picatinny Arsenal and the surrounding communities, killing 21 people, and seriously injuring 51 others. The monetary loss to the Navy alone was \$46 million (1926 dollars). Injuries occurred out to a distance of three

miles. Window breakage extended out to a distance of 5 miles. This event caused widespread concern and indignation among the public about the practice of building arsenals and storing dangerous explosives near populous communities.

1927 - In light of the Lake Denmark disaster and the general public's concern with military ammunition storage, the 70th Congress directed that the Secretaries of War and Navy prepare a report on the subject of ammunition storage conditions. The Secretaries subsequently assigned a Joint Board on Ammunition (JBA), consisting of four military officers, "to conduct a survey of points of supplies of ammunition and components thereof for use of the Army and Navy...". This Board convened on 9 Jan 1928. In their final report, submitted approximately two months later to the Secretaries, the Board made specific recommendations for correcting the storage problems they found; they also recommended the adoption of the New Jersey explosives law, which had incorporated the ATD as its standard of safety. The Secretaries approved the Board's report.

1928 - The Secretaries transmitted their final report on 9 Mar 1928 to the House of Representatives. The Committee on Appropriations printed the report and it became known as House Document No. 199. Subsequently, a special sub-committee of the House of Representatives was appointed to investigate the issue of explosives storage. During the hearings, the sub-committee chairman suggested that a permanent board of munitions storage, representing both the Army and Navy, be established. The sub-committee also recommended appropriations to carry out the recommendations of House Document 199. Congress approved both the recommendations and the appropriations. Subsequently, the Joint Army Navy Munitions Board (JANMB) was established on 6 August 1928. This Board used the ATD as its guide for the application of safe separation distances.

1945 - Reference 2-1 was published. This paper compared accident data (117 events from 1882 to 1909) used to develop the ATD to additional accident data (66 events from 1910 to 1945) that had occurred after the ATD was published. The data presented showed that the safety distances required by the ATD were inadequate for military explosives, and that an increase in the safety distances was warranted.

1948 - In a 19 Jan 1948 letter, the Army Navy Explosives Safety Board (ANESB) documented their concern that the barricaded inhabited building distance (IBD) and public traffic route distance (PTRD) criteria of the ATD did not provide reasonable and practical protection against loss of life, serious injury, and undue property damage. The ANESB recommended that greater barricaded IBD and PTR quantity distance (QD) be used in place of the ATD. This recommendation was a result of a reappraisal (reference 2-4) of the ATD performed by Dr. Ralph Ilesley of the ANESB and that was published in 1948.

1948 - In a 1 Nov 1948 letter, the Armed Services Explosives Safety Board (ASESB) proposed revised QD for mass detonating explosives and ammunition, for adoption by the Armed Services. No formal adoption of these rules was ever accomplished.

1950 - In a 1 April 1950 letter, the ASESB again proposed new QD criteria for mass-detonating materials,

1956 - DoD Directive 4145.17, QD Standards for Manufacturing, Handling, and Storage of Mass-Detonating Explosives and Ammunition, was published on 7 Dec 1956.

C2.2. MAGAZINE DESIGN EVOLUTION FROM PRE-1928 THROUGH 1970. The historical information provided in paragraph C2.2 below was extracted primarily from a December 1950 document (author unknown), and has, except for minor editing changes, been repeated verbatim. It chronicles the evolution of AE magazines from aboveground structures (sometimes barricaded) to the more modern earth-covered structures in existence today. The 1950 document also provides a unique insight into the thought process that drove this evolution. Testing to prove out the theories about QD associated with earth-covered magazines and their structural strengths did not begin in earnest until about 1945. The knowledge gained from this testing was responsible for future magazine designs and separation distance criteria. Testing also disproved many magazine designs that were considered standards for many years; and consequently they became unsatisfactory and obsolete. Paragraph C2.3 documents the testing that has had a significant impact on magazine design and magazine siting criteria.

C2.2.1. Magazines: PRE-1928. AE storage facilities were typically of three types. These were aboveground, casemate, and dumps. There was also one other design that was just starting to be constructed in the late 1920s. During the 129th Meeting of the ASESB on 13 May 1953, a discussion was held regarding the Lake Denmark accident of 1926 and the Navy-developed earth-covered magazine design that withstood nearby major explosions of surrounding facilities. At this meeting, the Navy representative to the Board stated the survival of this particular magazine design at Lake Denmark was what started the Navy's move towards construction of earth-covered igloos. This event also later sparked the Army's interest in the earth-covered magazine design concepts.

C2.2.1.1. Aboveground magazines were rectangular, gable-roofed or flat-roofed buildings constructed of masonry (typically tile), corrugated asbestos on a wood frame, or ordinary wood frame construction, with floors at grade or at car-floor level [**Note:** Refers to the presence of a loading dock at railcar floor level]. Occasionally, separate barricades were erected around the magazines, so that safety distances could be halved as permitted at that time by the ATD.

C2.2.1.2. Casemate magazines were masonry vaults in fortifications (sometimes in hills, etc.) and were used only at line stations, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.1.3. Dumps were stacks in the open. This type of AE storage was seldom used, except in wartime.

C2.2.1.4. The Navy's new earth-covered magazine design was constructed of either stone masonry walls or of reinforced concrete and had 1-foot of earth-cover over the top of the structure. The principle behind development of this design was that the structure itself was designed to be weak; in order to avoid confinement and minimize the effects of an internal explosion, but it would be strong enough to protect its contents from fire, wind pressure, snow

loads, and other external forces. The purpose of the earth cover was to provide greater protection against long-range missiles that might drop onto the top of the structure.

C2.2.2. **Magazines: 1928 - 1940.** During this time period, there were two major efforts to construct ammunition storage structures and ammunition storage depots. The first followed the 1926 Lake Denmark accident and continued until approximately 1934. This effort was in response to recommendations made by the JBA in their final report to the Secretaries of War and Navy, which then went to the 70th Congress. In their report, the JBA adopted the ATD for the establishment of safe separation distances and made a number of recommendations for constructing new storage areas and relocating ammunition to safer storage sites. The impact of adopting the ATD was that a number of ammunition storage locations, in use at the time, were not able to meet ATD safe separation distance criteria. In order to bring the storage into compliance with the recommendations that were made by the JBA, Congress appropriated funds to construct new magazines at certain existing installations, to construct new depots, and to relocate ammunition, as necessary. These efforts were coordinated, reviewed, and approved by the Joint Army Navy Munitions Board (JANMB), which was formed after the JBA completed their report. As part of this re-stowage effort, new magazines were constructed at Ft. Bragg, Savanna Ordnance Depot, Benecia Ordnance Depot, Delaware Ordnance Depot, Ogden Ordnance Depot, and Aberdeen Proving Ground. Navy installations that gained new magazines were: Navy Mine Depot - Yorktown, VA; Naval Ammunition Depot (NAD) St. Juliens Creek, VA; NAD Hingham, Mass.; NAD Iona Island, NY; NAD Lake Denmark; NAD Mare Island, CA; Naval Torpedo Station, Keyport, WA. New depots were also constructed at Hawthorne, Nevada and Kuahua, HI, in the Lualualei District. The second major ammunition storage (expansion) effort began in the early 1940's as a result of WWII. This effort constructed thirteen (13) new Army Ordnance Depots (see C2.2.3. below) and four (4) new NAD (Burns City, IN; Charleston, SC; Fallbrook, CA; New Orleans, LA).

C2.2.2.1. Aboveground magazines continued to be regarded as the standard and to be constructed. Casemate magazines tended towards obsolescence with the decline in importance of harbor defenses.

C2.2.2.2. The mounded concrete arch magazine was originally designated "under ground magazine" and was soon dubbed the "igloo-type magazine" or simply "igloo". This design appears to have been developed during the 1920s, possibly independently, in different places. The German "Munitionshaus" being constructed in 1938, and probably before, was of this type. U.S. Naval ammunition depots had igloos in existence by 1928. Brigadier General Hof of the Ordnance Department, U. S. Army, learned of the Navy igloos, and in light of their survival at Lake Denmark, directed adoption of this concept by the Army. [Note: General Hof was one of four military officers assigned to the 1928 Joint Board on Ammunition that reviewed ammunition storage following the Lake Denmark accident. He was also the first Chairman of the JANMB.]

C2.2.2.3. These igloos consisted of a reinforced concrete, approximately semi-circular barrel arch springing from a floor at grade (or occasionally at car-floor level). It was thus above natural grade, but was called "underground", because the arch and rear wall were covered over with earth.

C2.2.2.4. Factors that led to the preference for the "underground" magazine over the older aboveground types were:

C2.2.2.4.1. The thermal insulation qualities of the concrete and earth would eliminate the extreme high temperatures which were experienced in aboveground magazines and which accelerated the deterioration of smokeless powder and other stores.

C2.2.2.4.2. The earth-cover would facilitate camouflage.

C2.2.2.4.3. It was expected that the igloo would be less of a hazard to its environs than an aboveground magazine, particularly an unbarricaded, aboveground magazine. It was supposed that an explosion of the igloo's contents would be confined by the thick haunches of the concrete arch and by the thick earth fill at the sides, and would be vented upwards through the thin crown. It was expected that the radius of simultaneous ("sympathetic") detonation, the radius of structural damage, and the range of debris would all be reduced.

C2.2.2.4.4. In view of C2.2.2.4.3 above, intermagazine distances, inhabited building distances, etc., could be halved because of being "barricaded" without the necessity for separate barricades, and land area requirements would be substantially reduced.

C2.2.2.4.5. It was supposed that the igloo would be missile-proof and resistant to structural damage, with respect to an explosion at an adjacent igloo. In aboveground magazines, even though barricaded, explosives subject to initiation by missiles or by structural damage had to be separated from missile-forming and mass-detonating ammunition by inhabited building distance, rather than by intermagazine separation distance. With igloos, this requirement could be waived, with a further saving in land requirements, to provide increased flexibility and efficiency in space utilization.

C2.2.2.4.6. The possibility of propagation of an explosion from magazine to magazine would be reduced to practically zero.

C2.2.2.5. **First Army "Standard" Magazine ("old Savanna type")**.

C2.2.2.5.1. OQMG Drawings 6379-160 and 6379-161; changed to 652-311 and 652-312 (Ordnance Drawings. 19-2-03 and 19-2-04, Magazine Type 30), dated 19 July 1928. "Standard Underground Magazine".

C2.2.2.5.2. This reinforced concrete (RC) magazine had interior dimensions of 25 feet wide, 40 feet 4 inches long, and 10 feet high at the crown. The arch crown was 5 inches thick. The base of the arch was 10 inches thick. The front concrete wall had a thickness of 4 inches and the rear concrete wall was 6 inches thick. The arch and walls had wire mesh reinforcement that was electrically grounded. The magazine had a six-foot by eight-foot double steel-clad wood door. A full-timber headwall was provided. There was no platform or apron, and the magazine fronted directly onto the road. An optional front barricade, across the road, could be constructed. Vent louvers were provided. Earth cover, at the crown, was one-foot thick. [Note: The term "headwall" is now used to describe a magazine's front wall, and the term

"wingwall" describes the wall (located on both sides of the headwall) that supports a magazine's earth cover. In the early years of earth-covered magazine design, the term "front wall" denoted just the portion that fronted the magazine, with the "headwall" defining the portion supporting the magazine's earth cover.]

C2.2.2.5.3. This magazine was constructed at the following military installations: Savanna, Delaware, Benicia, and Aberdeen.

C2.2.2.6. **"Old Line" Type Magazine.**

C2.2.2.6.1. OQMG 652-295 and 652-296 (Ordnance Drawings 19-2-107 and 19-2-108, Magazine Type 42), dated 20 June 1933.

C2.2.2.6.2. Same as C2.2.2.5 above, except an exterior monorail was added, the doors were changed to steel plate, the headwall was changed to concrete, earth cover was increased to two feet thickness, a sand cushion was placed on the magazine's water-proofing, and the concrete front wall's thickness was increased to 6 inches.

C2.2.2.6.3. This magazine was intended for use at line stations, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.2.7. **"Old Depot" Type Magazine.**

C2.2.2.7.1 **Drawings.**

C2.2.2.7.1.1. **Forty-foot length:** OQMG Drawings 652-317 through 652-320 (Ordnance Drawings 19-2-121 through 19-2-124 and 19-2-130, Magazine Type 48), dated 9 December 1935, "Underground Magazine-Igloo Type" (Type 1).

C2.2.2.7.1.2. **Sixty-foot length:** OQMG Drawings 652-326 through 652-331 (Ordnance Drawings 19-2-125 through 19-2-129, Magazine Type 49), dated 23 July 1937. This magazine had an interior width of 26 feet 6 inches and an interior height of 12 feet 9 inches. A monorail was provided that was supported by pilasters projecting from the end walls. It had a single 4-foot wide door. Arch wire mesh was used for arch reinforcement. The crown thickness was 6 inches and the reinforced concrete front wall thickness was 7 inches.

C2.2.2.7.1.3. These types of magazine were constructed at "old ordnance depots" (Raritan and Benicia Arsenal, Charleston, Curtis Bay, Delaware, Nansmond, Ogden, San Antonio, Savanna, and Wingate) and at line stations, such as Coast Artillery and Harbor Defense installations and seacoast battery emplacements. During construction at Ogden, the headwalls were stubbed (shortened) by the elimination of wingwalls.

C2.2.3. **1940 - 1945.**

C2.2.3.1. **"New Depots" Type Magazine.**

C2.2.3.1.1. OQMG Drawings 652-340 through 652-349, dated 27 September 1940. The drawings were lost and replaced by OQMG Drawings 652-377 through 652-386, dated 30 October 1940. Reference is made in the original documentation to this being a Type 2 magazine. Reinforced concrete headwalls were 7 inches thick and the crown was 6 inches thick.

C2.2.3.1.2. This design provided for three optional interior lengths (40-foot 4 inches (1,003 square feet), 60-foot 8 inches (1,528 square feet), or 81-foot 0 inches (2,147 square feet)), deleted the monorail and pilasters, and deleted vents, which were subsequently restored by Revision C, dated 1941).

C2.2.3.1.3. This type magazine was constructed at the following new Ordnance Depots: Anniston, AL; Milan, TN; San Jacinto, TX; Portage, OH; Red River, TX; Seneca, NY; Navajo, AZ; Black Hills, SD; Blue Grass, KY; Sierra, CA; Pueblo, CO; Letterkenny, PN; and Umatilla, OR.

C2.2.3.2. **"World War II" Type Magazine.**

C2.2.3.2.1. OCE Drawings 652-686 through 652-693, dated 27 December 1941, "Underground Magazine-Igloo Type". Magazine Type O. Revised 14 March 1942. This design was available in 60 and 80-foot lengths.

C2.2.3.2.2. This design has fully reinforced arch and walls and a full concrete headwall, vents were restored, an alternate concrete door was added, the front wall thickness was increased to 10 inches, and sand fill was deleted.

C2.2.3.2.3. This type magazine was constructed at Army Ordnance Depots and at line stations. [Note: A 2 December 1944 document lists this magazine type being constructed at the following depots in 1941 and 1942: Umatilla (652 - 60'; 358 - 80'), Wingate (550 - 60'; 100 - 80'), Anniston (200 - 60'; 600 - 80'), Portage (354 - 60'; 100 - 80'), Milan (600 - 60'; 100 - 80'), San Jacinto (146 - 60'; 54 - 80'), Seneca (400 - 60'; 100 - 80'), Red River (300 - 60'; 400 - 80'), Letterkenny (200 - 60'; 600 - 80'), and Sierra (200 - 60'; 600 - 80').]

C2.2.3.3. **"Huntsville" Type Magazine.**

C2.2.3.3.1. OCE Drawings 652-1012 through 652-1014, dated 29 April 1942. Magazine Type A-O. This design was available in 40, 60, and 80-foot lengths.

C2.2.3.3.2. This magazine was a redesign of the World War II Type Magazine with the goal being to conserve critical materials needed for the war effort. Reinforcing was reduced, with the reinforcing bars replaced by 4" by 4" wire mesh weighing 62 lbs/ft² in the extrados (exterior surface of the arch) only; the headwall was stubbed (earth fill spilled around front corners); the door was changed to 6-foot double sheet steel; and the front wall thickness was reduced to 8 inches.

C2.2.3.3.3. This magazine type was constructed at Ordnance Department industrial installations [Notes: An Ordnance Department industrial installation was an activity operated by the Ordnance Department for the production of ammunition. A 2 December 1944 document states that 40, 60, and 80-foot magazines were constructed at the following depots in 1942: Pueblo (200 - 60', 600 - 80'), Black Hills (200 - 60', 600 - 80'), Blue Grass (200 - 60', 600 - 80'), Navajo (200 - 60', 600 - 80'), and Tooele (200 - 60', 600 - 80'). Two forty-foot magazines were constructed at each of the following ordnance depots: Umatilla, Wingate, Anniston, Portage, Milan, San Jacinto, Seneca, Red River, Letterkenny, Pueblo, Black Hills, Blue Grass, Navajo, and Tooele]

C2.2.3.4. **"Corbetta and Beehive" Type Magazines.** This has also been called a "Dome-Type" Magazine.

C2.2.3.4.1. OCE Drawings 652-1000 through 652-1010, dated 19 February and 23 March 1942, "Underground Magazines 52-foot 0 inches and 44-foot seven inches, Corbetta and Beehive Types".

C2.2.3.4.2. This design has a reinforced concrete dome (oblate hemispheroid) and the floor is at grade level. Other features include 2-feet of earth cover, a single 6-foot double sheet-steel door, and a buried counter-poise (ground loop), to which was grounded the magazine's metallic masses (reinforcing steel, door, ventilator). The ventilator also had an air terminal for lightning protection.

C2.2.3.4.3. This type magazine was constructed at Curtis Bay (location for pilot model magazine), Sioux (A 2 December 1944 document lists the following quantities as being constructed 202 - Corbetta; 600 - Beehive), Susquehanna, and Ordnance Department industrial installations.

C2.2.3.5. **"Richmond" Type Magazine.**

C2.2.3.5.1. OCE Drawing 652-1017 and 652-1018, dated 13 May 1942.

C2.2.3.5.2. This magazine is not an igloo, but it has been frequently so miscalled. It has massive masonry side and rear walls, which are banked with earth. It has a wood frame front wall, with asbestos shingles, and a wood frame gable roof.

C2.2.3.5.3. This type magazine was constructed at Ordnance Department industrial installations.

C2.2.4. **1945 Through 1970s.**

C2.2.4.1. The following door design/installation drawings and sketches were provided to the Armed Services Explosives Safety Board (ASESB) for review. Prints were furnished to OCE along with ASESB recommendations for their use in lieu of the typical four-foot, single blast-proof door being used at the time.

C2.2.4.1.1. Office of the Chief of Ordnance (OCO) Sketch UD-29, dated 11 February 1946 (revised 14 March 1946), was for a 6-foot double blast-proof door.

C2.2.4.1.2. OCO Sketch UD-29A dated 14 Mar 1946, for installation of Sketch UD-29 6-foot double blast-proof door on existing igloos.

C2.2.4.1.3. FP 3a, dated 23 April 1946, for a double blast-proof door, was designed by Mr. Stradley of Code ORDFT, for special projects at Ordnance Depot Wingate.

C2.2.4.2. **"Engineer" Type Magazine.**

C2.2.4.2.1. OCE Drawing 33-15-01 (7 sheets), dated 27 January 1948.

C2.2.4.2.2. This magazine design was similar to the World War II Type, except that door was changed to an un-reinforced 6-foot single, steel plate; the headwall was stubbed; the platform and apron were rearranged; the front wall was restored to a 10-inch thickness; full reinforcement was restored; and sand fill was restored.

C2.2.4.2.3. This design was issued primarily for line station use, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.4.3. **Observed Magazine Design Problems.**

C2.2.4.3.1. The door of the "Engineer" Type Magazine was questioned as to its blast resistance capability.

C2.2.4.3.2. The "Corbetta and Beehive" Type Magazines, originally approved by OCO, were considered unsatisfactory following their approval and were officially made obsolete.

C2.2.4.3.3. The "Huntsville" Type Magazine had never been approved and was considered unsatisfactory.

C2.2.4.3.4. The "Richmond" Type Magazine, a wartime substitute, was never classed as an igloo magazine for quantity-distance purposes.

C2.2.4.3.5. All pre-World War II Magazines were no longer considered fully satisfactory with respect to explosives safety.

C2.2.4.4. **Correction of Design Problems.** In 1945, preliminary magazine testing had begun with the goal of proving out magazine designs and the separation distances being used by the Services. As a result of the data obtained from this preliminary testing, the ASESB issued a report, dated 1 April 1950, that called for the front walls of magazines to be increased in strength. This report also recommended that doors be widened to provide for safer handling of AE. On February 26, 1951, the Air Force concurred with criteria for a revised magazine design and Drawing DEF-E-33-15-04, Magazine, Mounded Concrete Igloo, Type MA-5, dated 29 May 1951

was created. With this design, magazine designs evolved from those based on theory to magazine designs founded on test results.

C.2.2.4.5. **New Army Magazine.**

C2.2.4.5.1. OCE Drawing 33-15-06 (6 sheets), dated 1 August 1951.

C2.2.4.5.2. This magazine represented a redesign of Drawing 652-686 through 652-692: The headwall thickness was increased to 12 inches; larger diameter and more reinforcing was used; and the door design was changed to two 4-foot wide doors that were 4-inches thick and were provided with vertical stiffeners.

C2.2.4.6. **Steel Arch Magazine.**

C2.2.4.6.1. In 1963, three semi-circular, corrugated steel-arch magazines with hinged double-leaf, steel plate doors were developed by Black and Veatch for the Air Force and the Defense Atomic Support Agency (DASA). (**Note:** It appears that both of these drawings were each a corrugated steel magazine design that had a 12-inch thick reinforced concrete headwall, a corrugated steel arch, and a reinforced concrete rear wall. A flow-through design also was developed which had two headwalls and no rear wall). Access to the magazine was provided via a hinged double-leaf steel plate door. A minimum of 2 feet earth-cover was specified. These magazines were:

C2.2.4.6.1.1. AW 33-15-63 (Air Force), dated 5 Mar 1963. Two separate designs were identified as part of this drawing: (a) Flow through design consisting of two headwalls and no rear wall. The magazine measured 11 feet wide by 68 feet long, and (b) a magazine design that measured 11 feet wide by 17 feet long. The door opening for both designs measured 10 feet wide by 8 feet high.

C2.2.4.6.1.2. AW 33-15-64 (Air Force), dated 10 May 1963. This design measured 25 feet wide by 60 feet long and had a door opening that measured 10 feet wide by 10 feet high.

C2.2.4.6.1.3. 33-15-65 (DASA), dated 10 Jan 1963. This drawing also had two separate designs identified on it: (a) 7 feet 6 inches by 11 feet long (min) to 27 feet (max), in increments of 2 feet, and (b) 9 feet wide by 11 feet long (min) to 27 feet (max), in increments of 2 feet. Each design had a door opening that measured 6 feet wide by 6 feet 4 inches high.

C2.2.4.6.2. Because these corrugated steel arch designs reflected a major conceptual change to the typical arch design (reinforced concrete) previously tested and upon which criteria were based, it was unknown whether existing magazine separation distance criteria could be applied to the semi-circular corrugated steel arch magazine design. Consequently, a series of tests were initiated at Naval Ordnance Test Station (NOTS), China Lake, CA, between January 1962 and December 1963. The results from the testing, which established minimum criteria for semi-circular, corrugated steel-arch magazines are summarized in C2.3.6.

C2.2.4.6.3. The 3 semi-circular, corrugated steel-arch magazine designs were approved at the 225th ASESB Meeting as Standard designs for 500,000 lbs NEW storage using separation distances determined by the NOTS testing.

C2.2.4.6.4. Subsequently, the door and headwall design was further tested during the Explosive Safety Knowledge Improvement Operation (ESKIMO) 1 test to evaluate the possibility of further reductions of intermagazine distance and to develop additional information to indicate the minimum safe distance to use between the concrete headwall of a magazine and the earth-covered side and rear walls and barricaded headwall of another magazine. These tests are summarized in C2.3.7. The principal conclusions arrived at from the test were that earth-covered, semi-circular steel-arch magazines, without intervening barricades, could be separated in a face-to-rear orientation by $2.0W^{1/3}$ and in a face-to-side orientation by a distance of $2.75W^{1/3}$. In addition, as a result of ESKIMO I data, the DDESB adjusted the spacing for a face-to-face orientation to $11W^{1/3}$ when unbarricaded, and to $6W^{1/3}$, when barricaded.

C2.2.4.7. **Modification of Steel Arch Thickness.** In response to a Navy query regarding NAVFAC Standard Steel Arch Magazines and an interest by the Navy in moving from a 1 gage corrugated steel arch to an 18 gage corrugated steel arch, ASESB-PP Memorandum of 18 June 1971 states that "The ASESB has recommended new standards for separation of earth-covered igloos which provide the same separation distances between earth covered surfaces of standard types regardless of the material of construction. The results of a number of recent tests including the Air Force Big Papa series indicate the volume of earth interposed is more important than other factors in preventing communication of detonation. If the headwall and rear wall construction proposed by the Navy are identical to the standard steel arch magazine, and the arch is of sufficient strength to permanently support the standard earth cover, these may be considered standard for the application of the siting criteria."

C2.2.4.8. **Oval Steel Arch Magazine.**

C2.2.4.8.1. OCE Drawing 33-15-73, dated February 1975.

C2.2.4.8.1. In the period 1972 through 1974, the Office, Chief of Engineers (OCE), contracted for and supervised the design of a new magazine design. The structure was built of a corrugated steel arch having a non-circular (oval) cross section, with a single leaf sliding door mounted on a reinforced concrete headwall. This design was considered optimal for unitized loads of rectangular shape and its relative construction economy (as compared to an all reinforced-concrete arch and headwall magazine design).

C2.2.4.8.2. Since the design represented a departure from the previously approved semi-circular steel arch design, it was incorporated into a series of tests, known by the acronym ESKIMO, the DDESB was developing and sponsoring to further define magazine separation distance requirements. A full-scale prototype of the oval steel arch magazine was tested at the Naval Weapons Center, China Lake, CA. The tests demonstrated the safety of the oval arch magazine design at the minimum separation distances permitted by QD standards for side-to-side orientations and for certain permissible headwall exposures. In January 1976, the DDESB

approved the oval steel arch magazine (specifically OCE 33-15-73) as a Standard magazine for the storage of up to 500,000 lbs NEW at minimum separation distances permitted.

C2.3. **MAGAZINE TESTING.**

C2.3.1. **Magazine Siting (From Laws of New Jersey - 1925).** As discussed at the start of this chapter, the JMB adopted the explosives laws of the State of New Jersey for its standard of safety. These laws, which incorporated the ATD, specified the following with respect to explosives storage:

C2.3.1.1. Magazines in which more than 50 pounds of explosives are kept or stored must be detached from other structures and magazines.

C2.3.1.2. Magazines where more than 5,000 pounds of explosives are kept or stored must be located a minimum of 200 feet from other magazines.

C2.3.1.3. Magazines where quantities of explosives over 25,000 pounds are kept or stored must be located a minimum of 200 feet from other magazines, with an increase of two and two-thirds (2-2/3) feet for each 1,000 pounds of explosives in excess of 25,000 pounds.

C2.3.1.4. "No quantity in excess of 250,000 pounds of explosives ... shall be had, kept, or stored in any factory building, or magazine in this state."

C2.3.2. **Magazine Siting (post 1928).** In March 1928, this Board established additional AE storage rules to complement the ATD. These rules were:

C2.3.2.1. The Army could store up to 250,000 pounds NEW at a minimum IMD of 400 feet.

C2.3.2.2. The Navy could store up to 143,000 pounds NEW at a minimum IMD of 500 feet.

C2.3.3. **Naval Proving Ground, Arco, Idaho, 1945 Testing.**

C2.3.3.1. During this period of history, the armed services were limited to an allowable quantity per storage unit of 250,000 pounds, which for strategic and economic reasons was regarded as the maximum quantity whose loss could be risked at one time. However, with the close of World War II, on-hand ammunition tonnage quantities were so vast that the earlier considerations were no longer valid and the question of safety of surrounding populations and structures and the avoidance of major losses became the only impediments to raising the limit. It was out of this concern that the JANASB, in October 1944, recommended to the Secretaries of War and Navy, that testing be conducted to determine whether standard intermagazine distance might safely be reduced and whether AE might safely be stored in open stacks midway between existing magazines. Successful testing would help alleviate safety concerns, eliminate the need to purchase additional land for the construction of new magazines to handle the influx of returning AE, extend available data on QD relations for storage of high explosives, and provide a check on

the inhabited building safety distances for barricaded storage, as prescribed by the ATD. The ATD permitted the reduction of inhabited building safety distances by 50%, if a barricade stood between the explosives and the inhabited building. In October 1947, the Secretaries of War and Navy approved testing and each service contributed funding to conduct the tests, which required the construction of four test igloo magazines, three revetments, and a wood-frame barracks test building.

C2.3.3.2. The 1945 tests are documented in reference 2-5. The following conclusions were reached from the tests:

C2.3.3.2.1. The Army standard intermagazine spacing of 400 feet (K6.4), clear distance edge-to-edge, between earth-covered, reinforced concrete, arch-type (igloo) magazines that were limited to 250,000 pounds net pounds of high explosives in each, could be reduced to 185 feet (K2.94), without appreciable risk that a detonation of the entire contents of one such magazine would propagate to another. This 185-foot clear distance results when an additional magazine is built midway between two existing magazines at the Army standard intermagazine spacing of 400 feet.

C2.3.3.2.2. Structural damage done to an igloo when a 250,000-pound charge is detonated in a neighboring igloo at 185-foot (K2.9) clear distance is slight.

C2.3.3.2.3. When 250,000 pounds of high explosives are detonated in an open revetment located midway between igloos 400 feet (K6.4) apart, it is improbable that the explosion will propagate to either igloo, and they will not suffer severe damage.

C2.3.3.2.4. A two-story, wood-frame, standard-type barracks building is not entirely safe from structural damage, and its occupants are likely to suffer severe injury from flying fragments of window glass, when 250,000 pounds NEW of high explosives are detonated within an igloo magazine at a distance of 2,155 feet (K34.2), the safety distance specified by the Table of Distances for inhabited buildings from a barricaded storage of such quantity.

C2.3.3.3. In February 1946, the JANASB voted to continue the test program begun in 1945, with the primary interest in further investigating the possibility of safely increasing the potential storage capacities of existing storage facilities, without acquiring additional land, by raising the allowable explosive limit per igloo magazine to 500,000 net pounds of high explosives. In addition, the Board contemplated that it might be safe and feasible to double the quantity of high explosives per igloo magazine (to 500,000 pounds), while reducing by 50% the required 400-foot intermagazine separation distance used between magazines. In order to evaluate this possibility, the Board chose to use a 185-foot (K2.3) spacing (side-to-side) between test magazines and a 360-foot (K4.5) spacing (front-to-rear) spacing between test magazines. One other area that the Board decided to evaluate was the effect that increased earth-cover might have on the blast phenomena. This would be done using a number of 1/10-scale model igloos, which were already available, and a full-scale igloo magazine remaining from the 1945 test series.

C2.3.4. Scale Model Testing at Underwater Explosives Research Laboratory, Woods Hole, MA, 1945 Testing, and Naval Proving Ground, Arco, Idaho, 1946 Testing.

C2.3.4.1. Scale model tests of detonations of high explosive charges in igloo magazines and in open storage were conducted at Naval Proving Ground, Arco as a sequel to similar tests by the Woods Hole Oceanographic Institution, in order to further study the effects of such explosions on next-in-line igloos, to investigate whether the model law holds for determining various phenomena from explosions, and to determine how increased earth cover on the exploding donor magazine affects these phenomena. In order to investigate the effects of explosions in igloos on adjacent igloos, without going to great expense, the Board arranged for tests to be conducted using 1/10 linear scale models of the standard Army and Navy 27-foot by 80-foot igloo magazine and 1/1000 ratio of charge weights. Eight tests were held, six with 250-pound charges and two with 500-pound charges, simulating certain phases of the 1945 and 1946 full-scale test programs.

C2.3.4.1.1. The 1945 Woods Hole scale model testing is recorded in reference 2-6, while the 1945 Arco scale model test report is provided by reference 2-7. The following conclusions were reached from the this series of tests:

C2.3.4.1.1.1. The model law holds for air blast, crater diameters, horizontal earth movement, and damage to structures by air blast.

C2.3.4.1.1.2. The model law does not hold for crater depths, vertical ground movement, vertical component of ground shock, or damage to target igloos (which is partially caused by ground shock).

C2.3.4.1.1.3. Increased earth cover on a donor igloo magazine reduces air blast and damage to target structures.

C2.3.4.1.1.4. Use of standard service igloos does not justify halving the distances, specified by the ATD, for safety of inhabited buildings from unbarricaded charges. The ATD permitted halving required distances, if a barricade was present. [Note: Use of the term "standard" in 1945 and 1946, to describe an igloo, merely indicated that it was typical of what was being constructed by the Services at the time. During this period of magazine design history, the explosives safety community was still trying to determine what the strengths of these magazine designs were and what role these strengths played in preventing propagation. It was a result of these early tests that the term "standard" was revised to describe a magazine that, because of its inherent strength, met specific construction criteria that would permit it to be located closer to adjacent magazines containing up to 500,000 pounds NEW, as compared to those magazine designs that did not meet the more robust construction criteria.]

C2.3.4.1.1.5. Standard Army revetments around open charges do not reduce air blast generated by detonation of their contents.

2.3.5. Full-Scale Reinforced Concrete, Arch-Type Igloo and Revetment Tests at Naval Proving Ground, Arco, Idaho, 1946.

C2.3.5.1. **Test Description.** This series of tests was the continuation of testing begun in 1945, as described in paragraph C2.3.3, above. One of the proposed tests would utilize the remaining full-scale igloo from the 1945 test series, in order to obtain further data on the effects of augmented earth cover on a donor igloo with respect to blast damage and window breakage in nearby habitation-type buildings. The new facilities constructed in support of the 1946 testing included two reinforced concrete arch, earth-covered igloo magazines, two revetments, and three modified barracks structures. One of the igloos was constructed to Army Drawings (OCE) 652-687 through 652-693, while the second igloo was constructed to Bureau of Yards and Docks Drawings 357428 through 357430, except an Army-type door was installed. The Army igloo had no barricade, while the Navy igloo was provided a front barricade. These two igloos were tested with 500,000 pounds NEW of high explosives. The igloo used for the increased earth cover test was also of the Army design (Drawings 652-687 through 652-693) and its earth-cover at the crown was increased to a depth of approximately 6-1/2 feet. This igloo was tested with 250,000 pounds NEW of high explosives. The revetments were of the standard Army-type in use at the time.

C2.3.5.2. **Test Conclusions.** The report for this series of tests is provided by reference 2-8. The following conclusions were reached from these tests:

C2.3.5.2.1. Clear distances between standard reinforced concrete, arch-type igloos could be reduced to 185 feet (side-to-side), which equates to $2.3W^{1/3}$, for 500,000 pounds NEW.

C2.3.5.2.2. The maximum quantity of high explosives permitted in each igloo tested could safely be raised to 500,000 net pounds of high explosives.

C2.3.5.2.3. Army magazine design (OCE) 652-687 through 652-693 and Bureau of Yards and Docks (Bureau Y&D) magazine design 357428 through 357430, modified with an Army blast door, were qualified as standard magazines for 500,000 pounds of high explosives.

C2.3.5.2.4. Based on the damage experienced by the barracks structures from an explosion involving 500,000 pounds of high explosives, the 50% reduction of inhabited building distances, as permitted by the ATD when there is a barricade between the explosives and the inhabited buildings, is unwarranted in the case of standard earth-covered magazines. Testing showed that only a 20% reduction of the unbarricaded inhabited building distance is warranted.

C2.3.5.2.5. No evidence was produced to support the theory that an increase in earth-cover was sufficient to warrant reduction in inhabited building distances.

