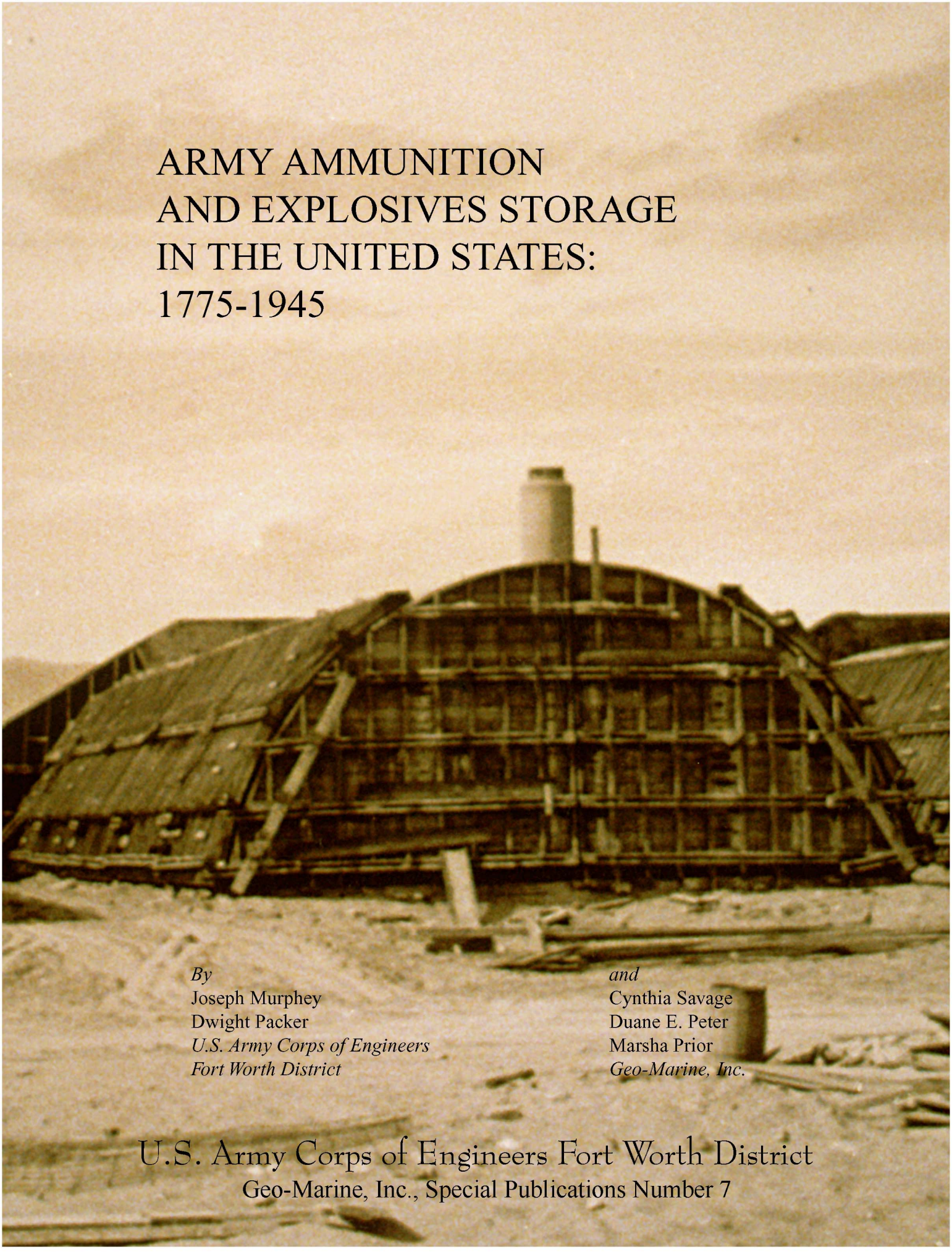
ARMY AMMUNITION AND EXPLOSIVES STORAGE IN THE UNITED STATES: 1775-1945



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This report presents a national historic context for World War II-era Army ammunition storage magazines. The objective of this document is to present the themes and events that influenced the construction, modification, and use of ammunition storage magazines during World War II and during the mobilization effort prior to this war. The historic context covers the evolution of ammunition storage magazines from 1775 to the present with particular attention given to the growing concerns for safety after the 1926 Lake Denmark explosion and the increased need to conserve material during World War II. In addition to the historic context, this document presents a Planning Level Survey in which a classification system for all ammunition storage magazines is presented and includes a discussion of National Register eligibility requirements. The most comprehensive array of ammunition storage magazines with the highest degree of integrity are found at Hawthorne Army Ammunition Plant (A.A.P.), Nevada; McAlester A.A.P., Oklahoma; Pine Bluff Arsenal, Arkansas; Ravenna A.A.P., Ohio; Blue Grass Army Depot, Kentucky; Louisiana A.A.P., Louisiana; Aberdeen Proving Ground, Maryland; Camp Stanley, Texas; and Cornhusker A.A.P., Nebraska.

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MANAGEMENT SUMMARY

This report provides a historic context for Army ammunition and explosives storage structures, usually referred to as magazines, in the continental United States. Although there are over 20,000 magazines within the Army real property inventory that were built between 1775 and 1945, these structures have been largely overlooked by cultural resource managers. This study conducted by the U.S. Army Corps of Engineers (USACE), Fort Worth District, and Geo-Marine, Inc., for the Army Environmental Center was designed to create a historic context in which both aboveground and underground magazines (igloos) could be evaluated. Recommendations concerning potentially significant examples of Army ammunition bunkers, including representation of each identified design type, were made.

The original archival and field investigations were conducted by the USACE, Fort Worth District. The archival research conducted at the Library of the Ordnance Museum, the National Archives, the Corps of Engineers Office of History, the Center for Military History, and the John Byrd Technical Library of the Defense Army Ammunition Center, documented that literature related to magazine design and technology is extremely rare. An oral history supplied by Dr. Chester E. Canada of the Department of Defense Explosives Safety Board provided the most useful information. Field investigations involved visits to Savanna Army Depot, Hawthorne Army Ammunition Plant, Picatinny Arsenal, and Frankford Arsenal.

