

# Development and Technical Bases of U. S. Department of Defense Intermagazine Distances to Earth Covered Magazines

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# Presentation Outline

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- Introduction
- Lake Denmark accident
- Introduction of explosives safety requirements
- Siting of (arch-type) Earth Covered Magazine (ECM) designs during WWII
- 1945-46 full-scale detonation tests of arch-type ECMs, Naval Proving Grounds, Arco, ID
- 1963 full-scale detonation test of corrugated steel arch ECM design prototype, China Lake, CA
- 1971 ESKIMO test of corrugated steel arch ECM design, China Lake, CA
- Siting of legacy standard/7-bar (arch-type) ECMs - 1974 to present



# Introduction and Terminology

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## Introduction

- Most ECMs currently in use by the Services were constructed during the WWII/Korean War era.
- The introduction of 7-bar, 3-bar and undefined ECM definitions and siting requirements in 1997 has caused considerable confusion over minimum protection requirements to acceptor AE in these older, legacy ECMs.
- This presentation reviews the development of the Intermagazine Distances (IMDs) applied to legacy ECM and reviews the protection criteria upon which they're based.

**Terminology** – DWESB's name has varied over the years.

- Joint Army-Navy Ammunition Storage Board (1928-1945)
- Army-Navy Explosives Safety Board (1945-1948)
- Armed Services Explosives Safety Board (1948-1971)
- Department of Defense Explosives Safety Board (1971-2025)<sub>3</sub>



# Terminology

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DESR 6055.09, “DoD Explosives Safety Standards,” 25 Nov 2025 (current version) – Previous iterations of this document.

- “Quantity-Distance Standards for Manufacturing, Handling and Storage of Mass-Detonating Explosives and Ammunition”
  - DoD Directive 4145.17 – 7 Dec 1956
  - DoD Instruction 4145.23 – 11 Mar 1966
- “DoD Ammunition and Explosives Safety Standards”
  - DoD Manual 4145.27 – Mar 1969
  - DoD 5154.4S – Jul 1974
  - DoD 6055.09-STD – Jul 1984 through 29 Feb 2008
  - DoD Manual 6055.09 – 4 Aug 2010 through 29 Dec 2017
- Defense Explosives Safety Regulation (DESR) 6055.09 – 13 Jan 2019 to present



# 1926 Lake Denmark Naval Storage Depot Accident



- Over a 30-minute period, a fire from a lightning strike led to detonations in a storage magazine which propagated to another storage building and to a shell house.
- Each building contained large quantities of AE (WWI surplus)



# 1926 Lake Denmark Naval Storage Depot Accident



DEVASTATION. After the explosion, a lone Marine stands guard where the gates to the U.S. Naval Powder Depot once stood. Only several telephone poles survived the blast. Everything else was destroyed by the series of explosions, fires, and shock waves that bounced from hill to hill, leveling most buildings at the depot and arsenal. (U.S. Army Photograph-Picatinny Arsenal.)

- Smaller propagations/fires continued for three days.
- Approx. 200 buildings were destroyed, including 53 AE storage buildings – 10 for HD 1.1 AE, 19 for smokeless powder, 13 for projectiles, and 11 for black powder.
- 21 deaths (lightning strike Sat. at 5:15 p.m.; minimal staff)



# Introduction of Explosives Safety Requirements

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- In response to the Lake Denmark accident, a Special House Subcommittee on Ammunition Storage was established; it directed the Army and Navy to conduct a joint survey of their points of storage of ammunition and components.
- Based on the survey's recommendations, an act of Congress was approved on May 29, 1928.
  - Adopted the laws of the state of New Jersey, which incorporated the "American Table of Distances" (ATD), as the standard of safety for Army and Navy AE storage.
  - Directed the establishment of a joint Army-Navy Board which shall keep advised of storage supplies of ammunition and components with special reference to:
    - Keeping such supplies properly dispersed and stored.
    - Preventing hazardous conditions from arising to endanger life and property within and without storage reservations.



# Pre-WWII Magazine Siting IAW ATD/NJ Laws

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- Magazine defined as “...any building or other structure, other than a factory building, used for the storage of explosives.”
- Defines two classes of magazines, both of which “shall be constructed of brick, concrete, iron or wood with outside covering of iron...”
- In addition, first class magazines “...shall have openings only for ventilation and entrance...” and ventilation openings must be screened to prevent entrance of fire sparks.
- HD 1.1 storage limits: 250,000 lbs. in a “first class magazine” and 50-lbs. in a “second class magazine.”
- Minimum Inter magazine Distance (IMD) between two first class magazines sited for HD 1.1 NEW limit is 800-ft.
- If an adequate artificial barricade is constructed between two first class magazines, the IMD may be reduced by one-half (or 400-ft for at 250,000 lb. storage limit).