C2.3.5.3. **Criteria Change as a Result of Testing.** Based on the results of this testing, Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, and other magazines of equivalent strength, were required to use a side-to-side magazine

separation distance of 210 feet (K3.3) for quantities up to 250,000 net pounds of high explosives and a magazine separation distance of 400 feet (K6.3 to K5.0) for quantities over 250,000 pounds and up to 500,000 pounds. When modified by the addition of an Army blast door, these magazines were permitted to store up to 500,000 pounds with a side-to-side intermagazine separation distance of 185 feet (K2.3). [Note: There is a 9-year gap between when the above testing of Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430 occurred (1946) and when the Bureau Y & D blast door design, Drawing 626739, dated 19 March 1954, was published. The 1955 ASESB explosives safety standard specified that, in order to qualify as a "standard" magazine, Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, was required to be modified in accordance with Bureau Y&D Drawing 626739, dated 19 March 1954. Between the years 1946 and 1954 Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, was considered as a "standard" magazine when it had been modified with an Army blast door. It is therefore concluded that if the blast door being used on an arch-type igloo was equivalent to that being used with approved Army magazine design (OCE) 652-687 through 652-693, then it qualified the igloo to be considered a "standard" magazine.]

C2.3.6. Earth-Covered, Steel-Arch Magazine Tests, Naval Ordnance Test Station (NOTS), China Lake, CA, 1962 -1963.

C2.3.6.1. **Test Description.** Full-scale and model testing experiments conducted previously had demonstrated that the historical criteria for the storage of high explosives could be substantially improved for standard, reinforced-concrete, arch-type igloo magazines. The series of tests conducted between January 1962 and December 1963, at NOTS, had three goals; 1) determine the feasibility of reducing the land area required for high explosives storage by further reducing intermagazine spacing, 2) establish the minimum safe distance permissible between earth-covered, steel-arch magazines, and 3) compare the intermagazine protection afforded by the more economical steel-arch magazine with that afforded by the reinforced concrete, arch-type magazine. The steel-arch-type magazine designs to be tested were the Air Force's 33-15-63 and 33-15-64.

C2.3.6.2. **Test Conclusion.** The test series are documented in reference 2-9. The test concluded that steel arch magazine igloos could be safely located at side-to-side separation distance of K1.25; rear-to-rear separation distance of K1.5, and rear-to-front (unbarricaded) of K4.5.

C2.3.6.3. **Criteria Change as a Result of Testing.** Based on the results of this test series, the 225th ASESB of 19 February 1964 approved the siting of earth-covered, steel-arch magazines, constructed per Drawings AW 33-15-63 (5 March 1963), AW 33-15-64 (10 May 1963), and 33-15-65 (10 January 1963), or their equivalent, as standard magazines, using the following criteria:

- * Spacing is to be $1.25W^{1/3}$ for side-to-side and side-to-rear orientations.
- * Spacing is to be $1.5W^{1/3}$ for a rear-to-rear orientation.
- * Spacing is to be $4.5W^{1/3}$ for front-to-rear or front-to-side orientations.

* No magazine shall be spaced one from another at less than 7 feet.

C2.3.7. Explosive Safety Knowledge IMprovement Operation (ESKIMO) test series (I through VII), Naval Weapons Center, China Lake, CA., 1971 through 1985. Testing prior to the ESKIMO Series confirmed that some selected arch-type magazines, extant at that time, could be sited side-to-side at a scaled distance of $1.25W^{1/3}$, and that the separation distances for other orientations were overly safety conservative. Since these earlier tests did not satisfactorily answer questions about necessary separation distances for other orientations, additional testing was necessary. These questions led to the development of the ESKIMO Test Series (ESKIMO I through VII), which was conducted as part of a continuing program to determine more accurately minimum safe separation distances between earth-covered magazines storing high explosives. The reports for these tests are provided by references 2-10 through 2-18.

C2.3.7.1. ESKIMO I, 8 December 1971. Previous testing had demonstrated that earth-covered, steel-arch magazines could be safely spaced side-to-side at a distance of $K=1.25W^{1/3}$. However, little information had been developed to indicate the minimum safe distance to use between the concrete headwall of a magazine and the earth-covered side and rear walls and barricaded headwall of another magazine. The most recent data from the 1962 NOTS Test (reference 2-9) showed that a spacing of $4.5W^{1/3}$ for a front-to-rear orientation appeared to be conservative. ESKIMO I was designed to evaluate the possibility of further reductions of intermagazine distance.

C2.3.7.1.1. Test Description. The test required the construction of four acceptor steel-arch magazines constructed per OCE Drawing AW 33-15-64 (their lengths were limited to 20 feet) and one barricade. The donor magazine was a remaining structure from earlier 1963 testing. The acceptor magazines were oriented with respect to the donor, so that the desired relationships (i.e. front-to-side, etc.) could be tested. The donor charge consisted of 200,000 pounds of TNT contained in 13,696 155-mm projectiles. The test was fully instrumented in order to obtain the data described in the test objectives. High-explosive charges were located in each of the acceptor igloos to provide further evidence of the probability of the explosion propagating to the acceptor magazines. Each magazine contained eight acceptor charges, arranged in two rows of four, across the face of the magazine, one about 18 inches off the floor, and the other above it, about five feet off the floor.

C2.3.7.1.2. Test Objectives. Principal test objectives for ESKIMO I were: evaluation of igloo intermagazine spacing; measurement of fragment mass and distribution resulting from the mass detonation of typical high-fragmentation ammunition stored in a standard earth-covered igloo; measurement of air blast in the area surrounding such an explosion; and measurement of the structural motion of an earth-covered igloo in response to the explosion in an adjacent magazine.

C2.3.7.1.3. Test Conclusions. The principal conclusions arrived at from the test were that earth-covered, steel-arch magazines, without intervening barricades, could be separated in a face-to-rear orientation by $2.0W^{1/3}$ and in a face-to-side orientation by a distance of $2.75W^{1/3}$. In addition, as a result of ESKIMO I data, the DDESB adjusted the spacing for a face-to-face orientation to $11W^{1/3}$ when unbarricaded, and to $6W^{1/3}$, when barricaded.

C2.3.7.2. **ESKIMO II, May 1973.** This was the second in a DDESB-sponsored series of tests, whose main purpose was the evaluation of the protection afforded by five steel-arch acceptor igloo magazines, against communication of explosion, when their headwalls faced a barricaded donor site (bombs in a revetment).

C2.3.7.2.1. **Test Description.** ESKIMO II was a full-scale proof test of other existing and modified door and headwall designs; in this test, the separation distances from a donor stack of bombs, in a revetment, were approximately the same for all five acceptor igloo magazines facing the stack. The donor stack consisted of 72 M117 bombs, with a TNT equivalency of 24,000 pounds. This explosion source was designed to produce an impulse load of 1100 psi-ms on the headwalls of the five acceptor magazines, each located 147 feet away from the explosion source. Two of the three acceptor magazines had no acceptor charges inside them. The remaining three acceptor magazines each contained twelve M15 land mines as acceptor charges. The land mines were positioned in two rows of six, one row approximately three feet from the floor, and the second row was located approximately six feet from the floor. The rows were located three feet from the headwall and door.

C2.3.7.2.2. **Test Objectives.** The objectives of ESKIMO II were:

C2.3.7.2.2.1. Evaluation of the resistance of several types of igloo door and headwall designs, and of proposed modifications to existing door and headwall designs, to withstand the blast environment associated with an explosion. The headwall and door designs tested were one Navy Type II Magazine (NAVFAC Drawing 649-604), with its hinged, double-leaf doors; one proposed non-circular, steel-arch (oval) Army Stradley Magazine (OCE Drawing 33-15-61), with its bi-parting, sliding doors; and three Army steel-arch magazines (OCE 33-15-64), with three different door designs. One was the double-leaf, hinged doors specified on OCE Drawing 33-15-64, the second was a proposed single-leaf, sliding door designed by Black and Veatch and shown on an unnumbered drawing dated 25 October 1972, and the third was a proposed double-leaf, hinged door, with removable steel beam reinforcing, which represented a Black and Veatch modification of the door shown on OCE Drawing 33-15-64.

C2.3.7.2.2.2. Investigation of hazards associated with window glass and window frames placed at several distances from explosions, with the emphasis on using window types common in commercial and institutional buildings.

C2.3.7.2.2.3. Evaluation of blast damage to both foreign and domestic vehicles placed at distances specified by various authorities for public traffic routes.

C2.3.7.2.2.4. Acquisition of data regarding fragment hazards associated with an M117 bomb.

C2.3.7.2.3. **Test Conclusions.** This was an over-test, because the near-field blast loading exceeded that planned. The conclusions from testing were as follows:

C2.3.7.2.3.1. Though there was a wide range of door and headwall responses, no change to DDESB separation distance standards were considered necessary at that

time. In addition, the results provided guidance for the selection of promising types of headwalls and doors to be tested more extensively.

C2.3.7.2.3.2. The Black and Veatch single-leaf, sliding door withstood the blast with minor distortion, although the accompanying headwall suffered severe damage. The proposed Stradley-type magazine headwall withstood a face-on impulse of 1,750 psi-msec with only minor damage and its non-circular (oval) steel-arch withstood the blast without breakup or severe distortion. Further, the test reaffirmed a need for achieving a closer balance in the strength of headwalls and doors.

C2.3.7.2.3.3. The test supported DDESB inhabited building and public traffic route distances. NATO distances were questionable.

C2.3.7.3. **ESKIMO III, June 1974.** In this third test of the ESKIMO Series, approximately 350,000 pounds of Tritonal explosives (in M117 Bombs) were detonated simultaneously within a steel-arch, earth-covered igloo flanked by two adjacent igloos and near three other igloos located with varying degrees of face-on exposure and at varying distances from the donor magazine. There were no acceptor charges used in this test.

C2.3.7.3.1. **Test Objectives.** The objectives of ESKIMO III were to:

C2.3.7.3.1.1. Qualify the redesigned oval steel-arch magazine (OCE 33-15-73), at the minimum side-to-side spacing of $1.25W^{1/3}$, which was permitted for semicircular and other standard earth-covered magazines. This was the primary objective of the ESKIMO III test.

C2.3.7.3.1.2. Evaluate a less expensive, deeply corrugated, 14-gage (0.075-inch thickness), semi-circular steel-arch, earth-covered magazine. At that time, the standard gage used for steel-arch construction was 1-gage (0.20-inch thickness).

C2.3.7.3.1.3. Test a single-leaf, sliding door installed on an existing headwall remaining from the 1963 test, at a distance of $2.75W^{1/3}$ from the donor, with a face-to-side orientation.

C2.3.7.3.1.4. Further investigate intermagazine separation distances for other than side-to-side orientation.

C2.3.7.3.1.5. Investigate the hazards associated with window glass located at varying distances (based on DDESB and NATO inhabited building distances) from the donor magazine.

C2.3.7.3.1.6. Evaluate blast damage to highway vehicles placed at public traffic route distances specified by DDESB and NATO criteria, from magazine structures.

C2.3.7.3.2. **Test Conclusions.** The conclusions resulting from the ESKIMO III test were as follows:

C2.3.7.3.2.1. The oval steel-arch igloo (OCE 33-15-73) was qualified, at the minimum side-to-side spacing of $1.25W^{1/3}$ permitted for standard magazines.

C2.3.7.3.2.2. The deeply corrugated, 14-gauge, circular steel-arch magazine design survived the minimum side-to-side spacing, as well. Though the degree of damage was more extensive and arch movement greater than that experienced by the oval, steel-arch magazine, it was considered that the arch structure would have provided protection against explosion communication for common explosives stores.

C2.3.7.3.2.3. The single-leaf, sliding door experienced little damage or deformation and was found to be effective whether mounted on a new structure or on an existing headwall.

C2.3.7.3.2.4. Door and headwall response of the standard magazine OCE 33-15-64 was unsatisfactory at a test separation distance based on $3.7W^{1/3}$. A successful test would have possibly justified a reduction of the required separation distance (based on $K6 W^{1/3}$) for this orientation. However, test results showed that a relaxation of front-to-front criteria ($K6 W^{1/3}$) for this magazine was not warranted. The test consisted of a single barricade between the donor and the acceptor magazines.

C2.3.7.3.2.5. Test results supported DDESB criteria for inhabited building and public traffic route separation distances. [Note: In the final report, no conclusions were provided regarding NATO criteria.]

C2.3.7.4. **ESKIMO IV, September 1975.**

C2.3.7.4.1. **Test Description.** In this test, three earth-covered magazine structures each faced an unbarricaded explosion source, located 147 feet away; the source consisted of 37,000 pounds of TNT contained in a hemisphere built of 8-pound blocks. The donor explosion size was selected to duplicate the free-field peak pressure and impulse observed at a scaled distance of $2.0W^{1/3}$, to the rear of the donor magazine in ESKIMO III, which contained M117 bombs filled with a total of 350,000 pounds of Tritonal at full-scale quantity. The three structures tested included; an existing oval, steel-arch magazine used in ESKIMO III, with a single-leaf, sliding door (OCE Drawing 33-15-61); a new circular steel-arch magazine constructed to OCE Drawing 33-15-64, with its specified double-leaf, hinged door; and an existing circular steel-arch magazine used in ESKIMO III, with a rebuilt OCE Drawing 33-15-64 headwall and a single-leaf, sliding door. The second structure described served as the control structure to demonstrate directly the relative strengths of the primary target, which was the oval, steel-arch structure. There were no acceptor charges used in this test.

C2.3.7.4.2. **Test Objectives.** The objectives of ESKIMO IV were:

C2.3.7.4.2.1. To demonstrate the resistance of a newly designed headwall and door combination (the oval, steel-arch magazine with a single-leaf, sliding door) to a blast simulating that possible at the minimum front-to-rear spacing permitted for semicircular and other standard earth-covered magazines. This was the primary objective.

C2.3.7.4.2.2. To test the single-leaf, sliding door installed on a standard headwall (OCE Drawing 33-15-64), at a level of blast loading equal to that experienced by the newly designed headwall and door combination.

C2.3.7.4.2.3. To acquire data on the response of a standard headwall and standard double-leaf, hinged door design to blast loading from a hemispherical charge of TNT, which has well-documented blast characteristics.

C2.3.7.4.3. **Test Conclusions.** Based on test results, the following conclusions were arrived at:

C2.3.7.4.3.1. The blast produced by the donor stack was essentially as predicted and properly simulated conditions at a scaled distance of $2.0W^{1/3}$, to the rear of the donor magazine in ESKIMO III.

C2.3.7.4.3.2. The newly designed headwall and door combination (the oval, steel-arch magazine with a single-leaf, sliding door) responded within acceptable limits and was considered adequate to protect all magazine stores against propagation of explosion under the conditions simulated and blast effects produced in the test.

C2.3.7.4.3.3. The response of the control magazine was as expected, with door failure creating a hazard to more sensitive types of explosive stores, that could prove unacceptable.

C2.3.7.4.3.4. The response of the test circular steel-arch magazine used in ESKIMO III, with a rebuilt OCE Drawing 33-15-64 headwall and a single-leaf, sliding door, showed significant damage to the reinforced concrete headwall and a marked imbalance in strength between the one-piece, horizontally-spanning door and the concrete headwall.

C2.3.7.5. **ESKIMO V, August 1977.**

C2.3.7.5.1. **Test Description.** Test magazines were oriented side-on to the explosion source, at centerline separations of 155 feet. The test was designed to simulate the same loadings on the acceptor magazines as produced by the ESKIMO III donor, where the explosion source consisted of 350,000 pounds of Tritonal (contained in stacked M117 bombs), placed inside an 80-foot long, lightweight, 14-gauge, deeply corrugated, steel-arch magazine. Magazines in ESKIMO III were separated by a scaled distance of $1.25W^{1/3}$. The oval, steel-arch magazine (OCE Drawing 33-15-61) used in ESKIMO II, III (for side-on loading) and ESKIMO IV (headwall loading) was again tested. However, for ESKIMO V, the earth cover was removed, the concrete thrust beams were removed, and the earth cover replaced. ESKIMO V also included a newly constructed magazine of the FRELOC concrete-arch type (Stradley), U.S. Army Engineer Command, Europe, Drawing 33-15-13. Door response was not a concern in the ESKIMO V test; therefore, non-permanent steel doors were spot-welded and/or bolted to the door openings of both test magazines. There were no acceptor charges used in this test.

C2.3.7.5.2. **Test Objectives.** In this test, a hemispherical charge of approximately 75,000 pounds of TNT was detonated with the principal objectives being to justify the removal of concrete thrust beams from an oval, steel-arch igloo and to demonstrate the safety of applying the current side-to-side separation distances to concrete-arch igloos, which had never been tested at those distances.

C2.3.7.5.3. **Test Conclusions.** The ESKIMO V test produced the following conclusions:

C2.3.7.5.3.1. The blast produced by the donor stack was essentially as predicted and acceptably simulated conditions at a scaled distance of $1.25 \text{ ft/lb}^{1/3}$, to the side of the donor magazine as in ESKIMO III.

C2.3.7.5.3.2. Structural response of the FRELOC concrete-arch magazine (U.S. Army Engineer Command, Europe, Drawing 33-15-13) was well within acceptable limits, and the structure was considered to be adequate to protect all magazine stores against propagation of an explosion under the conditions simulated and blast effects produced by the test.

C2.3.7.5.3.3. The response of the oval, steel-arch magazine, without concrete thrust beams was also within acceptable limits. Comparison of magazine response from this test to the response of the steel-arch and the concrete thrust beams in ESKIMO III showed that the absence of concrete thrust beams did not significantly affect the response of this type structure under blast loads comparable to, or less than, those of ESKIMO III and ESKIMO V. Based on the test results, thrust blocks were removed from OCE magazine design Drawing 33-15-61.

C2.3.7.6. **ESKIMO VI, July 1980.** This was the sixth in a series of explosives tests involving earth-covered magazine structures. This test was designed to test and evaluate the safety and performance, under blast loading, of two box-shaped storage magazines. These magazines included the existing Navy Type IIB Magazine and the newly designed NAVFAC Type A Magazine. Prior to ESKIMO VI, box magazines in the field had not been tested or specifically designed for overpressure loads. Safety policy, therefore, required that they be sited at non-standard intermagazine separation distances and that their maximum storage capacity be limited to 250,000 pounds of high explosives.

C2.3.7.6.1. **Test Description.** In order to keep the costs associated with ESKIMO VI down, one-half scale test structures were proposed. However, because a box magazine's geometry is so different from an arch-type, earth-covered magazine, it was expected that the blast environment produced by the donor and the effect of the acceptor geometry on loads would be significantly different than those measured for arch-type magazines. Therefore, the U.S. Army's Ballistics Research Laboratory (BRL) conducted 1/50th-scale model tests of box-shaped magazines, to determine the blast environment on the acceptors to the front, side, and rear of a model donor. These are documented in reference 2-16. Pre-shot predictions were developed for nonstandard and standard intermagazine distance for box-type magazines. The donor charge consisted of 60 MK 16 torpedo warheads containing the equivalent of 44,000 pounds of TNT, which corresponded to 350,000 pounds of TNT at full scale, the design charge weight of the new

NAVFAC Type A magazine. This charge was placed in a donor structure, which was constructed to simulate the mass properties and geometry of the earth-covered Type IIB magazine. There were no acceptor charges used in this test.

C2.3.7.6.2. **Test Objectives.** The objectives of ESKIMO VI were to:

C2.3.7.6.2.1. Evaluate the safety of existing box-shaped magazines that used non-standard intermagazine spacing. The Navy's Smokeless Powder/Projectile Magazine, Type IIB, Bureau Yards and Docks Drawing 749771, was used to meet this objective because they were in abundant use and had dimensions that were identical to those of the blast-resistant Type A magazine. The Type IIB magazine was oriented side-to-side with the donor magazine with a separation distance of 44 feet ($1.25W^{1/3}$).

C2.3.7.6.2.2. Demonstrate the safety of the new NAVFAC box-magazine designs for use at standard intermagazine spacing. The structure that was tested was the new Box Magazine, Type A, NAVFAC Drawing 1404000, which had been designed to resist the blast loads associated with standard intermagazine separation distances. In the test, the rear of the Type A magazine was oriented to the front of the donor magazine at a separation distance of 70.5 feet ($2.0W^{1/3}$).

C2.3.7.6.2.3. Develop improved load criteria, structural performance requirements, and appropriate intermagazine spacing criteria for box-shaped magazine roofs, walls, and doors. The new NAVFAC Type A Magazine and its single-leaf, sliding doors were selected to meet this objective.

C2.3.7.6.3. **Test Conclusions.** The ESKIMO VI test produced the following conclusions:

C2.3.7.6.3.1. The safety and performance of the Type A magazine, under "worst-case" standard intermagazine distance pressure loads was confirmed. The test report noted that the minor damage experienced by the Type A magazine might imply the possibility of reducing steel and construction requirements while still maintaining satisfactory performance under blast loading. The Type A magazine roof had been designed for a maximum support rotation of 2 degrees, in accordance with the tri-service manual on explosion resistant structures (TM 5-1300, NAVFAC P-397, and AFM 88-22, dated Jun 1969) in use at the time.

C2.3.7.6.3.2. It was demonstrated that the Type IIB magazine would sustain only light to moderate structural damage when exposed to non-standard side-to-side intermagazine distance pressure loads. The door design is inadequate for resisting loads generated by a 350,000-pound NEW charge. Redesign of the headwall and door system would be needed to resist such loads. Consequently, non-standard intermagazine separation distance criteria should continue to be used by the Type IIB magazine.

C2.3.7.6.3.3. Loading criteria were developed for box magazines (full-scale) located to the side and forward of a donor. A magazine located to the side of a donor at $1.25W^{1/3}$, as the Type IIB magazine was, can be expected to experience a maximum roof

overpressure of 105 psi, with a corresponding impulse of 754 psi-msec. The headwall will experience a peak overpressure of 50 psi and an impulse of 764 psi-msec. A magazine located to the front of a donor at $2.0W^{1/3}$, as the Type A was, can be expected to experience a peak roof overpressure of 360 psi, with a corresponding impulse of 1,312 psi-msec. The headwall will experience a peak overpressure of 50 psi and an impulse of 1,218 psi-msec.

C2.3.7.7. ESKIMO VII, 5 and 12 September 1985.

C2.3.7.7.1. **Test Description.** The existing Type A and Type IIB structures remaining from the ESKIMO VI test were utilized for ESKIMO VII. ESKIMO VI had demonstrated an ample, possibly excessive margin of safety in the Type A magazine roof. ESKIMO VI also had shown that the door system design of the Type IIB magazine was inadequate to resist the loading resulting from a detonation of 350,000 pounds in a similar magazine located at the minimum side-to-side spacing. To address these two areas, two tests were conducted: TEST A-ROOF and TEST IIB-DOORS. There were no acceptor charges used in these tests. Details of the test and the results are provided in the test report (reference 2-17).

C2.3.7.7.2. **Test Objectives.** The objectives of these two tests were to:

C2.3.7.7.2.1. Validate the performance of a redesigned door and headwall system for the Type IIB magazine, under blast loading conditions approximating those at the minimum side-to-side spacing of earth-covered magazines.

C2.3.7.7.2.2. Evaluate the reserve strength inherent in the Type A magazine design at roof slab deformations corresponding to large rotations at supports.

C2.3.7.7.2.3. Provide test data to support improved load criteria, structural performance requirements, and design methods for the roofs, walls, and doors of more economical box-shaped magazines that can be sited at the minimum separation distances permitted by explosives safety standards.

C2.3.7.7.3. **TEST A-ROOF, 5 September 1985.** To produce the required airblast loading on the roof, it was necessary to accurately simulate the overpressure component of the airblast generated by a high explosive surface burst. To accomplish this, a test procedure called the High Explosive Simulation Technique (HEST), developed by the Air Force Weapons Laboratory for the Defense Nuclear Agency (DNA), was used to produce the required blast overpressure and impulse on the roof of the Type A magazine. This technique involved distributing a high explosive over a relatively large surface area and covering the explosive with a soil overburden. The HEST charge density used for TEST A-ROOF was designed to produce a peak overpressure of 800 psi and an impulse of 2,300 psi-msec.

C2.3.7.7.3.1. **TEST A-ROOF Results.** The average measured impulse was 2,500 psi-msec. Both internal columns catastrophically collapsed, changing the roof configuration from a flat slab (with column supports) to a rectangular two-way slab restrained on only four sides. The permanent center deflection at midspan of the roof was 45.5 inches. Both the back wall and headwall were forced inward with the maximum inward displacement being 8

inches and 2.5 inches for the back wall and rear wall, respectively. The performance of the Type A test structure in ESKIMO VI demonstrated an ample, possibly excessive margin of safety in the Type A box magazine roof, which had been initially designed for a maximum support rotation of 2 degrees (**Note:** Based on ESKIMO VI test results, allowable roof rotations was subsequently increased to 8 degrees.)

C2.3.7.7.3.2. **TEST A-ROOF Conclusions.** In summary, because the columns failed, it was not possible to directly assess the inherent ultimate rotational capacity of the box magazine flat slab configuration. What could be concluded was that support rotations of slabs are possible beyond the 8-12 degree range if tensile membrane behavior can be mobilized. It was noted that these large rotations occurred without the presence of any roof shear reinforcement. The NAVFAC box magazines are now designed for maximum support rotation of 8 degrees. Additional information on the test results and conclusions arrived at are provided in reference 2-18.

C2.3.7.7.4. **TEST IIB-DOORS, 12 September 1985.** As part of this test, the door/headwall combination was redesigned to address problems found as a result of ESKIMO VI. The doors were designed for a maximum allowable support rotation of 12 degrees. The hemispherical donor charge consisted of 13,616 pounds of TNT, located to the side of the Type IIB magazine being tested, at a distance of 108.6 feet from the magazine headwall centerline. This charge and distance was calculated as providing a blast environment similar to that observed in the ESKIMO VI test.

C2.3.7.7.4.1. **TEST IIB-DOORS Results.** The redesigned door and headwall system remained intact and more than satisfied the explosives safety deficiencies uncovered with the previous door and headwall system in ESKIMO VI. The maximum door responses measured for the two doors were 2.5 and 3.6 degrees, well below the allowable 12 degrees.

C2.3.7.7.4.2. **TEST IIB-DOORS Conclusions.** Upgrading the explosives safety integrity of older box type magazines can be accomplished by replacing the double leaf hinged doors with sliding (built-up) single leaf doors supported along the door sides and top by a strengthened reinforced concrete headwall. Additional information on the test results and conclusions are provided in reference 2-18.

2.3.7.8. **ESKIMO SERIES TEST SUMMARY.** The ESKIMO tests:

C2.3.7.8.1. Validated the acceptability of using a side-to-side spacing of K1.25 for earth-covered, arch-type magazines, for hazard division (HD) 1.1 NEW up to 350,000 pounds. [**Note:** The DDESB subsequently determined that the results of the ESKIMO Series were valid for HD 1.1 NEW up to 500,000 pounds.]

C2.3.7.8.2. Showed that the roofs of flat-roofed magazines needed specific design considerations (ESKIMO VI and VII).

C2.3.7.8.3. Showed that the headwalls and doors of some of the magazines in use at the time (i.e., the magazine described in OCE Drawing 33-15-61) required strengthening to qualify for storage of 500,000 pounds NEW, at the reduced intermagazine separation distances eventually approved for "standard" magazines.

C2.3.7.8.4. Indicated that several of the magazines in use at the time, and separated by the intermagazine distances at which they were originally built, could safely contain up to 500,000 pounds NEW of HD 1.1 material. Prior to the ESKIMO tests, Army magazines and unbarricaded Navy magazines were typically separated by 400 to 500 feet. Barricaded Navy magazines were typically separated by 185 feet.

C2.3.8. **NAVAJO Depot Activity, Flagstaff, Arizona, 1979 Tests.**

C2.3.8.1. **Test Description.** Full-scale field tests were conducted in 1979, by the Ballistics Research Laboratory, to characterize the hazards to an exposed site when either a 150-pound or 450-pound TNT charge, positioned inside earth-covered, reinforced-concrete igloos, were statically detonated. Test results took the form of airblast profiles and concrete fragment distributions in terms of densities, weights, and their locations relative to igloo orientation. These tests were conducted at the NAVAJO Depot Activity near Flagstaff, Arizona, using igloos constructed in 1942 to Army standards. The tests are described in reference 2-19.

C2.3.8.2. **Test Objective.** The objective of these tests was to demonstrate that the NATO Explosives Safety Manual, which required a minimum of 400 meters (1,312 feet) between inhabited buildings and igloos containing HD 1.1 AE, was overly conservative for small quantities of explosives in magazines. No minimum quantity of AE was associated with this 400-meter restriction.

C2.3.8.3. **Test Conclusions.** The conclusions reached in the Flagstaff tests were:

C2.3.8.3.1. The 400-meter minimum distance requirement between inhabited buildings and igloos containing HD 1.1 AE is excessive for small explosive charges. This was true for both fragment and peak overpressure hazards.

C2.3.8.3.2. The use of a barricade in front of the headwall and a redesign of the vent stack at the rear of the igloo would have reduced the density of hazardous fragments to an insignificant level.

C2.3.8.3.3. The peak overpressure and fragment hazards to the sides and rear of earth-covered igloos are significantly less than those to the front for relatively small explosive weights. These directional effects should be considered when establishing minimum distance requirements.

C2.3.8.4. **Test Result.** Though these tests were initially conducted to support a hazards analysis for a particular activity, the results of the test were subsequently used to support changes to the NATO Explosives Safety Manual.

C2.3.9. **HASTINGS Igloo Hazards Tests for Small Explosive Charges, Hastings, Nebraska, 1984.** The Hastings testing was conducted to supplement, with additional full-scale testing, the Flagstaff testing described in the previous paragraph.

C2.3.9.1. **Test Description.** These tests were conducted at the then Nebraska State National Guard Weekend Training Site near Hastings, Nebraska, using 12 excess, standard-size igloos built to Navy standards. The test igloos were abandoned structures. Prior to testing, these igloos all had developed hairline cracks on all walls and their arches. There was also erosion of the earth-cover that was observed on many of the structures due to lack of maintenance. An earth-backed concrete blast shield (barricade) fronted each test igloo. The igloos' headwall thickness was 8 inches. The test report is provided by reference 2-19. Test results are in the form of overall structural response, airblast measurements, and hazardous fragment distribution for explosive charge weights from 5.4 kg (12 pounds) to 68 kg (150 pounds).

C2.3.9.2. **Test Objectives.** The objectives of the Hastings tests were to:

C2.3.9.2.1. Determine the explosive quantity which, when detonated inside a standard-size, earth-covered igloo, produces no significant external effect.

C2.3.9.2.2. Evaluate the dispersal of structure debris and measure external airblast for the range of explosive quantities up to 68 kg (150 pounds).

C2.3.9.3. **Test Conclusions.** Test conclusions were:

C2.3.9.3.1. The maximum distance requirements between inhabited buildings and standard-size, earth-covered igloo magazines containing small explosive charge weights will be determined by door displacement and not by concrete fragments from the headwall. Blast shields (front barricades) will reduce this distance and change the critical direction of the hazard from the front to the sides, at small charge weights.

C2.3.9.3.2. Blast shields are effective in controlling concrete fragment hazards from the headwalls at explosive charge weights up to 18 kg (39.6 pounds). At higher explosive charge weights, significant numbers of fragments will be projected over the blast shield.

C2.3.9.3.3. Igloo magazines will suffer severe structural damage when explosive charges as small as 5.4 kg (12 pounds) TNT detonate inside a magazine. An explosive charge weight of 7.3 kg (16 pounds) can completely destroy an igloo.

C2.3.9.3.4. There are no significant overpressure hazards, outside of a magazine, associated with the detonation of up to 68 kg (150 pounds) TNT inside a magazine.

C2.3.10. **Summary of Flagstaff and Hastings Testing.** The tests described above that were conducted at NAVAJO Depot Activity, Flagstaff, Arizona, in 1979 and at Hastings, Nebraska, in 1984, were conducted to determine if the (then current) NATO fragment criteria of 400 meters should apply for small amounts of explosive material in earth-covered magazines. Based on the results of these tests, DDESB siting criteria for standard ECM containing small

quantities of explosives (less than/equal to 450 pounds NEW of HD 1.1) were revised to permit the use of lesser inhabited building and public traffic route distances.

C2.3.11. Modular Igloo Test, 1988.

C2.3.11.1. **Test Description.** The Modular Igloo that was tested by the Air Force, in 1989, at the Utah Test and Training Range (UTTR), was constructed of precast reinforced concrete panels and had a box shape. The intent of the test was to evaluate the design for possible certification as a standard earth-covered magazine, for allowable storage NEWs up to 500,000 pounds of HD 1.1. The test involved one modular donor igloo with 500,000 pounds NEW of HD 1.1 and four modular acceptor igloos. Three of these acceptor magazines contained explosives-loaded MK 82 (48 each in two magazines) and MK 84 (36 in the remaining magazine) bombs. The fourth acceptor magazine contained empty AGM-65 Missile Containers. The acceptor magazines were sited to the front, sides and rear of the donor magazine, at required minimum separation distances for standard magazines. Data to be collected from the test included blast overpressure, structural and ground acceleration measurements, and limited debris collection. The test is documented in reference 2-20.

C2.3.11.2. **Test Results.** Based on results of this test, the DDESB did not accept the Modular Igloo design as a standard magazine. The primary reason for rejection was that the roof of an acceptor magazine collapsed and a second magazine fell within the crater produced by the donor. Though there was no propagation of any of the acceptor charges in any of the acceptor magazines, the DDESB felt that the damage experienced by the two severely damaged acceptor igloos fell outside the level of acceptable damage to an acceptor standard magazine. The DDESB suggested that the Air Force re-design the roof and then utilize a High Explosive Simulation Test (HEST) to validate the modified roof design. This was done and is reported in reference 2-21. As a result of successful redesign and HEST Testing, in 1994 the DDESB granted final approval to the Modular Storage Module (previously called the Modular Igloo) as a standard, earth-covered magazine.

C2.3.12. **Reexamination of Airblast and Debris Criteria, 1991.** A reexamination of the airblast and debris produced by explosions inside earth-covered igloos was conducted in 1991, at the request of the DDESB, by the Naval Surface Warfare Center. This reexamination reviewed available airblast and fragmentation/debris data produced by explosions within standard ECM. The intent of this review was to recommend possible changes to the standards and to provide the best predictive tools for both fragmentation and airblast. Based on the review of data available at that time, this study determined that the present criteria for airblast appear to be safety conservative. It was discovered that there is a major deficiency in the data relating to the debris/fragmentation produced by explosions in ECM. The report of this reexamination can be found in reference 2-22. [Note: Facility debris studies based on data obtained from UK, Australian, and U.S. tests conducted since 1991, indicate that safety criteria based on facility debris distances are not conservative. Additional studies and testing are on-going in the debris arena.]

C2.3.13. **High Performance Magazine (HPM).** The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, developed the HPM design with a primary goal of

reducing the encumbered land associated with an explosives storage site. They were able to accomplish this goal through the design of a facility that used non-propagation wall (NPW) technology, developed by NFESC to limit the maximum credible event (MCE) to the amount of AE in one storage cell plus the amount of AE that might be present in the shipping/receiving area. The MCE associated with the HPM design reduces the inhabited building distance by 60% and the amount of encumbered land by 80%, as compared to a typical ECM containing the total quantity of AE that could be located in all the storage cells of a HPM. Another benefit of the HPM design is that it permits the storage of non-compatible material within the same storage structure, though in different storage cells. The basis of design for the HPM is provided by reference 2-23. Based on the results of the testing described below, the DDESB granted approval of the HPM as a 7-Bar magazine at its 319th Board Meeting on 27 January 2000.

C2.3.13.1. The following work was conducted to prove out the HPM concept:

C2.3.13.1.1. In FY93, NFESC conducted two full-scale explosive tests, which demonstrated the explosives safety performance of the NPW concept.