The development of the context and analysis of the real property inventory revealed that ammunition magazines consist of a few basic types that are redundant in both design character and general layout when used in multiples (e.g., at depots). Aboveground magazines, designed for particular classes of ammunition are similar in design throughout the twentieth century. Earth-covered magazines, or igloos, were developed after the 1926 Lake Denmark disaster and became the standard for the storage of high explosives. Design changes were limited and many occurred in response to materiel shortages during World War II or in response to the storage needs of new weapons (chemical, biological, and nuclear). With only a few basic types and an abundance of examples, the preservation of every magazine or depot would be an unwise use of the limited funds available for cultural resource management. It is recommended that those installations with the most comprehensive array of the various magazine designs may be eligible for the National Register under this context. It is recommended that the following installations provide the most comprehensive array of both aboveground and underground magazines with a high degree of integrity: Hawthorne Army Ammunition Plant (A.A.P.), Nevada; McAlester A.A.P., Oklahoma; Pine Bluff Arsenal, Arkansas; Ravenna A.A.P., Ohio; Blue Grass Army Depot, Kentucky; Louisiana A.A.P., Louisiana; Aberdeen Proving Ground, Maryland; Camp Stanley, Texas; and Cornhusker A.A.P., Nebraska. Potentially eligible aboveground or underground magazines, with the exception of isolated structures, exist in groups that may constitute districts, which encompass a number of similar structures within their original setting. The exact number of structures may be arbitrarily defined; however, the number should be sufficient to

reflect the layout and infrastructure related to the function of the complex and the associated safety concerns. The highly redundant nature of these resources, however, and their evaluation within a national context precludes the preservation of all aboveground and underground storage facilities. Those installations not listed above, but which contain ammunition storage facilities (Appendix A) are considered to have lesser examples of ammunition storage facilities, and may be considered not eligible under this context. However, such property types, in rare instances may have had such an exceptional impact on a State or locality that they could be eligible for the National Register under other State or local themes.

TABLE OF CONTENTS

MANAGEMENT SUMMARY iii

INTRODUCTION TO THE NATIONAL HISTORIC CONTEXT FOR ARMY AMMUNITION AND EXPLOSIVES STORAGE IN THE UNITED STATES, 1775–1945 1
- Research Design 4
- Methodology 5
  - Archival Research 5
  - Field Investigation 6

CHRONOLOGICAL OVERVIEW OF THE HISTORY OF AMMUNITION AND EXPLOSIVES STORAGE 7
- Eighteenth Century—Forming A Republic: Ammunition and Explosives Storage During and After the Revolution 7
- Nineteenth Century—Expansion of the Country: Storage of Ammunition and Explosives 10
- Twentieth Century—World War and Standardization: Developments of Ammunition and Explosives Storage 15
  - American Table of Distances 15
  - The Great War 18
  - The Lake Denmark Disaster 22
  - Development of the Igloo Magazine 26
  - Naval Ammunition Depot, Hawthorne, Nevada 28
  - Igloos and the Army 28
  - Preparing for War 35
  - Army Depot System 36
  - Architectural Design and Layout of Ordnance Depots 47
  - Post-World War II Ammunition Storage Facilities 54

PLANNING-LEVEL SURVEY 67
- Aboveground Magazines 67
- Igloo Magazines 68
- Summary of Types of Ammunition Storage Magazines 75

GENERAL STATEMENTS OF DESCRIPTION, SIGNIFICANCE, AND REGISTRATION REQUIREMENTS 85
- Description 85
- Significance 87
- Registration Requirements 90

Table of Contents
(cont'd)

Aboveground Magazines 90
Underground Igloos and Richmond Magazine 91
Conclusions 91

REFERENCES CITED 95

APPENDICES
A: CONUS Installations with Ammunition Storage (FY00) A-1
B: American Table of Distances B-1

LIST OF FIGURES

1. Back view of Hessian Magazine built in 1777, located at Carlisle Barracks 8
2. Fort Sam Houston ammunition building, constructed in 1888 11
3. West Magazine at Watervliet Arsenal in New York, constructed in 1849 13
4. 1845 map of Watervliet Arsenal 14
5. Detail plans and drawing for Powder Magazine (Building 280) at Rock Island Ordnance Center 16
6. Powder Magazine (Building 280) at Rock Island Ordnance Center 17
7. Magazine L-13 at Rock Island Ordnance Center 20
8. Magazine details for Drawing 104261 29
9. Magazine plan, elevations, and sections for Drawing 104260 30
10. Magazine 56-AT-2 at Hawthorne Naval Ammunition Depot 31
11. Triple Arch Magazine at Hawthorne Naval Ammunition Depot 32
12. Plans, elevations, and sections for Smokeless Powder Magazine at Hawthorne Naval Ammunition Depot 33
13. Plans for standard underground magazine constructed at Benicia Ordnance Depot 37
14. Standard underground magazine at Savanna Army Depot 39
15. Typical half section and front elevation for underground magazine, Drawing 652–317 41
16. Floor plan and longitudinal section for underground magazine, Drawing 652–317 43
17. Location of ordnance storage facilities in 1942 45
18. Floor plan and front elevation for underground magazine, Drawing 652–383 50
19. Drawings for Corbetta Beehive 51
20. Drawing for Corbetta Beehive 53
21. Front and rear elevations for Richmond Magazine 55
22. Typical details for Richmond Magazine 57
23. Drawings for Stradley Magazine 61
24. Igloo at Pine Bluff Arsenal that has been modified with refrigeration for biological weapons storage 63
25. Plans and elevations for standardized aboveground magazine for high explosives 69
26. Plans and elevations for standardized aboveground magazine for smokeless powder 73
27. Hollow clay tile aboveground magazine 75
28. Plans and elevations for Army Standard Igloo (Type 49) 77
29. Army Standard Igloo (Type 49) 79
30. Plans and elevations for Triple-Barrel Vault 81
31. Exterior and interior views of a Stradley Magazine 83
32. Map of Seneca Army Depot 89

LIST OF TABLES

1. Locations of Military Installations (1775–1945) Referenced in This Document 2
2. Army Ammunition Depots Constructed for World War II Mobilization Effort..... 3
3. Reinforced-Concrete Underground Magazines Constructed During World War II and Initial Mobilization Effort..... 59
4. Types of Magazines Associated with Army Installations 64
5. Number of Ammunition/Explosives Storage Buildings by MACOM..... 65
6. Summary Characteristics of Aboveground Magazines 71
7. Classes of Ammunition Storage Magazines within AMC Property Inventory..... 84
8. Recommended Locations Where Primary Examples of Ammunition and Explosives Storage Facility Classes May Be Eligible for the National Register 93

INTRODUCTION TO THE NATIONAL HISTORIC CONTEXT FOR ARMY AMMUNITION AND EXPLOSIVES STORAGE IN THE UNITED STATES, 1775–1945

Ammunition and explosives storage structures, usually called magazines, are present to some degree at most former and present United States Army installations (Table 1). Ammunition and explosives storage is an area of historical study that has been overlooked in the study of military cultural resources. In general, storage buildings at military installations are a ubiquitous necessity with a mundane function, usually translated into a utilitarian form that lacks excitement to the casual observer. Storage does not usually attract the interest of historic preservation societies or the attention of cultural resources managers. In particular, ammunition storage is especially overlooked, separated by the explosive nature of its contents from the daily activity of military life.

Numerically, ammunition and explosives structures constitute the largest single property type in the current Army real property inventory. Of the estimated 169,000 resources in the Army inventory, over 20,000 are magazines in current use. While there are a number of historic magazines scattered throughout the country at Army forts, the preponderance of magazines date from the World War II-era. As part of the large-scale mobilization efforts for World War II, the Army authorized the construction of 16 new ammunition storage depots and over 10,000 ammunition and explosives storage magazines.