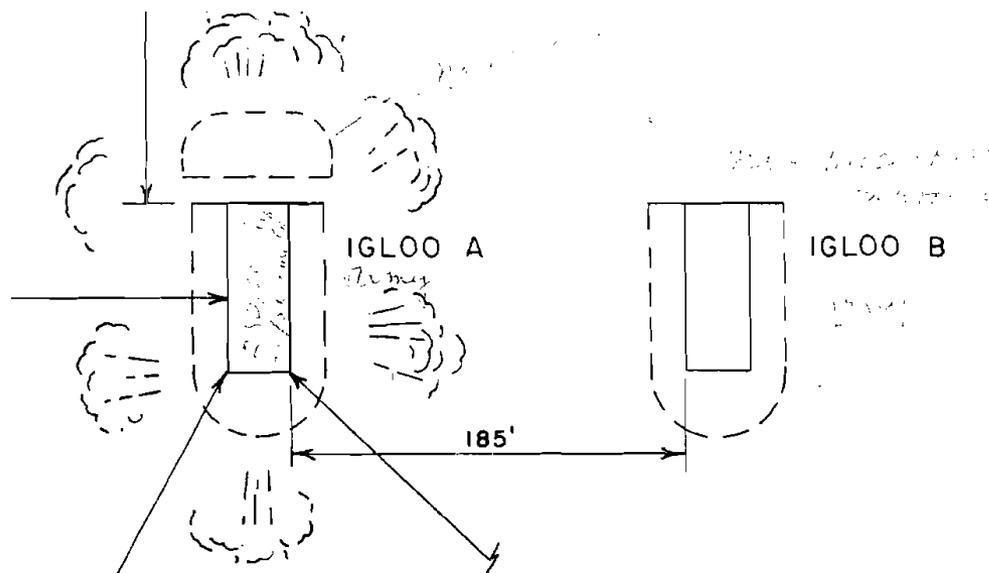
## Siting of Arch-Type ECMs in the 1940's

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- During 1930's, Services developed the first Earth-Covered Magazine (ECM) design concepts for AE storage.
- Rationale: For most exposures, the earth cover will provide an adequate artificial barricade between ECMs, allowing use of a 400-ft IMD.
- During WWII, DDESB and Services recognize the limited scope of the ATD/NJ laws, leading to an expansion in DDESB's mission.
- DDESB received authority to hire its first permanent technical staff in 1944.



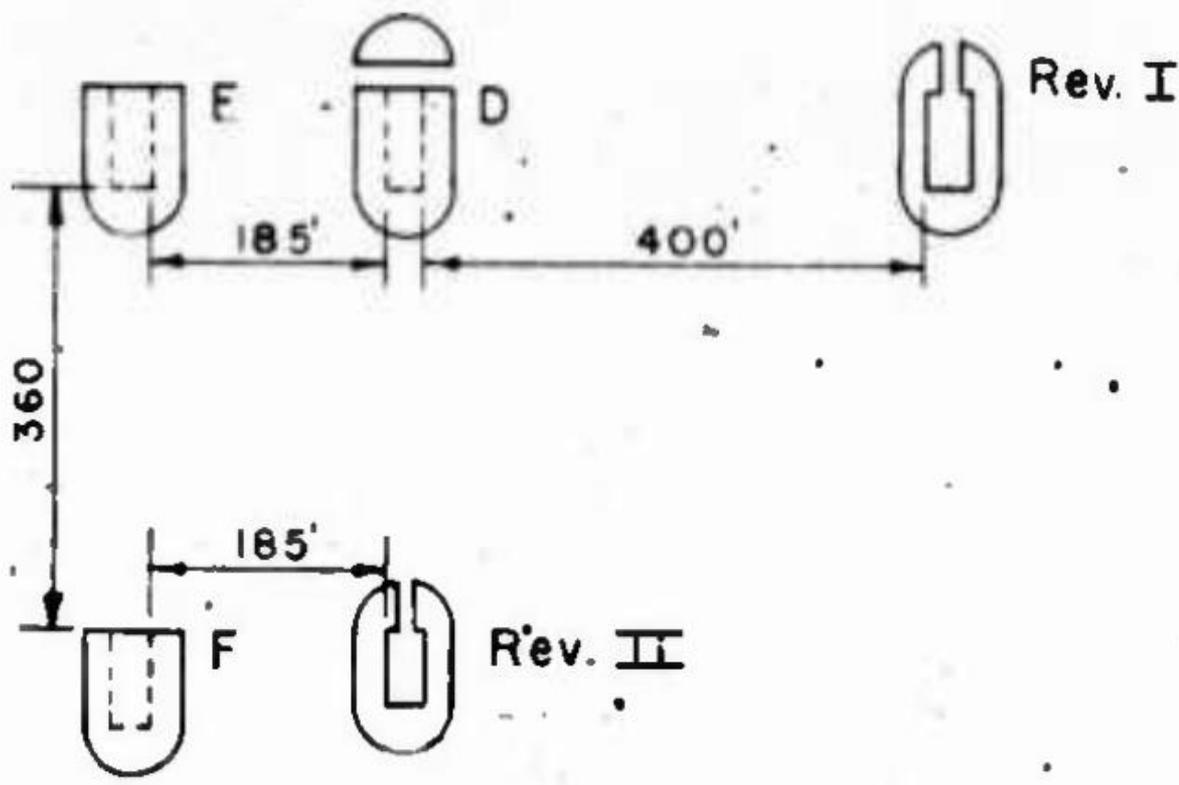
# 1945 Full-Scale Arch-Type ECM Detonation Tests