C2.3.13.1.2. In FY95 and FY96, NFESC conducted two full-scale magazine certification tests (CT1 and CT3), to certify explosives safety of the prototype design of the HPM. These tests confirmed that the HPM design prevents sympathetic detonation under the two most critical hazard scenarios. CT1 tested the MCE in a covered storage area (30,000 pounds NEW of HD 1.1) to obtain the maximum cell wall loading. CT3 tested the MCE in uncovered storage/transfer (60,000 pounds NEW of HD 1.1 (total) in the Shipping/Receiving Area, the open storage cell, and the crane load) to obtain the greatest loading on a storage cell. The Test Plan and Debris Density Report for CT1 are provided in references 2-24 and 2-25. Planning and results of Certification Tests CT3 and CT2 (described below) are provided in reference 2-26.

C2.3.13.1.3. A certification test of the pit cover (CT2) was conducted to certify the required cross section of the storage cell cover for preventing fragment penetration.

C2.3.13.1.4. Analytical modeling was used to certify the explosives safety of the prototype design for an MCE fire in either the Shipping/Receiving Area or a storage cell

C2.3.13.2. The following summarizes critical areas associated with the HPM's NPW design and the basis for the criteria associated with it. Detailed information about development of NPW sympathetic detonation (SD) criteria, the method for classifying munitions into the five sensitivity groups (SG), and the method for designing composite NPW can be found in references 2-27 and 2-28. The preliminary design document developed by NAVFAC for construction of an HPM is provided by reference 2-29.

C2.3.13.3. **NPW Technology.**

C2.3.13.3.1. The most important factor in the improved performance of the HPM is the reduction of the MCE to a detonation involving only a fraction of the total quantity of explosives stored in the HP magazine. This performance is achieved through the use of specially

designed NPW and cell covers that prevent prompt SD caused by primary fragment impact, air shock, and heat flux.

C2.3.13.3.2. The NPW design eliminates the hazards associated with NPW debris impact and resulting kinetic trauma. The primary hazard to acceptor ordnance in the HPM is the secondary debris generated by NPW and cell covers as they break up under loading. During the design effort, these loads were conservatively estimated by transferring the total impulse of the air shock to the mass-velocity of the wall and cover debris. In addition, the calculated energy and mass-velocity of the debris was not reduced to account for dispersion before it impacted the acceptor munitions. Secondary kinetic trauma hazards occur after the acceptors begin moving under the impact loads from the wall debris. As the acceptor munitions move, they impact other ordnance and magazine components, causing kinetic trauma to the acceptors.

C2.3.13.3.3. This kinetic trauma is mitigated by reducing loads on the acceptors (to reduce the free body velocities) and by using “crushable” lightweight concrete in the magazine walls and covers to reduce peak shock loads and create a more uniform loading on the acceptors. The HPM's NPW cell covers, and magazine storage area external walls have been designed to mitigate loads on the acceptors, as follows: NPW use relatively weak and crushable lightweight concrete external panels with heavy granular fill materials (sand and steel shot). The mass of the wall reduces the energy in the moving debris. The weak lightweight concrete, with a high void ratio, crushes on contact with the acceptors to reduce the peak shock loads on the acceptor when it is impacted by wall debris and when it makes contact with magazine walls. The granular fill materials flow around the acceptors, disperse their energy, and reduce the impulse coupling from the wall debris to the acceptors.

C2.3.13.3.4. In addition to the limits on the load environment, a debris velocity limit threshold is applied to non-propagation structural elements. This debris velocity limit is based on the calculated NPW debris velocities from the certification tests (CT1 and CT3) of the HPM. Because these tests provide the best available data on successful prevention of SD, the velocity limit threshold for the NPW in the HPM were established as follows:

330 feet-per-second for NPW wall impulse loads of > 10 psi-sec

500 feet-per-second for NPW wall impulse loads of < 10 psi-sec

C2.3.13.3.5. Non-propagation walls have not been designed to prevent SD of acceptor ordnance from effects of directed energy weapons, therefore all directed energy ordnance must be oriented toward an exterior wall of the HPM.

C2.3.13.4. **SD Criteria.** Flyer plate impact tests were conducted to determine reaction thresholds for groups of ordnance items with similar sensitivities. Detailed information on the testing that was conducted can be found in reference 2-27. In summary, ordnance tested in the flyer plate impact tests were representative of the ordnance to be stored in the HPM including the MK 82 bomb, MK103 and MK107 torpedo warheads, the WAU-17 Sparrow missile warhead, the M864 projectile, CBUs, and the TOW II missile. The results of those impact tests were used to develop SD threshold criteria for the five SG that have been established for all HD 1.1 and 1.2

ordnance [**NOTE:** Since HD 1.3 and 1.4 material do not detonate, it is not necessary to assign them to one of the five SG. Appropriate mixing rules of reference 1-1 apply]. These thresholds limit the applied unit impulse and energy loads on acceptor ordnance in order to prevent SD. Sympathetic detonation design criteria (see Figure 2-1) are based on allowable unit impulse loads, the unit kinetic energy of the NPW, and the NPW velocity, which must all be less than or equal to the threshold limits of the acceptor ordnance in order to prevent SD. The following five SG have been established and approved by the DDESB for application to NPW scenarios:

- C2.3.13.4.1. SG1 - Robust or thick-skinned
- C2.3.13.4.2. SG2 - Non-robust or thin-skinned
- C2.3.13.4.3. SG3 - Fragmenting
- C2.3.13.4.4. SG4 - Cluster bombs/dispenser munitions
- C2.3.13.4.5. SG5 - SD sensitive

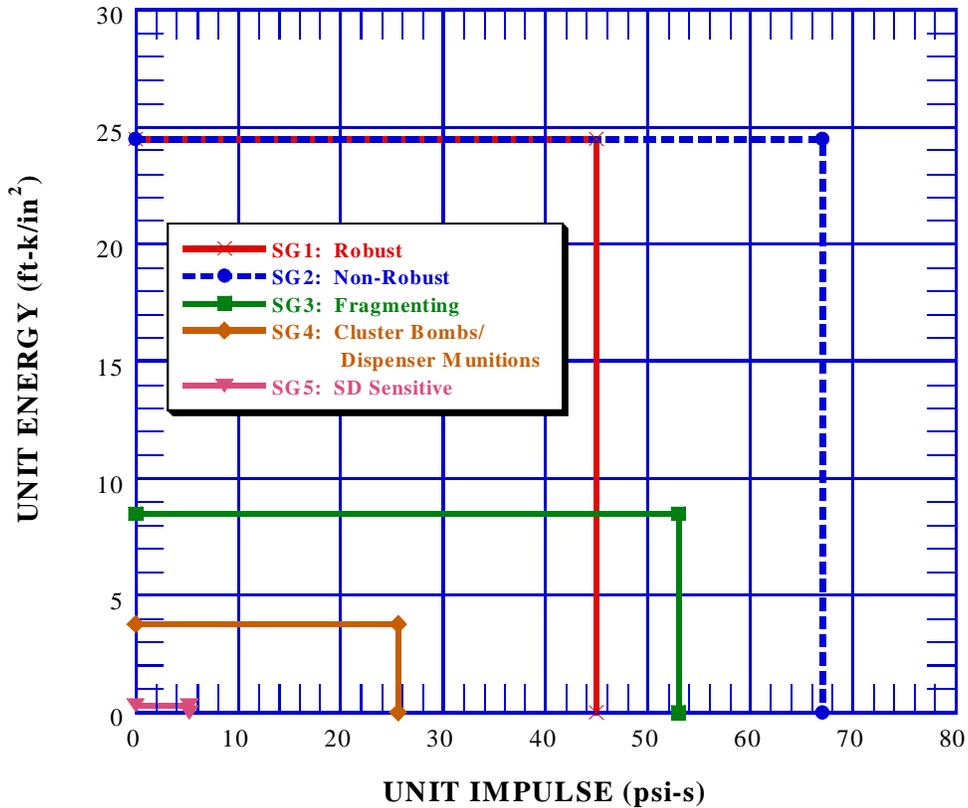


FIGURE 2-1. SD Unit Energy and Unit Impulse

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C3. CHAPTER 3

EARTH COVERED MAGAZINE (ECM) DESCRIPTIONS

C3.1. GENERAL.

C3.1.1. Prior to 1997, the terms "Standard" and "Non-standard" were used to designate the structural strengths of ECM and their ability to protect their contents from propagation and damage due to an explosion at an adjacent magazine. Of the two designations, a "Standard" ECM had the greatest structural strength and provided the highest level of protection to its contents, while a "Non-standard" ECM was the weaker of the two and provided the lowest level of protection to its contents. Consequently, a "Standard" ECM was permitted to be sited at reduced intermagazine separation distances and to have a higher HD 1.1 storage capacity of 500,000 pounds NEW of HD 1.1, while a "Non-standard" ECM was required to apply greater intermagazine separation distances and was limited to a smaller HD 1.1 storage capacity of 250,000 pounds NEW of HD 1.1.

C3.1.2. In 1997, the terms "Standard" and "Non-standard" were replaced with the terms "7-Bar", "3-Bar", and "Undefined". The terms "7-Bar" and "Standard" designations are synonymous, as are the terms "Undefined" and "Non-standard". The new structural strength designation of "3-Bar" has no pre-1997 equivalent and was established in recognition of the fact that there could be ECM designs that have greater structural strength than an Undefined ECM, but less structural strength than a 7-Bar ECM. Due to the additional protection offered to the magazine's contents, as compared to that provided by an Undefined ECM, a 3-Bar ECM can be sited using intermagazine separation distance criteria that are not as stringent as those required for an undefined ECM. Separation distance criteria and design criteria for all AE storage structures are found in reference 3-1.

C3.1.3. Chapter 4 provides additional information pertaining to ECM designs that have been constructed, and Tables AP1-1 through AP1-4 identify the known magazine designs (ECM and aboveground) that exist, and the structural strength designation assigned to them. If a particular ECM design is not listed in the tables, then it must be treated as an Undefined ECM, until such time as DDESB approval is obtained for a change in structural strength designation.

C3.1.4. **APPLICABILITY OF REDUCED ECM IBD AND PTR DISTANCES TO NON-STANDARD ECM.** In 1990, the Army's Technical Center for Explosives Safety asked the DDESB Secretariat about the applicability of reduced IBD and PTR distances in Table 9-1, columns 2, 3, and 4, of DoD 6055.9-STD to non-standard ECM. [Note: The July 1984 Version of the STD was in use at that time. Table 9-1 has since been changed to delete the column numbers discussed below from Table 9-1, however, the column titles (i.e., front (column 2), side (column 3), rear (column 4) remain unchanged as compared to the current version of DoD 6055.9-STD in use.] The Secretariat's response to the Army's question is documented in DDESB-KT Memorandum of 27 July 1990, which is titled "Application of DoD 6055.9-Quantity Distance (QD) Standards to Non-Standard Magazines". Their response, which remains unchanged to this date, was as follows:

C3.1.4.1. Columns 3 and 4 (side and rear) may be used for a non-standard ECM, provided the magazine cover is equivalent or better than that of a standard ECM, and the ECM's dimensions are 26 feet wide by 60 feet long or larger.

C3.1.4.2. Columns 2, 3, and 4 (front, side, and rear) may be used for a non-standard ECM with dimensions less than 26 feet wide by 60 feet long, provided the MCE loading density is less than or equal to 0.028 lbs/ft³, and the earth-cover is equivalent to or better than that of a standard ECM.

C3.1.4.3. All other default applications of columns 2, 3, and 4 apply only to standard ECM with dimensions of 26 feet wide by 60 feet long or longer.

C3.2. **ECM DESIGN CRITERIA**. An ECM's primary objective is to protect AE. To qualify for the default IMD of reference 3-1, 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. ECM design criteria (blast loads) for a 7-Bar, a 3-Bar, and an Undefined ECM are specified in reference 3-1.

C3.3. **ECM TYPES**.

C3.3.1. **7-Bar ECM**. A 7-Bar ECM provides the highest level of asset protection and permits the use of the least restrictive separation distances. The 7-Bar ECM is approved by the DDESB, for a maximum allowable NEW of 500,000 pounds HD 1.1. Most 7-Bar magazine designs are of the arch-type; however, there are a number of box-type designs that have been approved as well. The Navy's box-type, 7-Bar ECM designs have been approved with allowable NEWs up to 350,000 pounds HD 1.1, while the Air Force's box-type, 7-Bar ECM (Hayman) has been approved with an allowable NEW up to 500,000 pounds HD 1.1.

C3.3.2. **3-Bar ECM**. The headwall and doors of a 3-Bar ECM are not structurally as strong as those of a 7-Bar ECM, but are stronger than the headwall and doors of an Undefined ECM. As a result, IMD for 3-Bar ECM are generally more restrictive than for a 7-Bar ECM, but not as restrictive as for an Undefined ECM. A 3-Bar ECM is permitted to store up to 500,000 pounds NEW of HD 1.1, unless otherwise noted.

C3.3.3. **Undefined ECM**. An Undefined ECM is the weakest of the three ECM design types specified in reference 3-1. A magazine placed in this structural strength category is either known to be a weak structure or there is insufficient information available for a particular design to prove that it provides greater than "Undefined" protection. Consequently, the Undefined ECM generally requires the application of the greatest IMD. An Undefined ECM is permitted to store up to 500,000 pounds NEW HD 1.1. This has not always been the case, as discussed in C3.1.1 above. Prior to January 1996 (312th DDESB Board Meeting), the maximum allowable explosives limit for an Undefined (Non-standard) ECM was 250,000 pounds NEW and any quantity over 250,000 pounds required the Undefined ECM to be sited as an aboveground magazine.

C3.4. **TYPICAL ECM FEATURES**. A typical ECM has the following typical features:

C3.4.1. A semicircular arch or oval arch constructed of reinforced concrete or steel, or a combination of the two. Arches are not designed to contain the effects of an internal explosion. The only design requirement for the arch is that it be capable of supporting dead loads. **[NOTE:** Most Navy and Air Force ECM designs are reinforced concrete box-type with flat roofs. The flat roof of a box-type ECM must meet blast load requirements of reference 3-1.]

C3.4.2. A reinforced concrete floor slab that is sloped for drainage.

C3.4.3. A reinforced concrete rear wall **[NOTE:** There are existing ECM designs that have no rear wall, but are designed instead with two headwalls. These type magazines are known as “flow-through” designs.]

C3.4.4. A reinforced concrete headwall that extends at least 2-1/2 feet above the top of the ECM. The headwall is designed to withstand the external blast pressures and impulses resulting from an explosion in an adjacent AE storage facility. This is a critical feature that directly contributes to the strength designation assigned to an ECM. The stronger the headwall, the more protection it can provide to its contents. Some designs have two headwalls, rather than the traditional headwall and rear wall (see C3.4.3 above). A headwall’s entrance header and pilasters are strengthened to support the loads transferred from the door when an external blast load impacts it. If the door or headwall fails at the door interface, then the design is considered inferior. However, if the door and headwall survive, but the door in rebound falls to the ground, the magazine is considered to have accomplished its goal. That said, the goal should always be for the door to remain in place following an external explosion at an adjacent AE magazine.

C3.4.5. Reinforced concrete wingwalls on either side of the headwall. The wingwalls may slope to the ground or may join wingwalls from adjacent ECM. The wingwalls may be monolithic (of single construction) or separated by expansion joints from the headwall. The purpose of wingwalls is to retain the earth fill along the side slopes of the ECM.

C3.4.6. Robust steel entrance doors in the headwall, typically constructed of two thick steel plates with reinforcing elements (I or C Beams) placed between them, which are either manually operated or motorized. Approved box-type ECM, to date, have as many as five of these doors in their headwall, while, to date, approved arch-type ECM have as many as two doors on each headwall, though one door is more typical. Doors are either of the swinging (hinged) or sliding type. Sliding doors are generally used on the larger ECM or where a large entrance is needed for the AE being stored, while swinging doors are primarily used on smaller ECM or where it’s not critical to have a large door. Doors are designed to withstand the dynamic forces from an explosion in an adjacent AE storage facility, and are therefore, another critical element associated with the structural rating of an ECM design. Doors are not designed to provide resistance to the effects resulting from an internal explosion. Past designs included single and double hinged doors and single or bi-parting sliding doors. The trend is to provide larger doors to accommodate longer munitions in today’s inventory. Many projects have been initiated to expand the entrance into existing magazine structures. The structural hardness must be maintained when modifying magazine headwalls and/or doors, or there may be a significant penalty associated with the modification (e.g., an existing 7-Bar ECM modified for a larger door must have the replacement headwall and door also rated for 7-Bar, or the design will have to be treated as an

Undefined ECM or a 3-Bar ECM if data or analysis so indicates). DDESB site approval is required for the replacement design, prior to commencing work.

C3.4.7. Earth cover over the top, sides, and rear of the ECM. A minimum of 2 feet (24 inches) of earth cover is required over the ECM. The requirements for earth cover are specified in Chapter 5 of reference 3-1. Where allowed by reference 3-1 for permissible exposures, the earth covered sides and rear of an ECM can be considered as barricades. Where insufficient earth-cover exists on top of an ECM, then the ECM must be sited as an aboveground magazine. If earth slope requirements are met, it can be sited as an aboveground, barricaded magazine. [**NOTE**: The use of 2-feet of earth cover on ECM did not become a standard depth until sometime in the early 1940's. Therefore, unless 2 feet of earth cover is provided over an earth-covered magazine constructed prior to 1940, it will have to be sited as an aboveground magazine.]

C3.4.8. Lightning protection and grounding systems are installed and integral to the ECM reinforcing. Reinforcing steel in the walls, floor, and arch or box must be interconnected and bonded together and must have a continuous path to ground. For steel arch-type ECM, the arch is interconnected with reinforcing steel in the floor and walls of the ECM. Continuous bonding of metallic structural components, as described above, produces a faraday-like shield, which shields the contents of the ECM from lightning hazards. Lightning protection criteria are specified in Chapter 7 of reference 3-1. [**NOTE**: No specific design information has been found for grounding and lightning protection systems that were associated with ECM designs from 1928 through 1940.]

C3.4.9. Incoming utilities are installed to meet the construction, installation, grounding, and lightning surge protection criteria of Chapters 6 and 7 of reference 3-1. In general, electrical, communication, and signal wiring will need to be provided underground the last 50 feet to an ECM, in metallic piping that is grounded to the ground counterpoise system prior to entering the ECM.

C3.4.10. When required, internal electrical work and equipment must be rated for the hazardous environments expected within the ECM, in accordance with Chapter 6 of reference 3-1.

C3.4.11. At one time, flappers on ECM ventilators were a standard requirement in ECM design. The flapper is the closure device that is held in the open position with a fusible link. When an ECM is exposed to an external fire, the fusible link melts, allowing the flapper to close and to block off the ventilation openings into the ECM. This action keeps out flames, hot gasses, and burning embers, all of which can threaten the contents of an ECM. For a fusible link to be effective, it has to be located outside the ECM in a location where flames can impinge on it and cause it to function properly. Flappers are no longer required on ECM; however, many ECM still use flappers and fusible links. If used as originally designed, flappers on existing ECM must be secured with a fusible link that complies and is installed in accordance with Underwriters' Laboratory (UL) or Factory Mutual (FM) Systems. Flappers must also be kept free of corrosion. A temperature rating of 160/165 °F is recommended for fusible links used with ECM flappers. If the flappers do not meet these requirements, they should be secured in an open position or completely removed.

C3.4.12. In the case of a box-type ECM, the walls and roof may be constructed of reinforced concrete or of prefabricated concrete panels that are assembled in the field. Earth cover, lightning and grounding criteria described above would also apply to box-type ECM.

C3.4.13. The only current exception to the typical 7-Bar ECM features described above is the HPM, which consists of multiple barricaded, reinforced concrete storage areas, separated by specially designed non-propagation interior walls, with reinforced concrete covers over the storage areas. Removal of AE from the storage pits involves the use of an overhead crane. Though given a 7-Bar designation, the HPM is not an earth-covered magazine. The HPM is earth-bermed (except for the truck entrance) and moveable reinforced concrete (RC) lids form the roof of each storage cell. The area above the storage cell is enclosed by a lightweight metal panel building, within which is contained the crane used for ordnance movement in the HPM. Additional information about the HPM can be found in C2.3.13.

C3.5. **ECM DESIGN APPROVALS.**

C3.5.1. **7-Bar and 3-Bar ECM Design Approvals.**

C3.5.1.1. All new 7- and 3-Bar ECM designs must be approved by the DDESB, before they can be sited as 7- or 3-Bar ECM. A request for approval must be accompanied by supporting documentation to prove the structural strength being claimed for the design. These data can consist of an ECM test report, a detailed structural analysis, etc. In the past, hybrid 7-Bar ECM have been designed, using component features from other 7-Bar ECM designs. This type of ECM design is not considered pre-approved for construction and would require DDESB approval before it could be sited as a 7-Bar ECM. The design of hybrid ECM offers no clear advantages and is not recommended. Close coordination with the DDESB should be conducted prior to the start of a new 7- or 3-Bar ECM design, in order to avoid problems arising that may prevent obtaining the desired structural strength rating.

C3.5.1.2. Once approved, 7- and 3-Bar ECM designs do not have to be re-approved every time they are to be constructed; however, any use of any 7- or 3-Bar ECM design for new construction requires DDESB approval of the site plan, which must clearly identify by drawing number the design being constructed.

C3.5.1.3. Changes to approved 7- and 3-Bar ECM designs are not permitted, without specific DDESB approval of the proposed changes. If there is any doubt about the impact of a proposed change to the structural integrity of a 7 or 3-Bar ECM, only the DDESB can make a final determination of the change's impact on the design.

C3.5.1.4. **IMPORTANT.** When using an approved 7- or 3-Bar ECM design and site adapting it for construction at a new location, identify the core drawing numbers of the ECM design selected for construction on the new drawings. There have been numerous construction projects where the original ECM design drawing numbers were not captured in a new drawing package, and the pedigree of the design was lost, which by default placed the new design into the "Undefined" structural strength category. Significant effort is required to revise a structural strength designation upward from an "Undefined" designation.

C3.5.2. Undefined ECM Approval.

C3.5.2.1. New Undefined ECM designs require DDESB approval, to insure minimum design and construction criteria are met (e.g., earth cover depth and slope, grounding, lightning protection). In addition, any use of an Undefined ECM design for new construction requires DDESB approval of the site plan.

C3.5.3. Changes to Undefined ECM Structural Strength Designation. Reference 3-2 may be used to evaluate the blast resistance of headwalls of existing Undefined, steel or concrete arch-type ECM having an internal radius of approximately 13 feet. This reference may also be used for determining the amount of explosives that can be stored in adjacent undefined steel or concrete arch-type ECM (internal radius approximately 13 feet), without creating a blast propagation hazard between ECM. Procedures are provided for determining the adequacy of an undefined ECM headwall to withstand the blast from a known quantity of explosives at a known distance. This is accomplished by comparing the impulse capacities of the various headwall elements (wall, pilaster, and door) to the impulse generated by an imposed blast environment. The results of such an analysis may be used to revise the structural strength designation of an undefined ECM design to another strength designation. DDESB approval of such an analysis is required before an ECM's structural strength designation can be revised.

C3.6. FOREIGN ECM DESIGNS. The DDESB has certified some foreign ECM designs as meeting 7-Bar or 3-Bar criteria of reference 3-1. These approvals have typically come through one of the Services as part of a site submission package, such as to construct or site a NATO magazine(s) at a NATO facility jointly operated/shared by U.S. Forces. On occasion, the DDESB has determined that a magazine design was not able to meet 7- or 3-Bar criteria and had to be sited to meet Undefined ECM separation distance criteria. In other cases, foreign magazine designs have been given 7- or 3-Bar designations, for exposure to a maximum quantity of explosives. In excess of that quantity, the magazine is required to be sited as an Undefined ECM. Foreign ECM designs that have been through this process are included in the magazine tables of Appendix AP1. Restrictions and NEW limitations applicable to use of those designs is also provided by AP1.

C3.7. REFERENCES

- 3-1. DoD 6055.9-STD, "DoD Ammunition and Explosives Safety Standards," Under Secretary of Defense for Acquisition, Technology, and Logistics (current edition).
- 3-2. "Guide for Evaluating Blast Resistance of Nonstandard Magazines," HNDED-CS-S-95-01, U.S. Army Corps of Engineers, Huntsville Division, Huntsville, AL, January 1995.

C4. CHAPTER 4

MAGAZINE LISTINGS

C4.1. GENERAL.

C4.1.1. Tables AP1-1 through AP1-3 of Appendix AP1 list all known ECM designs. Table AP1-4 identifies all known aboveground magazines and ECM that have been approved with a reduced NEW and/or a reduced QD. Also included in Table AP1-4 are shipping containers that are capable of containing or greatly reducing hazards produced by an explosion of a known quantity of explosives while in the container. For specific shipping containers, this mitigation capability allows the assignment of a hazard classification based on the lesser risk (e.g., MK 663, LD-1000 and LD-2250).

C4.1.2. The tables are set up in a manner to preserve the historical, structural strength designations assigned to magazine designs. A discussion of those structural strength designations is provided in Chapter 3. As a reminder, "7-Bar" and "Standard" structural strength designations are synonymous, as are the structural strength designations "Undefined" and "Non-standard".

C4.1.3. A numerical-first, alphabetical-second methodology was used for listing magazine designs in Tables AP1-1 through AP1-3. This approach was selected because it is expected that users will typically approach these tables first with a drawing number that they are trying to identify. Magazine designs are first listed by their drawing number(s), in ascending order. Since magazine designs usually have multiple drawing numbers associated with them, the lowest drawing number in the magazine design drawing set was used to determine where the magazine design was placed in the numerical list. Those designs that do not have a drawing number(s) then follow, in alphabetical order, after the numeric listing. Table AP1-4 is an exception to this approach, because of the large number of magazine designs for which no drawing numbers exist and the wide variation of magazine and container types listed. To simplify the use of Table AP1-4, the magazine design's MCE has been listed. The MCE may be identified as NEW or TNT equivalence.

C4.2. ECM DESCRIPTIONS. Figure 4-1 below illustrates the various ECM cross-section variations (described below) that exist for arch-type ECM. The names associated with those cross-sections are also used in the description fields of Tables AP1-1 through AP1-4.

C4.2.1. Arch. Also known as a circular arch. A single radius is used to define the interior face of the arch, which may be constructed of reinforced concrete, steel (corrugated, laminate, or single gage), or a combination of reinforced concrete and steel to form a composite arch (steel interior arch with overlying concrete).

C4.2.2. Arch, Oval. This arch is in the shape of an oval, with the lower portion of each sidewall bowing in towards the direction of the centerline. The arch can be constructed of steel, reinforced concrete, or a composite of both. The shape is defined by the use of a single radius for the vast majority of the arch, with a separate radius called out for the lower portions of the arch. The modified FRELOC-Stradley ECM design is an example of an oval-arch ECM.

C4.2.3. **Arch, Semi-Circular.** The sidewalls are elongated with the arch defined by a radius that originates approximately 3 to 5 feet above floor level. A radius originating at the opposite sidewall defines the lower portion of the arch. The arch can be constructed of either reinforced concrete or steel.

C4.2.4. **Stradley.** This reinforced concrete ECM is characterized by vertical sidewalls that blend into the arched roof. Three radii are used to define the arch and the transition from the vertical sidewalls to the roof arch. Another feature of the Stradley ECM is that its walls are significantly thicker at the base of the sidewalls and thinner at the crown of the arch. The Stradley magazine is named after a Mr. Stradley, its designer.

C4.2.5. **FRELOC-Stradley.** The FRELOC-Stradley ECM is constructed of reinforced concrete. Its interior shape is similar to a Stradley ECM, except that the sidewalls and arch have the same uniform thickness. The FRELOC design has its origins in the late 1960s, in Germany, and was developed by the U.S. Army Engineer Command (Europe) to reduce construction costs and improve its constructability.

C4.2.6. **Modified FRELOC-Stradley.** This ECM design was the first ECM constructed with an oval arch. See the information above for the oval arch.

C4.2.7. **Box.** This term describes any ECM that has an internal box shape. Explosives limits can range from less than a pound NEW of HD 1.1 to 500,000 pounds NEW HD 1.1.

C4.2.8. **Dome.** This shape was used only with the Corbetta ECM. The interior wall of the magazine is circular. The magazine roof is convex, and the magazine diameter is approximately three times the height of the magazine.

C4.3. **MAGAZINE TABLES** (Found in Appendix AP1):

C4.3.1. **TABLE AP1-1. 7-Bar and 3-Bar ECM Approved for New Construction.** This table identifies all 7- and 3-Bar ECM currently approved by the DDESB for new construction. Also included are a number of foreign-designed ECMs that have been approved as 7-Bar structures. Notes are provided to identify those ECM that have NEW limitations and/or restrictions associated with their DDESB approval.

C4.3.2. **TABLE AP1-2. 7-Bar and 3-Bar ECM No Longer Used for New Construction, But Still in Use.** This table identifies all 7- and 3-Bar ECM that are generally no longer constructed but may still be in use. The table's contents either were previously approved by the DDESB as 7- or 3-Bar (Standard) ECM or were placed into this category by the DDESB as a result of an analysis. In most cases, the restriction on the use of the design for new construction is a result of the Service superceding the design with another design. The information in the table can be used for assistance in siting existing magazines that were previously approved for construction. NEW limitations and/or restrictions associated with their DDESB approval must be observed. Because these designs are no longer actively maintained, they may not comply with current explosives safety criteria. If there is a desire to use a design from this table, and DoD

Component approval is obtained, the design may be used for new construction, provided it has been completely evaluated for compliance with current criteria of reference 1-1 and the design drawings updated. DDESB approval of the revised design is required and all changes that have been made must be clearly identified on the drawing.

C4.3.3. **Table AP1-3. Undefined ECM Listing.** Table AP1-3 lists all magazine designs that are considered to be Undefined. This structural strength designation is assigned to an ECM design if it was determined by analysis, testing, or DDESB assessment to be inherently weaker than a 7-Bar or 3-Bar magazine design, or if its structural strength is simply unknown due to a lack of supporting information to prove its ability to meet 7- or 3-Bar criteria. Each DoD Component provides its own guidance as to which of these magazines can be constructed.

C4.3.4. **Table AP1-4. Magazines (Earth-covered and Aboveground) and Containers with Reduced NEWs and/or a Reduced QD.** Table AP1-4 lists AE storage structures and containers that have been approved by the DDESB for specific NEWs and/or reduced QD. The items in this table were generally designed for a particular application; however, as approved items, they can be used by other DoD Components and for other applications, provided all conditions, restrictions, design elements, etc., are observed. All documentation pertaining to the use of the storage structure or container must be obtained prior to their use. Table AP1-4 also identifies restrictions/conditions, as applicable, for use of the items listed.

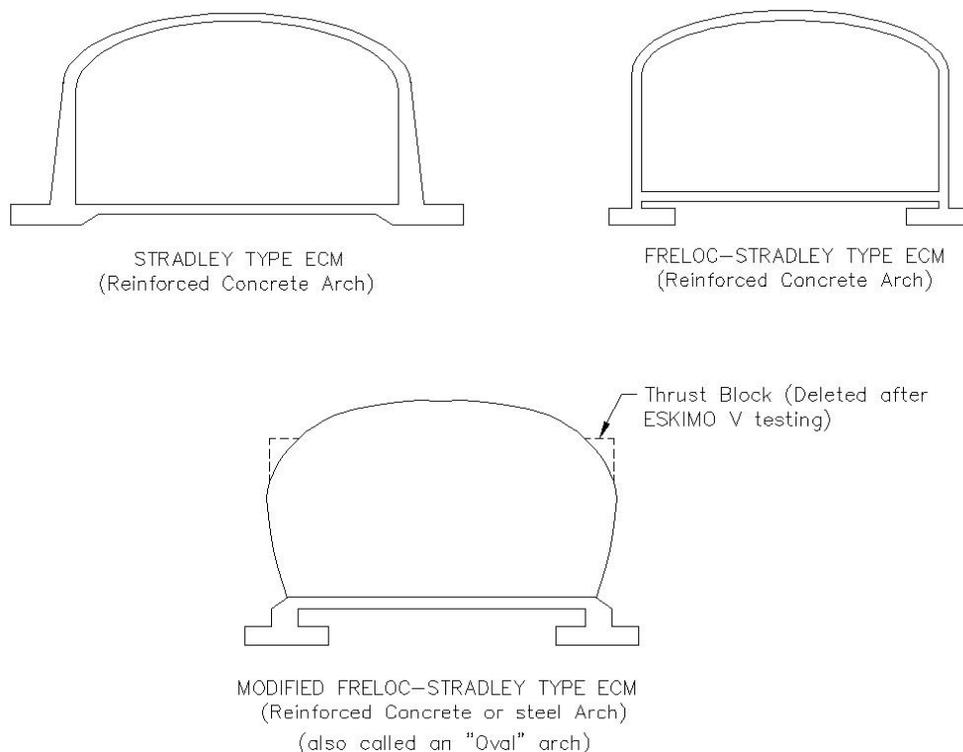
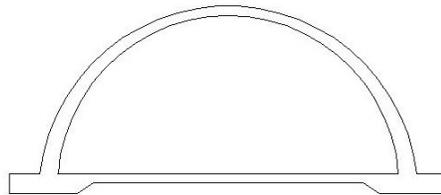
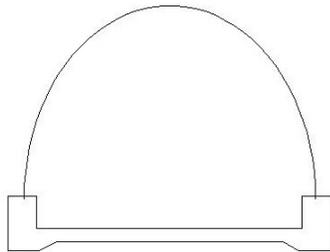


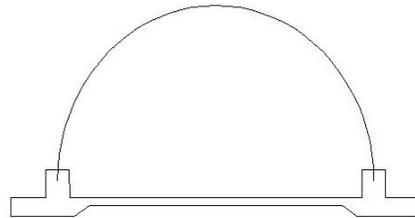
FIGURE 4-1. ECM CROSS-SECTIONS



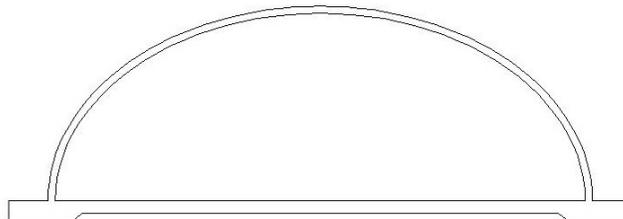
REINFORCED CONCRETE ARCH ECM
(Circular)



SEMI-CIRCULAR TYPE ECM
(Steel Arch)



STEEL ARCH ECM



DOMES TYPE ECM
(Reinforced Concrete)

FIGURE 4-1. ECM CROSS-SECTIONS (continued)

C5. CHAPTER 5

UNDERGROUND AMMUNITION STORAGE FACILITY

C5.1. GENERAL.

U.S. Army Corps of Engineers Definitive Drawing 421-80-04, dated 18 Nov 96, was approved by the DDESB on 8 December 1996 and provides general advice and guidance in the planning, siting, and construction of underground ammunition storage facilities. This drawing provides details regarding facility layout, tunnel and chamber dimensions, a frontal barricade, closure blocks, and blast doors, as well as on rock classifications. Copies of this drawing can be obtained from the U.S. Army Corps of Engineers, Engineering and Support Center, Code CEHNC-ED-CS-S, P.O. Box 1600, Huntsville, AL 35807-4301.

C5.2. UNDERGROUND MAGAZINE CRITERIA.

Explosives safety criteria for underground ammunition storage facilities are located in Section C9.7, Chapter 9 of DoD 6055.9-STD (reference (5-1)).

C5.3. REFERENCES.

- 5-1. DoD 6055.9-STD, "DoD Ammunition and Explosives Safety Standards," Under Secretary of Defense for Acquisition, Technology, and Logistics (current edition).

C6. CHAPTER 6

BARRICADES

C6.1. GENERAL.