Until the mid-1920s, the Army did not have a standardized approach to the storage of ammunition and explosives. Generally, aboveground warehouse-type structures were constructed to house the volatile materiel. Typically, the magazines were built of stone or brick, which provided a less incendiary environment than timber buildings. For the most part, these magazines were successful in providing isolated, dry, ventilated, and secure storage for ammunition and explosives. However, they did have their limitations, particularly for the mass storage of ammunition and explosives that became common in the twentieth century. Following the disastrous, chain reaction explosion at Lake Denmark, New Jersey, in 1926, it became apparent that the storage of ammunition and explosives required study. In response to the Lake Denmark explosion, a new type of magazine was developed which ameliorated the shortcomings of previous magazines. The new earth-covered, concrete magazines, popularly known as igloos, directed the force of the explosion upward rather than outward, decreasing the chances of sympathetic explosions. Igloo-type magazines continued to be used and built through the 1980s. At that time, a revised design that required less construction material and less land area was designed. This new magazine was designed primarily for use in Europe where land constraints posed a special problem (Howdyshell 1981:5). The majority of magazines currently in use in the United States are igloos or a derived igloo-type magazine.

Although ammunition and explosives structures pale in comparison to other buildings on Army installations that serve more high-profile functions, they are resources that require specialized construction techniques and certain considerations in siting. As a distinct entity, they also have certain terms that apply to them in particular ways. Commonly, ammunition and explosives storage structures are called magazines. The original, late sixteenth-century sense of the word "magazine" meant store. By the mid-eighteenth century, the use of the word began to refer to a "chamber for holding a supply of cartridges in a firearm." In more modern times, "magazine" has come to mean a "military store for arms, ammunition and explosives." In the late 1920s, a new type of earth-covered, barrel-arched, concrete magazine was developed that generally became known as an "igloo" due to its similarity in form to the dome-shaped, Eskimo buildings of the same name (Abate 1998:359).

Table 1
Locations of Military Installations (1775–1945) Referenced in This Document

Military Installation	Military Installation
Aberdeen Proving Ground, MD	Nansemond Ordnance Depot, VA
Allegheny Arsenal, PA	Navajo Army Depot Activity, AZ
Amatol Arsenal, NJ	Neville Island Supply Depot, PA
Anniston Ordnance Depot, AL	Newport Army Depot Activity, IN
Augusta Arsenal, GA	Ogden Depot, UT
Badger Army Ammunition Plant, WI	Old Hickory Powder Plant, TN
Benicia Arsenal, CA	Perriman Ordnance Depot, VA
Camp Stanley, TX	Pig Point General Ordnance Depot, VA
Carlisle Barracks, PA	Picatinny Arsenal (Dover Powder Depot/Lake Denmark Naval Ammunition Depot), NJ
Charleston Army Depot, SC	Pine Bluff Arsenal, AR
Chicago Storage Depot, IL	Portage Ordnance Depot, OH
Columbia Arsenal, TN	Pueblo Ordnance Depot, CO
Columbus Arsenal, OH	Radford Army Ammunition Plant, VA
Coosa River Storage Annex, AL	Raritan Arsenal, NJ
Cornhusker Army Ammunition Plant, NE	Red River Ordnance Depot, TX
Crane Army Ammunition Activity, IN	Redstone Arsenal, CO
Curtis Bay Ordnance Depot, MD	Rock Island Arsenal, IL
Delaware Arsenal, NJ	San Jacinto Ordnance Depot, TX
Dover Powder Depot (U.S. Powder Depot/Picatinny Arsenal), NJ	Sandy Hook Proving Ground, NJ
Erie Howitzer Plant, OH	Savanna Army Depot/Proving Ground, IL
Erie Proving Ground, OH	Seneca Ordnance Depot, NY
Fort D. A. Russell, WY	Seven Pines General Ordnance Depot, VA
Fort Herkemer, NY	Sierra Ordnance Depot, CA
Fort Monroe, VA	Sioux Ordnance Depot, NE
Fort Sam Houston, TX	Sparta General Ordnance Depot, WI
Fort Towson, OK	Springfield Armory, MA
Fort Wingate Ordnance Depot, NM	Susquehanna General Ordnance Depot, MD
Frankford Arsenal, PA	Tooele Army Depot, UT
Hawthorne Naval Depot/Army Ammunition Plant, NV	Tullytown Arsenal, PA
Holston Army Ammunition Plant, TN	Umatilla Ordnance Depot, OR
Indiana Arsenal, IN	Volunteer Army Ammunition Plant, TN
Lake Denmark Naval Ammunition Depot (Picatinny Arsenal), NJ	Watertown Arsenal, MA
Letterkenny Ordnance Depot, PA	Watervliet Arsenal, NY
Longhorn Army Ammunition Plant, TX	West Point, NY
McAlester Naval Ammunition Depot/Army Ammunition Plant, OK	Wingate Ordnance Depot, NM
Middletown Ordnance Depot, PA	Woodberry General Ordnance Depot, [NJ?]
Morgan General Ordnance Depot, NJ	Yorktown Naval Depot, VA
Milan Ordnance Depot, TN	
Mississippi Army Ammunition Plant, MS	

Although ammunition and explosives storage structures are present to some degree at most former and present Army forts, they are located in quantities at Army ordnance depots. According to a 1934 text on Arsenal Organization and Administration, an ordnance depot was a facility for the storage and issuance of ordnance supply. An arsenal, in contrast, was a government-owned and -operated installation for the acquisition, fabrication, and repair of arms and "munitions of war." Arsenals were further broken into two categories: the "manufacturing arsenal" where the primary function was the production of ordnance materiel, and the "field service arsenal" which operated to repair and maintain ordnance materiel. During the nineteenth century, the government maintained numerous arsenals, as well as several armories. Federal armories were used primarily for the manufacture and repair of small arms. Over the course of the nineteenth century, armories developed into storehouses and meeting places for local militia groups. As such, the use of the term for federal facilities became less common over the course of the century (Ordnance School 1934).

Ammunition and explosives magazines did not exist in large numbers prior to World War II; the vast majority were constructed for the war mobilization effort. The Army constructed 16 new ammunition storage depots and over 10,000 magazines for the storage of ammunition and explosives during the war (Table 2). While depot magazines are a reminder of the nation's commitment to large-scale mobilization in World War II, the retention of the ordnance depots after the war clearly demonstrates the United States commitment to maintaining a large-scale military during the Cold War.

Given the association of ammunition and explosives storage with military endeavors critical to the struggle for independence, protection of territory, westward expansion, and international conflict (Criterion A), the history of such facilities is most closely related to national level themes. Most of the installations listed in Table 1 were built in anticipation of or in response to threats to our national security. Although all played an important role as part of our national defense system, it should not be assumed that all installations are of equal integrity or importance. These installations are also redundant in character and layout; consequently, there should be no compulsion to protect every installation or portion of it. One purpose of this document is to define those ammunition and explosives storage facilities that best represent key developments between 1775 and 1945.