- Eight full-scale detonation tests were performed at Naval Proving Grounds, Arco, ID in 1945.
- Three tests evaluated the protection afforded acceptor AE in WWII arch-type ECM designs from a 250,000-lb HD 1.1 detonation in a donor ECM.
- The damage sustained by an Army standard series 652-686 through 652-692 ECM at a side-to-side IMD of 185-ft were minimal; no damage to acceptor AE.



# 1946 Full-scale Arch-Type ECM Detonation Tests



IGLOO & REVETMENT AREA

Based on the results of the 1945 tests, six full-scale detonation tests were performed at Arco NPG in 1946.



# 1946 Full-scale Arch Type ECM Detonation Tests

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- 500,000-lb detonation test with donor AE in ECM “D” were used to evaluate the protection afforded acceptor AE in ECM “E” (at side-to-side IMD of 185-ft)
- Fine cracks in arch barrel and rear wall; no arch debris reported.
- Circumferential joint between arch barrel and headwall ruptured with much spalling.
- Main cracks in headwall went through from inside to out and were open to about ½-inch
- Single-leaf door deflected outward at center about 7/16-inch but remained operable.
- No damage or displacement of acceptor munitions.



# 1946 Full-scale Arch-Type ECM Detonation Tests

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- 500,000-lb detonation in ECMs “D” and “E” used to evaluate the protection afforded acceptor AE in ECM “F” (rear to front IMDs of 400-ft and 360-ft).
- Damage from 2 detonations:
  - Headwall cracking; fragments from donor ECM impacted headwall but were defeated.
  - Headwall deflected outward approx. 2-inches, creating gap with floor slab.
  - Vertical pilasters experienced severe spalling.
  - Door and frame bent inward slightly but remained operational
  - No appreciable damage to rest of ECM.
  - No damage or displacement of acceptor bombs.



# Implementation of 1945-46 Arco NPG Test Results

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- **US Attorney General Opinion (27 Oct 1949):** The Board in the execution of its statutory duties “...had the authority to establish safety standards and has the authority now to make changes therein...”; these standards “...must be considered binding, but only as minimum safety standards.”
- **DoD Directive 4145.17 (7 Dec 1956)**
  - Defines four categories of ECMs and defines HD 1.1 storage limits and minimum IMD requirements for each.
  - “Standard Igloo Magazine” category applied to ECMs which qualify for increased HD 1.1 NEW limits or reduced IMDs based on the 1945-46 ECM tests at Arco NPG.
  - Army standard series 652-686 through 652-692 ECM
    - IMDs: 185-ft (if barricaded) and 360-ft (if unbarricaded)
    - HD 1.1 storage limit: 500,000-lbs.



# 1962-63 Corrugated Steel Arch ECM Tests

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- Series of reduced-scale detonation tests performed on prototypes; one full-scale test used to validate the O.C.E. Specification 33-15-64-62 corrugated steel arch ECM design.
- Data from full-scale detonation test:
  - Donor NEW: 100,000-lbs Comp B
  - Damage primarily to double doors.
    - Acceptor ECM at K1.25 side to side: Both doors bowed leaves blown inward; one leaf remained attached to a door hinge/frame, the other leaf detached, falling immediately inside doorway; igloo floor randomly raised and lowered.
    - Acceptor ECM at K1.5 side to side: Both door leaves detached; one leaf fell immediately inside the doorway, the other leaf propelled 50-feet to the front of the ECM.
  - No initiation of acceptor AE in either ECM.