C6.1.1. Hazardous effects produced by an explosion generally consist of airblast, fragments, debris, and thermal. Given sufficient distance from the explosion source, these effects can eventually be reduced to a point where the worst hazard of consideration no longer presents any risk. However, the use of large protective zones is typically not acceptable because of the vast quantities of real estate that would be needed. Consequently, explosives safety criteria of DoD 6055.9-STD (reference 6-1) provide for the minimum required default separation distances for the prevention of propagation (prompt and subsequent) and for the protection of personnel (related and non-related) and assets, after consideration of the type of explosives operation being conducted, the protection level required, the explosives material involved, the type of facilities involved, as well as other factors. For example, personnel exposed to an intentional detonation operation or a high risk operation (e.g., motor firing in a test cell, a detonation range) would require a higher level of protection, as compared to an operation where only an accidental (non-intentional) explosion was expected. Reference 6-1 permits the use of lesser separation distances if DDESB approved protective construction/mitigation is used that is capable of providing an equivalent level of protection to that required at the minimum default separation distance. Testing and/or analyses are necessary to demonstrate to the DDESB that the mitigation method selected is adequate.

C6.1.2. The purposes of this chapter are to consolidate in one location the many protective construction and mitigation methods and designs that have been approved by the DDESB; to provide sufficient information to enable a user of TP 15 to make an initial assessment of the methods available to them for their specific needs; and to provide sources for additional information.

C6.1.3. Conditions and restrictions (e.g., maximum NEW, minimum standoff distances, minimum barricade height, required construction materials) always apply to the use of protective construction and mitigation methods/designs. These conditions and restrictions ensure that any planned use of the method/design falls within the boundaries and parameters that were defined by testing or analyses. Use of one of those methods/designs outside its established boundaries and parameters may yield a different result from that tested and could negate the benefit that was intended. Consequently, it is extremely critical that before a method/design is selected, that all pertinent information and approvals be obtained, read and understood, and all conditions and restrictions followed. Additional testing or analyses may be conducted if there is an interest in evaluating other applications and uses for a specific method/design.

C6.2. **BARRICADES.** Barricades are available in many different shapes and sizes, and if properly constructed can be very effective in controlling fragments and debris and, in certain circumstances, blast effects. The various uses for a barricade are described below:

C6.2.1. A barricade can provide an effective means of stopping high-velocity, low-angle fragments that are the primary cause of prompt propagation of an explosion from one explosives site to another explosives site. In the event of an explosion at an explosives site, the presence of a barricade will not necessarily prevent subsequent explosions from occurring at other nearby sites; however, each explosion may be viewed as a separate event.

C6.2.2. A barricade can provide adjacent operations and facilities protection from high-velocity, low-angle fragments, which present a high risk of injury or death to personnel, and a high damage potential to facilities and equipment. A barricade will not provide any protection from high-angle fragments, which can pass over a barricade.

C6.2.3. A barricade can provide limited protection from blast overpressure, in an area immediately behind the barricade. The amount of protection provided by a barricade is governed by the barricade's height and width and the distance the exposure is from the rear of the barricade. Protection increases as separation distance decreases. A barricade is ineffective in reducing blast overpressure at far-field distances, such as those associated with IBD or PTRD.

C6.2.4. In certain situations, explosives safety criteria permit the use of reduced separation distances between explosives sites and from explosives sites to adjacent operations and facilities, when properly constructed, intervening barricades are present.

C6.2.5. Some barricades are designed for specific applications, such as to contain fragments or to minimize potential fragment throw distances. Examples where such barricades could be used are at an ordnance environmental (OE) cleanup site, to protect from an unintentional detonation of an AE item being worked, or at an EOD site where only limited quantities of explosives material will be detonated/burned. Use of such fragment defeating barricades may permit a reduction in QD, by allowing other factors, such as blast overpressure or maximum expected fragment distance, to govern the application of QD.

C6.2.6. When there is a need for AE to be in close proximity to other AE, a barricade can be used to limit the MCE to a single AE item, stack, vehicle, etc. As a result, the QD arc emanating from the site can be reduced because it is based on the MCE involved and not all the AE on-site. The DDESB has approved the use of a number of barricade designs and these are listed below. Barricade design and construction criteria are provided in Chapter 5 of reference 6-1.

C6.2.7. Approved barricade designs.

C6.2.7.1. DEF 149-30-01 Barricades. The Huntsville Division of the U.S. Army Corps of Engineers has developed a definitive drawing, DEF 149-30-01, which provides construction information for numerous barricade designs that can be used to protect facilities and equipment located close to explosives sites from high-velocity, low-angle fragments. The definitive drawing provides details for the construction of a traditional earthen barricade, a sandbag barricades, numerous retaining wall barricades, and other types of barricades. The DDESB approved Definitive Drawing DEF 149-30-01 on 25 February 1992. The various barricade configurations are recognized as effective for the applications shown on the drawings

and, consistent with constraints indicated on the drawings, are approved for site-adaptable implementation. Copies of Definitive Drawing DEF 149-30-01 can be obtained from the U.S. Army Corps of Engineers, Engineering and Support Center, Code CEHNC-ED-CS-S, P.O. Box 1600, Huntsville, AL 35807-4301.

C6.2.7.2. Jungle Growth. Dense vegetation can be effective in preventing prompt propagation of an explosion from one explosives site to another, due to the jungle growth's ability to stop high-velocity, low-angle fragments. The density of jungle growth plays an important role in stopping these fragments. On 27 July 1976, the DDESB approved the use of barricaded, aboveground separation distance (K6) between aboveground, unbarricaded explosives storage sites at Andersen Air Force Base, Guam. Their approval was based on testing which showed that high-velocity fragments could be effectively stopped by a medium that had a gross average density of at least 2000 grains/ft³, about four times the density of air at standard conditions. The DDESB approved restricted use of jungle growth as an effective barricade for the storage of relatively insensitive, finished ammunition, such as bombs and separate-loaded projectiles, without fuzes or propelling charges. In addition, a regular program of surveillance is required to insure that the average gross density of the jungle growth is not compromised.

C6.2.7.3. Earth-filled, Steel Bin-Type Barricades. These barricades, also known as ARMCO Inc. revetments, are earth-filled, steel bins that have been used to separate munitions awaiting scheduled processing; for example, munitions on flight lines associated with aircraft parking/loading operations, or the temporary positioning of munitions awaiting transfer to preferred, long-term storage. These barricades are also used to separate uploaded aircraft. These barricades are typically formed into cells and are designed to limit the MCE (for QD purposes) to the munitions stored in each cell. Criteria were approved during the 314th DDESB Meeting for siting of munitions in ARMCO revetments during flight line "load and unload operations." The DDESB Secretariat maintains a list of the munitions suitable for storage in revetments and has developed a methodology for adding other munitions to the list in the future. The initial list and methodology are documented on an 18 April 1997 DDESB memorandum. The Type A ARMCO Inc. revetment has an allowable MCE of 30,000 pounds NEW of HD 1.1 (prompt propagation protection), and the Type B ARMCO Inc. revetment has an allowable MCE of 5,000 pounds NEW of HD 1.1 (prompt propagation protection). Restrictions associated with the use of these ARMCO Inc. revetments are found in reference 6-1. Reference 6-2 is the technical report describing the analyses conducted for the ARMCO revetments. These bin-type barricades can also be used around storage sites and operations area, where use of barricaded intermagazine and barricaded intraline separation distances is allowable by reference 6-1.

C6.2.7.4. Ammunition Quickload and Safeload Programs. These programs were developed by the U. S. Army Project Manager for Ammunitions Logistics, in response to a 1986 DDESB Survey of U. S. Army camps in Korea, which revealed that a number of explosives safety storage violations (primarily involving explosives loaded vehicles) existed in proximity to occupied areas. These programs, through testing, developed barricades to help reduce MCE to smaller NEW that were more manageable and that permitted reductions in QD. These barricades are to be used primarily in Theatres of Operation. The following barricades were developed under these programs:

C6.2.7.4.1. AGAN Steel Panel (ASP) Walling System. The ASP Walling System consists of formed metal sheets, which are joined together to constitute both the permanent framework for the wall and the reinforcement for the concrete that is then poured into the metal framework and allowed to cure. The DDESB approved the use of this system initially on 18 September 1990 and then approved a revised technical data package (TDP) for the Walling System on 25 September 1990. Reference 6-3 is the revised TDP for the ASP Walling System and it details the construction techniques that are required to properly assemble the ASP Walling System. The system permits the parking of 155mm loaded trucks, carrying up to one hundred and sixty (160) 155mm projectiles (M107 or M483) and their associated propellant charges, side-to-side with an intervening ASP Walling System between trucks. This quantity of 155mm projectiles equates to about 2,500 pounds NEW. A minimum of 15 feet must separate trucks. In this configuration, the MCE is the AE on one truck, and QD can be based on this MCE.

C6.2.7.4.2. Sand Grid Wall. The Sand Grid Wall uses commercially available honeycomb grid sections that are expanded and sand-filled, in accordance with the instructions provided in reference 6-4, to construct the barricade needed. Once built up to the required height, the sand grid wall can be used as a barricade to separate individual truck or trailer loads of 155mm artillery projectiles plus their associated propellant charges. Up to one hundred and sixty (160) 155mm projectiles and their associated propellant charges, may be on any truck or trailer, which represents the MCE for QD purposes. A minimum separation distance of 15 feet must be maintained between trucks or trailers. Initial DDESB approval for the Sand Grid Wall was granted on 22 February 1991, for use as a barricade for twenty-one (21) different projectile types and their associated propellant charges. Subsequent DDESB approval for an additional four projectiles and their propellant charges was granted on 24 June 1991. The total number of projectile types permitted to use the Sand Grid Wall barricade is currently twenty-five (25).

C6.2.7.4.3. Geotextile Stabilized Sand Walls as Barricades. A 6 February 1991 DDESB memorandum found acceptable the concept of a stand-alone, geotextile stabilized sand wall barricade, which was at least three feet thick at its crown, provided it could meet lifetime requirements through validated erosion control techniques. This barricade design had to have side slopes exceeding 1.5 horizontal to 1 vertical. Based on this DDESB acceptance, the Project Manager, Ammunition Logistics, at Picatinny Arsenal published a TDP which described methods for constructing three different types of geosynthetic reinforced barricades, using sandy soil as a backfill, as an improvement to ordinary sandbag walls. The TDP, reference 6-5, provides detailed instructions for constructing a double-faced geotextile wall, a geotextile-wrapped sandbag wall, and a geocell wall. It was envisioned that these walls would be used in a Theatre of Operation, to protect and separate ammunition. However, use of these walls is allowed wherever permitted by reference 6-1, for the reduction of separation distances (such as barricaded, intermagazine or barricaded, intraline). Painting of exposed portions of the two-geotextile walls has been found to be essential for barricade longevity.

C6.2.7.4.4. 4.2-Inch Mortar Rack. The 4.2-inch mortar rack is contained in a Container Express (CONEX) container and is built of wooden modules and steel plates, arranged in a specific configuration. Each module can contain one box of two M39A2 Composition B loaded mortar rounds. A steel plate is used to separate rows of modules. A passive fire suppression system is used, which consists of plastic containers filled with a fire suppression

liquid that are placed in select spaces in the rack. The sidewalls and roof of the CONEX must be sandbagged, and a door barrier must be constructed in front of the CONEX container. The 4.2-inch Mortar Rack was approved by the DDESB on 30 December 1991. If constructed and used in accordance with reference 6-6, the MCE is one box of two mortar rounds. The rack requires a front IBD arc of 310 feet within a 30-degree arc (+/-15 degrees from the CONEX centerline) and a 100-foot IBD arc around the remainder of the storage site.

C6.2.7.4.5. Improved Loading Configuration for 8-Inch Artillery. A 27 March 1987 DDESB memorandum approved loading configurations for TNT-filled 8-inch (M106) artillery ammunition, with associated propelling charges and fuzes, aboard transport vehicles. Transport vehicles using these approved spacing and shielding configurations are permitted to be parked near each other within a holding area, with the MCE considered one transport vehicle. Reference 6-7 provides details regarding spacing, shielding, and load configurations that were approved.

C6.2.7.4.6. 105 MM Tank Rack Design. A rack was developed for the temporary storage of 105 mm tank ammunition in congested areas, such as when a tank has to be downloaded for maintenance. The rack is designed to limit the MCE to one tank round, which permits the application of a 50-foot IBD arc around the facility containing the rack. The facility has soil cover on its sidewalls, rear wall, and roof and uses a front barricade. The rack/facility design was approved by the DDESB on 23 December 1986. A modification of the initial approval, to add additional 105mm ammunition types to those already approved to be placed in the rack/facility, was approved by the DDESB on 19 March 1987. Reference 6-8 provides construction details for the rack, the facility that contains it, and identifies the 105 mm ammunition types permitted to be stored within it.

C6.2.4.7.7. 105 MM/120 MM Tank Ammunition Download Rack. Several construction options have been developed for the storage of 105 mm and 120 mm ammunition in facilities containing ammunition download racks that are designed to limit the MCE to one projectile only. These facilities use soil containment elements for the sidewalls, rear wall, and roof and have a front barricade. Reference 6-9 provides the specifics for construction and use of the rack designs approved by the DDESB on 21 November 1989. The 105 mm versions of the rack require a 50-foot IBD arc, while the 120 mm versions of the rack require a 75-foot IBD arc.

C6.2.4.7.8. TOW Missile Rack. A 28 April 1989 DDESB memorandum approved the use of the Tube-Launched, Optically-Tracked, Wire-Guided (TOW) Missile Rack. The rack, which limits the MCE to a detonation involving 50 pounds NEW (TNT equivalent), is contained within a CONEX container. The rack is assembled using stacking modules and steel plates between rows, in a manner similar to that described above for the 4.2-inch mortar rack. The CONEX container is sandbagged on the sides, rear, and roof, and a barricade is constructed in front of the door. When assembled and used in accordance with reference 6-10, the rack requires a front IBD arc of 740-foot within a 60-degree arc (+/-30 degrees from the CONEX centerline) and a 350-foot IBD arc is required around the rest of the container.

C6.2.4.7.9. QD Reduction Using Concertainer Barricades. DDESB approval memorandum DDESB-KT of 28 October 2002 approved a TDP, reference 6-11, for the

use of a HESCO-Bastion concertainer barricade, configured as shown in the TDP, for prevention of prompt propagation between munitions storage cells, each containing 4,000 kg (8,820 lbs) NEW of HD 1.1, when separated by less than the required IM (K6) default criteria. For the NEW quantity involved, K6 separation criteria would normally require an intervening barricade and a separation distance of 124 feet. In a full-scale test using worst-case (SG 5) HD 1.1 and HD 1.3 acceptor munitions, it was demonstrated that an intervening HESCO-Bastion concertainer barricade was capable of preventing prompt propagation of acceptor munitions located at an IMD of 28 feet from the detonation of a donor munition stack containing 4,000 kg (8,820 lbs).

C6.2.4.8. Ordnance Explosive (OE) Removal Sites. The U.S. Army Engineering and Support Center, Huntsville (USAESCH) has been involved with projects that require the disposal of uncovered/discarded ordnance and explosives from OE Removal Sites. These sites could be on public or private lands. Actions that can be taken when an ordnance item is found include detonation on-site or transportation of the item to another site for proper disposal. Safety to the public and to personnel involved in the disposal action is of utmost concern. In response to the need to insure this safety, the Structural Division of the Huntsville Division, COE, was tasked to develop procedures and barricades for blast and fragment mitigation, for use by personnel performing disposal operations. The barricades that have been approved for this purpose are listed below:

C6.2.4.8.1. Sandbags to Mitigate Fragmentation and Blast Effects.

Reference 6-12 was approved by the DDESB on 23 February 1999. This approval permits use of sandbagging procedures for the intentional detonation of munitions up to 155 mm (M107), at OE sites. Only one munition item can be detonated at a time. Detailed guidelines are provided for the selection and use of sandbag enclosures of various thicknesses to mitigate fragments and blast, and for determining minimum withdrawal distances to be used during detonation operations. A methodology is also provided for determining sandbag enclosure thickness and withdrawal distance for a munition item that is smaller than a 155 mm (M107) projectile, but which had not been tested as part of the sandbag test program.

C6.2.4.8.2. Open Front Barricade (OFB). The OFB is designed to defeat the primary fragments of select ordnance, in the event of an accidental detonation that occurs while performing an intrusive operation at an OE removal site. The OFB is not intended for intentional detonations and is not designed for repeated use. The OFB is used by placing it over the UXO being worked on. The OFB is designed for use with ordnance items that generate an explosives weight-to-OFB internal volume ratio of 0.29 pounds/ft³ or less. If the weight-to-volume ratio is met, then the "minimum separation distance (MSD) for unintentional detonation" associated with the OFB is 300 feet from the three covered sides, and default distances from reference 6-1 must be used from the front of the OFB. The OFB consists of an aluminum frame on which aluminum plates can be mounted to form the three sides and roof. The OFB frame is capable of supporting an aluminum plate thickness of up to 2.75 inches. Sandbags are then used, as necessary, to seal off any gaps under the OFB. Reference 6-13 was approved by the DDESB on 9 December 1999 and provides specific guidelines for the use of the OFB and for aluminum plate thickness selection, for the ordnance items that might be encountered at the OE removal site. If the OFB is to be used for any ordnance item that has a weight-to-volume ratio that exceeds 0.29 pounds/ft³, then the appropriate "MSD for unintentional detonation" for that particular munition

needs to be determined using an approved analysis method or by testing or default IBD distances of reference 6-1 will apply.

C6.2.4.8.3. Enclosed Barricade (EB). The EB serves the same purpose as the OFB described above, except that it has a front barricade associated with it. The conditions/restrictions for its use are the same as for the OFB and are contained in reference 6-13, as well. The “MSD for unintentional detonation” associated with the EB is 300 feet, all around. The DDESB approved use of the EB on 9 December 1999.

C6.2.4.8.4. Miniature Open Front Barricade (MOFB). The MOFB is a smaller version of the OFB described above. Reference 6-13 provides details on the restrictions/conditions pertaining to use of the MOFB. DDESB approval of reference 6-14 was granted on 23 February 1999. The MOFB defeats primary fragments to its sides, rear, and top and is to be used for an unintentional detonation, which might occur during an intrusive operation at an OE removal site. Select UXO items for which it is designed are listed in reference 6-14. It can be used for other items provided the munition item does not have an NEW in excess of 2.3 pounds, and an analysis determines that the thickness of aluminum needed to stop primary fragments does not exceed 1.5 inches. The DDESB approval letter explains what analysis has to be performed. The MOFB is permitted to use a “MSD for unintentional detonation” of 200 feet from its sides and rear, and default distances from reference 6-1 must be used from the front of the MOFB.

C6.2.4.8.5. Guide for Selection and Siting of Barricades for Selected Unexploded Ordnance. Reference 6-15 was developed to enhance safety to the public and personnel conducting OE removal operations. It provides guidance to field personnel to assist them in controlling the potential primary fragment hazard generated by a suspected buried explosive filled ordnance item being uncovered. These barricades are not designed to control overpressure. A number of barricade designs are presented in reference 6-15, with guidance given on how to select the best barricade for the job being conducted.

C6.2.4.8.6. Buried explosion module (BEM). An analytical method to calculate public and operational personnel withdrawal distances for buried munitions disposal has been developed. The method includes cratering calculations and calculations of the velocity of the fragment as it exits the soil and fragment trajectory calculations using an approved trajectory analysis code. The maximum ejecta radii of large soil chunks produced by the cratering are then calculated with an appropriate safety factor. In order to simplify and standardize these calculations, software has been developed. The theory and the software, which is called the buried explosion module (BEM), are discussed in reference 6-16. DDESB approval of the BEM was provided on 3 November 1998. The BEM methodology approved by the DDESB has since been incorporated into reference 6-17.

C6.2.4.8.7. Use of Water for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonation of Munitions. In 1999, the Structural Branch of the U.S. Army Engineering and Support Center, Huntsville (USAESCH), AL, sponsored a test program to evaluate the use of water for fragment and blast mitigation for intentional detonations at OE sites. The program was broken into two phases, with the first phase determining the minimum water depth needed to defeat fragments from four different munitions, and the second phase testing

various water containment systems for the four munitions. DDESB memo of 27 February 2001 approved the use of water for mitigation of fragmentation and blast effects due to intentional detonations. The techniques provided in reference 6-18 are approved for field use on OE removal action projects.

C6.2.4.9. Buffered Storage. From 1986 through 1987, the Air Force conducted a series of tests to prove out the concept of "buffered storage", which used specific palletized AE material as a buffer between specified quantities (stacks) of Mk 82 or Mk 84 bombs, in order to prevent propagation between stacks and thereby reduce the MCE. The MCE was based on the NEW in the largest stack, plus the NEW of the buffer material (when HD 1.4 material is used as buffer material, then the HD 1.4's NEW does not need to be included). The QD was determined using the combined NEW. Test results of these tests are recorded in references 6-19 and 6-20. The Air Force received DDESB approval for use of the "buffered storage concept" in ECM, aboveground magazines, and at outdoor storage areas. A 30 April 1990 DDESB-KO memorandum approved 12 buffered storage configurations that were documented on Drawings AFISC 900402A through AFISC 900402L. Initially, the buffer material approved for use consisted of only palletized 20-mm, 30-mm, and CBU 58. DDESB-KT memorandum of 10 May 1990 authorized palletized CBU 71 to be used as a buffer material, and DDESB-KT memorandum of 28 November 1990 authorized the use of palletized CBU 52 as buffers.

C6.2.4.10. Composite (sand-filled foam panel) Walls for Sub-dividing Magazine MCEs.

C6.2.4.10.1. At the 261st meeting (24 April 1972) of the DDESB, there was a discussion regarding the use of sandbag walls, constructed per Defense Nuclear Agency (DNA) criteria, which permitted storage igloos to be subdivided by sandbag walls generally 6 ft. high by 22" wide using a prescribed configuration. At this meeting, a representative of DNA presented a wall system developed by DNA and Dow Chemical Co., to provide equivalent protection as the sandbag wall, and used as a replacement to the sandbag wall. The system consisted of high-density extruded polystyrene (styrofoam) sections that were assembled into walls and which were filled with sand as the wall was erected. The DDESB approved the use of the new wall system at this meeting.

C6.2.4.10.2. The above concept of using polyurethane type walls also found its way into the Blast Tamer Explosive Damping Blast-Wall System used in Air National Guard (ANG) magazine designs listed in Table AP1-4 and defined by drawings ANG-DWG-94-001, ANG-DWG-94-002, ANG-DWG-96-001, ANG-DWG-99-001, and ANG-DWG-00-001. The General Plastics Manufacturing Company, at the request of the Vermont ANG, developed this composite wall system (polyurethane wall panels filled with sand) to allow the ANG to reduce the MCE of ECM to the NEW contained in a single cell, rather than all the ordnance contained in the ECM. The wall was approved by the DDESB for a maximum of 425 lbs NEW, with a reduced IBD arc of 700 feet to the front of the ECM and a reduced IBD arc of 250 feet to the side of the ECM. By reducing the MCE to 150 lbs NEW, the required IBD arcs could be reduced further to 500 feet to the front and 250 feet to the side and rear.

C6.2.4.10.3. The ability of a composite polyurethane panel/sand wall system (as a non-propagation cell wall) to prevent prompt propagation was analyzed for the ANG by the Naval Civil Engineering Laboratory (NCEL) in January 1993, using AUTODYN-2D analysis. The results of their analysis are documented in reference 6-21. In addition, personnel from the Vermont ANG and General Plastics Manufacturing Company gave a presentation on the Blast Tamer design at the 28th DDESB Seminar, reference 6-22.

C6.2.4.11. QD for Ammunition in ISO Containers. A significant study was undertaken in the late 1990s by the DDESB to (a) develop realistic estimates of the safety hazard ranges (e.g., IBD) for accidental explosions of ammunition in ISO shipping containers, and (b) investigate methods for reducing QD for ammunition containers at temporary storage sites. Co-sponsors of the study were the U.S. Transportation Command (TRANSCOM), the Explosives Storage and Transport Committee (ESTC) of the British Ministry of Defence (MOD), and the U.S. Army Corps of Engineers. The study consisted of 2 phases.

C6.2.4.11.1. Phase 1 of the study was an analytical effort, in which QD were calculated using accepted analytical methods. The goals of Phase 1 were to:

C6.2.4.11.1.1. Review the state-of-the-art for establishing QD for munitions in shipping containers.

C6.2.4.11.1.2. Examine the composition of typical container loads of ammunition.

C6.2.4.11.1.3. Develop preliminary, revised QD for ammo containers, based on existing data and the best available hazard prediction methods.

C6.2.4.11.1.4. Identify the most critical needs for additional test data.

C6.2.4.11.1.5. Design a program of experiments to provide the most needed test data and to verify the revised QD.

C6.2.4.11.2. Phase 2 was a program of experiments conducted to provide test data on:

C6.2.4.11.2.1. The effect of the steel ISO container walls on fragment impact velocities against acceptor munitions,

C6.2.4.11.2.2. Safe separation distances between ISO containers to prevent propagation by blast pressures.

C6.2.4.11.2.3. The performance of sand-filled barricades for preventing propagation at the proposed minimum separation distances between containers.

C6.2.4.11.3. As part of the Phase 1 effort, an extensive survey of available literature was conducted to identify and review previous research related to the objectives of the

program. This effort was conducted to extract any information that would be useful to the analysis and to avoid duplicating any work previously performed. This search resulted in 613 references being selected for inclusion in the listings, and data from over 2,500 explosion tests being tabulated in spreadsheets. The results of Phase 1 are documented in reference 6-23.

C6.2.4.11.4. The remainder of the study is documented in reference 6-24. The principal conclusions developed from the analyses and experiments were;

C6.2.4.11.4.1. IBD and PTRD for ISO containers with HD 1.1 components are the same as in open storage.

C6.2.4.11.4.2. Calculations indicated that IMD between containers with fragment-producing HD 1.1 components may be reduced slightly by the reduction of fragment impact velocities due to the shielding effect of acceptor container walls.

C6.2.4.11.4.3. IMD for containers with non-fragmenting HD 1.1 components can be reduced by significant amounts - down to a scaled separation of $3.0 \text{ ft/lb}^{1/3}$ ($1.0 \text{ m/kg}^{1/3}$) - if there are no highly sensitive munitions (such as M2 demolition shaped charges) in the container loads.

C6.2.4.11.4.4. IBD, PTRD, and IMD values for HD 1.2 munitions in containers (with no HD 1.1 components) are significantly less than indicated by the current standards, according to FRAGPROP calculations. Again, however, the container walls provide only a minor shielding effect, at best, for acceptor munitions.

C6.2.4.11.4.5. The IMD for HD 1.3 material is limited to that necessary to prevent initiation by spread of a fire. Since the containers shield their contents against firebrands, the recommended minimum IMD is 8 ft, for inspection and fire control access.

C6.2.4.11.4.6. "Blast-Tamer" barricades can be easily and quickly constructed by 3 or 4 workers with minimal training. It should also be possible to disassemble this type of barricade and re-construct it elsewhere.

C6.2.4.11.4.7. The slope-sided barricade design did not appear to provide any advantage in blast protection over a normal barricade with vertical sidewalls, except for better stability.

C6.2.4.11.4.8. The use of sand-filled barricades allows ISO containers of HD 1.1 munitions to be spaced at IMD of 20 feet (6 m).

C6.2.4.11.4.9. Barricades with a sand thickness of only 18 inches (0.5 m) are effective in preventing fragment damage between ISO containers of HD 1.1 munitions.

6.3. **SUPPRESSIVE SHIELDS**. A suppressive shield is a vented, steel enclosure, which is capable of controlling or confining the hazardous blast, fragment, and flame effects of internal

detonations. Conditions and limitations associated with each design must be followed in order to receive the level of protection described.

6.3.1. A great deal of interest existed in the 1970s with respect to suppressive shielding, and an extensive manufacturing technology program was undertaken by the Army to design and proof-test several prototype structures and to develop a technology base for suppressive shield designs. As part of this effort BRL, NASA, Southwest Research, Inc., Huntsville Division (COE), and AAI Corporation conducted extensive testing to develop design procedures and analytical techniques for use in suppressive shielding. Reference 6-25 is a product of this effort. Because of the interest in suppressive shielding, the DDESB established a Suppressive Shielding Technical Steering Committee, which included Dr. Zaker of the Secretariat, to review test data and subsequent design documentation. This committee approved five basic suppressive shield designs for use in hazardous operations, and reference 6-25 presents design details for these designs (Groups 3, 4, 5, 6 (A and B), and 81mm (prototype and Milan)), along with engineering guidance on their selection and modification to meet operational requirements. Reference 6-25 includes information on other groups (1, 2, and 7) that, at that time, were either not funded or had not yet received approval because they were still in preliminary design stages. Approval has since been given for a Group 1 suppressive shield that was installed within a production facility at Indian Head Division, Naval Surface Warfare Center (NSWC). Reference 6-25 also provides guidelines and techniques for the design and proof testing of new suppressive shields. Reference 6-26 is a report that contains descriptions of five groups of DDESB-approved suppressive shields and the engineering data and analysis supporting the safety approval recommendations. Copies of the approval documentation are provided in this report. The following describes each approved group:

C6.3.1.1. **Group 1**. Rated for an NEW of 2,000 pounds. Contains all fragmentation and reduces blast overpressure at unbarricaded intraline distance by 50%.

C6.3.1.2. **Group 3**. Rated for an NEW of 37 pounds. Contains all fragmentation and provides K24 protection at 6.2 feet from the shield.

C6.3.1.3. **Group 4**. Rated for an NEW of 9 pounds. Contains all fragmentation and provides K24 protection at 19 feet from the shield.

C6.3.1.4. **Group 5**. Rated for an NEW of 30 pounds propellant material or pyrotechnics or 1.84 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 3.7 feet from the shield.

C6.3.1.5. **Group 6A**. Rated for an NEW of 0.962 pounds TNT equivalent. Contains all fragmentation and provides K24 protection at 1-foot from the shield.

C6.3.1.6. **Group 6B**. Rated for an NEW of 0.5545 pounds TNT equivalent. Contains all fragmentation and provides K24 protection at 1-foot from the shield.

C6.3.1.7. **Prototype 81mm Shield**. Rated for an NEW of 6.72 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 3 feet from the shield.

C6.3.1.8. **Milan 81mm Suppressive Shield.** This is an adaptation of the Prototype 81mm Shield and is rated for an NEW of 4.2 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 7.3 feet from the shield.

C6.4. **UNEXPLODED ORDNANCE (UXO) DEMOLITION CONTAINER.** Structures that contain all effects (blast and fragments) produced by the intentional detonation of UXO have been designed for use in locations where open detonation may not be an acceptable or desired method of disposal. Such situations can exist as a result of the proximity of exposed persons or property or where transportation of UXO to remote sites may be hazardous, impractical, or economically not feasible. The following containers have been approved by the DDESB:

C6.4.1. **On-site Demolition Container (ODC).** The COE, Huntsville Division, has designed the ODC for the containment of fragments and overpressure produced by the detonation of UXO up to 81mm in diameter. The maximum explosives weight is 6 pounds of TNT equivalent explosives. The ODC is a cylindrical steel container that is mounted on an integral support frame and working platform. Inside the container, an innovative system of different materials is used to capture fragments. The system includes a layer of sand surrounding the ordnance item to be destroyed, a set of steel cable blasting mats, and a segmented inner steel liner. Water bags, at a ratio of five pounds of water for each pound of TNT equivalent explosives, are used to reduce quasistatic pressures. Water bags, sand, and their containers need to be replaced after every shot. The mats are good for eight to ten shots, while the liner is good for 30 or more shots before they have to be replaced. Reference 6-27 provides information regarding the ODC and how to obtain safety approval for its use. DDESB-KO Memorandum of 15 September 1998 approved use of the ODC and is included as part of reference 6-27. During a detonation, the minimum withdrawal distance for related personnel is 75 feet. The minimum withdrawal for unrelated personnel and the public is the applicable IBD associated with the ordnance item being destroyed. This distance is specified because of hazards associated with operations leading up to an intentional detonation in the container.

C6.4.2. **T-10 Transportable Donovan Blast Chamber.**

C6.4.2.1. Reference 6-28 documents the patented T-10 transportable Donovan Blast Chamber (DBC), which is capable of containing all pressures and fragmentation resulting from the detonation of UXO up to 81mm in diameter. Demil International, based out of Huntsville, AL, designed the DBC. DDESB-KO Memorandum of 31 January 2000 approved the use of the DBC and is included in reference 6-28. The maximum explosives charge (donor weight and NEW of the projectile) approved for the DBC is 10 pounds HMX (13 pounds TNT equivalency). A round with a diameter no greater than 81mm can be destroyed within the DBC provided its fragment hazard has been determined and falls within specific parameters (i.e., mass, velocity) to insure that it will not penetrate the chamber walls. The T-10 chamber was not approved for chemical, biological, white phosphorus (WP), or plasticized WP munitions. The following information is provided about the design of a T-10 DBC:

C6.4.2.2. The DBC design consists of a box within a box. The void between these boxes is filled with silica sand to dampen and absorb detonation shock. The detonation chamber is

lined with replaceable 12-inch X 12-inch X 0.5-inch thick armor plates that are used to stop fragments and to mitigate damage to the interior walls of the detonation chamber. Water bags are suspended inside the chamber to reduce temperatures. The design of the DBC permits the chamber to be used repeatedly. The noise level produced by the detonation of 10 pounds of HMX inside the DBC measures approximately 130 dB at a distance of 30 feet from the DBC. Related personnel are considered to meet all criteria of reference 6-1 when located at a distance of 18 feet from the DBC during detonation operations. However, hearing protection is still required at this distance. The minimum withdrawal for unrelated personnel and the public is the applicable IBD associated with the ordnance item being destroyed. This distance is specified because of hazards associated with operations leading up to an intentional detonation in the container.

C6.4.2.2.1. Following an internal detonation, blast pressures, along with detonation byproducts, are vented into a hardened expansion chamber and then through the Air Pollution Control Unit (APCU), where the air-stream is cleaned prior to venting to the environment.

C6.4.2.2.2. In March 2002, an amendment requested by the Defense Ammunition Center (DAC) was approved (DDESB-KT Memo of 2 July 2002, subject: Amendment to Explosives Safety Submission (ESS) for a Commercially Developed Portable Contained Detonation Chamber (Donovan T -1 0)). The amendment allows the use of the T-10 for detonation of fragmenting munitions with diameters up to and including 105 mm, provided a minimum of .75-inch thick armor plating is installed on the interior of the T-10 detonation chamber. The maximum NEW remains unchanged at 10 lbs HMX (13 lbs TNT equivalency).

C6.4.2.2.3. A second amendment requested by DAC was also approved (DDESB-KT memo of 10 October 2002, subject: Amendment 1, 28 February 2002, as Revised 5 June 2002, to Approved Explosives Safety Submission (ESS) for a Commercially Developed Portable Contained Detonation Chamber for Unexploded Ordnance, 30 November 1999. This amendment permits use of the T-10 for destruction of WP-filled munitions with diameters of 8 1 mm or less. In order to insure destruction of the WP, the ratio of donor charge (in TNT equivalent weight) to WP is required to be a minimum of 3 to 1, subject to the maximum TNT equivalent explosives limit of 13 lbs. Destruction of munitions containing plasticized WP is currently not permitted.

C6.5. NAVY MISSILE TEST CELLS (MTC).

C6.5.1. In 1986, the Naval Civil Engineering Laboratory (NCEL), now known as NFESC, was funded by Naval Ship Weapon Systems Engineering Station to develop NAVFAC Standards for Navy MTC. It was envisioned that there would be six types of MTC as described in Table 1-1 of reference 6-29. These were as follows:

C6.5.1.1. Type I and II (40' L x 25' W x 15' H) with a 300 lbs TNT rated capacity.

C6.5.1.2. Type III (20' L x 15' W x 15' H) with a 105 lb TNT rated capacity.

C6.5.1.3. Type IV (30' L x 20' W x 8' H) with a 1,231 lb TNT rated capacity.

C6.5.1.4. Type 5 (10' L X 10' W X 10' H) with a 40 lb TNT rated capacity.

C6.5.1.5. Type 6 (6' L X 6' W X 8' H) with a 10 lb TNT rated capacity.

C6.5.2. The MTC is a component of an Intermediate Level Maintenance Facility (ILMF), which has the capability to assemble missiles from new or fleet-return sections, test missile all-up-rounds (AURs) or sections, and handle, store, or ship AURs or sections in support of Fleet requirements. The missile is tested in the MTC to certify its performance and reliability before delivery to the Fleet. The test simulates the actual flight and intercept capabilities of the missile. The test missile is an AUR, which includes the rocket motor, guidance and control sections, warhead, and arming device. The test is remotely controlled by personnel and equipment located outside the MTC in a test control room.