Army ammunition and explosives storage facilities may be eligible for listing in the National Register of Historic Places under Criterion A for properties "associated with events that have made a significant contribution to the broad patterns of our history"; Criterion C because they "embody the distinctive characteristics of a type, period, or method of construction . . . or represent a significant and distinguishable entity whose components may lack individual distinction"; or Criterion D because they "have yielded, or may be likely to yield, information important in . . . history" (U.S. Department of the Interior 1991:2). As structures, Army ammunition and explosive storage facilities may be considered for eligibility either as single properties or as districts. The concept of a district is particularly applicable to the World War II facilities that were built as a planned landscape that addressed both functional needs and safety concerns.

Table 2
Army Ammunition Depots Constructed for World War II Mobilization Effort

World War II Name	Date Established
Anniston Ordnance Depot, AL	1941
Blacks Hills Ordnance Depot, SD	1942
Blue Grass Ordnance Depot, KY	1941
Letterkenny Ordnance Depot, PA	1942
Milan Ordnance Depot, TN	1941
Navajo Ordnance Depot, AZ	1942
Portage Ordnance Depot, OH	1940
Pueblo Ordnance Depot, CO	1942
Red River Ordnance Depot, TX	1941
San Jacinto Ordnance Depot, TX	1941
Seneca Ordnance Depot, NY	1941
Sierra Ordnance Depot, Ca	1942
Sioux Ordnance Depot, NE	1942
Tooele Ordnance Depot, UT	1942
Umatilla Ordnance Depot, OR	1942
Wingate Ordnance Depot, NM	1940

Source: Thomson & Mayo 1960:384.

RESEARCH DESIGN

This study relies on two central concepts to evaluate eligibility for inclusion in the National Register of Historic Places: historic context and historic integrity. A historic context is an approach to organizing data according to geographic location, time period, and theme. The local, state, or national significance of a property is assessed within its appropriate historic context. Historic integrity is the ability of a property to convey its significance through its physical characteristics.

A historic context is essential to the evaluation of properties but is especially critical for facilities that are spread nationwide, as is the case in Army ammunition and explosives storage buildings. It is through the historic context that trends and patterns associated with certain property types are brought to light. A historic context also reveals the impact of national concerns or issues upon the development of particular property types. In the case of Army ammunition and explosives storage facilities, single properties or even groups of properties do not convey their significance without a historic context that reveals the evolution of such properties and the impact of national events upon their development. Design changes are intricately linked to events of national importance.

The historic context developed for this study integrates the three conceptual components generally found in a historic context—time period, geographic area, and theme—with the associated property types. This integration is designed to establish the connections between major historical themes in military and history, and real property. All three components were provided in the scope of work provided by the Army Environmental Center. The time period established for the study is 1775–1945. This period covers the development of the military from the early national period through the end of World War II. The end date of 1945 was chosen because the design of various ammunition storage structure types had been refined, and the majority of the Army's current national inventory of ammunition bunkers had been constructed. The geographic area for the investigation is the continental United States (CONUS). Thus, military construction in Hawaii, Alaska, and the U.S. territories was not included in the study.

The theme or subject matter was defined in the scope of work as "ammunition storage bunkers." Subsequent investigation revealed that the terminology that best describes the property type in question is "ammunition and explosives storage." This property type includes the storage of ammunition, explosives, pyrotechnics, and chemical and biological weapons, and includes special weapons (i.e., nuclear devices).[1] This project emphasizes extant military construction at active duty installations, and the historical developments and property types related to the types of installations that remain under Army control. However, several major Army installations that played pivotal roles in magazine design and construction (e.g., Hawthorne Army Ammunition Plant) were originally constructed and operated by the United States Navy. The Navy role in magazine design pertains only as it affects magazine design development or the current Army real estate inventory.

Central to the development of a useful historic context is to answer key research questions that will assist cultural resources managers in the inventory, assessment, and management of historically significant ammunition and explosives storage buildings and structures:

- What were the significant events in the evolution of the building type during the time period in question?
- What were the primary themes and trends emerging from these events that affected the evolution of the building type?
- What are the significant extant examples of ammunition and explosives storage that reflect those primary themes, trends, and events?
- Using the comparative analysis method, how significant are the extant examples in comparison to each other on a nationwide basis?
- How does state and local significance apply to the assessment of ammunition and explosives storage in a nationwide military context?

[1] The real property category codes associated with this property type are presented in the Planning Level Survey.

- How does the traditional concept of a historic district apply to the assessment of ammunition and explosives storage?
- What level of integrity must exist for a significant example to be eligible for the National Register?

Since the majority of ammunition and explosives storage structures are earth-covered igloos dating from World War II, the focus of the study is on the development of this building type.

METHODOLOGY

Five primary tasks were completed in the implementation of the research design. These tasks involved archival research, field investigation, data synthesis, context application, and report preparation. Data were collected and analyzed to identify the broad patterns of military history and trends over time, as well as to develop specific historic themes and to identify ammunition storage property types related to military construction.

Archival Research

The development of a context via archival research for this study proved to be a challenge. For example, primary research materials that contained a tremendous amount of information on the development of magazine design in the *U.S. Army in World War II, The Technical Series*, have been destroyed. Despite the potential significance of the property type and the large number of magazines in the Army inventory, the lack of a written history of this property type is a testament to the forgotten nature of ammunition and explosives storage. Until a major disaster at an ammunition depot in 1926, very little was written on the design and construction of ammunition magazines as a building type. Even after this event, which revolutionized the property type form, design, and layout, the documented history of the evolution is almost nonexistent. Not until 1995, when *Ammunition Storage: Early Twentieth Century Design and Context, Fort McClellan, Alabama* (Reed 1995) was written, had an entire report been the subject of ammunition storage from a cultural resources perspective.

Sources expected to yield considerable amounts of information proved to be of little value. The Library of the Ordnance Museum in Aberdeen, Maryland, contains a plethora of information on ordnance, yet little or no information on ordnance storage. Primary sources, such as *Ordnance Magazine*, again yielded little more than two articles in 70 years of publication, the same information gathered in the study by Reed.

Other sources consulted were the National Archives in Washington, D.C.; the National Archives II in College Park, Maryland; the Corps of Engineers Office of History; and the Library of Congress. Of particular interest were the completion reports for Ordnance Department depots in Record Group 77 of the Corps of Engineers in the National Archives.

The library of the Center for Military History in Carlisle Barracks, Pennsylvania, was consulted but with limited results. The library did have a good collection of Ordnance Department materials, but, again, the focus on the development of magazine design was absent.

The most disappointing avenue of research was the John Byrd Technical Library of the Defense Army Ammunition Center at McAlester, Oklahoma. The center is a wealth of information on safety practices regarding ammunition storage and handling but lacks specific information on past ammunition storage design and development.

One of the best sources of information was an oral history supplied by Dr. Chester E. Canada of the Department of Defense Explosives Safety Board. The DoD Board—established in 1928, two years after the Lake Denmark disaster—has information relating to the regulation of safety concerns regarding ammunition and explosives storage. Dr. Chester has extensive personal knowledge of explosives and the effects of sympathetic detonations.