# Siting of Corrugated Steel Arch ECMs

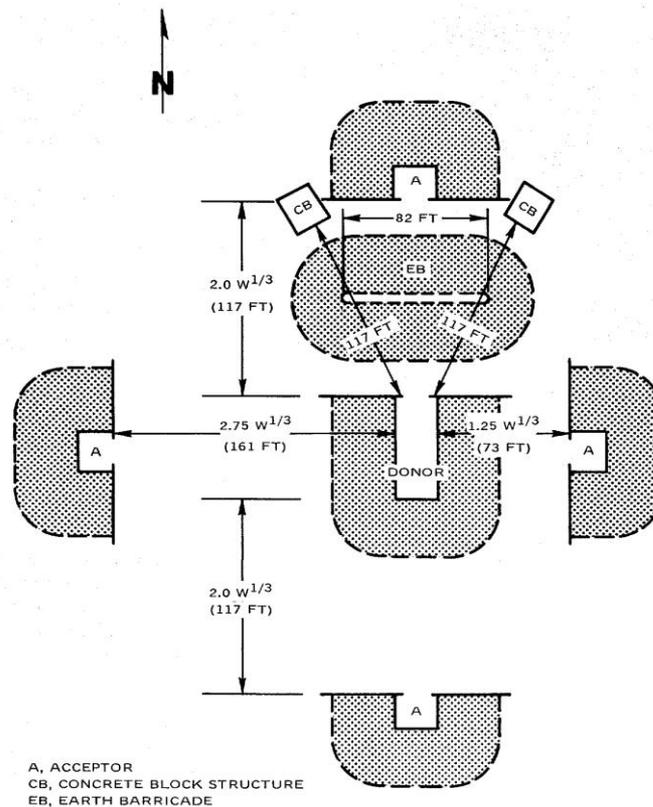
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## DoD Instruction 4145.22 (11 March 1966)

- Approved IMDs to selected corrugated steel arch ECM designs of K1.25 side to side; K1.5 rear-to-rear; K4.5 front to rear and K4.5 front to side.
- ***No rear to front IMD defined.***
- ***An important caveat: These criteria are only for prevention of propagation of explosions between adjacent steel arch magazines and will not necessarily prevent damage to acceptor magazines and their contents.***



# ESKIMO I Test (1971)



- The Explosives Safety Knowledge IMprovement Operation (ESKIMO) funded seven detonation tests of HD 1.1 ECM designs and design concepts between 1971 and 1986.
- All acceptor magazines were 33-15-64 corrugated steel arch ECMs with a shortened longitudinal arch length.



# Responses of North and South Acceptor ECMs



- Damage to acceptor ECM at K2 rear to front:
  - Both leaves of double doors forced inward
  - Earth cover from donor ECM thrown into ECM.
  - Cracking of concrete headwall, particularly around door frame.
  - Acceptor munitions somewhat damaged but did not initiate.
- Damage to acceptor ECM at front to front (with barricade) – Doors propelled violently inward; 4 acceptor munitions burned. <sup>18</sup>



# Introduction of Standard Arch-Type ECMs (1974)

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- ECMs reorganized into two categories – standard and nonstandard.
- More robust WWII-era designs – such as the Army standard series 652-686 through 652-692 ECM tested in 1945-46 at Arco NPG – became standard ECMs.
- IMDs to standard ECMs were based, in part, on the 1963 (full-scale) corrugated steel arch test and the 1971 ESKIMO I; these IMDs were later used when defining expected 7-bar, 3-bar and flat roof loads.
  - 7-bar load (K2 rear-to-front))
  - 3-bar load (K1.25 side to side)
  - Flat roof load (K2 front to rear)
- In 1997, legacy standard ECMs became 7-bar ECMs and nonstandard ECMs became undefined ECMs.
- IMDs to standard/7-bar ECMs have not changed since 1974.



## Transition to 7-bar/3-bar/Undefined ECMs (1997)

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- While both standard and 7-bar ECM designs must adequately reduce the risk of (prompt) propagation to acceptor AE, the specific performance requirements applied when siting these ECMs differ.
- Legacy (arch-type) ECM designs approved for standard/7-bar siting were validated through full-scale detonation tests.
- After ESKIMO I, there were sufficient blast load data to develop blast designs of critical ECM structural elements; full-scale ECM detonation tests continue to be used to validate protection from other hazards (e.g., hazardous fragments from a donor ECM).
- DDESB Board members recognized both approaches when voting to adopt 7-bar/3-bar/undefined IMDs, verifying that all legacy arch-type ECMs previously approved for siting as a standard ECM would qualify for siting as a 7-bar ECM.



# Siting of Legacy Arch-Type ECMs

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DESR 6055.09, section V1.E8.2.1.4.3. Earth-Covered Magazines (ECMs) – “...When separated from each other by the minimum distances required by Table V3.E3.T6, ECMs (as addresses in section V2.E5.5) provide virtually complete protection of AE against the propagation effects of an explosion. ***However, AE in adjacent ECMs may be damaged and structural damage ranging from cracks in concrete to damage to ventilators and doors to complete structural failure may occur.***” [emphasis added]



# Siting of Newer HD 1.1 ECM Designs

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[DESR 6055.09, section V2.E5.5. ECM.](#) An ECM's primary purpose is to protect AE. To qualify for the default IMD in Table V3.E3.T6, 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 door from striking the contents.