C6.5.3. Certain operations, such as an AUR test described above, are considered high risk. The MTC must be designed to protect assets and personnel from either inadvertent ignition of the rocket motor or inadvertent detonation of the warhead. Mitigation of these hazards is performed through protective construction. Each MTC Type is designed to contain/limit the explosion effects associated with specific weapons/items.

C6.5.4. Each MTC is a rectangular-shaped, reinforced concrete structure with a covered passageway leading to the main part of the Missile Processing Building (MPB) and a barricaded area at the opposite end. The barricade is located outside the building and is designed to stop fragments and debris existing the MTC. The end of the MTC facing the barricade is provided a frangible panel for the venting of explosion byproducts. A typical MPB may have several MTC nested side-by-side along one or two faces of the building. Two MTC are usually dedicated to each variant of the missile. This eliminates the need to change test equipment each time a different variant of the missile is tested. It also increases the production rate by allowing a test to be underway in one MTC while another missile is being set up for test in an adjacent MTC. The following MTC have been approved to date:

C6.5.4.1. Type I: Designed to NCEL Basis of Design (BOD) N-1752R of June 1988 (reference 6-29). The BOD is used by the Architect and Engineering contractor to guide development of MTC construction drawings and specifications. The BOD specifies that construction drawings, specifications, and design calculations be submitted to NFESC (Code 62) for their review to insure compliance with the requirements of the BOD. The drawings, specifications, and calculations shall be submitted for 35 and 100% design reviews. The maximum NEW for the Type I MTC is 300 lbs TNT or equivalent NEW. Refer to reference 6-29 for the weapon types that can be accommodated in the Type I MTC. The Basis of Design was approved by the DDESB on 7 Dec 1988, and a number of MTC have since been constructed.

C6.5.4.2. Type II: Designed per BOD for NAVFAC Type II Missile Test Cell developed by NCEL (reference 6-30). The maximum NEW is 300 lbs TNT or equivalent NEW. Refer to reference 6-30 for the weapon types that the Type II MTC can accommodate. The BOD was approved by the DDESB on 7 Dec 1988.

C6.6. **SUBSTANTIAL DIVIDING WALLS (SDW).** As an extension of the efforts described in C2.3.13.3 for the HPM's NPW, there was an interest in finding out if SD criteria, which are based on allowable energy and impulse loads on acceptor munitions, could be applied to SDW. Substantial Dividing Walls are 12-inch thick reinforced concrete (RC) walls meeting certain construction requirements that have been in use since the 1960s for the prevention of prompt propagation between explosives stacks. To answer these questions and expand NPW criteria for SDW use, a series of three tests were conducted between August 2000 and November 2001 by NFESC. The objectives for these tests were to determine SD criteria for SDW and to develop a methodology to design homogeneous RC NPW. Additionally, there was a need to complete additional testing to further refine NPW criteria for NEW in the range of 500 lbs to 3,000 lbs. References 6-31 and 6-32 document the results of the three tests that were conducted and which are described below.

C6.6.1. Test 1 (August 2000) was conducted in a small 4-wall (16' L x 12' W x 12' H) cubicle using 12-inch thick RC gravity walls, with the donor NEW being 425 lbs (440 lbs TNT equivalent explosives) with acceptors being a MK 82 bomb (SG1: selected so that MK82 response could be compared with previous flyer plate test results and finite element analysis), a CBU-87 (SG4), and a M864 Projectile (SG4). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptors being thrown against an adjacent wall. A minimum 3-foot standoff was applied between the donor and specific walls and the floor. This equates to a scaled standoff distance $< 1.0 \text{ ft/lb}^{1/3}$. The goal of Test 1 was to evaluate response of CBU ammunition to debris impact from local breaching wall response. Calculated velocities of wall fragment ranged from 300 to 500 ft/sec. The results of this test were favorable. There were no reactions of the acceptor munitions, though there was severe deformation of the CBU-87. All submunitions from the CBU-87 were recovered.

C6.6.2. Test 2 (September 2001) was conducted in a larger 4-wall (24' L x 13' 6" W x 8' H) cubicle assembled with various, lightweight (100 pcf) and normal-weight (150 pcf), 24-inch thick reinforced concrete gravity walls. The donor in this test was 3,000 lbs NEW and the acceptors included MK 82 bombs (SG1), M864 projectiles (SG4), and TOW warheads (SG5). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptors being thrown against an adjacent wall. The goal of Test 2 was to obtain acceptor responses to two debris types: breached wall, high velocity, small debris; and unbreached, sheared wall, low velocity, large debris. Test results were favorable. There was no reaction of the MK 82 or M864 projectiles, though there was minor deformations of the M864 projectiles, and all submunitions were recovered. There were low-order reaction (no detonations) of TOW II warheads. One MK 82 (opposite lightweight concrete wall) experienced severe deformation and cracking.

C6.6.3. Test 3 (November 2001) was conducted in a small 4-wall cubicle using 12-inch thick reinforced concrete gravity walls, with the donor NEW being 440 lbs with acceptors being MK 82 Bombs (SG1), M864 Projectile (SG4), CBU-87 (SG4), and TOW II (SG5). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptor being thrown against an adjacent wall. A minimum 3-foot standoff was applied between the donor and all walls and the floor. This equated to a scaled standoff distance $< 1.0 \text{ ft/lb}^{1/3}$. The goal of Test 3 was to extend SD criteria for SDW to include SG5 acceptors and observe acceptor responses to debris hazards from localized breaching of wall (high velocity, low mass) and direct shear failure at

supports (low velocity, high mass). Calculated velocities of wall fragments ranged from 100 to 500 ft/sec. The results of this test were favorable. There were no reactions of any of the acceptor munitions. The CBU-87 experienced minor deformation of the M864 projectile, and all its submunitions were recovered. The TOW II warheads did not react.

C6.6.4. **TEST RESULTS.** The three tests described above demonstrated that SDW and large dividing walls can prevent SD of acceptor ordnance if HPM SD criteria for unit impulse and energy and wall velocity are satisfied. Also, SD criteria developed for HPM walls apply to designs of conventional (145 pcf) homogeneous reinforced concrete NPW for NEW < 3000 lb. Current SDW wall design criteria and operational constraints are sufficient to prevent SD to SG1, SG2, SG3, and SG4 acceptors, though SG5 acceptors must meet NPW SD criteria (by mitigating loads; for example, by using greater than 3' donor standoff).

C6.6.5. **DDESB SDW Criteria.** DDESB-KT Memorandum of 14 May 2001 provided initial guidance regarding the application of and criteria for SDW for the prevention of prompt detonation reactions or propagation of burning reactions (involving AE) between adjacent bays and to provide personnel protection from remotely controlled operations. There was no intent to determine the capability of an SDW to provide intraline protection to personnel. Since this initial guidance was issued, NFESC completed the test series described above and additional analyses, which further increased our knowledge of SDW protection capabilities. The results of those tests and analyses indicated a need to further clarify and define SDW criteria from that provided by the initial guidance. Accordingly, additional controls were identified to limit use of SDW only to those conditions addressed by testing and analysis, and these were incorporated into revised SDW guidance that is addressed in reference 6-33. Additional work is ongoing which will necessitate further revised guidance in the near future, to include the development of a DDESB TP to document the methodology that is used by NFESC to determine the protection capability of an SDW.

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C7. CHAPTER 7

BARRICADED MODULE STORAGE

C7.1. **HISTORY.** The following information was extracted from reference 7-1, the Air Force's High Explosives Storage (Big Papa) Test Series Report.

C7.1.1. In July 1966 CINCPACAF informed the Chief of Staff, USAF, of problems encountered in stockpiling required munitions (bombs) at Southeast Asia air bases in compliance with existing explosives quantity-distance criteria. The problem was caused by the shortage of land upon which the bombs could be stored. Explosives safety criteria required that the separation distance (in feet) between aboveground barricaded storage facilities containing mass-detonating explosives be $6W^{1/3}$, and real estate was not available to accommodate these separation distances for the quantities of explosives in theater. The Explosive Safety Branch of the Directorate of Aerospace Safety, HQ USAF, Norton Air Force Base, California, was therefore directed to investigate this critical explosives storage problem. A three-step plan was established. The first step taken was to establish an eight-member USAF Special Study Group (AFSSG), augmented by personnel from the ASES and BRL, to research and analyze data on both accidental and planned explosions of large quantities of high explosives and to determine if existing QD criteria could be reduced. The AFSSG expended considerable effort searching for data and evidence, which would identify those parameters pertinent to the propagation of sympathetic simultaneous detonations of adjacent barricaded bomb stacks. They found that very little planned experimentation, which was pertinent to the problem at hand, had been accomplished. They also determined that high-speed fragments impinging on adjacent stacks of bombs would be the most likely cause of sympathetic simultaneous detonations from one bomb stack to another and that barricades would be necessary to stop these fragments if any reductions in separation distances were to be possible.

C7.1.2. The AFSSG made a number of recommendations, which are listed below, to the USAF Chief of Staff. The Vice-Chief of Staff, USAF approved the recommendations on 27 September 1966, for immediate use in combat zones.

C7.1.2.1. A modular concept of munitions storage should be utilized. A module was defined as a barricaded area containing a maximum of five cells separated from one another by an intermediate barricade.

C7.1.2.2. The NEW within each cell could not exceed 100,000 pounds. The distance between the nearest edge of the stacks of bombs in adjacent cells would be a minimum of 50 feet. These distance and weight criteria were based on a K factor of 1.1.

C7.1.2.3. The distance between the nearest edge of stacks of bombs in adjacent modules could not be less than 200 feet. This value was based on a K factor of 2.5 applied to the total NEW content of the module.

C7.1.3. The AFSSG also recommended that a test program be conducted to develop minimum separation distances between single stacks of bombs in the 125,000 - to 500,000-pound range, as it was foreseen that the storage of 100,000 pounds per cell would only temporarily

alleviate the storage problem being experienced at the time. Conduct of this test program, Explosive Storage (Big Papa) Test Series, was approved by the Air Force Chief of Staff on 28 March 1967 and was directed to proceed as soon as ordnance was available.

C7.2. EXPLOSIVES STORAGE (BIG PAPA) TEST SERIES.

C7.2.1. The proposed testing was basically required to determine minimum separation distances between single barricaded aboveground stacks of bombs in the 125,000- to 500,000-pound range and optimum barricade geometry and materials to be used in an explosives storage area. Secondly, testing was required to validate the 100,000-pound modular concept, which had been approved for use in combat zones, and also to investigate the possibility of using this concept universally. It was agreed to by representatives from the Air Force, ASESB, COE, BRL, and NOTS that tests should represent standard barricaded field storage conditions for tritonal-loaded bombs (such as the 750-pound M117), with at least six "samples" of acceptors located at the same separation formula distance of the approved five-cell module (K1.1), or less, from donors containing 250,000 pounds of explosives. Additionally, one of the Air Force representatives proposed a barricade comparison test be conducted and agreed to provide complete details for constructing a test array of six barricades around a donor of 100,000 pounds of explosives.

C7.2.2. **Test Objectives.** The primary objectives of the Big Papa Test Series, conducted between 1 June and 15 October 1967, at Hill Air Force Test Range, UT, were as follows:

C7.2.2.1. Determine the minimum distance needed between single stacks of barricaded mass-detonating explosives to prevent simultaneous detonation of adjacent stacks and to minimize non-simultaneous propagation.

C7.2.2.2. Determine the validity of the criteria being used in the 100,000-pound NEW cell (five cells per module), approved for combat zone use by the Vice Chief of Staff, USAF, on 27 September 1966.

C7.2.2.3. Determine if the detonation of a single general-purpose bomb, with current explosives fill, within a stack would hurl other bombs into the air above the barricade and subsequently detonate the bombs suspended in the air, resulting in the detonation of adjacent bomb stacks by fragment impingement.

C7.2.2.4. A secondary test objective was to obtain a substantial amount of airblast and ground-shock data for use in future Air Force Weapons Laboratory (AFWL) QD studies.

C7.2.3. **Test Phases.** Testing was divided into four separate phases.

C7.2.3.1. Phases I and II were designed to demonstrate the feasibility of reducing existing, barricaded intermagazine distance criteria to the maximum practical extent for barricaded bomb storage in single stacks in the range of 125,000 to 500,000 pounds NEW of high explosives. Phases I and II were also designed to validate the five-cell module concept, which had been approved for use in combat zones.

C7.2.3.2. Phase III of this test series was designed to determine optimum barricade geometry and materials for use in munitions storage, by comparing the fragment attenuating effectiveness of six different barricades. Four vertical-faced metal-bin barricades, a soil-cement barricade, and a standard earth barricade were tested. A secondary objective of this portion of the test was to obtain a multipurpose barricade, which could be used for aircraft protection, munitions storage, and for protection of habitable buildings. At that period in time, metal-bin barricades were not being used in combat zones for the storage of large quantities of mass-detonating explosives,

C7.2.3.3. Phase IV was an attempt to determine what would happen when only one bomb in an 80-bomb donor stack was detonated. Two acceptors were placed with centerlines 80 feet from the center of a donor. A standard earth barricade separated the donor from the acceptors.

C7.2.4. **Test Conclusions.** Test conclusions were as follows:

C7.2.4.1. A substantial reduction can be made in the then current Department of Defense (DoD) barricaded, aboveground IMD criteria for mass-detonating explosives in open storage (revetments without structures that would burn or create heavy falling weights or damaging secondary fragments).

C7.2.3.2. Bombs located at $K = 1.1$, or less, from the donor explosions will be covered with earth and unavailable for use until extensive uncovering operations are completed. Bombs at $K = 2.5$ separations will be readily accessible.

C7.2.3.3. The minimum barricaded distance between single stacks of mass-detonating explosives stored in adjacent cells of a module could be based on a K factor of 1.1 with a high degree of confidence since six stacks, located at distances of $K = 1.1$ or less (four at 1.1 and one each at 0.9 and 0.8), were tested without causing any sympathetic simultaneous or delayed detonations. However, some possibility of non-simultaneous propagation exists under some circumstances. Dunnage flammability and some possibility of damaging fragments escaping over the barricade are a few of the factors influencing probabilities in this connection.

C7.2.3.4. The modular concept, developed by the AFSSG and approved for use in combat zones, is sound for large-quantity munitions storage.

C7.2.3.5. Since no sympathetic simultaneous or delayed detonations occurred within the test modules, the spacing between modules could be based on a K factor of 2.5 as related to the net weight of explosives in one cell rather than the $K2.5$ based upon the entire module, as the AFSSG recommendation specified.

C7.2.3.6. The AFSSG recommendation of 100,000 pounds per cell could be increased to 250,000 pounds NEW, provided that the spacing corresponding to a K factor of 1.1 was maintained.

C7.2.3.7. Since no sympathetic simultaneous or delayed detonations occurred, the number of cells per module (five recommended by the AFSSG) was determined to be arbitrary.

C7.2.3.8. The vertical acceleration delivered to a bomb stack resting on the natural ground surface was about twice the magnitude of one standing on a concrete storage pad.

C7.2.3.9. The frontal air pressure was consistently higher than the ground surface pressure at any given distance out from the detonation.

C7.2.3.10. The standard earth barricade does, in fact, affect the airblast in the immediate vicinity of the barricade, but the disturbance dissipates rapidly as the blast front moves out from the detonation. The pressure at a given point on the ground beyond the toe of the barricade was the same as to be expected where no barricades were employed.

C7.2.3.11. Since very few fragments of significance were found out to the barricaded highway/railway distance, most damage to structures would probably result from airblast effects.

C7.2.3.12. The Air Force "2-degree" theory for proper barricade height was determined to be sound.

C7.2.3.13. The standard earth barricade provides excellent fragmentation protection for adjacent bomb stacks stored within a module, as was the case in Phases I and II of the test series.

C7.2.3.14. Cell-to-cell propagation purely by airblast probably will not occur.

C7.2.3.15. Metal-bin barricades having many small parts should not be considered for the storage of large quantities of high explosives, because of the production of secondary fragments (barricade components). The secondary fragments, which had sufficient mass, would be hazardous in an explosives storage area.

C7.2.3.16. The use of steel beams or pilings as anchoring devices for the metal-bin barricades will create hazards in an explosive storage area, in the event of an explosion.

C7.2.3.17. Foam concrete, used as a fragment-catching mechanism to obtain energy data, did not function as designed since no fragment penetrations were detected in any of the 10 acceptors. However, the crater that enveloped the front faces of the acceptors precluded analysis of that portion.

C7.2.3.18. Based on acceleration data, the standard earth barricade remained in position longer and thus performed the fragment-catching function longer than any of the other five barricades tested.

C7.2.3.19. The "high-order" detonation of a single bomb loaded with tritonal or an equivalent fill, within a stack, can be expected to cause the "simultaneous detonation" (practically instantaneous) of all bombs in the stack.

C7.2.3.20. Stacks of bombs spaced at a K-factor distance of 1.1 will require considerable recovery effort if one of the stacks detonates, whereas stacks spaced at a K-factor distance of 2.5 would require very little recovery effort.

C7.2.4. **Post-Test Actions.**

C7.2.4.1. Following the test series, the Air Force contacted the ASESB to inform them of the test results and to describe the proposed recommendations that would be made to the Air Staff. An opinion on these recommendations was requested from the ASESB. A 31 October 1967 ASESB letter documented the conversation. This letter stated that, based on the results of testing, recommendations appeared reasonable, however, an opinion could not be offered by the ASESB until the results of the testing and the recommendations were received in writing.

C7.2.4.2. A 7 December 1967 ASESB letter, written following review of Interim Change 1 to Air Force Manual (AFM) 127-100, which would permit the application of barricaded modules, identifies concerns the ASESB had with the proposed AF use of barricaded modules. In general, the concerns dealt with a perception that AF planners were moving towards application of barricaded module criteria for situations other than operational theaters and for more types of munitions than just those tested in "Big Papa" and that unwarranted capability would be attributed to the "Big Papa" type storage revetments. The last concern had to do with the fact that a detonation in one of the barricaded cells would not protect the serviceability of other munitions in the same module. With respect to using barricaded modules for other than conventional bombs (or munitions of similar mass-detonating characteristics as bombs), plans to store other munitions that had not been tested could result in simultaneous propagation between cells as a result of having materials of a more sensitive nature. At this point, the ASESB had not yet received the test report and had never formally had the opportunity to review the barricaded module concept.

C7.2.4.3. The AF module concept was placed on the agenda (Item 3i.) for the 257th ASESB meeting that was held 10 March 1970. During this meeting, the Board reviewed the Air Force module concept, siting criteria, and utilization and voted to incorporate this concept into DoD Manual 4145.27M, titled DoD Ammunition and Explosives Safety Standards, as a standard in connection with bombs and other cased Class 7 (current designation is Class 1.1) munitions and to undertake a series of tests to determine the applicability of this concept to other type munitions. A summary of the 257th Meeting of the ASESB is provided by ASESB Memorandum of 31 March 1970.

C7.2.4.4. Barricaded module criteria never appear to have made it into 4145.27M. However, these criteria were placed in DoD 5154.4S (the predecessor of DoD 6055.9-STD), dated July 1974, which superseded 4145.27M, dated March 1969.

C7.2.4.5. CBU testing was completed by in September 1972 and recommendations were made to the DDESB for the placement of CBUs in barricaded modules. A 31 October 1972 DDESB-PP letter concurred with the AF's recommendation that mass-detonating CBUs be stored using the same criteria as Class 7 bombs. Subsequent to this DDESB approval, DoD criteria for use of barricaded modules was revised in DoD 5154.4S, (July 1974 version), which stated "The

items, which may be stored in modules, are limited to high explosives bombs, similarly cased Class 7 ammunition, and CBUs in authorized, non-flammable shipping containers."

C7.2.4.6. The DDESB approved the AF's request to change module storage criteria as follows:

"The items which may be stored in modules are limited to high explosive bombs, similarly cased Class 1 Division 1 ammunition, CBUs in authorized non-flammable shipping containers, and 20/30mm ammunition in metal shipping containers."

C7.2.4.7. The decision for the inclusion of 20/30mm ammunition in metal shipping containers was based on the similarity of response to CBU munitions. The non-propagating classification and the metal shipping containers assure that the 20/30mm ammunition will not propagate from cell to cell in a module; therefore, module criteria are adequate to limit the effects of a mishap to a single cell.

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C8. CHAPTER 8

HARDENED AIRCRAFT SHELTERS (HAS)

C8.1. HAS DEVELOPMENT. This historical information was extracted from references 8-1 through 8-4. In the early 1960s, the AF began an intensive effort to develop a protective arch shelter for tactical aircraft. The impetus for this was the need to protect parked aircraft at Southeast Asia (SEA) installations. Beginning in 1967 with the Concrete Sky test program, the AF began developing and testing various elements of the aircraft shelter in order to optimize the arch and protective cover configuration. A hardened version of the original SEA aircraft shelter was developed as a result of those tests – the TAB VEE hardened aircraft shelter (HAS). This HAS was also known as the 1st Generation (TAB VEE). Later, when NATO specified requirements for hardened shelters for use within the European theater, the TAB VEE HAS design was modified and re-named the 1st Generation (modified TAB VEE). This design was constructed at NATO installations throughout Europe. The results of the Dice Throw Series of high explosives tests (reference 8-3) were used to substantiate the TAB VEE and the Modified TAB VEE designs and to obtain test data to support further HAS structural design improvements. Subsequently, the introduction of newer and larger tactical aircraft, such as the F-111 with its wings fully extended, necessitated modification of the basic 48-foot arch shelter, and the Second (2nd) Generation HAS was developed to accommodate this aircraft. A Third (3rd) Generation HAS was later developed for A-10 or F-15 aircraft, because the 2nd generation HAS was larger than required for those smaller aircraft. By 1977, the AF had 1st (TAB VEE and modified TAB VEE), 2nd, and 3rd Generation HAS in existence, and they are still in use today. These structures are steel-arch, sheet metal structures with a 2-foot sinusoidal wave covered by a minimum of 18 inches of concrete. Concrete cover on the arch itself ranges from 18 to 42 inches thick. The rear wall is constructed of 24-inch thick reinforced concrete with an internal 1/8th-inch thick steel facing. The sliding door is a steel form filled with concrete. There are three basic sizes: 48-foot width (1st Generation), 82-foot width (2nd Generation), and 71-foot width (3rd Generation).

C8.2. HAS SITING AND TESTING.

C8.2.1. In 1977, reference 8-4 proposed siting criteria for Group I (1st Generation), II (2nd Generation), and III (3rd Generation) HAS relative to ECM. The proposed criteria were based on the results of the Concrete Sky Phase IXB test of explosive propagation between HAS (reference 8-1) and the 1/3-scale model HAS testing conducted during Dice Throw (reference 8-3). In summary, the Air Force proposal suggested that HAS be sited at IMD distance from ECM, based on their perception that HAS provided the same hardness (protection capability) as a standard ECM. An 18 March 1977 DDESB-KT Memorandum disagreed that the testing showed the HAS designs were completely equivalent to standard ECM. However, the DDESB did agree that the testing showed the HAS designs were capable of providing an increased level of protection. As a result, the DDESB approved HAS exposures to adjacent ECM as follows:

C8.2.1.1. Un-strengthened Group I (1st Generation-TAB VEE) HAS were permitted to be sited side-by-side to one another with no separation distance between them, provided each HAS was limited to one aircraft load containing not more than 4,800 pounds of mass detonating explosives.

C8.2.1.2. The sides of un-strengthened Group I (1st Generation-TAB VEE) HAS were permitted to be oriented toward the side or rear of an ECM at $2.75W^{1/3}$ or toward the front of the ECM at $6W^{1/3}$, provided the ratio of explosives weight to ECM internal volume did not exceed 6 lbs/ft³.

C8.2.1.3. The sides or ends of strengthened Group I (1st Generation-modified TAB VEE) HAS, with strengthened end enclosures, were permitted to be oriented towards the sides or rear of an ECM at $6W^{1/3}$ or the front at $5W^{1/3}$, provided the ratio of explosives weight to ECM internal volume did not exceed 6 lbs/ft³.

C8.2.1.4. Group II (2nd Generation) and III (3rd Generation) HAS were permitted to be located side-by-side to one another and to Group I (TAB VEE or modified TAB VEE) HAS, with no minimum separation distance between them, provided each HAS was limited to one aircraft load containing not more than 4,800 pounds of mass detonating explosives. For any other application of QD standards, HAS of Group II (2nd Generation) or III (3rd Generation) were to be treated as barricaded, aboveground magazines.

C8.2.2. By 1979, the AF was finding it more and more difficult to site HAS in compliance with then existing explosives safety criteria. Those problems were primarily related to real estate constraints and the AF's operational need to place HAS closer to runways and taxiways. Though a number of HAS-related tests and analyses had been conducted between 1969 and 1977, (reference 8-1 provides a chronology of these), for a number of reasons these tests and analyses only provided limited data capable of supporting further reductions of HAS QD criteria. As a consequence, siting criteria were primarily based on the Concrete Sky Phase IXB Test that was conducted in 1971. That test used a single detonation of 4,632 pounds NEW and a fueled aircraft in an open-ended SEA-type shelter constructed of un-reinforced concrete. By contrast, the HAS constructed in the 1970s were made of reinforced concrete and had reinforced bulkheads and front closure systems. It was felt that these structures were capable of offering more protection, both as explosion sources and as targets, than criteria acknowledged. By closely working with the DDESB, the AF was able to obtain some relief from the then current HAS siting criteria. However, in order to obtain further DDESB-approved QD reductions, additional testing was required. In 1979, the AF initiated the Aircraft Shelter Explosive Test (ASET) Program to develop better QD for HAS.

C8.2.2.1. The overall goals of the ASET Program were to:

C8.2.2.1. Assess the capability of HAS to protect internal assets (aircraft, munitions, and personnel) from external weapons effects (airblast and ground shock).

C8.2.2.2. Assess the capability of HAS to prevent or suppress propagation.

C8.2.2.3. Assess collateral damage effects to and vulnerability of nearby runways and taxiways.

C8.2.2.2. The ASET test program was named DISTANT RUNNER and was separated into two phases. The first phase was to investigate the response of two full-scale 3rd Generation HAS to an external pressure loading, and the second phase was to investigate an internal pressure loading. A total of five tests were conducted and these are described below. Preliminary test analyses, test results, and conclusions are recorded in references 8-5 through 8-11.

C8.2.2.2.1. Event 1 exposed a HAS to an internal detonation of 42 pounds NEW (four Sidewinder (AIM-9) warheads). This weapon arrangement was selected to simulate a weapons load for an aircraft loaded with air-to-air weapons. The primary objective of this test was to demonstrate the ability of a 3rd Generation HAS to completely suppress all effects resulting from an internal detonation involving four AIM-9 missiles.

C8.2.2.2.2. Event 2 exposed both HAS to an external loading of 15 psi produced by the detonation of 240,000 pounds of Ammonium Nitrate/Fuel Oil (ANFO). One of the HAS was oriented side-on to the blast, while the second HAS was oriented rear-on to the blast. Obsolete aircraft were located inside the HAS. The primary objectives of this test were to demonstrate that a 3rd Generation HAS could withstand an external pressure loading of 15 psi in rear-on and side-on orientations to the detonation source, and to demonstrate that a 3rd Generation HAS could prevent internal pressure buildup in these orientations.

C8.2.2.2.3. Event 3 exposed one of the 3rd Generation HAS to an external loading of 15 psi and the other to an external loading of 7.8 psi produced by the detonation of 240,000 pounds of ANFO. The HAS exposed to 15 psi was oriented head-on to the detonation source, while the other HAS was oriented at an oblique angle (26 degrees off normal) to the detonation source. Obsolete aircraft were located inside the HAS. The primary objectives of this test were to demonstrate that a 3rd Generation HAS could withstand external pressure loading of 15 psi in a front-on orientation and 7.8 psi in an oblique orientation to the detonation source and to demonstrate that a 3rd Generation HAS could prevent internal pressure buildup in these orientations.

C8.2.2.2.4. Event 4 exposed a HAS to an internal pressure loading from the detonation of 2,292 pounds NEW (12-MK 82 bombs) inside the HAS. The primary objectives of this test were to demonstrate the blast attenuation characteristics of a 3rd Generation HAS, exposed to an internal detonation involving 2,292 pounds NEW, to evaluate debris distances, and to determine the structure's failure mode.

C8.2.2.2.5. Event 5 exposed a HAS to an internal pressure loading from the detonation of 9,168 pounds NEW (48 MK 82 bombs) inside the HAS. The primary objectives of this test were to demonstrate the blast attenuation characteristics of a 3rd Generation HAS, exposed to an internal detonation involving 9,168 pounds NEW, to evaluate debris distances, and to determine the structure's failure mode.

C8.2.2.2.6. A common secondary objective for Events 2 through 5 was to assess/evaluate the damage (from ground motion effects and fragmentation) to the runway /taxiway as a result of each event.

C8.2.2.3. DISTANT RUNNER results supported the reduction of QD for:

C8.2.2.3.1. Side or rear of an ECM (275,000 pounds NEW TNT) to a 3rd Generation HAS from K30 to K5.

C8.2.2.3.2. Open storage (100,000 pounds NEW TNT) to a 3rd Generation HAS from K30 to K8.

C8.2.2.3.3. ECM (275,000 pounds NEW TNT) to a taxiway/runway from K18 to K4.

C8.2.2.3.4. Open storage (100,000 pounds NEW TNT) to a taxiway/runway from K18 to K4.

C8.2.2.4. DISTANT RUNNER results were unable to support a reduction of QD for HAS to occupied (inhabited) structures, but instead demonstrated a need for increased separation distances. Consequently, increased QD was required as follows:

C8.2.2.4.1. Distance (d) = $50 W^{1/3}$ from the front of a HAS.

C8.2.2.4.2. D = $62 W^{1/3}$ from the sides of a HAS.

C8.2.2.4.3. D = $40 W^{1/3}$ from the rear of a HAS.

C8.2.3. At the 283rd Meeting of the DDESB, which met on 19 January 1982, the AF presented their rationale as to why the separation distances between HAS and ECM, approved previously by the DDESB for 3rd Generation HAS, should apply to all HAS, except the door of a 1st generation HAS. DDESB approval of the proposed AF changes can be found in 1 February 1982 DDESB-IK memorandum. These changes, as well as those previously approved by the DDESB for HAS siting, were published in reference 8-12.

C8.2.4. Additional 3rd Generation HAS siting criteria changes were proposed in 1995. Those changes resulted from U.S. involvement in the NATO AC/258 (Group of Experts on Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) Small Quantities Workshop. The AF subsequently recommended DDESB adoption of these proposed revised third-generation HAS siting criteria, and they were discussed during the 310th Board Meeting; however, they were not put forward as a voting item. The DDESB Secretariat felt that additional analyses and test data were needed before the proposed changes could be presented to the Board as a voting item. Subsequently, based on data presented (references 8-13 through 8-15) at the 26th DoD Explosives Safety Seminar, and based on DDESB Secretariat and DDESTSG review of the proposed changes, the original proposal was revised and then presented to the 311th Board that met on 19 January 1995, for a vote. The Board unanimously approved the modified changes governing siting of third-generation HAS, which permitted reduced QD for a third-generation HAS, for selected ranges of NEW present within the HAS.

C8.2.5. On 3 December 1998, a revised version of Chapter 10 of DoD 6055.9-STD was approved by the Chairman, DDESB, based on previous written endorsement of the revision by Board members. As part of this approval, a statement was to be added to Chapter 9 permitting the use of Chapter 10 HAS criteria to peacetime operations as well as to contingency and combat operations.

C8.2.6. DoD HAS criteria are lacking in a number of areas, particularly with respect to Korean-type HAS. These are unique HAS found only at U.S. Air Force installations in South Korea. There are three different designs and these are the Korean TAB VEE, a hardened Korean TAB VEE (concrete rear wall with the rear vent opening protected by a steel bin barricade and a first generation front closure), and a Korean flow-thru (no front or rear wall). The arches of those Korean HAS are identical to either the first or third generation HAS arch, thus providing significant protection. In addition, siting criteria are missing with respect to the more traditional first, second, and third Generation HAS and surrounding ES. In order to correct this deficiency, DDESB and Air Force Safety Center (AFSC) representatives have been working together since 2003 to develop the missing HAS criteria. The product of the team's work will be submitted by the AF as a proposed change to DoD criteria at a future Board meeting.

C8.3. REFERENCES.

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- 8-4. 18 February 1977 letter from HQ, Air Force Inspection and Safety Center, to the DDESB; subject: Hardened Aircraft Shelter Explosives Quantity-Distance Evaluation.
- 8-5. "Aircraft Shelter Explosives Test (ASET) Program, Phase I - Preliminary Test Planning and Analysis," DNA 5385F, 30 April 1980, prepared by BDM Corporation for Defense Nuclear Agency (DNA).
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- 8-7. Thomas, R. A. (Major, USMC), "DISTANT RUNNER, Test Execution Report," POR 7062, 29 January 1982.
- 8-8. "Project DISTANT RUNNER, Shelters and Taxiways, Passive Damage Measurements," U.S. Army Engineer Waterways Experiment Station, Structures Laboratory, POR 7198, 1 November 1983.
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- 8-14. Jenus, J. Jr., "Quantity-Distance Determination for Third Generation Hardened Aircraft Shelter," Minutes of the 26th Explosives Safety Seminar, DoD Explosives Safety Board, Miami, FL., Aug 1994.
- 8-15. Bowles, P., "Earth-Covered Ammunition Storage Magazines Quantity-Distance Model, DISPRE2," Minutes of the 26th Explosives Safety Seminar, DoD Explosives Safety Board, Miami, FL., Aug 1994.

AP1. APPENDIX 1
MAGAZINE LISTINGS

TABLE AP1-1. 7- AND 3-BAR ECM APPROVED FOR NEW CONSTRUCTION
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION (1)	DESIGN AGENT	DDESB APPROVAL DATE	ECM DESIGNATION	COMMENTS: (Notes 2 and 3)
10400001 through 10400027	05-Jan-04	RC Box, Type M	NAVFAC	01-Dec-99	7-Bar	Internal dimensions are 81' wide by 124' long by 24' 6" high (measured at interior face at each side wall). The design provides for 2 entrances on the headwall. Each door measures 14' 8" wide by 14' 2" high. The design provides for internal magazine access by rail and truck. Sited for 350,000 pounds NEW. This drawing number represents the most recent design of three versions of the Box Type M Magazine that have been constructed. The initial design was approved by DDESB-KO memo of 9 Apr 93 for construction at NAVWPNSTA Seal Beach. Two subsequent design variations were approved by DDESB-KO memo of 1 Dec 99, for construction at NAVWPNSTA Yorktown. All new construction of Box Type M ECM will be in accordance with drawings 10400001 through 10400027.
1404310 through 1404324	12-Sep-83	RC, Circular Arch	NAVFAC	15-Jul-83	7-Bar	Superseded NAVFAC's original (1954) Standard Drawings 627954 thru 627957, 649602 thru 649605, 658384 thru 658388, 724368, 751861, 764596 thru 764597, 793746 thru 793748, 803060, and 822978 thru 822989. Magazine internal dimensions are 25 feet wide by 80 feet (maximum) length. The magazine has a single entrance with 2 size options for the entrance. Corresponding optional sliding door sizes are: a) 11' 10" wide by 10' high, and b) 17' 10" wide by 10' high. DDESB approval signature of 15 Jul 83 on drawings.
1404375 through 1404389	31-Oct-85	Composite, Circular Arch	NAVFAC	14-Jan-86	7-Bar	Composite circular arch design composed of an internal 10 gage (0.138 inch) corrugated steel arch with reinforced concrete overlay. Magazine internal dimensions are 25 feet wide by 80 feet (maximum) length. Design provides for 2 door sizes: a) 11' 10" wide by 10' high, and b) 17' 10" wide by 10' high. Each door is a single-piece sliding door. DDESB approval signature of 14 Jan 86 on drawings.
1404390 through 1404398	31-Oct-85	Composite, Oval Arch	NAVFAC	14-Jan-86	7-Bar	Composite oval arch design composed of an internal 10 gage (0.138 inch) corrugated steel arch with reinforced concrete overlay. Internal dimensions are 25' 11" wide (measured from base of steel arch) by 20' (minimum) to 80' maximum length. Arch height is 14' 5". Design provides for a single sliding door with dimensions 10' high by 11' 2.5" wide. DDESB approval signature of 14 Jan 86 on drawings.
1404430 through 1404444	20-Sep-85	RC Box, Type C	NAVFAC	05-Nov-85	7-Bar	Internal dimensions are 50' deep by 94' 8" wide by 13' 8" (rear of magazine) to 15' 10" (front of magazine) high. Three (3) entrances are provided on the headwall. Each of the 3 sliding doors measures 26' 6" wide by 12' high. Sited for 350,000 pounds NEW. DDESB approval signature of 11 May 85 on drawings.
1404523 through 1404537	30 June 1987, Rev 9 June 1988	RC Box, Type E	NAVFAC	17-Jul-87	7-Bar	Internal dimensions are 50' deep by 94' 8" wide by 13' 8" (rear of magazine) to 15' 10" (front of magazine) high. Three (3) entrances are provided on the headwall. Each of the 3 sliding doors measures 17' 6" wide by 12' high. Sited for 350,000 pounds NEW. DDESB approval signature of 30 Jun 87 on drawings.
33-15-74	11 Apr 79, Rev 3, 11 June 98	RC FRELOC Stradley	COE	22-Jul-80	7-Bar	Internal dimensions are 25' wide by 90' maximum (normally length is 60' or 80') by 14' high (largest clearance at center of magazine). The magazine has a single entrance with 2 door-size options. Corresponding optional sliding door sizes are: a) 8' 10" wide by 8' 3" high or b) 10' 10" wide by 10' 3" high.