The lack of any centralized archival information on the subject of ammunition and explosives storage design is partly due to the nature of military construction regarding the building type. Magazine design never had a centralized clearing-house for the issuance of standardized plans for construction prior to the World War II

mobilization. The selection of plan type and the details of construction were historically left to the individual installation commander, resulting in an ever-widening variety of deviations and specialty magazines. Therefore, although upon initial inspection all earth-covered magazine igloos look the same, each installation built and modified its standard plan to suit its individual mission requirements. Design changes and lessons learned were not centrally shared, which thus hinders tracing a linear evolution of the design.

Copies of photographs and line drawings included in this report are on file at the U.S. Army Corps of Engineers, Fort Worth District, with the exception of the photograph of the Hessian Powder Magazine, which is courtesy of the U.S. Army Military History Institute, Carlisle, PA, and the photograph of the Fort Sam Houston ammunition building, taken by Joseph Murphey of the U.S. Army Corps of Engineers, Fort Worth District.

Field Investigation

Field investigation took place at the seminal points of twentieth-century magazine design: Savanna Army Depot, Illinois, where the Army built its first prototype igloos after the Lake Denmark, New Jersey, disaster of 1926; Hawthorn Army Ammunition Plant, Nevada, where the Navy built the first prototype of a modern depot; and Picatinny Arsenal, New Jersey, where a large collection of magazine types is extant and is the site of the Lake Denmark explosion. Frankford Arsenal, Pennsylvania, one of the Army's old-line arsenals, was visited in search of an extant example of the Civil War-era powder magazine design.

CHRONOLOGICAL OVERVIEW OF THE HISTORY OF AMMUNITION AND EXPLOSIVES STORAGE

EIGHTEENTH CENTURY—FORMING A REPUBLIC: AMMUNITION AND EXPLOSIVES STORAGE DURING AND AFTER THE REVOLUTION

In 1775, the Continental Congress appointed a committee to determine the ways and means of supplying the Army with arms and ammunition to fight the Revolutionary War. Previously, the individual colonies had developed their own systems of military procurement and supply. In 1776, the Congress created the Board of War and Ordnance that was composed of five members of the Congress. Part of the responsibilities of the Board of War and Ordnance included making arrangements for the storage and maintenance of arms and ammunition. The board was authorized to rent private magazines at public expense until permanent national facilities could be built (U.S. Army 1956).

In addition to creating the Board of War and Ordnance, the Continental Congress also authorized the establishment of an ordnance center in December 1776 (U.S. Army 1956). The new ordnance site, known as Washingtonburg, was located near Carlisle, Pennsylvania. Subsequently, Washingtonburg was called Carlisle Arsenal, and later, Carlisle Barracks. The primary purpose of the facility was the manufacturing of cannons and ammunition to supply the Continental Army. Within a year of authorization, a rugged gunpowder magazine had been constructed at the site, reportedly by Hessian prisoners of war. Built of fieldstone, the magazine, named Hessian Magazine after the supposed builders, still stands at Carlisle Barracks. The magazine was located at the side of the complex, away from the major buildings. In addition to the gunpowder magazine, the 1777–1782 ground plans for public works at Washingtonburg included a powder house on each side of the magazine (Carlisle Barracks 2000; Figure 1).

Also in 1777, another Continental Congress arsenal was established, this one at Springfield, Massachusetts. Although the arsenal was authorized to manufacture cartridges and gun carriages, during the Revolutionary War no arms were made. Instead, the arsenal was used to store muskets, cannons, and other weapons. Facilities at the site included barracks, shops, and storehouses, as well as a magazine. According to the original authorization for the site, the magazine at Springfield was to be able to hold 10,000 stand of arms and 200 tons of gunpowder. Following the end of the war, the Springfield Arsenal continued in operation as a major ammunition and weapons depot (Springfield Armory 2000).

In 1782, the Revolutionary War was drawing to a close. The British had been defeated at Yorktown, and negotiations were underway to end the hostilities. However, the safe storage of gunpowder was still a significant concern to the military. General Washington issued the following order on the subject:

> To prevent the accidental communication of fire to the powder magazines which would endanger the lives of many persons and total demolition of the fortifications, besides the inconveniences that must arise from the loss of the powder, the Commander in Chief directs that the quartermaster or commissary of military stores may, as soon as possible, have grates fixed to the air holes of the magazines, and that lanthorns [lanterns] made of transparent horn or glass be immediately provided instead of those made of pierced tin, which are at present very imprudently used. Until the horn or glass lanthorns are provided the greatest care is to be taken not to open the door of lanthorns in the magazines, and at all times to have water in the bottom to extinguish sparks. It is, moreover, positively ordered that no person whatever, be permitted to enter a powder magazine without first pulling off his shoes [Hall 1956:8].

Obviously, incidents in the storing of explosives materiel had occurred.

Figure 1. Back view of Hessian Magazine built in 1777, located at Carlisle Barracks (Courtesy of U.S. Army Military History Institute, Carlisle, PA.).

Following the formal end of the Revolutionary War in 1783, the Army began reducing its ranks. However, the manufacture and, therefore, storage needs of arms and ammunition by the national government continued. Government-owned arms and ammunition were deposited at federal facilities at Providence, Rhode Island; Springfield, Massachusetts; Fort Herkemer, New York; West Point, New York; Carlisle, Pennsylvania; Philadelphia, Pennsylvania; New London, Virginia; Manchester, Virginia; and Charleston, South Carolina. Subsequently, several arsenals and armories were established in various areas of the new republic by about 1810.

According to an early Ordnance Department report, arsenals were used as "depots, for the collection and preservation of artillery, arms, ammunition, and military supplies generally, and for the fabrication of gun carriages and other military equipment, for the preparation of ammunition, and for the repair of arms" (U.S. Ordnance Department n.d.). Armories, in contrast, were designated for the manufacture and repair of small arms. Arsenal facilities constructed by the federal government included Rocky Mount, South Carolina; Gray's Ferry, Philadelphia, Pennsylvania; Charlestown, Massachusetts; Bergen Heights, New Jersey; Norfolk, Virginia; Washington, D.C.; Newport, Kentucky; and one in New York. Armories were located at Springfield, Massachusetts, and Harper's Ferry, Virginia. All of these facilities had some type of ammunition storage; however, due to the functional nature of these resources, little information specifically related to magazines is readily available.

In addition to the federal force, individual states also maintained militia groups. During the early years of the Republic, these state-based militia groups were required by the Continental Congress. The Congress believed that standing armies "were inconsistent with the principals of republican governments, dangerous to the liberties of a free people, and generally converted into destructive engines for establishing despotism" (Fogelson 1989:3). As such, they reduced the federal army to a small force and looked to required service by citizens in state-based militias as the primary means of maintaining order and repulsing foreign powers. In May 1792, the Congress enacted the Uniform Militia Act, which required states to conscript free, white men between the ages of 18 and 45 to train in militia units. Men serving in the militia were required to furnish their own arms and equipment and to serve in case of an emergency declared by the governor. The Congress passed additional legislation in May 1792 that allowed the president to call up the state militia in case of invasion (Everett n.d.:1–2).