TABLE AP1-1. 7- AND 3-BAR ECM APPROVED FOR NEW CONSTRUCTION

June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION (1)	DESIGN AGENT	DDESB APPROVAL DATE	ECM DESIGNATION	COMMENTS: (Notes 2 and 3)
33-15-74 (Korean Version)	28-Aug-00	RC FRELOC Stradley	Korean Ministry of Defense	23-Sep-03	7-Bar	This design is the latest approved version of the Republic of Korea Army (ROKA) drawing for 33-15-74. The original basis for the Korean version was U.S. Army COE 33-1-74. The Korean drawings assure that all reinforcing steel is electrically continuous. The design specifies the use of a single sliding door which measures 10' 10" wide by 10' 3" high. The previous version of this drawing was approved by the DDESB as a 7-Bar magazine on 25 May 2002.
421-80-01	05-Feb-88	Steel, Semi-circular Arch	COE	28-Jun-88	7-Bar	Replaced 33-15-73. Drawing permits the use of a 2" deep or 5.5" deep corrugated steel arch. Internal width and height dimensions are approximately 26' wide by 13' 6" high. The minimum internal length is 19', expandable up to the most commonly used magazine length of 89'. The magazine has a single entrance with 2 size options for the entrance. Corresponding optional sliding door sizes are: a) 8' 10" wide by 8' 3" high or b) 10' 10" wide by 10' 3" high.
421-80-03	30-Oct-92	Steel, Oval Arch	COE	28-Dec-92	7-Bar	Replaced 33-15-73. Arch design composed of a 1 gage (0.280 inch) corrugated steel arch. Internal dimensions are 24' wide (measured from base of steel arch) by 21' (minimum) to 89' maximum length. Arch height is 14' 5". Design provides for a single sliding door with dimensions 10' high by 11' 2.5" wide. DDESB approval signature of 28 Dec 1992 on drawings.
421-80-05	01-Sep-98	RC Arch	COE	08-Sep-98	7-Bar	Constructed using the Techspan Precast Concrete System, developed by the Reinforced Earth Company, for arch construction. The headwall and door are derived from 33-15-74. Internal dimensions are 25' 11" wide by 90' maximum (normally length is 60' or 80') by 14' high (largest clearance at center of magazine). The magazine has a single entrance with 2 size options for the entrance. Corresponding optional sliding door sizes are: a) 8' 10" wide by 8' 3" high or b) 10' 10" wide by 10' 3" high.
421-80-06 (modified)	10/01/1999, as modified by COE Sketches S- 9 through S-13, dated Mar 2002	RC Box	COE/AFSC	17-Apr-02	7-Bar	This design reflects a modified version of 421-80-06, which had been considered as a 7-Bar ECM until its structural rating was downgraded to undefined due to deficiencies in the door design. Modified 421-80-06 (either new construction or retrofitted 421-80-06 ECM) meeting the requirements of DDESB memo of 17Apr 2002, and modified per COE sketches S-9 through S-13, are considered 7-Bar ECM. Internal dimensions are 24' wide by 20' minimum length to 80' maximum length by 11' high. The front wall consists of two hinged doors, each measuring approximately 12' wide by 11' high.
6037-2-5006 to 6037-2-5018	UNK	RC Box	Israel	09-Oct-98	7-Bar (See comments)	This design is for a Box Type ECM provided with 2 entrances. The design does not have substantial blast doors. A retaining wall is positioned in front of the front wall, however, the ECM is not to be considered barricaded. A DDESB-KO Memo of 9 Oct 1998 provided siting criteria for this design, which was brought back by a DDESB survey team that visited U.S. Forces in Israel. It was specified that USAFE (Dominant User for that AOR) would use this information for preparation of a site plan, which would also have to address other requirements of ECM (cover slope and depth, grounding, LPS, etc.) The siting guidance provided by the DDESB was based on a methodology where a constant impulsive loading is maintained on the ECM headwall as NEW and distance increase. For a PES with explosives weights up to 100,000 lbs, site as a 7-Bar ECM (front unbarricaded). When in excess of 100,000 lbs, use the siting guidance contained in the DDESB memo.

TABLE AP1-1. 7- AND 3-BAR ECM APPROVED FOR NEW CONSTRUCTION

June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION (1)	DESIGN AGENT	DDESB APPROVAL DATE	ECM DESIGNATION	COMMENTS: (Notes 2 and 3)
6448522 through 6448554	27-May-97	RC Box, Type D	NAVFAC	05-Nov-85	7-Bar	Superceded NAVFAC 1404465 through 1404478. Internal dimensions are 50' deep by 158' 8" wide by 13' 8" (rear of magazine) to 15' 10" (front of magazine) high. Five (5) entrances are provided on the headwall. Each of the 5 sliding doors measures 26' 3" wide by 12' high. Sited for 350,000 pounds NEW. DDESB approval signature of 30 Jun 87 on original drawings. Sited for 350,000 pounds NEW.
6448555 through 6448588	27-May-97	RC Box, Type D (HSILS)	NAVFAC	05-Nov-85	7-Bar	Sited for 350,000 pounds NEW. This design is identical to NAVFAC 6448522 through 6448554, Box Type D, except that it incorporates a High Security Integrated Locking System (HSILS).
6448589 through 6448621	27-May-97	RC Box, Type F	NAVFAC	17-Jul-87	7-Bar	Superceded NAVFAC 1404541 through 1404555. Internal dimensions are 50' deep by 158' 8" wide by 13' 8" (rear of magazine) to 15' 10" (front of magazine) high. Five (5) entrances are provided on the headwall. Each of the 5 sliding doors measures 17'6" wide by 12' high. Sited for 350,000 pounds NEW. DDESB approval signature of 30 Jun 87 on original drawings. Sited for 350,000 pounds NEW.
Modular Storage Magazine (MSM)	May-02	RC Box	Hill AFB	11-Jul-02	7-Bar	This 14-foot ceiling height Modular Storage Magazine (MSM) design was developed for construction of magazines 2580 and 2581 at Hill AFB, Ogden, Utah, and is basically a larger version of the MSM (11-foot ceiling height) shown on Drawing 421-80-06. Internal dimensions are 24' wide by 14' high by 80 feet long. A total of 40 MSM (14') are planned to be constructed at Hill AFB.
High Performance Magazine (HPM)	Preliminary Design dated 3 July 2001	RC Box (multi-cell)	NAVFAC	27-Jan-00	7-Bar	Additional information on the Navy's HPM can be found in paragraph C2.3.13. The HPM design concept was granted DDESB approval as a 7-Bar magazine during the 319th Board Meeting of 27 January 2000. A preliminary design document, dated 3 July 2001, is available from NAVFAC. The HPM consists of four separate ordnance storage bays that are treated as independent magazines (i.e., independent MCE). Each storage bay can store up to 30,000 lbs of NEW. Each bay can optionally be subdivided into two separate storage areas with the use of the "Re-locatable" Modular Wall. Each subdivided storage area can also store up to 30,000 lbs of net explosive weight, thereby increasing the total storage capacity of the HPM. The separation of the storage bays or subdivided storage areas also allows for the storage of incompatible ordnance in adjacent bays. The maximum storage capacity of a HPM with no subdivided bays is 120,000 lbs net explosive weight (NEW). If all four bays are subdivided, the maximum storage capacity is 240,000 lbs NEW.
Munitionslagerhaue (MLH) 90B	UNK	RC Box	German	12 Dec 77/18 Aug 87	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an HD 1.1 NEQ of 75,000 kg (NEW=165,000 pounds). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes and treat as a non-std ECM. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.
Munitionslagerhaue (MLH) 90S	UNK	Steel, Oval Arch	German	12 Dec 77/18 Aug 87	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an HD 1.1 NEQ of 75,000 kg (NEW=165,000 pounds). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes and treat as a non-std ECM. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.

TABLE AP1-1. 7- AND 3-BAR ECM APPROVED FOR NEW CONSTRUCTION
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION (1)	DESIGN AGENT	DDESB APPROVAL DATE	ECM DESIGNATION	COMMENTS: (Notes 2 and 3)
Munitionslagerhause (MLH) 180B	Jul-88	RC Box	German	12 Dec 77/18 Aug 87	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an HD 1.1 NEQ of 75,000 kg (NEW=165,000 pounds). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes and treat as a non-std ECM. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.
Munitionslagerhause (MLH) 180S	Sep-76	Steel, Oval Arch	German	12 Dec 77/18 Aug 87	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an HD 1.1 NEQ of 75,000 kg (NEW=165,000 pounds). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes and treat as a non-std ECM. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.

Notes accompanying Table AP1-1:

1. Each line represents a separate ECM design. Where UNK appears, it indicates that no information was found for that particular field.
2. 7-Bar and 3-Bar ECM are permitted to store up to 500,000 pounds NEW of HD 1.1, unless otherwise noted.
3. There are currently no 3-Bar ECM approved for new construction.
4. No HPM, other than a test magazine, has been constructed. Construction drawings must be finalized and approved by the DDESB prior to construction start. The HPM design consists of multiple cells, which use NPW technology to prevent propagation of an incident to adjacent cells. Therefore, the MCE and QD associated with the HPM are based on 60,000 pounds NEW vice the total quantity of explosives stored in all cells of the HPM. Specific mixing and compatibility criteria will apply to storage of ammunition within each cell. As part of the approval, all HD 1.1 and 1.2 AE are placed within five possible HPM Sensitivity Groups. The Joint Hazard Classification System (JHCS) identifies these groups, which define what can be stored together in an HPM. The HPM is not an ECM. The HPM is earth-bermed (except for the truck entrance) and moveable RC lids form the roof of each storage cell. The area above the storage cells is enclosed by a lightweight metal panel building, within which is contained the crane that is used for AE movement in the HPM.

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
June 2004

DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
1059128 through 1059132 modifications 1069906, and 1355460 through 1355461	18-Mar-64	Steel Arch	NAVFAC	1964	7-Bar	Designed for NOTS test of 18 Dec 1963. Listed in DDESB minutes as a STD ECM. NAVFAC MIL-BUL-340 (YD), Jul 93, listed this magazine design as canceled. Drawing 1351905 provided for an optional deeply corrugated, light gauge arch vice the 1 gauge specified on 1059128.	
1404000 through 1404007	01-May-78	RC Box, Type A	NAVFAC	13-Aug-82	7-Bar	Superceded Drawings 749771 through 749774 and 793751. NAVFAC MIL-BUL-340 (YD), Jul 93, lists these ECM drawings as canceled.	
1404018 through 1404025, 952132, through 952134	25-Sep-78	RC Box, Type B	NAVFAC	13-Aug-82	7-Bar	Superceded Y & D Drawings 952127 through 952131 and 952135. NAVFAC MIL-BUL-340 (YD), Jul 93, lists these ECM drawings as canceled.	
1404026 through 1404034	UNK	Steel, Oval Arch	NAVFAC	27-Jan-76	7-Bar	Listed in DDESB minutes as STD magazine. NAVFAC MIL-BUL-340 (YD), Jul 93, lists these ECM drawings as canceled.	
1404328 through 1404342	07-Aug-84	Steel Arch	NAVFAC	15-Jul-83	7-Bar	Superceded NAVFAC's original (1964) Standard Drawings (1059128 thru 1059130, 1059132, 1069906, and 1355460 thru 1355461.	
1404465 through 1404478	20-Sep-85	RC Box, Type D	NAVFAC	05-Nov-85	7-Bar	DDESB (P. Price) approval signature of 5 Nov 85 on drawings. Sited for 350,000 pounds NEW. Superceded by NAVFAC Drawings 6448522 through 6448554 (Standard Box Magazine Type D) and NAVFAC Drawings 6448555 through 6448588 (HSILS Box Magazine Type D), both dated 27 May 97 .	
1404541 through 1404555	09-Jun-87	RC Box, Type F	NAVFAC	17-Jul-87	7-Bar	Superceded by NAVFAC Drawings 6448589 through 6448621. This magazine design was sited for 350,000 pounds NEW. A site specific site approval was granted to Naval Weapons Station, Seal Beach, for the construction of four Box Type F Magazines with the dehumidification system located on top of the magazine, vice behind the magazines as was shown on the approved design drawings. This modification was not approved by the DDESB as a standard design, since the Navy never came in with a modified standard magazine drawing set to incorporate the addition of the dehumidification system onto the magazine roof.	
219-25-321	23-Apr-90	RC FRELOC Stradley	COE (Sacramento District)	Acceptance based on COE analysis	7-Bar	This design was constructed at Luke AFB. It was evaluated by the COE, Huntsville, to determine its structural rating. Their analysis, documented on memo CEHNC-ED-CS-S (210-2b) of 23 January 2002, found that the design shown on the drawings came from existing 7-Bar ECM design 33-15-74.	
33-03-0028	20-Jun-88	RC Stradley	COE (Pacific Ocean District)	Acceptance based on COE analysis	7-Bar	This design was constructed at Osan Air Base, Korea and is based on OCE Drawing 33-15-61, 30 Dec 1959, which is considered a 7-Bar ECM. The drawings provides for two different ECM designs. One design is a typical ECM with a single headwall and the ventilator out the rear of the ECM, while the second design includes two headwalls and a ventilator that is centered on the roof of the ECM. Based on a review by the Huntsville COE, the headwall and doors used on 33-03-0028 match the headwall and doors of 33-15-61. The doors of the three designs are all 6-foot wide sliding doors. Two of these doors are required per entrance.	

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
33-03-31	UNK	RC FRELOC Stradley	U.S. Army Engineer Command (Europe)	1978	7-Bar	This design is similar to 33-15-61, the DDESB approved Standard Freloc-Stradley Magazine. 33-03-31 was designed for construction at VILSECK ASP-1 (Germany) for USAFE. It measured 26' W X 80' L and had a ceiling height of 14' at the centerline. The entrance measured approximately 10' by 10'. It had a reinforced concrete arch of uniform thickness, a heavily reinforced headwall, and bi-parting, double-leaf steel doors. A Sep 1977 dynamic analysis of this Freloc design, performed by Agbabian Associates for the COE, European Division, determined that the headwall was sufficiently strong to meet NATO face-on loading criterion, but the door was not. Recommendations were provided in Agbabian Associates Report R-7745-4503 to strengthen the doors by adding additional horizontal and vertical stiffeners on the exterior side of the doors. DDESB-KT Memos of 27 Jan and 4 May 1978 states that the door of the ECM analyzed by Agbabian Associates (33-03-31) met U.S. standard magazine criteria.	
33-03-43	01-Apr-76	RC Arch	COE, Europe Division	19-Mar-76	7-Bar, See Comment section.	Known as a Quick Reaction Site (QRS) magazine, which were only constructed in Germany. Permitted to store a maximum of 4,000 kg NEQ. DDESB-KT Memo of 19 March 1976 evaluated this design and compared its structural components to counterpart features of standard ECM, particularly those in 33-15-61 and 33-15-64, which had undergone extensive testing. Based on this review, the design was approved for the storage of 4,000 kg NEQ in each arch uit. In addition, the design of the door was considered to qualify the ECM design for the minimum separation distances permitted.	
33-13-02	15-May-51	RC Stradley	OCE	26-Jan-99	7-Bar	A COE, Huntsville, letter of 13 Apr 98 determined this ECM was a revision of 33-15-06 (a 7-Bar ECM) and recommended it be considered a 7- Bar ECM as well. A 26 Jan 99 DDESB ltr approved use of ECM constructed in accordance with Drawing 33-13-02, as a 7-Bar magazine.	3
33-15-01	01-Jul-78	RC Stradley	COE (Omaha District)	Acceptance based on DDESB comparison to existing approved 7-Bar ALCM design.	7-Bar	A double-headwall (flow-through) design with a single sliding door on each headwall. The headwall and door design are consistent with the COE, Omaha District, ALCM magazine design (AW 33-15-01), a 7-Bar design.	

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
AW 33-15-01	1979	RC Stradley	COE (Omaha District)	26-Feb-80	7-Bar	This design was known as the Air Launched Cruise Missile (ALCM) Igloo and is a double-headwall (flow-through) design with two large sliding doors on each headwall. The design provides 7-Bar protection. A 26 Feb 1980 DDESB letter approved AW 33-15-01 as a typical layout for ALCM storage and considered this design equal to a standard ECM. There are two designs in existence, with the only differences being the footings and floor slab. The initial design constructed at Griffis AFB, NY, had wall footings and a floating slab-on-grade. The subsequent design revised the foundation and flooring to a mat foundation slab. The subsequent design is believed to have been constructed at the following Air Force Bases: Grand Forks, ND; Minot, ND; Fairchild, WA; Ellsworth, SD; Wurtsmith, WI; K.I. Sawyer, MI; Barksdale, LA; Blythville, AR; McConnell, KS; Carswell, TX; and Andersen, Guam. Internal dimensions are 40' wide by 112' long by 18'6" high along the longitudinal centerline. Each of the sliding doors measures 18' 10" long by 13' 7 5/8" high.	
AW 33-15-02	21-Aug-67	RC Arch	COE (Los Angeles District)	Acceptance based on COE analysis	7-Bar	Constructed at Luke AFB. Analyzed by COE, Huntsville, to determine its structural rating. Their analysis, documented on memo CEHNC-ED-CS-S (210-2b) of 23 January 2002, found that the design of the headwall and door meets 7-Bar criteria.	
33-15-02	01-Jul-78	Steel, Oval Arch	COE (Omaha District)	Acceptance based on DDESB comparison to existing approved 7-Bar ALCM design.	7-Bar	A double-headwall (flow-through) design with a single sliding door on each headwall. The headwall and door design are consistent with the COE, Omaha District, ALCM magazine design (AW 33-15-01), a 7-Bar design.	
33-15-02	01-May-51	RC Arch	COE (Little Rock Division)	Acceptance based on COE analysis	7-Bar	Constructed at Barksdale AFB, LA. Analyzed by COE, Huntsville, AL, to determine structural rating. Their analysis, documented on memo CEHNC-ED-CS-S of 15 July 2003, found that the design of the headwall and doors met 7-Bar criteria.	
33-15-03	01-Jul-78	RC Stradley	COE (Omaha District)	Acceptance based on DDESB comparison to existing approved 7-Bar ALCM design.	7-Bar	A double-headwall (flow-through) design with a single sliding door on each headwall. The headwall and door design are consistent with the COE, Omaha District ALCM magazine design. Similar design to Omaha District 33-15-01, but with a larger door opening.	
33-15-04	01-Jul-78	Steel, Oval Arch	COE (Omaha District)	Acceptance based on DDESB comparison to existing approved 7-Bar ALCM design.	7-Bar	A double-headwall (flow-through) design with a single sliding door on each headwall. The headwall and door design are consistent with the COE, Omaha District ALCM magazine design. Similar design to Omaha District 33-15-02, but with a larger door opening.	
33-15-06	01-Aug-51	RC Arch	OCE	29-Jul-55	7-Bar	Previously called the "YURT" Magazine. This magazine design superceded Drawings 652-686 through 652-693 and 33-15-01. A 1 Apr 87 COEHQ letter stated that ECM design 33-15-06 was no longer being used for new construction.	4

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
33-15-13	16-Jan-68	RC FRELOC Stradley	U.S. Army Engineer Command (Europe)	19-Aug-75	7-Bar	A 4 May 78 DDESB letter restated that 33-15-13 was a standard ECM and that variations of this design were acceptable, provided new designs were at least equal to it structurally. This design is known as the "thin-wall" magazine and is known to have been built at Camp Darby, Italy. Similar designs, based on the 33-15-13 design are known to have been constructed in Germany and elsewhere.	
33-15-15	UNK	Modified FRELOC Stradley (Steel Oval Arch)	U.S. Army Engineer Command (Europe)	22-Apr-80	7-Bar	This design includes a double leaf door system, similar to the 33-15-61 two-leaf sliding door tested as aprt of ESKIMO II.	
33-15-16	26-Mar-79	RC FRELOC Stradley	U.S. Army Engineer Command (Europe)	01-Apr-79	7-Bar	Also known as the "TYPE 16" Magazine. This design corrected strength deficiencies found in ECM design 33-15-14, which was determined to be a non-standard ECM.	
33-15-208	UNK	Steel Arch	U.S. Army Engineer Command (Europe)	07-Aug-87	7-Bar	Replaced design 33-15-28 that was previously approved by DDESB for construction at Larson Barracks, Kitzingen, GE. This design has only one entrance vice the 2 shown on 33-15-28.	
33-15-28	UNK	Steel Arch	U.S. Army Engineer Command (Europe)	11-May-83	7-Bar	Constructed at Larson Barracks, Kitzingen, GE. Based on QRS magazine, which were only constructed in Germany (see 33-03-43 design). This design had 2 front headwalls and doors and no rear wall.	
33-15-58	03-Feb-58	RC Stradley	OCE	14-Oct-70	7-Bar	Approved during 259th ASES meeting of 14 Oct 70 and was considered to be atomic blast resistant. This drawing replaced former drawings YT-1-1 though YT-111. At that meeting, the Chairman, ASES, also read into the record that Stradley (Yurt) magazines which are constructed in accordance with Standard OCE Drawings 33-15-58 and/or 33-15-61 are considered to be equivalent in strength to the OCE's standard earth covered igloo magazines.	
33-15-61	30-Dec-59	RC Stradley	OCE	14-Oct-70	7-Bar	Approved during 259th ASES meeting of 14 Oct 70. This drawing replaced former drawings YT-1-1 though YT-111. At that meeting, the Chairman, ASES, also read into the record that Stradley (Yurt) magazines which are constructed in accordance with Standard OCE Drawings 33-15-58 and/or 33-15-61 are considered to be equivalent in strength to the OCE's standard earth covered igloo magazines. Two door sizes are shown on the drawing: a 10' X 10' door and a 12' X 12' door. DDESB memo of 22 Apr 1980 discusses the successful testing of the two-leaf sliding door of 33-15-61 as part of ESKIMO II.	
33-15-61-6	UNK	RC Stradley	UNK	Acceptance based on COE analysis	7-Bar	Very similar to 33-15-61, which is a 7-Bar ECM. Only differences were the use of a 10' door and 3,000 psi concrete vice a 12' door and 2,500 psi concrete. Doors and headwall were analyzed and were found to meet 7-Bar criteria. COE Huntsville e-mail of 24 January 2003 to DDESB documents results of review and analysis.	

**TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
33-15-62	13-Jan-60	N/A	OCE	12-Dec-75	N/A	This is not an ECM design drawing. This drawing permitted installation of larger doors on specific magazines, on the basis that the strength of the modified structures remained unchanged as a result of the door modifications. This drawing applied to ECM 33-15-01, 33-15-06, and 652-686 through 652-692.	
AW 33-15-63	05-Mar-63	Steel, Semi-Circular Arch	OCE	19-Feb-64	See note 5	Approved during 225th ASES meeting of 19 Feb 64 as a standard magazine design. A 1 Apr 87 COEHQ letter stated that ECM design AW 33-15-63 was no longer being used for new construction. Drawing AW 33-15-63 had two designs shown on it. One is a traditional magazine with a single 12-inch thick reinforced concrete headwall, while the second is a design with two headwalls and doors (flow through design). COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection.	5
AW 33-15-64	10-May-63	Steel Arch	OCE	19-Feb-64	See note 5	Approved during 225th ASES meeting of 19 Feb 64 as a standard magazine design. A 1 Apr 87 COEHQ letter stated that ECM design AW 33-15-64 was no longer being used for new construction. COE structural evaluation of AW 33-15-64 door in 2003 determined the door would not provide 7 or 3-Bar protection.	5
AD 33-15-67 R2	5/8/1964, Rev 2 dated 8 Mar 65	Steel, Semi-Circular Arch	AF	See comment	See note 5	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. Added to the magazine listing in DoD 6055.9-STD, based on COE analysis. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection.	5
AD 33-15-68 R2	5/8/1964, Rev 2 dated 8 Mar 65	Steel, Semi-Circular Arch	AF	See comment	See note 5	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. Added to the magazine listing in DoD 6055.9-STD, based on COE analysis. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection.	5
AD 33-15-69 R2	08-May-64	Steel, Semi-Circular Arch	AF	See comment	See note 5	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. Added to the magazine listing in DoD 6055.9-STD, based on COE analysis. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection.	5

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
AD 33-15-70 R1	08-May-64	Steel, Semi-Circular Arch	AF	See comment	See note 5	This ECM was required to be constructed IAW Drawing AW 33-15-64. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. Added to the magazine listing in DoD 6055.9-STD, based on COE analysis. COE structural evaluation of AW 33-15-64 door in 2003 determined the door would not provide 7or 3-Bar protection.	5
33-15-73	21 Feb 75, Revised 23 Sep 77	Steel, Oval Arch	OCE	07-Feb-75	7-Bar	A 1 Apr 87 COEHQ letter stated that ECM design 33-15-73 was no longer being used for new construction. A 25 Feb 1985 OCE ltr had rescinded use of this design, due to excessive deflections that could occur at the crown of the steel arch, due to the weight of the earth cover, and as a result of the collapse of an ECM in the field because of this problem. A 7 Feb 1975 DDESB memorandum approved OCE 33-15-73 (Oval Steel Arch) as a substitute igloo for AW 33-15-64, for use for any application for which a standard igloo is specified. This memorandum was in response to a Ft. Leonard Wood project (Project No. 109,Ammunition Storage Facility). Superseded by 421-80-01.	
33-31-01	UNK	RC Arch	UNK	04-May-99	7-Bar	DDESB letter of 4 May 1999 identifies this magazine as being located at Incirlik AFB, Turkey. Dr. Canada of the DDESB evaluated the strength of this ECM design located at Incirlik AFB.	
33-31(JCASE)-01	UNK	RC Arch	UNK	04-May-99	3-Bar	DDESB letter of 4 May 1999 identifies this magazine as being located at Incirlik AFB, Turkey. Its blast door was determined to be incapable of providing 7-Bar protection, although the magazine arch and headwall were designed to meet 7-Bar criteria. Dr. Canada of the DDESB evaluated the strength of this ECM design located at Incirlik AFB.	
FI-350 through FI-356	18-Apr-51	RC Arch	OCE	Acceptance based on COE analysis	7-Bar	This Black and Veatch design was constructed at Rapid City Air Force Base (now known as Ellsworth AFB), Rapid City, SD. The Huntsville District COE reviewed this design and determined the design met 7-Bar criteria. Their results are documented on CEHNC-ED-CS-S (210-20b) of 6 March 2003. Some of the the magazines were subsequently modified with larger doors, as shown on COE Omaha District Drawing AW 33-13-01, dated 18 May 1960. The original door measures 9'11 3/4" H X 8 5 1/2" W (double, hinged, swinging doors), while the modified larger door measures 11' H X 10' 1 1/2" W and are also double, hinged, swinging door. The magazine with the modified door is treated as an Undefined ECM.	

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(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
357428 through 357430, modified IAW OCE Drawing 626739	9 Aug 44, modification 19 Mar 54	RC Arch	Bureau Y&D	25-Oct-56	7-Bar	This magazine design, modified with an Army blast door, was successfully tested in 1946 at Naval Proving Ground, Arco, Idaho, with an NEW of 500,000 pounds NEW. Refer to paragraph 2.3.5 of TP 15 for additional information regarding the test. DoD 4145.27M, March 1969 permitted this ECM to be separated by 210 feet for quantities up to 250,000 pounds NEW and 400 feet for quantities between 250,000 pounds and 500,000 pounds NEW. The 1 December 1955 ASESB QD Standards permitted this ECM design, if it had been modified IAW Bureau Y&D Drawing 626739, dated 19 Mar 54, to use a 185-foot separation distance for quantities up to 500,000 pounds NEW. If not, then a minimum separation distance of 210 feet was required for NEW quantities up to 250,000 pounds and a 400-foot separation distance was required for NEW quantities from 250,000 to 500,000 pounds. Paragraph 2.3.5.3. of TP 15 provides additional information to address the door, with respect to the nine year gap between when the 1946 test occurred and 1954, when Bureau Y&D Drawing 626739 was approved. Bureau Y&D Drawing 626739 provided for a 13-inch thick headwall and improved door design.	
421-80-02	15-Dec-92	Composite Box	COE	01-Mar-00	7-Bar	This magazine uses a Blast and Fragment Resistant (BFR) wall system that is also known as the AGAN Steel Panel (ASP) System. Removed from the authorized new construction list on the advice of Huntsville Division COE, as the U.S. distributor for this magazine design is no longer in business.	
422-264-001	01-Aug-93	RC Stradley	COE (Omaha District)	26-Feb-80	7-Bar	Constructed at Whiteman AFB, MO. This design is based on Air Launched Cruise Missile(ALCM) Igloo AW 33-15-01 and is a double-headwall (flow-through) design with double (2) sliding doors on each headwall. The design provides 7-Bar protection. A 26 Feb 1980 DDESB letter approved AW 33-15-01 as a typical layout for ALCM storage and considered this design equal to a standard ECM. Internal dimensions are 40' wide by 112' long by 18'6" high along the longitudinal centerline. Each of the sliding doors measures 18' 10" long by 13' 7 5/8" high.	
4374567 through 4374578	UNK	M-Type RC Box	NAVFACNA VFAC, Atlantic Division	01-Dec-99	7-Bar	This design superceded the initial M-Type magazine design constructed at NWS Seal Beach, CA (see 8027514 through 8027532). The DDESB approved the modified Type M magazine as a "default", 7-bar structure for storage of up to 350,000 pounds of HD 1.1 explosives and approved the siting of 14 Type M (modified) magazines at WPNSTA, Yorktown. The proposed modification increased the ceiling height by four (4) feet and upgraded the magazine's foundation to carry the additional weight of the increased height. Two of the 14 ECMs constructed have foundations with slightly less carrying capacity. This is because their construction was started as the Type M design was evolving.	

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(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
5167368 through 5167413	21-Aug-87	RC Arch	NAVFAC	06-May-85	7-Bar	This is a magazine design developed for storage of Trident rocket motor storage at Kings Bay, GA. The headwall/door design from this magazine was also used to upgrade existing Huntsville-type (drawings 1012 through 1014) constructed at Camp Navajo (formerly Navajo Ammunition Depot), see NAVFAC Drawings 8150953 through 8150971.	
627954 thr 627957, 751861, 764597, 793747	05-Apr-54	RC Arch, Type 1	Bureau Y&D	07-May-54	7-Bar	Listed in 1954 DDESB minutes as Standard ECM. This design was an original Bureau Y&D Standard. The 1 Dec 55 ASESQ Standards listed ECM 627954 through 627957 as a Standard ECM for storage of NEW up to 500,000 pounds. A 185-foot separation distance was required from other magazines. Bureau Y&D Drawing 817104 provides general information regarding this ECM and was used for planning purposes.	
652-686 through 652-692	27 Dec 41, Revised 14 Mar 42	RC Arch	OCE	24-Dec-98	7-Bar if proper spacing provided, See Comment.	This ECM design was tested as part of the 1946 Naval Proving Grounds, Arco, Idaho, tests. The 130th ASESQ (18 May 53) acknowledged COE Drawings 652-686 through 652-694, dated 27 Dec 41, revised 14 Mar 42, as a Standard ECM. 1Dec 55 ASESQ Standards list this ECM as a standard, with 185-foot separation for barricaded, 360-foot separation for unbarricaded. A 24 Dec 98 DDESB ltr states that an ECM constructed to Drawings 652-686 through 652-692 is not robust enough to qualify as a 7-Bar ECM. However, it is robust enough to protect its contents if it is spaced about 400 feet from a detonation of 500,000 pounds NEW in an adjacent ECM. In addition, these ECM constructed with "Medium" or "Rock Only" footings do not satisfy present requirements for electrically continuous reinforcing steel, therefore ECM with these type footings do not meet current lightning protection criteria. Superseded by 33-15-01. .	
6521000 through 6521010	19 Feb & 23 Mar 42	RC Dome	OCE	12-Jul-90	7-Bar if proper spacing provided, See Comment and Note 6.	Called a Corbetta, Beehive, or Dome Magazine. At a 23 Feb 1942 meeting, the Joint Army and Navy Board of Ammunition Storage (predecessor of ASESQ) approved the Corbetta Magazine as an alternate type magazine (i.e. Non-Standard). A 12 Jul 90 DDESB ltr approved a 27 Nov 89 COE ltr, requesting approval to modify doors on Corbetta Type ECM at Volunteer Army Ammunition Plant (AAP) and Holston AAP. Once modified, each ECM can be sited for 500,000 pounds NEW, provided the conditions of Note 6 below were met. If they cannot be met, then the ECM must be treated as a non-standard.	6
658384 through 658388, modifications 724368, 764596, and 793746	23-Nov-54	RC Arch	Bureau Y&D	9-May-84	7-Bar	Listed in 1954 DDESB minutes as Standard ECM. This design was an original Bureau Y&D Standard. The 1 Dec 55 ASESQ Standards listed ECM 658384 through 658388 as a standard ECM for storage of NEW up to 500,000 pounds. A 185-foot separation distance was required from other ECM. Superseded by NAVFAC Drawings 1404310 through 1404324. Bureau Y&D Drawing 817103 provides general information regarding this ECM and was used for planning purposes.	