While men serving in the militia usually supplied their own arms and equipment, a central location was required by the different states to store state-owned arms and ammunition. For example, in 1808, the state of Pennsylvania constructed the powder magazine at Magazine Lane near Penrose Ferry Road in Philadelphia, Pennsylvania. The state built the magazine to store powder and other military stores. The magazine provided both security and the proper dry and ventilated conditions to store the ammunition. The structure had a 52-by-70 foot double-barrel vault running the length of the magazine. It was built with three- to four-foot-thick stone walls with stone buttresses. The stone was acquired locally. The magazine had cut stone and brick trim around the doors and windows, three brick chimneys that served as ventilators, and a simple, single ridge, timber-framed roof with stone gables and a slate covering. The windows on the magazine were bricked-in with voids to allow ventilation and had decorative wood and iron shutters.

By the 1830s and 1840s, most states were not enforcing the compulsory militia laws. Although many militia units disbanded, volunteer units began to take the place of the mandatory units. Many of the volunteer units continued to aid the regular Army during the times of crisis through the end of the century, often with distinction. For the most part, the majority of local units stored their arms and ammunition in rented, frequently inadequate buildings until the 1870s. Due to social unrest during and after the Civil War, local volunteer units were called out 481 times between 1861 and 1906. Over 150 of these incidents involved labor riots. As a consequence of the increased prominence of the local volunteer militia, an armory building movement swept the country. Between 1880 and 1910, hundreds of armories were constructed throughout the nation (Everett n.d.:2–13). However, the local units, rather than the regular Army used these armories. As such, they are outside the boundaries of this study.

NINETEENTH CENTURY—EXPANSION OF THE COUNTRY: STORAGE OF AMMUNITION AND EXPLOSIVES

Twenty-seven years after the signing of the Declaration of Independence, the United States more than doubled its size with the 1803 Louisiana Purchase. In 1819, the southern boundary of the country was extended with the acquisition of Florida from the Spanish. Additionally, under the Adams-Onis Treaty that gave Florida to the United States, a stepped line was drawn along the eastern edge of the remaining Spanish territory up to the Arkansas River. This line defined the western boundary of the area acquired by the federal government under the Louisiana Purchase of 1803. Importantly, this treaty gave to the United States the area between the Arkansas River and the Forty-second Parallel, known as the Oregon Territory. With the acquisition of the Oregon Territory, America claimed for the first time land on both the Atlantic and Pacific coasts. In 1848, the last major segment of land was annexed into the continental United States. Under the treaty of Guadalupe Hidalgo, Mexico gave up its claims to Texas north of the Rio Grande and conveyed rights to California and New Mexico to the United States. Total, the United States grew by over a million square miles with the signing of the treaty. Five years after the treaty of Guadalupe Hidalgo, the United States picked up 30,000 more square miles south of the Gila River in the present states of New Mexico and Arizona under the Gadsden Purchase.

With the acquisition of all this new territory came more responsibility for the Army to protect its ever-changing borders. Additionally, although the United States purchased the land from the countries that claimed it, the local native inhabitants were frequently hostile to the settling of the land by European-Americans. As such, the Army spent much of the nineteenth century establishing various forts and camps along the frontier line, which kept expanding. Countless numbers of forts and temporary camps were established during this period. The majority of these installations were similar, although they were established by different people under diverse environmental conditions. By the 1890s, the frontier era in the continental United States had essentially ended. Because the Army was maintained as a peacekeeping force after this, many existing installations were maintained and a few new ones established to house and train the troops (Prucha 1964:1–36).

All of the installations established by the Army during the nineteenth century required some type of ammunition and explosives storage. Primarily, these magazines stored gunpowder, although explosives would also have been stored there. Additionally, because of the secure nature of the magazine, payrolls, and other precious commodities were sometimes temporarily stored in the magazine. Usually a fort only required one structure for ordnance storage, but multiple structures were constructed at larger installations. If possible, the magazine was constructed of brick or stone. However, depending on the availability of materials at the particular location, sometimes the magazine was constructed of wood. Typical examples include the magazine at Fort D. A. Russell, Wyoming. Constructed in 1890, the magazine had a stone foundation, brick walls, and a hipped, slate roof. Another example is the ammunition building at Fort Sam Houston, constructed in 1888 (Figure 2).

The Army did not provide plans for the layout of forts during the nineteenth century. Much depended on the particular environmental requirements of the site, as well as the overall purpose of the installation. Frequently, the ammunition storage structures were located on or near the parade ground in the vicinity of the officers' quarters. This was probably done for accessibility purposes, as well as security. In other instances, the magazine was located off to the side by other auxiliary function buildings, such as the guard house or even the hospital or chapel.

The design of the individual magazines differed from installation to installation. Generally, the magazines employed more elaborate construction techniques than other fort buildings. For example, the powder magazine located at Fort Towson, Indian Territory, built between 1827 and 1833, was a brick structure measuring about 20-by-16 feet. The magazine had a concrete floor, a single door, two barred windows, and a heavy timbered roof. The primary feature that set this structure apart from the other resources on the fort was the dead air space in the wall. One-brick wide, the dead air

Figure 2. Fort Sam Houston ammunition building, constructed in 1888 (Photograph by Joseph Murphey, U.S. Army Corps of Engineers, Fort Worth District).

space encircled the building one foot in from the outside edge of the wall. The only wall area without dead air space was the single doorway. The magazine probably had the dead air space to act as insulation to keep the ammunition and explosives dry, as well as to serve as a buffer in case of fire. One other feature that set the magazine apart from other buildings at Fort Towson was the informal drain for the interior of the magazine. The magazine was the only structure that featured a drain and remains, to this day, the only resource on the parade ground that does not hold water during a heavy rain (Scott 1975).

In addition to patrolling the frontier during the nineteenth century, the Army was also involved in several congressionally declared wars. The first major crisis the Army faced in the nineteenth century was the War of 1812. With the threat of war looming, Congress recognized the need for an agency that would provide the necessary war materiel. One month before the formal declaration of war was made, Congress established the Ordnance Department on 14 May 1812. The newly created Ordnance Department was responsible for the construction of gun and ammunition wagons and other wheeled ordnance vehicles, had oversight of munitions laboratories, and was responsible for inspection of powder and preparation of ammunition (Thomson 1954).

Although producing much of the ammunition needed during the war, the existing federal arsenals were unable to supply all the required gunpowder. As such, the Ordnance Department bought powder from private firms in Wilmington, Philadelphia, and Georgetown. In addition to the already established federal facilities, arsenals were activated at Marblehead, Massachusetts; Stonington, Connecticut; New Castle, Delaware; and Wilmington, Delaware, during the War of 1812. These arsenals were to serve as coastal fortifications. Following the war, the Bellona Arsenal at Richmond, Virginia, and Frankford Arsenal at Philadelphia, Pennsylvania, were established. Ten additional arsenals in various locations were authorized by

1819. Much of this arsenal building was due to exaggerated war consciousness rather than necessity. However, it must be noted that there was no major munitions-making industry in the United States as there was in Europe. Thus, the United States Army was forced to build its own manufacturing arsenals. By 1830, the Army had 11 arsenals and two armories.

In 1835, the Army became involved in the Seminole War that lasted until 1842. Four years later in 1846, Congress declared war on Mexico. The Mexican War lasted only two years. Both of these wars, in addition to the engagements with Native Americans throughout the western portions of the country, kept the military establishment actively engaged. As such, arsenal building continued as a major activity.

As previously noted, a part of an arsenal's function was to store ammunition and explosives. One example of a powder magazine used as a prototype by other arsenals was the West Magazine at Watervliet Arsenal, New York. The magazine was designed by Colonel Rufus L. Baker, Watervliet Arsenal Commander. Constructed in 1849, the magazine contained no iron in order to avoid any lightning attraction. The magazine had a capacity of 3500 barrels. Each barrel could contain up to 100 pounds of powder. The magazine was located away from the principal workshops and a stone wall was built around the magazine to protect it from fire (Figures 3 and 4).

The Civil War brought new challenges in the Army's manufacture and storage of ammunition and explosives. By the time war was declared in 1861, all of the southern ordnance installations were held by the Confederacy, except for Saint Louis. Additionally, the national armory at Harper's Ferry was attacked by abolitionists in 1859 and was the site of several battles during the war due to its geographic location in the Shenandoah Valley. Combined with the rapid growth of the U.S. Army to over one million men, it was apparent a procurement program for ordnance materiel had to be established immediately. As the conflict continued and ammunition supplies dwindled, the arsenals had to be staffed and production stepped up. Further, new facilities needed to be rapidly established to keep up with demand. The Columbus Arsenal and Indiana Arsenal, among others, were established during the war to replace the lost arsenals. Additionally, ordnance depots were established at Lafayette, Tennessee; Alpine, West Virginia; Baltimore, Maryland; and Denver, Colorado.

The principal magazine at the Frankford Arsenal in Philadelphia is an example of an ammunition storage structure built during the War Between the States. The post commander, Colonel T. T. S. Laidley, emphasized that the construction of the magazine should minimize damage caused by explosion. Laidley worked closely with the arsenal's primary supplier of powder, the duPont Company, to use structural iron in the magazine to fireproof it. The magazine featured brick construction with a slate roof and possibly a cavity wall. The gutters, door hinges, lighting rods, and wainscoted interior of the magazine were of copper. Additionally, the magazine had a ventilator similar to those used on masonry barns.

Following the end of the Civil War, the federal government closed and sold many arsenals. Other arsenals were redesignated. During the 1870s, the need for establishment of a proving ground and development of powder depots for the Army became apparent. As such, the Sandy Hook Proving Ground was quickly established as the Army's first full-scale testing facility. In 1880, two powder depots were established. One powder depot was located at Dover, New Jersey, the other at Saint Louis, Missouri. The Dover Powder Depot was later known as the U.S. Powder Depot and, subsequently, Picatinny Powder Depot. A 200-by-50-foot powder magazine of stone was completed in 1881 at the Dover Powder Depot. The magazine had wood flooring on brick arches spanning wrought-iron beams leveled with concrete. The ceiling was supported by a row of cast-iron columns down the center of the building. The ceiling consisted of brick arches and wrought-iron I-beams with wrought-iron roof trusses. Interestingly, the magazine had a basement. By November 1886, four powder magazines were completed, and the depot received its first shipment of powder, 300,000 pounds. In 1891, 315 acres of the Picatinny Powder Depot site were transferred to the Navy for the construction of the Lake Denmark Powder Depot (Nolte et al. 1998:22).

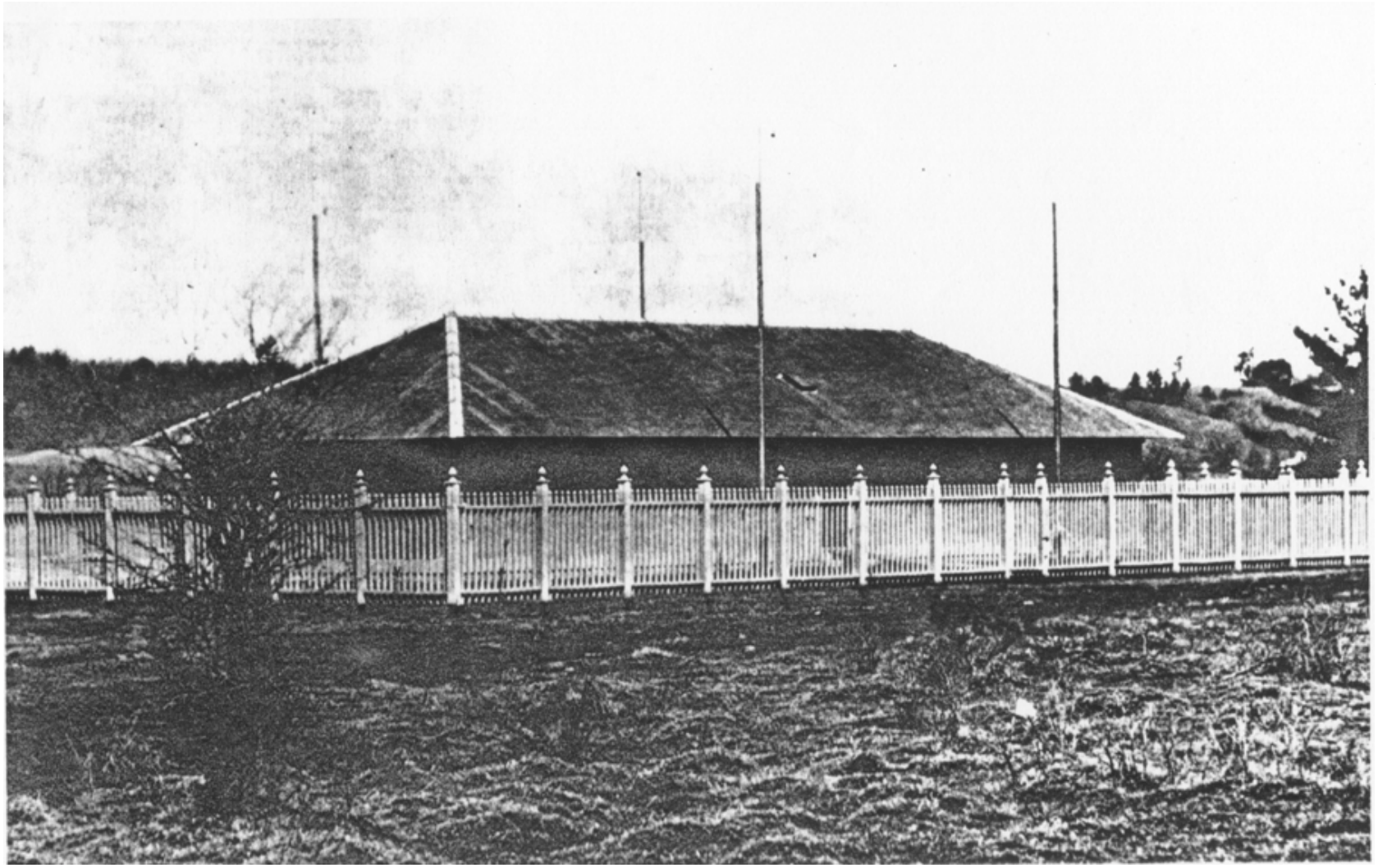


Figure 3. West Magazine at Watervliet Arsenal in New York, constructed in 1849. This is probably the oldest powder magazine in continuous use in the Army. Walls are of limestone and are four feet thick. The fence was a safety measure, and the vertical rods were lightning arrestors. Both features are no longer extant.