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DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
725738 through 725746	09-Sep-56	RC Stradley	Bureau Y&D	Acceptance based on COE analysis	7-Bar	COE Huntsville memo (CEHNC-ED-CS-S (210-2b) of 27 June 2002, subject: 7-Bar Magazines, states that the magazines constructed to this drawing at Moron Air Base, Spain, are 7-Bar ECM. The basis for their determination is that this design is identical to 33-13-02, which is a 7-Bar design.	
8027514 through 8027532	1990	RC Box	NAVFAC SW Division	09-Apr-93	7-Bar	Initial M-Type Navy magazine designed for and constructed at NWS Seal Beach, CA as part of MILCOM P-137. Approved as a site-adaptable magazine with a maximum NEW of 350,000 lbs NEW. Subsequently modified and constructed at NWS Yorktown. Replaced by NAVFAC Drawings 10400001 through 10400027 for new construction.	
8150917 through 8150988	10/19/2002 (final)	RC Arch	NAVFAC	26-Dec-96	7-Bar	As part of FY2001 MILCON Project P-114, this design modified eight existing Undefined ECM built in the 1940s timeframe (Huntsville Type 652-1012 through 652-1014, with inadequate headwall reinforcing steel) by replacing their headwalls and doors with those that met 7-Bar criteria. This occurred at Army National Guard Training Site, Camp Navajo, AZ. The new headwall and door, a single sliding door, are similar to NAVFAC headwall and door designs (drawings 5167380 through 5167413) previously approved by DDESB at SUBASE Kings Bay, SC.	
Incirlik, Turkey (Cephane Deposu) ECM	UNK	Modifed RC Stradley	UNK	04-May-96	3-Bar	DDESB letter of 4 May 1999 identifies this magazine as being located at Incirlik AFB, Turkey. Its blast door was determined to be incapable of providing 7-Bar protection, although the magazine arch and headwall were designed to meet 7-Bar criteria. Dr. Canada of the DDESB evaluated the strength of this ECM design located at Incirlik AFB.	
Incirlik Turkey ECM	UNK	RC Arch	UNK	04-May-96	3-Bar	DDESB letter of 4 May 1999 identifies four ECM (1995, 2059 (Modified NATO-16), 2323, and 2327) as being located at Incirlik AFB, Turkey. These four ECM were evaluated by Dr. Canada of the DDESB and determined to be as follows: 2059 and 2323 are 3-Bar ECM, and 1995 and 2327 are 7-Bar ECM. The blast doors of the 3-Bar ECM were determined to be incapable of providing 7-Bar protection, although the magazine arch and headwall were designed to meet 7-Bar criteria.	
Lone Star AAP ECM	UNK	RC Arch	UNK	13-Jul-99	3-Bar	A 23 Sep 89 site visit to Lone Star, by Adib Farsoun of the Huntsville Division, Corps of Engineers (Code CEHND-ED-CS) concluded that the Lone Star magazines were almost equivalent to standard ECM design 33-15-06 with one exception: 33-15-06 had a double leaf door as compared to a single leaf door on the Lone Star magazines. In addition, magazines are sited 400 feet apart. On this basis, DDESB determined that magazines equivalent to those at Lone Star AAP may be treated as 3-Bar magazines and are authorized to contain up to 500,000 pounds NEW OF HD 1.1.	

TABLE AP1-2. 7-BAR AND 3-BAR ECM NO LONGER USED FOR NEW CONSTRUCTION, BUT STILL IN USE *
June 2004

DRAWING NO.	DRAWING		DESIGN	DDESB APPROVAL	ECM	COMMENTS: (NOTE 2)	NOTES:
(NOTE 1)	DATE	DESCRIPTION	AGENT	DATE	DESIGNATION		
Munitionslagerhouse (MLH) 25	UNK	RC Portal Type	German	02-Dec-77	7-Bar	DDESB determined that MLH 25, MLH 90, and MLH 180 ECM designs could be equated to a standard igloo. Construction of 19 of these magazines was approved for Forward Storage Site (FSTS) Ottrau, Germany. Maximum explosives limit assigned to this ECM design, as a standard magazine was 37,500 kg (82,753 pounds). The Ottrau ECM were separated at 25 meters (side-to-side).	
Munitionslagerhouse (MLH) 30	UNK	RC Box	German	18-Aug-87	7-Bar	Approval was on the basis of the 12 Dec 77 DDESB letter that determined the MLH design could be equated to a standard ECM. Separation distances were $d=1.25W^{1/3}$ (side to side) and $d=2.00W^{1/3}$ (front to rear), which were used at the time to site standard magazines. Approved maximum limit for this design is 77,900 kg (171,884 pounds). The minimum side to side distance used was 25 m (82 feet). The site plan to construct 20 magazines at FSTS Seckach (Kuelsheim), GE was approved.	
Munitionslagerhouse (MLH) 50	UNK	RC Box	German	02/10/82 & 08/18/1987	7-Bar	DDESB approved the construction of seventeen MLH 180, six MLH 90, and three MLH 50 at FSTS Grebenhain, Germany. Approval was on the basis of the 12 Dec 77 DDESB letter that determined the MLH design could be equated to a standard ECM. Separation distances were $d=1.25W^{1/3}$ (side to side) and $d=2.00W^{1/3}$ (front to rear), which were used at the time to site standard magazines. Approved maximum limit for this design is 77,900 kg (171,884 pounds). The minimum side to side distance used was 25 m (82 feet).	
Munitionslagerhouse (MLH) 60B	UNK	RC Box	German	18-Aug-87	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an NEQ of HD 1.1 of 75,000 kg (165,000 pounds NEW). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.	
Munitionslagerhouse (MLH) 148, Dwg 41214	16-Feb-87	RC Box	German	28-Jun-88	7-Bar, See Comment section.	NATO explosives safety standards limit this magazine to an NEQ of HD 1.1 of 75,000 kg (165,000 pounds NEW). For siting at U.S installations, where encumbered land is completely within U.S owned or controlled property, an explosives limit of 250,000 pounds NEW can be used for siting purposes. Considered a standard (7-Bar) ECM for sitings involving 165,000 pounds NEW or less.	
Volkel (Netherlands) ECM	UNK	RC Stradley	Netherlands	31-Mar-99	7-Bar	DDESB letter of 31 March 1999 determined that the ECM in Block A at Volkel Air Base (Netherlands) met the criteria of 7-Bar ECM, based on an evaluation of Dr. Canada of the DDESB. The Strengths of the ECM in Blocks B and C could not be determined due to insufficient information.	

* Could be used for new construction with DoD Component approval, but must be evaluated to insure current requirements for grounding, lightning protection, etc., are met.

Notes accompanying Table AP1-2:

1. Each line represents a separate ECM design. Where UNK appears, it indicates that no information has been found to fill in that particular field. Table 4-2 lists magazines that have been constructed in the past and are still in use today, though they generally are no longer being used for new construction. However, at the discretion of DoD Components, these designs could be used for new construction, but the designs will need to be closely evaluated to insure current DoD requirements for ECM (e.g., grounding, lightning protection, earth-cover slope and depth, structural hardness) are met.
2. 7-Bar and 3-Bar ECM are permitted to store up to 500,000 pounds, unless otherwise noted.
3. A provision of the approval was that the separation distances between the rear or side of these ECMs, as the PES, to the front of one of these ECMs, as an ES, were at least 360 feet. Side to side exposures between the PES and the ES are required to be separated in accordance with the appropriate entries for either 3-bar or 7-bar ECMs in accordance with Table 9-5 of DoD 6055.9-STD.
4. ECM separation distances based in the following criteria: Side-to- side: use $1.5W^{1/3}$; back-to-back: use $1.5W^{1/3}$; front-to-back: use $4.5W^{1/3}$.
5. The conversion of these designs from Standard magazines to 7-Bar magazines in the early 1990s was in error in that the hinged doors of AW 33-15-63, AW 33-15-64 and 33-15-65 (all similar door designs) are not capable of providing 7 or 3-Bar protection to their contents. This determination was arrived at during ESKIMO III, which tested an AW 33-5-64 design and by a structural analysis of the door design that was conducted by the Huntsville COE at the request of DDESB-KT. Paragraph C2.3.7.3. **ESKIMO III, June 1974** provides further information regarding this test. If different doors than those shown of AW 33-15-63, AW 33-15-64, and 33-15-65 have been installed, then the headwall and alternate door(s) can be structurally evaluated to determine their strength. As a result of the ESKIMO series tests, Services began moving towards single and bi-sliding doors on hardened headwall pilasters and header.

Siting guidance: Do not use for new construction. Site existing magazines as :Undefined” structures to provide a higher level of protection to contents. Use of the K4.5 that is permitted for 7-Bar ECM (face-to-face) with intervening barricades or the K6 permitted for 7-Bar ECM (face-to-face) without a barricade provides a very high likelihood of prompt propagation between ECM designed to AW 33-15-63, AW 33-15-64 and 33-15-65.
6. A Corbetta-type ECM is considered as “Undefined” because its door is inadequate to prevent explosion communication. However, in 1990, the DDESB approved two improved door designs for installation onto Corbetta-type ECM. If modified with the

new doors, and provided they meet minimum separation distances of 400 feet, side-to-side or rear-to-front exposures between the donor and acceptor ECM and (K11) front-to-front exposures between the donor and acceptor ECM, then storage of up to 500,000 pounds NEW of HD 1.1 is permitted in modified Corbetta-type ECM.

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
104260 & 104261	15-Jul-27	RC Arch	Bureau Y&D	2004	DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement in the headwall. Treat as Undefined ECM. The door is identified as metal covered and a large ventilator is mounted in the headwall over the door. The drawing shows the magazine was constructed at Naval Mine Depot, Yorktown, VA, which is now called NWS Yorktown. An analysis of the stresses on the arch (from dead loads and blast loads) is provided by Bureau Y&D Drawing 104714.	
107368	20-Apr-29	RC Arch	Bureau Y&D	2004	DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement in the headwall. Treat as Undefined ECM. The drawing shows the magazine was constructed at Naval Ammunition Depot, Hawthorne, NV, which is now an Army Ammunition Depot.	
110-25-64	01-May-42	RC Arch	COE, Sacramento Office	2004	Constructed at Sierra Ordnance Depot, Hackstaff, CA. Drawings are marked to indicate the drawing set superseded 652-686 through 652-689 (see below). Drawings show a 10-inch thick headwall and 6 X 6 wire mesh reinforcing.	
130445	05-Jan-39	See Comments.	Bureau Y&D	2004	This is a variation of a RC Box ECM. The side walls are vertical for approximately 13 feet at which point the roof begins sloping towards the peak at slightly angle. Hoists and racks are provided for moving and storing warheads. The door consisted of a steel plate. DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement in the headwall. Treat as Undefined ECM. The drawing shows the magazine was constructed at Naval Ammunition Depot, Hawthorne, NV, which is now an Army Ammunition Depot.	
133959	18-Nov-39	RC Arch	Bureau Y&D	04-Apr-84	Headwall is 6 inches thick and uses 4 X 4 mesh steel for reinforcement. Treat as Undefined.	
142199	31-Jul-40	RC Arch	Bureau Y&D	2004	DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement in the headwall. Treat as Undefined ECM. The drawing shows the magazine was constructed at Naval Ammunition Depot, Hawthorne, NV, which is now an Army Ammunition Depot.	
157457	12-Apr-41	RC Arch	Bureau Y&D	2004	DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement of the headwall. Treat as Undefined ECM. Drawing indicates that this design was constructed at U.S. Naval Air Station Banana River, FL, which is now called NAS Key West.	
158632	UNK	UNK	Bureau Y&D	20-Jun-84	DDESB letter of 20 June 1984 determined the magazine could not be considered a standard magazine because its construction was not equivalent to a standard magazine.	
163582 & 163583	23-May-41	RC Box	Bureau Y&D	11-May-53	Known as the Keyport Magazine. 128th (4 May 1953) and 129th (11 May 1953) ASES minutes discuss the Keyport Magazine to great length. The 129th ASESB unanimously passed a motion to permit the Keyport Magazine to be sited for 4,000 pounds NEW with a minimum 30-foot separation distance (center to center) between Keyport Magazines. Greater separation distances would be required, if there is an unbarricaded front exposure.	
G165-177 & 178	20-Jan-53	RC Arch	Bureau Y&D	12-Apr-02	A 12 April 2002 e-mail from COE Huntsville informed DDESB that this design, located at Andersen AFB, Guam, is an Undefined structure due to the weakness of the headwall and door. Steel mesh was used vice reinforcing steel, similar to the Huntsville magazines built during WWII due to steel shortages.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
173649 through 173651	28-Aug-41	RC Box	Bureau Y&D	2004	This an early version of the Navy Smokeless Powder and Projectile Magazine and measures 52 feet X 103 feet. The design provides for glass block windows in the front wall to let in natural lighting. Treat as Undefined ECM. The drawing shows the magazine was constructed at Naval Ammunition Depot, Hawthorne, NV, which is now an Army Ammunition Depot.	
173658	03-Sep-41	RC Arch	Bureau Y&D	2004	DDESB review of drawing observed that headwall is only 6 inches thick and that 4 X 4 wire mesh was used for reinforcement in the headwall. Treat as Undefined ECM. The drawing shows the magazine was constructed at Naval Ammunition Depot, Hawthorne, NV, which is now an Army Ammunition Depot.	
187407 & 187408	UNK	UNK	Bureau Y&D	09-May-84	The 9 May 1984 DDESB approval letter provided an NEW rating of only 250,000 pounds. Treat as an undefined ECM.	
209854 & 209855	24-Jun-42	RC Arch	Bureau Y&D	UNK	This ECM measures 25-foot wide by 50-foot long. Its internal height is 12-foot 2-inches. Known to have been constructed at Crane Army Ammunition Plant.	
217867	14-Sep-42	RC Arch	Bureau Y&D	2004	Headwall is 6 inches thick and uses 4 X 4 wire mesh for reinforcement. Constructed at Hawthorne Army Ammunition Plant. Treat as Undefined.	
217869	14-Sep-42	RC Arch	Bureau Y&D	04-Apr-84	Headwall is 8 inches thick and uses 4 X 4 wire mesh for reinforcement. Constructed at Hawthorne Army Ammunition Plant. Treat as Undefined.	
226166	UNK	RC Box	Bureau Y&D	UNK	This design is for a 144 square-foot Fuze and Detonator Magazine. The design drawing specifies only 18 inches of soil cover. Current explosives safety criteria call for a minimum of 24 inches of earth cover. A magazine constructed to this drawing must be treated as an aboveground magazine. The addition of earth-cover, sufficient to meet current criteria, would allow this magazine to be treated as an undefined ECM. Bureau Y&D Drawing 817112 provides general details for this magazine and was used for planning purposes.	
33-03-01	09-Apr-81	RC FRELOC Stradley	COE, Savannah	14-Apr-94	A 2 March 1994 Huntsville Division, COE, letter determined that the basis for the 33-03-01 magazine design was standard magazine design 33-15-74, however, modifications were made which caused any ECM constructed IAW Drawing 33-03-01 to be considered non-standard.	
33-03-04	UNK	RC Arch	UNK	04-May-99	DDESB letter of 4 May 1999 identifies this magazine as being located at Incirlik AFB, Turkey and belonging to WSA Security. Its blast door was determined to be incapable of providing 7- or 3-Bar protection, although the magazine arch and headwall were designed to meet 7-Bar criteria.	
33-03-43	01-Apr-76	Steel Arch	COE (EUR Dist)	11-May-83	A 6 December 1982 Dept of Army, HQ, 21st Support Command (Subj: Proposed Construction of New Magazines at Larson Barracks, Kitzingen, Germany) called for the construction of 6 of these magazines. This letter also stated that DDESB-KO approval was granted on 19 April 1976, for construction of EUD 33-03-43 magazines at QRS Bindlach, Germany. The 19 April 1976 DDESB letter has not been located. These magazines were sited at a side-to-side separation distance of $0.5Q^{1/3}$ (equates to K1.25). This separation was applicable to standard ECM and to non-standard ECM (for NEWs less than 250,000 pounds HD 1.1.) Treat as an undefined ECM, until receipt of additional information to support some other designation.	
33-11-0002	27-Feb-84	Steel Arch	COE, Japan District	UNK	This design was constructed at Misawa Air Base, Honshu, Japan. Not all drawings available, but available details appear to be similar to 33-15-63 design.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
33-15-01	27-Dec-41	RC Arch	OCE	29-Oct-02	This design is different from magazine design AW 33-15-01 and 33-15-01 (Omaha District COE), listed in Table AP1-2 of TP 15. A 1950 document, which describes the history of magazines from pre-1928 to 1950, identified this magazine design as having an unreinforced steel door which had questionable blast resistance capability. Superseded by 33-15-06 of 1 August 51. Drawing 33-15-62 (13 June 1960) increased door size. An additional issue is that the headwall construction utilized steel mesh vice reinforcing bars, which was characteristic for that period due to steel shortages. COE, Huntsville, e-mail of 29 Oct 2002, to the DDESB identifies headwall design shortcomings and the need to classify the ECM as Undefined.	
E 33-15-02	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-15-03	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-15-04	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
DEF-E-33-15-04	29 May 51, Revised 10/1/1951	RC Arch	COE (Los Angeles District)	UNK	No additional information is available.	
EUD 33-15-05	UNK	RC FRELOC Stradley	COE (EUR Dist)	UNK	A 10 April 1979 DDESB Telephone Record states that EUD drawing 33-15-05 is said to be the same as the Standard FRELOC, 33-15-13, except that the footings are similar to those of a steel arch magazine, will be submitted through channels for consideration as a standard magazine. No record was found to show that this was ever accomplished.	
33-15-07	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
33-15-08	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-15-09	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-15-10	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
33-15-11 A	Sep-76	RC FRELOC Stradley	COE (EUR Dist)	UNK	No additional information is available. Design appears to be very similar to 33-03-31 design.	
AD 33-15-11 R2	29 Dec 61, Rev 2 dated 5 Jan 62	RC Arch	AF	UNK	This magazine was listed in a 1968 document, presented by a working group meeting to standardize magazine nomenclature, as a Type B (STD) magazine for Army and Air Force use. No documentation has been found to support anything other than an undefined designation.	
33-15-12	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
33-15-13	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
33-15-14	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
33-15-14	UNK	Modified FRELOC Stradley (RC Arch)	COE (EUR Dist)	05-Dec-78	This design represented a significant modification of standard ECM 33-15-13 (reduced reinforcement), and the DDESB determined it had to be considered a non-standard (undefined) until fully evaluated. No information was found to show an evaluation had ever been completed.	
33-15-19	UNK	RC Arch	AF	29-Nov-84	The DDESB determined this ECM could not be considered a standard ECM, because the headwall and doors were of weaker design than those of a concrete arch ECM that had been tested successfully. The DDESB review pertained to ECM located at Camp Edwards, Massachusetts, an Army National Guard Training Site.	
33-15-28	UNK	Steel Arch	COE (EUR Dist)	05-Aug-87	This design was initially approved by the DDESB 11 May 1983, for construction at Larson Barracks, Kitzingen, Germany, with an NEW of 4,000 pounds and a side-to-side separation of K1.25. This separation was applicable to standard ECM and to non-standard ECM (for NEWs less than 250,000 pounds HD 1.1.) Project was subsequently modified to use ECM design 33-15-208, which was almost the same as design 33-15-28 with some minor modifications. Treat as an undefined ECM.	
AW 33-15-63	05-Mar-63	Steel, Semi-Circular Arch	OCE	19-Feb-64	Approved during 225th ASES meeting of 19 Feb 64 as a standard magazine design. A 1 Apr 87 COEHQ letter stated that ECM design AW 33-15-63 was no longer being used for new construction. Drawing AW 33-15-63 had two designs shown on it. One is a traditional magazine with a single 12-inch thick reinforced concrete headwall, while the second is a design with two headwalls and doors (flow through design). COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	
AW 33-15-64	10-May-63	Steel Arch	OCE	19-Feb-64	Approved during 225th ASES meeting of 19 Feb 64 as a standard magazine design. A 1 Apr 87 COEHQ letter stated that ECM design AW 33-15-64 was no longer being used for new construction. COE structural evaluation of AW 33-15-64 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
33-15-65	10-Jan-63	Steel, Semi-circular Arch	OCE	19-Feb-64	This ECM was available in two widths: 8-foot and 10-foot. Approved during 225th ASES meeting of 19 Feb 64. However, an 18 Dec 89 DDESB ltr identifies problems with this ECM being able to meet standard magazine criteria and states that the COE would be asked to redesign 33-15-65 to strengthen it. The DDESB letter further state that Drawings 33-15-74 or 421-80-01 should be used for new construction of Standard ECM. Based on headwall strength issue, allowable NEW limited to only 250,000 pounds.	
AD 33-15-67 R2	5/8/1964, Rev 2 dated 8 Mar 65	Steel, Semi-Circular Arch	AF	See Comments	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. The design was added (at that time) to the magazine listing in DoD 6055.9-STD, based on the above COE assessment. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	
AD 33-15-68 R2	5/8/1964, Rev 2 dated 8 Mar 65	Steel, Semi-Circular Arch	AF	See Comments	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. The design was added (at that time) to the magazine listing in DoD 6055.9-STD, based on the above COE assessment. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	
AD 33-15-69 R2	08-May-64	Steel, Semi-Circular Arch	AF	See Comments	This ECM was required to be constructed IAW Drawing AW 33-15-63. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. The design was added (at that time) to the magazine listing in DoD 6055.9-STD, based on the above COE assessment. COE structural evaluation of AW 33-15-63 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	
AD 33-15-70 R1	08-May-64	Steel, Semi-Circular Arch	AF	See Comments	This ECM was required to be constructed IAW Drawing AW 33-15-64. A 13 Jan 1995 COE, Huntsville Division, ltr stated that since the design drawing calls for it to be constructed in accordance with a standard (7-Bar) design, then, by analogy, it also should be considered a standard. The design was added (at that time) to the magazine listing in DoD 6055.9-STD, based on the above COE assessment. COE structural evaluation of AW 33-15-64 door in 2003 determined the door would not provide 7 or 3-Bar protection. See Note 5 of Table AP1-2.	
33-15-71	UNK	Steel Arch	COE (EUR Dist)	UNK	An informal DDESB magazine listing, dated 26 Aug 80, shows this magazine design having only a 250,000-pound capacity. Treat as an undefined ECM until additional information is provided which supports another designation.	
AD 33-15-72	23-Mar-67	See Comments.	AF	UNK	This drawing identifies two ECM types. The first is a steel, oval arch ECM and the second is a steel arch ECM. Both types must be constructed IAW arch requirements of Drawing AW 33-15-64 and are economical open-ended models of the magazine design. Separate barricades may be used where end protection is necessary. These structures were used for covered field storage in austere areas. The design drawing designates these magazines as Combat Zone Type.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
33-15-208	UNK	Steel Arch	COE (EUR Dist)	8/5/1987 message	This design was initially approved by the DDESB 11 May 1983, for construction at Larson Barracks, Kitzingen, Germany, with an NEW of 4,000 pounds and a side-to-side separation of K1.25. This separation was applicable, at the time, to the siting of standard ECM and to non-standard ECM (for NEWs less than 250,000 pounds HD 1.1.) Project was subsequently modified to use ECM design 33-15-208, which was almost the same as design 33-15-28 with some minor modifications. Treat as an undefined ECM until further information is received to justify a designation change.	
E 33-31-01	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-31-02	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
33-33-03	UNK	Modified FRELOC Stradley (RC Arch)	COE (EUR Dist)	UNK	A 4 May 1978 DDESB -KT memo to COE European Division, mentions this design. It appears to be a design variation of 33-15-13, however, no details are available and it must be considered as Undefined until additional details are provided.	
E 33-31-04	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-31-05	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
E 33-31-06	UNK	UNK	UNK	UNK	This design was identified in a 29 January 1968 study entitled "A Standard System for Type Classification of Explosives Storage Magazines" as a Type C magazine (i.e., substandard earth-covered magazine). This design requires a technical analysis on a case-by-case basis to determine the structural hardness of its door(s) and headwall.	
FI-350 through FI-356, modified with larger door	18-Apr-51	RC Arch	OCE	08-Apr-03	This design reflects FI-350 through FI-356, with a modified door. The larger door was evaluated by the Huntsville COE and determined to be incapable of providing 7-Bar protection. Their determination is documented in an e-mail to the DDESB (8 Apr 2003). The original door design measures 9'11 3/4" H X 8 5 1/2" W (double, hinged, swinging doors). The modified larger door design (11' H X 10' 1 1/2" W) is also a double, hinged, swinging door. Treat as Undefined ECM.	
357428 through 357430	09-Aug-44	RC Arch	Bureau Y&D	UNK	A WW II Navy Standard design. It was upgraded by Bureau Y&D Drawing 626739 to provide a stronger headwall and door design, which was then accepted as a Standard magazine design.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
359870	UNK	RC Box	Bureau Y&D	UNK	This is a 68 square-foot Ready Magazine. The design drawing calls for only 18-inches of soil cover. Current explosives safety criteria call for a minimum of 24-inches of earth cover. A magazine constructed to this drawing must be treated as an aboveground magazine. The addition of earth-cover, sufficient to meet current criteria, will allow this magazine to be treated as an undefined ECM. Bureau Y&D Drawing 817112 provided general details for this magazine and was used for planning purposes.	
359871	UNK	RC Box	Bureau Y&D	UNK	This design provides construction details for both a 192 square-foot Fuze and Detonator ECM and a 266 square-foot Black Powder ECM. The design drawing specifies only 18-inches of soil cover. Current explosives safety criteria require a minimum of 24-inches of earth cover. A magazine constructed to this drawing will have to be treated as an aboveground magazine. The addition of earth-cover, sufficient to meet current criteria, will allow this magazine to be treated as an undefined ECM. Bureau Y&D Drawing 817112 provided general details for this magazine and was used for planning purposes.	
387740	15-Mar-45	RC Box	Bureau Y&D	UNK	Smokeless Powder Magazine. Has glass blocks in the face to allow natural lighting to enter.	
387744	22-Mar-45	RC Box	Bureau Y&D	09-May-84	This design provides construction details for both a 10-foot X 10-foot and a 10-foot X 14-foot Fuze and Detonator ECM. The design drawing specifies only 15-inches of soil cover. Current explosives safety criteria require a minimum of 24-inches of earth cover. A magazine constructed to this drawing will have to be treated as an aboveground magazine. The addition of earth-cover, sufficient to meet current criteria, will allow this magazine to be treated as an undefined ECM.	
387745	22-Mar-45	RC Arch	Bureau Y&D	09-May-84	This design is for a 25-foot X 20-foot Fuze and Detonator Magazine. A 9 May 1984 DDESB memorandum stated that the magazine was rated for only 250,000 pounds NEW. Treat as an undefined ECM.	
411428	UNK	UNK	Bureau Y&D	09-May-84	DDESB letter of 9 May 1984 showed that the magazine was rated for only 250,000 pounds NEW. Treat as an undefined ECM.	
421-80-06	01-Oct-99	RC Box	COE	02-Apr-02	Known as the Air Force "Hayman Igloo". This design represents an upgraded version of the AF Modular Storage Magazine (MSM) that was approved by the DDESB in 1994. 421-80-06 and the MSM design were previously considered as 7-Bar designs. Their rating was downgraded to "Undefined" by the DDESB in Apr 2002 due to identified problems with the door design. The door and door frame can be upgraded per DDESB memo of 17 Apr 02 in order to be again considered a 7-Bar design. See 421-80-06 (Modified) in Table AP1-1. Drawing 421-8-06 was assembled in 1990 at the request of the AFSC to consolidate USAF Drawings 9210827 through 9210832 and 9484969 under one drawing number.	
421-80-06 flow through version	UNK	RC Box	UNK	14-Sep-00	DDESB site approval was granted for the construction of 2 modified Hayman igloo (421-80-06 with two headwalls) at Kunsan Air Base, Korea. The structures were required to be treated as Undefined ECM. Doors can be upgraded to meet 7-Bar criteria.	
422-264-03	11-May-90	RC Box	Savannah District COE	02-Apr-02	An early version of the Air Force MSM. Unlike MSM design 9210827 through 9210832 (Hill AFB) and 9484969 (Eglin AFB), this design cannot be upgraded to a 7-Bar design because it has a weaker roof design. Has always been considered an Undefined ECM.	
516667	?	Steel Arch	Bureau Y&D	UNK	Superceded by Bureau Y&D Drawing 6027803. No additional information is available.	
544839 through 544842	25-Feb-52	RC Box	Bureau Y&D	UNK	Smokeless Powder and Ammunition Storage Magazine. Known to have been constructed at McAlester AAP. Front wall has glass block windows installed approximately 10 feet above floor level to let in natural lighting.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
550-001 & 550-002	02-Sep-41	RC Arch	Red River Ordnance Depot	2004	Though the door header and pillasters are reinforced and a 10-inch thick headwall is provided, the headwall reinforcing is 6 X 6 wire mesh, which does not provide the required headwall strength. Door details not available at this time - no drawing. Constructed at Red River Ordnance Depot.	
6027801	01-Mar-75	Steel Arch	NCEL	UNK	This is a 1,200 square-foot High Explosive Magazine. The design's grounding system does not meet current explosives safety grounding criteria. The magazine was designed by the Civil Engineering Support Office, Naval Construction Battalion Center, Pt. Hueneme, CA.	
6027802	01-Mar-75	Steel Arch	NCEL	UNK	This is a 576 square-foot High Explosive Magazine. The design's grounding system does not meet current explosives safety grounding criteria. The magazine was designed by the Civil Engineering Support Office, Naval Construction Battalion Center, Pt. Hueneme, CA.	
6027803	01-Mar-75	Steel Arch	NCEL	UNK	Superceded Bureau Y&D Drawing 516667. This is a 192 square-foot High Explosive Magazine. The design's grounding system does not meet current explosives safety grounding criteria. The magazine was designed by the Civil Engineering Support Office, Naval Construction Battalion Center, Pt. Hueneme, CA.	
649602 through 649605,793749, and 803060	05-Mar-54	RC Arch	Bureau Y&D	09-May-84	DoD 4145.27M, March 1969, identified this magazine as a non-standard structure, permitted to store 250,000 pounds NEW at a minimum separation distance of 185 feet. A 9 May 1984 DDESB memorandum confirmed that it was a non-standard ECM.	
652-295 and 652-296	20-Jun-33	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.2.6.	
652-311 and 652-312	19-Jul-28	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.2.5. Treat as an above-ground magazine, unless the required 2-foot of earth cover is provided. The design may need to be evaluated to insure the structure is capable of safely supporting 2 feet of earth.	
652-317 through 652- 320	09-Dec-35	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.2.7.	
652-326 through 652- 331	23-Jul-37	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.2.7.	
652-340 through 652- 349	27-Sep-40	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.3.1. These drawings were lost shortly after approval and were replaced by Drawings 652-377 through 652-386.	
652-377 through 652- 386	30-Oct-40	RC Arch	OQMG	UNK	See description information provided in paragraph C2.2.3.1.	
652-394 & 652-395	UNK	UNK	OQMG	UNK	Referenced on Red River Ordnance Depot, Texarkana, TX, drawing 550-001.	
652-535 through 652- 537	13-Feb-41	Steel Arch	OQMG	UNK	Superceded OQMG Drawing 652-354. The arch is constructed of 7-ga. corrugated steel panels. The design provided for 2-foot of earth cover.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
652-686 through 652-692	27 Dec 41, Revised 14 Mar 42	RC Arch	OCE	24-Dec-98	This ECM design was tested as part of the 1946 Naval Proving Grounds, Arco, Idaho, tests. The 130th ASESB (18 May 53) acknowledged COE Drawings 652-686 through 652-694, dated 27 Dec 41, revised 14 Mar 42, as a Standard ECM. 1Dec 55 ASESB QD Standards list this ECM as a standard, with 185-foot separation for barricaded, 360-foot separation for unbarricaded. A 24 Dec 98 DDESB ltr states that an ECM constructed to Drawings 652-686 through 652-692 is not robust enough to qualify as a 7-Bar ECM. However, it is robust enough to protect its contents if it is spaced about 400 feet from a detonation of 500,000 pounds NEW in an adjacent ECM. In addition, these ECM constructed with "Medium" or "Rock Only" footings do not satisfy present requirements for electrically continuous reinforcing steel, therefore ECM with these type footings do not meet current lightning protection criteria. Superseded by 33-15-01 listed above. If distances cannot be met, then the ECM must be treated as an undefined ECM.	
6521000 through 6521010	19 Feb & 23 Mar 42	RC Dome	OCE	12-Jul-90	Called a Corbetta, Beehive, or Dome Magazine. At a 23 Feb 1942 meeting, the Joint Army and Navy Board of Ammunition Storage (predecessor of ASESB) approved the Corbetta Magazine as an alternate type magazine (i.e. Non-Standard). A 12 Jul 90 DDESB ltr approved a 27 Nov 89 COE ltr, requesting approval to modify doors on Corbetta Type ECM at Volunteer Army Ammunition Plant (AAP) and Holston AAP. Once modified, each ECM can be sited for 500,000 pounds NEW, provided the conditions of Note4 below were met. If distance cannot be met, then the ECM must be treated as an undefined ECM.	4
652-1012 through 652-1014	29-Apr-42	RC Arch	OCE	UNK	Known as the Huntsville Magazine. This was a redesign of the Series 652686 through 652693 magazine, and its purpose was to conserve critical wartime materials. Reinforcing steel was reduced. The headwall stubbed by removal of wingwalls (earth fill spilled around front corners). The door was changed to a 6-foot, double-sheet steel. The headwall thickness was reduced to 8 inches.	
652-1017 and 652-1018	13-May-42	AG (see comments)	OCE	UNK	Known as the "Richmond"-Type Magazine (see C2.2.3.5). This is an aboveground structure constructed of massive masonry walls and a built-up wood frame roof. It was frequently called an igloo which was incorrect. Site as an aboveground magazine.	
6579-160 & 6579-161	12-Mar-29	RC Arch	OQMG	UNK	This magazine, as shown on the drawing, has insufficient earth-cover to qualify as an earth-covered ECM under today's standards. Treat as an aboveground magazine, unless earth-cover has been increased to meet the minimum required 2 feet of depth.	
7115-1400	UNK	RC Arch	OQMG	UNK	This Lone Star AAP drawing indicates that the details on this drawings were copied from 7115-1400.4. No date was given for the original drawing, though the copy effort was completed on 20 June 1969. Base on the original drawing number, the reinforcing design and door design shown, it is suspected that this an early 1940 era design. The drawing indicates 59 - 40'2" L X 26' 6" W; 138 60' 8" X 26' 6"; and 45 80' 8" X 26' 6" were constructed at Lone Star AAP per this drawing.	
7120-8101 and 652-538	27 Jan 1942/16 July 1941	RC Arch	OQMG	UNK	This design provided the contractor the option of replacing reinforcing bars with wire mesh at his option. The door is a 4-inch thick concrete door reinforced with 6" X 6" wire mesh on each face. Drawing 652-538 is for a concrete door design that has a bronze copper weatherstrip attached to the inside edge of the door. When the door closes, the copper weatherstrip presses against the steel angle that forms the door frame. This design may provide a ground path for the door, but it needs to be tested. This magazine design is known to have been constructed at Redstone Arsenal, AL.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
749767 through 749770	1956	RC Box, Type IIA	Bureau Y&D	UNK	Smokeless Powder/Projectile Magazine, Type IIA (52 feet X 161 feet). DDESB approval of this design (6 Oct 1976) as a standard magazine design was site specific for NAVWPSTA Yorktown only. In their approval letter, the DDESB encouraged the Navy to pursue designating this ECM as a standard design. No documentation has been found to show if this was ever performed. Original design of this drawing number had glass block windows in the magazine face to allow natural lighting to enter. Change C (dated 5 Jul 61) removed the glass blocks. DDESB approval as a Standard magazine was based on an analogous comparison of structural features to OCE 33-15-64. ESKIMO VI tested a similar magazine design (Bureau Y&D 749771 - 749774), which failed to meet Standard Magazine criteria.	
749771 through 749774, and 793751	31-Jul-56	RC Box, Type IIB	Bureau Y&D	UNK	Smokeless Powder/Projectile Magazine, Type IIB (52 feet X 97 feet). The original design had glass block windows in the magazine face to provide natural lighting within the magazine. Change C (dated 5 July 1961) removed the glass blocks. This magazine was tested by ESKIMO VI and failed to meet Standard magazine criteria, therefore it's considered an undefined ECM.	
752296 through 752299, 793749	UNK	RC Box	Bureau Y&D	UNK	Type 1, Smokeless Powder/Projectile Magazine (52-foot X 103-foot). Bureau Y&D Drawing 817109, dated 7 January 1958, provides general details of this magazine and was used for planning purposes.	
764596 & 764597	07-Sep-56	RC Arch	Bureau Y&D	15-Jul-83	Superceded by Bureau Y&D Drawing 1404310 through 1404324, which provided for a redesigned headwall and door design to reflect the latest blast loading data gathered from ESKIMO testing. Treat all existing construction as Undefined.	
X8745127 through X8745138, X8745146, and X8851911	UNK	RC Box	Hill AFB	02-Apr-02	An early version of the Air Force MSM. Unlike MSM design 9210827 through 9210832 (Hill AFB) and 9484969 (Eglin AFB), this design cannot be upgraded to a 7-Bar design because of its weaker roof design. Has always been considered an Undefined ECM.	
895065	UNK	RC Box	Bureau Y&D	UNK	Type II Missile Magazine. This design had six 11-foot wide X 11-foot high doors.	
895066	UNK	RC Box	Bureau Y&D	UNK	Type I Missile Magazine. This design had three 22-foot wide X 11-foot high doors.	
9210827 through 9210832 (Hill AFB) and 9484969 (Eglin AFB)	09-Apr-93	RC Box	Hill AFB/Eglin AFB	02-Apr-02	Superceded by 421-80-06. This MSM design was previously approved as a 7-Bar ECM by DDESB-KT Memo of 20 July 1994. It's structural rating was downgraded to "Undefined" by the DDESB in Apr 2002 due to identified problems with the door design. The door and door frame can be upgraded per DDESB memo of 17 Apr 02 in order to be again considered a 7-Bar design. See 421-80-06 (Modified) in Table AP1-1. (NOTE: Eglin AFB drawing 9484969 is a consolidation of Sheets S-8 and S-9 (doors and doorframe assembly) from Savannah District COE Drawings 422-264-03, dated 11 May 1990.)	
952127 through 952135	13-Dec-61	RC Box	Bureau Y&D	UNK	Type I Missile Magazine. This design had three 22-foot wide X 11-foot high doors.	

TABLE AP1-3. UNDEFINED ECM
June 2004

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	DDESB REVIEW DATE (IF KNOWN)	COMMENTS: (NOTES 2 AND 3)	NOTES:
Korean ECM	No number	Steel Arch	Korean	03-Dec-76	DDESB review this design and determined that the door would not provide the required level of protection to the contents of the ECM, therefore, the design was not considered equivalent to a standard ECM design. New Korean magazines are constructed to the Korean Version of 33-15-74, a 7-Bar design.	
M-30792	04-May-86	Steel Arch	AF	UNK	This design was developed by Eglin AFB. The ECM is 39 feet deep and has an internal radius of 13 feet. No approval documentation could be found for this design.	
Modified Type 16 for Air Force use	UNK	RC FRELOC Stradley	COE (EUR Dist)	30-Apr-91	COE (Europe) developed this modified TYPE 16 magazine design for Air Force use. This design modified the headwall to incorporate a 16-foot door opening. Ten of these modified magazines were to be constructed at Ramstein Air Base, Germany, by FY90 MCP, Project PAZY 90372.	
Munitionslagerhaue (MLH) 30B	UNK	RC Box	German	UNK	A 15 September 1986 Department of Army letter from Commander, V Corps (Attn: AETV-GAS) states that the MLH30 is identical to the MLH25, which was approved by the DDESB and constructed in FSTS Ottrau and FSTS Giesel. The letter states that the MLH30 is rated at 7-Bar. Sixteen MLH30 ECM were constructed at PSP4J, Muenster, Germany. Their separation distances were K=1.25W ^{1/3} (side to side) and K=2.0W ^{1/3} (front to rear), both applicable to the siting of standard magazines. The 15 September 1986 letter applied a 5,000 kg (11,023 lb) peace-time limit to the Muenster MLH30 ECM. Approval documentation has not been found. Treat as an undefined ECM until supporting information is provided to change the designation.	
Shipping Container, Earth-Covered	UNK	ISO and MILVAN container	DAC	22-May-95	The DDESB approved the use of earth-covered MILVANs and ISO Containers as undefined ECM, for NEWs up to 4,000 kg (8,800 lbs.), provided the earth-covering criteria of DAC letter SMCAC-EST (385{A}) of 10 February 1995 were met. Attachment C of this letter provides three methods for insuring the required earth-cover is provided. There is no reduction in ESQD as a result of these designs, however, containers meeting these criteria can be sited as undefined ECM with respect to adjacent AE storage structures.	
USAREUR German Type II	UNK	RC Box	German	10-Dec-68	A 10 December 1968 ASES approved a 330,000 pound NEW explosives limit for this magazine. A 21 September 1983 DDESB letter stated that for new construction involving this magazine, then the magazine shall be considered as a non-standard (undefined) magazine and sited accordingly.	5
USAREUR German Type III	17-Apr-68	RC Box	German	10-Dec-68	A 10 December 1968 ASES approved a 330,000 pound NEW explosives limit for this magazine. A 21 September 1983 DDESB letter stated that for new construction involving this magazine, then the magazine shall be considered as a non-standard (undefined) magazine and sited accordingly.	5
USAREUR German Type IIIA	UNK	RC Box	German	10-Dec-68	A 10 December 1968 ASES approved a 330,000 pound NEW explosives limit for this magazine. A 21 September 1983 DDESB letter stated that for new construction involving this magazine, then the magazine shall be considered as a non-standard (undefined) magazine and sited accordingly.	5
USAREUR German Type IV	UNK	RC Box	German	10-Dec-68	A 10 December 1968 ASES approved a 330,000 pound NEW explosives limit for this magazine. A 21 September 1983 DDESB letter stated that for new construction involving this magazine, then the magazine shall be considered as a non-standard (undefined) magazine and sited accordingly.	5

Notes accompanying Table AP1-3:

1. Each line represents a separate ECM design. This listing identifies ECM designs that were approved as either “Non-standard” or “Undefined”, and also includes those ECM designs for which no documentation could be found to support a structural designation other than “Undefined”. Where UNK appears in the table, it indicates that no information was found for that particular field.
2. “Undefined” ECM are currently permitted to store up to 500,000 pounds NEW of HD 1.1. Prior to 1992, a Non-standard ECM was only permitted to store a maximum of 250,000 pounds HD 1.1. [**Note:** Previously approved ECM site approvals, for NEW not exceeding 250,000 pounds remain valid; however, a DDESB site approval is required for any increase beyond 250,000 pounds HD 1.1].
3. Assignment of an ECM to this table does not necessarily mean that it cannot provide 7-Bar or 3-Bar protection. A number of the magazine designs listed could potentially be capable of providing 7-Bar or 3-Bar protection; however, their structural strengths have never been analyzed or tested.
4. Storage of up to 500,000 pounds NEW of HD 1.1 is permitted in Corbetta-type ECM, provided it has been modified with one of the two approved door designs and the required separation distances are met, as discussed in Note 6 of Table AP1-2.
5. Side-to-side of $2 W^{1/3}$ is required for existing ECM.

**TABLE AP1-4. MAGAZINES (EARTH-COVERED AND ABOVEGROUND) AND CONTAINERS WITH REDUCED NEWS AND/OR REDUCED QD
June 2004**

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	APPROVAL DATE	MAGAZINE DESIGNATION	MAGAZINE MCE (pounds of HD 1.1)	COMMENTS:	NOTES:
422-15-01	01-Jun-87	RC, 3-Compartment Mini-Magazines	COE	04-Mar-88	7-Bar	425	There is no reduced ESQD associated with this ECM design.	
422-15-02	21-Feb-96	RC, 3-Compartment Mini-Magazines	COE	28-Sep-98	7-Bar	150	When NEW described on approval letter are met, this ECM can be sited for overpressure (K40) only.	
422-15-03	21-Feb-96	RC, 3-Compartment Mini-Magazines	COE	28-Sep-98	7-Bar	400	When NEW described on approval letter are met, this ECM can be sited for overpressure (K40) only.	
A-1 (K9 Explosive Storage Facility)	10-May-94	RC shell with an internal steel magazine	AF (Hanscom AFB)	07-Apr-95	Undefined	18	Magazine designed by 66th Support Group, Hanscom AFB, MA., for the storage of explosives training aids used in SPS Detector Dog Training Kits.	2
Magazine design designated by AF-NGB as ANG-DWG-87-095	N/A	Steel Arch	AF-NGB	09-Apr-90	Undefined	150 or 450	Known as the Ellington ECM (40 ft by 80 ft). The design was approved under Site Plan ANG Ellington ANGB-85-S1 and S-2.	3
Magazine design designated by AF-NGB as ANG-DWG-87-112	N/A	Steel Arch	AF-NGB	09-Apr-90	Undefined	150 or 450	Known as the Fresno ECM (40 ft by 80 ft). The design was approved under Site Plan NGB-Fresno-85-S3 thru S6.	3
Magazine design designated by AF-NGB as ANG-DWG-89-115	N/A	RC Arch	AF-NGB	07-Aug-89	Undefined	150 or 450	Known as the Fargo ECM (40 ft by 80-ft). Approved under Site Plan ANG Fargo-88-S1 thru S-5 Hector Field, Fargo, ND.	3
Magazine design designated by AF-NGB as ANG-DWG-94-001	N/A	RC Arch	AF-NGB	29-Jul-94	Undefined	425	This design provides construction details for both a 26-foot X 66-foot ECM and a 30-foot by 60-foot ECM containing 5 barricaded cells. The design was approved under Site Plan NGB Des Moines ANG 91-S1 thru S6.	4
Magazine design designated by AF-NGB as ANG-DWG-94-002	N/A	RC Arch	AF-NGB	29-Jul-94	Undefined	425	This is a 40 foot X 80 foot ECM containing 8 barricaded cells. The design was approved under Site Plan ANGRD-Dannelly-93-S1 thru S7.	4
Magazine design designated by AF-NGB as ANG-DWG-96-001	N/A	RC Arch	AF-NGB	23-Dec-96	Undefined	425	This is a 40 foot X 80 foot ECM containing 8 barricaded cells. AF-NGB has restricted this design from new construction.	4
Magazine design designated by AF-NGB as ANG-DWG-99-001	N/A	Steel Arch	AF-NGB	13-Sep-99	Undefined	425	This is a 26 foot X 60 foot ECM containing 3 barricaded cells.	4
Magazine design designated by AF-NGB as ANG-DWG-00-001	N/A	Steel Arch	AF-NGB	30-Sep-02	Undefined	425	This is a 26 foot X 60 foot ECM containing 4 barricaded cells.	4
Blasting Cap Carrying Box	UNK	Metal box	NRL-USRD	12-Mar-92	AG	N/A	Capable of fully containing effects from initiation of up to five blasting caps. The ESQD is 0 feet when the container is closed.	
Class 5 Mosler Security Container	N/A	High security, heavy duty, file cabinet	NCEL	23-Feb-93	AG	0.3	This container is approved for full containment of an internal explosion involving up to 0.3 pounds NEW of HD 1.1. Approval is based on the condition that the cabinets being used are equivalent in strength to the Mosler safe design that was evaluated by NCEL in 1983.	

**TABLE AP1-4. MAGAZINES (EARTH-COVERED AND ABOVEGROUND) AND CONTAINERS WITH REDUCED NEWS AND/OR REDUCED QD
June 2004**

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	APPROVAL DATE	MAGAZINE DESIGNATION	MAGAZINE MCE (pounds of HD 1.1)	COMMENTS:	NOTES:
CONEX, HAZMAT, MILVAN, AND ISO CONTAINER STORAGE	N/A	Metal box	USADAC &USABRL	6 Feb 92, mod 6 May 96	AG	500	Approved for storage of bulk explosives and demolition charge material (i.e.composition C-4, TNT, etc.) and select HD 1.3 and 1.4 materials. If conditions are met, a 360-foot ESQD is permitted.	5
Use of Shipping Containers as ECM	N/A	Metal box, earth- covered	USADAC & Huntsville COE	22-May-95	Undefined ECM	4,000 kg/8,800 lbs NEW	Concept for converting shipping containers (e.g., MILVANs and ISO) into undefined ECM was evaluated. Since the skin of the container cannot support 2 feet of earth cover, three alternate methods are identified in USADACS memo SMAC-EST (385[A]) dated 10 Feb 1995, subject: Analysis of Earth Covered Shipping Containers as Earth-Covered Magazines (ECM), for providing the required earth cover on and around the container. No reduction in QD is permitted.	
Container Blasting Cap: MK-663 MOD 0	5206195 thru 520620	Schedule 40 Steel Pipe, 4 1/2-inch OD by 8 1/2- inch long	NAVSEA SYSCOM	DOT approved 29 March 2004	AG	5 grams (0.011 lbs.)	Refer to DOT-E 9571 Third Revision), dated 29 March 2002, which expires 30 Nov 2005. When packed in this container, explosives can be shipped essentially without regulation.	
Explosive Ordnance Disposal Ready Service Locker (EODRSL)	NAWS China Lake Drawings 104- 001 through 104-004	Metal box	Navy	27-Mar-98	AG	0.625	This design was developed by NAWC Weapons Division, China Lake. It uses a modified off-the-shelf Sam Nally magazine to provide additional venting and seven special pumice-lined containers to limit the MCE in the magazine to 0.625 pounds NEW. A 30-foot clear area is required around the EODRSL, within which no permanent personnel are permitted. NAWC China Lake Test Report NAWCWPNs TM 7979 defines all conditions and modifications associated with use of the EODRSL. On 25 Oct 2000, the DDESB approved the addition of an eighth pumice-lined container for the storage of no more than 10 explosives-loaded enhanced 1.5 liter Mineral Water Bottle (MWB) tubes and/or standard 1.2 liter MWB tubes. The MCE remains unchanged.	
Advanced EOD Magazine	ARMAG Corporation Drawing 72000 (21 sheets)	Metal box	Navy	27-Feb-01	AG	1.25	This design was developed by NAWC Weapons Division, China Lake, for Air Force EOD, which had a need for a deployable explosives storage magazine with a minimal ESQD. This design uses a modified off-the-shelf ARMAG Corporation magazine to provide additional venting and 17 special pumice-lined containers (for storage of HD 1.1 and 1.3 AE) to limit the MCE in the magazine to 1.25 pounds NEW of C-4. HD 1.4 items are stored within metal containers on the internal expanded metal shelves. The maximum NEW permitted in the magazine is 128.24 pounds. An Air Force EOD kit contains approximately 254 pounds NEW, therefore two of these magazines are required to hold the EOD kit. A 10-foot clear area is required around the Advanced EOD Magazine, within which no permanent personnel are permitted. NAWC China Lake Test Report NAWCWD TM 8331 defines all conditions and modifications associated with use of the Advanced EOD Magazine.	
Explosives storage building	N/A	RC Box	COE	10-Sep-93	AG	50	Approved for 1.1 and 1.3 bulk explosives and HD 1.4 ammunition. The ESQD is 147 feet and is based on overpressure (K40) only. A front barricade is required to stop the structures front panel and door.	
Explosives storage building	N/A	RC Box	COE	10-Sep-93	AG	100	Approved for HD 1.1 and 1.3 bulk explosives and HD 1.4 ammunition. The ESQD is 186 feet and is based on overpressure (K40) only. A front barricade is required to stop the structures front panel and door.	
Explosives storage building	N/A	RC Box	COE	10-Sep-93	AG	200	Approved for HD 1.1 and 1.3 bulk explosives and HD 1.4 ammunition. The ESQD is 234 feet and is based on overpressure (K40) only. A front barricade is required to stop the structures front panel and door.	
Explosives storage building	N/A	RC Box	COE	10-Sep-93	AG	300	Approved for HD 1.1 and 1.3 bulk explosives and HD 1.4 ammunition. The ESQD is 268 feet and is based on overpressure (K40) only. A front barricade is required to stop the structures front panel and door.	

**TABLE AP1-4. MAGAZINES (EARTH-COVERED AND ABOVEGROUND) AND CONTAINERS WITH REDUCED NEWS AND/OR REDUCED QD
June 2004**

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	APPROVAL DATE	MAGAZINE DESIGNATION	MAGAZINE MCE (pounds of HD 1.1)	COMMENTS:	NOTES:
2-Bay Explosives Storage building	N/A	RC Box	NCEL	1988 (undated memo)	ECM	250	This design, as described in NCEL TM 51-86-27, Basis of Design for PE 500R, Ammunition Magazine Mountain Warfare Training Center, Bridgeport, CA, is for a two bay ECM that is front barricaded. The MCE is 250 lbs HD 1.1 (lightly cased), the contents of one bay, since IMD is met between bays. The allowable QD with a front barricade is 320 feet. If the front barricade is not provided, the frontal QD will comply with DoD 6055.9-STD criteria.	
GOLAN 5 Protectainer	N/A	Metal cylindrical vessel with elliptical heads, both ends	Israeli company (see comments)	02-Oct-02	AG	11 lbs TNT Equivalent material	Refer to the DDESB approval memo for restrictions and conditions associated with the use of the GOLAN 5. Manufactured by Koors Metals Ltd of Israel. The U.S. distributor is Mistral Security, Inc. NAVFACENGCOM maintains the design drawings and specifications for this container. The GOLAN 5 Protectainer is designed to contain/limit explosion effects from an internal detonation of 11 lbs (5 kg) TNT equivalent explosives. It has an internal fragment defeating liner, but it has munition diameter limitations associated with it. Internal pressures are vented slowly through 2 vents in the bottom and around the door. The reduced QD are 30 feet IBD, 20 feet PTRD, and 10 feet ILD. IMD requirements provided by DDESB memo.	6
GOLAN 10 Protectainer	N/A	Metal cylindrical vessel with elliptical heads, both ends	Israeli company (see comments)	09-Jun-04	AG	23 lbs	Refer to the DDESB approval memo for restrictions and conditions associated with the use of the GOLAN 10. Manufactured by Koors Metals Ltd of Israel. The U.S. distributor is Mistral Security, Inc. NAVFACENGCOM maintains the design drawings and specifications for this container. The GOLAN 10 Protectainer is designed to contain/limit explosion effects from an internal detonation of 23 lbs (10.43 kg). It has an optional internal fragment defeating liner, but it has munition diameter limitations associated with it. Internal pressures are vented slowly through a small vent in the bottom and around the door. Previously, required QD were 30 feet IBD, 20 feet PTRD, and 10 feet ILD. Based on subsequent testing, the DDESB approved reduced QD of 3 feet IBD, PTRD, and ILD. IMD requirements are provided by DDESB memo.	6
NABCO SV-23	N/A	Metal cylindrical vessel with elliptical heads, both ends	NABCO, Inc.	21-Dec-01	AG	22	Refer to the DDESB approval memo for restrictions and conditions associated with the use of the NABCO SV-23. Manufactured by NABCO, Inc., of Pittsburgh, PA. The SV-23 is designed to contain/limit explosion effects from an internal detonation of 23 lbs NEW of HD 1.1. The SV-23 is available in two models, one with a fragment defeating liner and one without. Both designs have munition diameter limitations associated with them. Internal pressures are vented slowly through 2 vents in the top and around the door. The reduced QD are 5 feet IBD, 5 feet PTRD, and 2 feet ILD. IMD requirements provided by DDESB memo.	7
NABCO SV-23 (Increased NEW)	N/A	Metal cylindrical vessel with elliptical heads, both ends	NABCO, Inc.	10-Apr-03	AG	32	Through additional testing, NABCO, Inc. demonstrated that the SV-23 had the capability to contain explosion effects from 32 lbs (plus a 25% additional test charge). Based on the results of testing, the DDESB approved the SV-23 for a larger NEW quantity. QD were modified accordingly. Refer to the DDESB approval memo for restrictions and conditions associated with the use of the NABCO SV-23 for storage of explosives quantities up to 32 lbs NEW. The reduced QD are 15 feet IBD, 15 feet PTRD, and 5 feet ILD. IMD requirements provided by DDESB memo.	7
NABCO SV-50	N/A	Metal cylindrical vessel with elliptical heads, both ends	NABCO, Inc.	16-Apr-04	AG	50	Refer to the DDESB approval memo for restrictions and conditions associated with the use of the NABCO SV-50. Manufactured by NABCO, Inc., of Pittsburgh, PA. The SV-50 is designed to contain/limit explosion effects from an internal detonation of 50 lbs NEW of HD 1.1. The design has munition diameter limitations associated with it. Internal pressures are vented slowly through 2 vents in the top and around the door. The reduced IBD and PTR are 20 feet to the front and sides, which transitions to a 5-foot IBD and PTRD to the rear. IMD requirements provided by DDESB memo.	7

**TABLE AP1-4. MAGAZINES (EARTH-COVERED AND ABOVEGROUND) AND CONTAINERS WITH REDUCED NEWS AND/OR REDUCED QD
June 2004**

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	APPROVAL DATE	MAGAZINE DESIGNATION	MAGAZINE MCE (pounds of HD 1.1)	COMMENTS:	NOTES:
NABCO Portable Total Containment Vessel (PTCV)	N/A	Metal cylindrical vessel with elliptical heads, both ends	NABCO, Inc.	18-Jun-04	AG	2.25	Refer to the DDESB approval memo for restrictions and conditions associated with the use of the NABCO PTCV. Manufactured by NABCO, Inc., of Pittsburgh, PA. The PTCV is a dual-vessel containment system approved for containment of an internal detonation of 2.25 lbs NEW of non-primary fragment producing HD 1.1 (e.g., bulk explosives). After explosives are placed into the PTCV, a lever attached inner vessel is rotated 180 degrees in order to seal off the opening. Pressures from an internal detonation are slowly released fro around the door seal. The IBD, PTR, ILD, and IMD is 3 feet.	
Military Working Dog Training Aids Storage ECM	N/A	Metal box in an earth-covered RC box	NFESC	08-May-91	Undefined	17.9	This ECM has a reduced QD of 105 feet (maximum fragment throw). Two storage concepts were approved and these are described in NCEL TM Number 51-91-03. Default distances apply if a front barricade is not provided.	8
Modular Ready Magazine (MRM)	UNK	RC Box, with internal non-propagating walls	NFESC	31-Jul-97	Undefined	500	The allowable NEW for each of the five bays in the MRM is 500 pounds HD 1.1. The internal non-propagating walls limit the MCE to 500 pounds NEW. The ESQD associated with this ECM design is 1,250 out the front and 700 feet for the sides and rear. Constructed at MCAS Kaneohe Bay.	9
Prosser/Enpo Containment Magazine	UNK	Metal box	AF	01-May-89	AG	N/A	An aboveground metal magazine capable of completely containing fragments from an explosion involving up to 1,000 DUPONT E-117 detonators when stored in the defined configuration. The ESQD is based on blast only. Use of this magazine was approve for a DCMA contractor who was unable to meet a 670-foot ESQD requirement.	
Protectainer Model DROR 1	N/A	Metal box	Israeli company (see comments)	25-Jun-98	AG	1.1	Manufactured by Koors Metals Ltd of Israel. The U.S. distributor is Mistral Security, Inc. Called the Protectainer Model DROR-1 and is designed to fully contain the hazardous effects from the detonation of 1.1 pounds HD 1.1. Approved by the DDESB on a site approval for Building 568, Room 8, at Fort Detrick, MD (U.S. Army Technical Center for Explosives Safety, SIOAC-EST File Number 1258), and on a site approval for the TAIL Laboratory at the Detroit Arsenal (approval dated 18 Nov 99). Contact U.S. Army TCES for information. The ESQD for this container was specifically defined by the approval letters for the rooms they were sited in.	
Ready Service Magazine (C-2748)	22-Jun-87	RC Box	MCLB Albany	10-Apr-87	Undefined	20	Constructed at Marine Corps Logistics Base, Albany, GA, in accordance with local Drawing C-2748. ECM has internal dimensions of 5-foot square. A front barricade is required for application of a reduced ESQD. The ESQD is 110 feet, and PTRD is 65 feet. Explosives must be kept a minimum of 1-foot from walls and ceiling.	
Ready Storage Magazine for various grenades in pumice-filled containers	N/A	Metal box	Navy	08-Apr-93	AG	One grenade	This aboveground magazine was developed for storage of 40mm M433 HEDP Grenades, M67 Fragmentation Grenades, and MK3A2 offensive hand grenades in specially-designed pumice-filled containers, placed inside a specific, modified Sam Nally magazine. Conditions of 8 Apr 93 DDESB letter must be met. NAWC-WPNS TM 7263, dated February 1992, provides test and design criteria for the pumice containers and the magazine. Maximum credible event is one grenade. The grenade containing the largest NEW is the MK3A2 which contains 0.5 pounds of explosives. The ESQD for this magazine is 0 feet.	
Shipping Container for Transportation of Small Samples of Dry Primary Explosives	N/A	6-inch X 12 to 14-inch Schedule 80 Seamless Pipe with 6-inch dia. Malleable iron end caps	NAVSEA SYSCOM	DOT approved 3 March 2004	AG	25 grams (0.055 lbs.)	This shipping container is rated for explosive or pyrotechnic material, including waste containing explosives that has energy density not significantly greater than that of pentaerythritol tetranitrate. Refer to DOT-E 8451, dated 3 March 2004, which expires 31 Jan 2006. When packed in this container, treat contents as 1.4E.	

**TABLE AP1-4. MAGAZINES (EARTH-COVERED AND ABOVEGROUND) AND CONTAINERS WITH REDUCED NEWS AND/OR REDUCED QD
June 2004**

DRAWING NO. (NOTE 1)	DRAWING DATE	DESCRIPTION	DESIGNER	APPROVAL DATE	MAGAZINE DESIGNATION	MAGAZINE MCE (pounds of HD 1.1)	COMMENTS:	NOTES:
Shipping Container for Transportation of Small Samples of Dry Primary Explosives	N/A	4-inch X 14-inch Schedule 80 Seamless Pipe with 4-inch dia. forged steel end caps	NAVSEA SYSCOM	DOT approved 3 March 2004	AG	25 grams (0.055 lbs.)	This shipping container is rated for explosive or pyrotechnic material, including waste containing explosives that has energy density not significantly greater than that of pentaerythritol tetranitrate. Refer to DOT-E 8451, dated 3 March 2004, which expires 31 Jan 2006. When packed in this container, treat contents as 1.4E.	
Shipping Container for Transportation of Small Samples of Dry Primary Explosives	N/A	Metal box	Los Alamos National Laboratory	DOT approved 3 March 2004	AG	15 grams (0.033 lbs.)	Model LD-1000 explosive or pyrotechnic material, including waste containing explosives that has energy density not significantly greater than that of pentaerythritol tetranitrate. Refer to DOT-E 8451, dated 3 March 2004, which expires 31 Jan 2006. When packed in this container, treat contents as 1.4E.	10
Shipping Container for Transportation of Small Samples of Dry Primary Explosives	N/A	Metal box	Los Alamos National Laboratory	DOT approved 3 March 2004	AG	25 grams (0.055 lbs.)	Model LD-2250 rated for explosive or pyrotechnic material, including waste containing explosives that has energy density not significantly greater than that of pentaerythritol tetranitrate. Refer to DOT-E 8451, dated 3 March 2004, which expires 31 Jan 2006. When packed in this container, treat contents as 1.4E.	10
Shipping Container for Transportation of Small Samples of Dry Primary Explosives	N/A	Metal box	UNK	DOT approved 3 March 2004	AG	25 grams (0.055 lbs.)	Rated for explosive or pyrotechnic material, including waste containing explosives that has energy density not significantly greater than that of pentaerythritol tetranitrate. Refer to DOT-E 8451, dated 3 March 2004, which expires 31 Jan 2006. When packed in this container, treat contents as 1.4E.	11
Small Explosives Magazine, TYPE I	91-11-1F through 91-11-3F	Metal box	NFESC	12-Mar-92	AG	1	The ESQD is 20 feet. Intraline distance is 12 feet. Operational requirements are contained in NCEL TM M-51-91-07, dated Feb 91.	
Explosive Containment Device (ECD)	Covered by U.S. Patent 6,196,107 B1	Metal Box filled with rigid polyurethane foam	NSWC Carderock Division	Patent approval - 6 Mar 2001	AG	5 lbs TNT	The ECD measures roughly 78 inches long x 48 inches high X 34 inches wide. Designed to fully contain an explosives event involving up to 5 lbs. TNT or equivalent. Initially designed for the FAA as a bomb containment vessel to complement lugagae screening operations, it is suitable for other applications as well. A paper on the ECD was given at the 26th DDESB Seminar in Orlando, FL. The DDESB is currently awaiting the documentation package for review.	
Non-Propagating Explosives Storage Cabinet	N/A	RC Box, earth-covered	Sandia National Laboratory	UNK	ECM	5 lbs TNT	Sandia National Laboratories (SNL), Albuquerque, working with New Mexico Engineering Research Institute (NMERI), developed a design for a non-propagating explosives storage cabinet capable of preventing propagation to an adjacent cabinet for 5 lbs TNT. The design was to be incorporated into ECM housing 20 such cabinets (2 rows with 10 back-to-back) with the MCE remaining 5 lbs NEW. A maze is provided to stop the door and other debris and to attenuate blast effects. A description of the development program and testing results can be found in Sandia Report SAND90-1906, dated August 1991, "Development of a Non-Propagating Explosives Storage Cabinet." Due to insufficient data, the default QD will need to be used, until such time as additional information is made available.	
Spherical Shields	N/A	Metal containers of various shapes and dimensions	Edgewood Arsenal	See Comments	AG	See Comments	A suppressive shield is a vented, steel enclosure, which is capable of controlling or confining the hazardous blast, fragment, and flame effects of internal detonations. There are 8 Groups of suppressive shields that have been developed and approved by the DDESB, and these are described in paragraph 6.3. Allowable NEWS range from 2,000 lbs to approximately 1 lb. Some of these shields, such as the Group 6A and 6B, will provide full containment of effects, while others had specific goals of providing very high levels of personnel protection at less than the required default separation distances.	

Notes accompanying Table AP1-4:

1. Each line represents a separate magazine design. Where UNK appears in the table, it indicates that no information was found for that particular entry.
2. The ECM's shell is constructed of 8-inch thick RC. A 1/4-inch thick steel magazine with wood lining is placed inside the RC shell. The ECM must have 38-inches of earth cover, and the sides of the earth cover must have a 2:1 slope. Explosives must be stored two feet from the magazine walls. The ECM has a reduced IBD arc of 92 feet and a PTRD arc of 55 feet. A front barricade is required.
3. Approved for up to 450 pounds NEW HD 1.1. An IBS arc of 250 feet applies to the sides of these ECM. A 700-foot IBD arc applies to the front sector of these ECM, with one exception. When the MCE is 150 pounds of HD 1.1 or less, a 500-foot IBD arc can be used from the front sector of these ECM. The front sector of the ECM is defined by angles of plus and minus 15 degrees, drawn normal to the door.
4. Approved for a maximum of 425 pounds NEW HD 1.1 of Sensitivity Group (SG) 1 through 4 per cell as permitted by DDESB-KT memo of 30 September 2002, subject: Approval of Multi-Barricaded Storage Cell, Magazine Design ANG-DWG-00-001. The conditions and restrictions established for ANG-DWG-00-001 also apply to ANG-DWG-94-001, ANG-DWG-94-002, ANG-DWG-96-001, and ANG-DWG-99-001, ANG-DWG-00-001. Those designs all have layouts that provide for multiple internal cells, separated by sand-filled (2.5 feet sand thickness) Styrofoam walls (Blast Tamer). Those internal walls prevent prompt propagation thereby allowing the ECM's MCE to remain the largest explosive quantity in one cell, not to exceed 425 lbs. An IBD arc of 250 feet applies from the sides of these ECM. A 700-foot IBD arc applies from the front sector of these ECM, with one exception. When the MCE is 150 pounds of HD 1.1 or less, a 500-foot IBD arc can be used from the front sector of these ECM. The front sector of the ECM is defined by angles of plus and minus 15 degrees, drawn normal to the door. When SG 5 munitions are placed inside any cell, a minimum of 3 feet of sand is required to separate the SG 5 from munitions in adjacent cells. A layer of sandbags can be used to augment the existing Blast Tamer wall in order to obtain the additional sand thickness requirement.
5. The concept for using a container express (CONEX) container, as an explosives storage container for certain mixed munitions, is described in Quickload Program Technical Data Package (TDP), dated 25 Nov 91, and was issued by the U.S. Army Ballistic Research Laboratory, Aberdeen Proving Grounds, MD. The TDP lists the specific item that can be stored in these containers. Use of a sandbag barricade between CONEX containers allows them to be stored at IMD of 8 feet, allowing the MCE and QD to be based on a single container. Subsequently, DDESB approval was obtained to permit storage of these same AE items in hazardous material (HAZMAT) containers, Military-owned Demountable Containers (MILVAN), and International Organization for Standardization (ISO) containers. Specific container dimensions apply to the approval and must be met. CONEX containers shall have internal

dimensions of 92" long by 72" wide by 70" high, 0.125" thick corrugated steel walls and floor. HAZMAT containers shall have internal dimensions of 222" long by 126" wide by 84" high, 0.100" thick corrugated steel floor and 0.125 thick epoxy-coated plywood deck. MILVAN containers shall have internal dimensions of 232" long by 90" wide by 85" high, 0.0787" thick corrugated steel walls and a hardwood floor. ISO containers shall have internal dimensions of 231" long by 92" wide by 92" high, 0.0787" thick corrugated steel walls and a hardwood floor.

6. The GOLAN 5 and 10, manufactured by Mistral Security, Inc., are approved for storage of fragmenting munitions with diameters up to 1.6 inches (40mm) and explosives materials weighing up to 11 lbs TNT equivalent explosives (Golan 5) and 23 pounds NEW (Golan 10). The use of NEW with the Golan 10 is intentional and results from testing at 125% of the rated TNT equivalence capacity of 23 lbs, with minimal damage to the container. A minimum internal standoff for explosives from the nearest inside wall apply (19 inches for the GOLAN 5 and 23 inches for the GOLAN 10). The minimum IMD from a GOLAN container to another exposed explosives site (acting as an ES) is based on K1.25. The minimum IMD from any PES that does not totally contain blast hazards to an ES Golan container shall be based on K6. Use of these containers will be in accordance with DDESB approval memorandums. For the Golan 5, DDESB-KT memorandum of 2 October 2002 applies to its use, while for the Goal 10, DDESB-KT memorandum of 9 June 2004 governs its use.
7. The SV-23, increased NEW SV-32, and SV-50, manufactured by NABCO Inc., are approved for storage of fragmenting munitions with diameters up to 1.6 inches (40mm) and explosives materials weighing up to 23, 32, and 50 pounds NEW, respectively. A minimum internal standoff distance for explosives separation from the nearest inside wall is required (24 inches for the SV-23, and 30 inches for the increased NEW SV-23 and SV-50). Refer to DDESB approval memorandum for specific requirements for each SV version.
8. Two storage concepts have been approved. The first storage concept consists of 12-inch reinforced masonry walls with a RC roof and floor slab and 3 feet of earth cover. A metal storage locker is located within the cavity. The second storage concept uses railroad ties to form the walls and roof of the structure. Three feet of earth are required on top of this structure. A metal storage locker is located within the cavity. A front barricade is needed with both concepts.
9. The MRM is a five-cell ECM designed to store one, loaded AERO 51 trailer in each cell. The only ordnance items permitted within the cells are MK50 Torpedoes; GM Tactical Penguin; Sonobuoy HE, SSQ-110; GM Tactical Maverick; Bomb, GP MK 82; Bomb, GP MK 83; Bomb, Rockeye MK 20; MK 46 Torpedo (MK 103 Warhead); and GM Tactical Harpoon Missile. Other limitations are: the maximum height from the floor of any ordnance item is 6.5 feet; a 1.5-foot separation distance is required between weapon and walls; a stand-off of 1-foot is required from the floor; bombs cannot be fuzed while in MRM storage; and the Maverick and MK 50 Torpedo

(directed energy weapons) must be oriented so that their directed effects are towards the front or back wall of the MRM. The BOD of the MRM, constructed at Marine Corps Air Station (MCAS) Kaneohe, HI, is found in NFESC Technical Report TR-2056-SHR, May 96.

10. Construction of Models LD-1000 and LD-2250 is described in "Shipping Containers for Small Samples of High Explosives" by Richard A. Hildner and Manuel J. Urizar, Los Alamos National Laboratory Report No. LA-9107-MS/UC-71, Hercules Incorporated's application, dated January 14, 1993.
11. Construction of this shipping container is described in "Handling Procedures and Design of a Shipping Container for Transportation of Small Samples of Dry Primary Explosives" by Harold K.H. Bartles, presented at the 12th Symposium of Explosives and Pyrotechnics on March 13, 1984 in San Diego, CA.

AP2. APPENDIX 2
OPERATIONAL FIELD STORAGE

- IN PROGRESS -

LAST PAGE