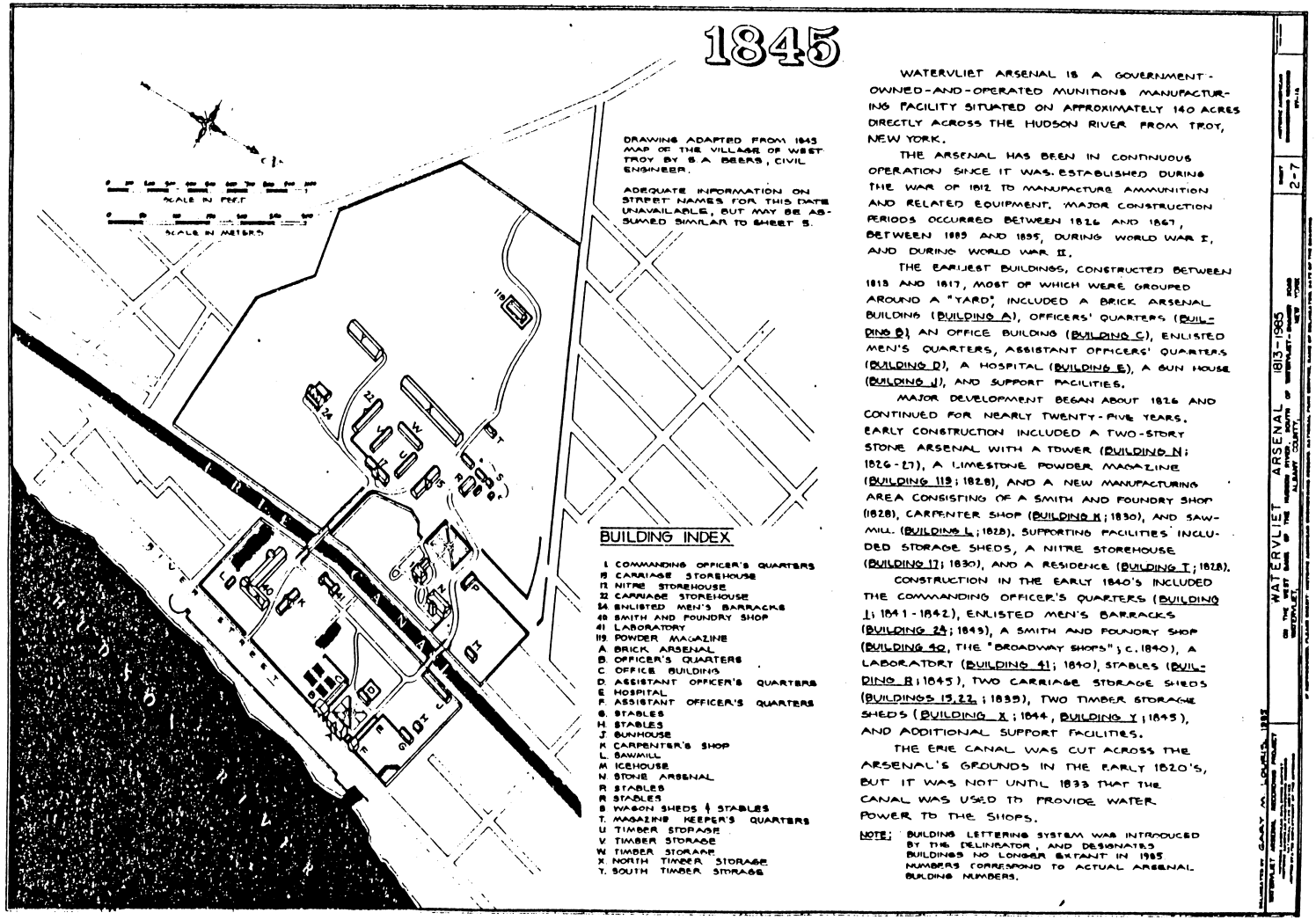


Figure 4. 1845 Map of Watervliet Arsenal. The West Powder Magazine, Building 119, is separated from the other buildings at Watervliet.

Although the government closed some arsenals following the Civil War, it continued to expand the facilities at others through the end of the century. In 1879, a 2,400-square-foot powder magazine was constructed at the Rock Island Arsenal. The structure had a clear height of 12 feet 6 inches. The magazine was constructed of wood frame walls with a brick veneer. It had a stone foundation set on bearing rock. The magazine had a wood floor and a wood roof deck covered with slate shingles (Figures 5 and 6).

In 1898, the Army undertook its first overseas troop movement in support of the Spanish-American War. New arsenals were established to support this venture, both stateside and overseas. By the turn of the century, the Army had 13 installations that manufactured and supplied ordnance. In addition to the Springfield Armory in Massachusetts; the Frankford, Rock Island, Watertown, and Watervliet arsenals were all engaged in the manufacture of ordnance and provided supply and maintenance support. Field service arsenals were located at Allegheny, Augusta, Benicia, Columbia, Fort Monroe, Indianapolis, New York, and San Antonio.

TWENTIETH CENTURY—WORLD WAR AND STANDARDIZATION: DEVELOPMENTS OF AMMUNITION AND EXPLOSIVES STORAGE

American Table of Distances

Among the twentieth-century developments in the storage of ammunition and explosives was the development of distance tables. In June 1909, Colonel B. W. Dunn, Chief Inspector of the Bureau of Explosives, brought to the attention of explosives manufacturers the need for changes in the locations of magazines as related to certain other resources. The resulting conference then appointed a special committee formed by the Association of Manufacturers of Powder and High Explosives to investigate the matter. The work of the committee resulted in the establishment of the American Table of Distances for Inhabited Buildings and Public Railways in December 1910. Subsequently, further study was undertaken concerning the distance needed between structures containing explosives and public highways. Thus, in 1914, the American Table of Distances for Inhabited Buildings, Public Railways and Public Highways was issued (Appendix B) (Assheton and Coy 1919).

In establishing the American Table of Distances for Inhabited Buildings and Public Railways, the committee determined that distance requirements utilized in foreign countries did not meet the needs of the United States or even provide a basis upon which to formulate the American distances. As such, the committee undertook an intensive worldwide study of explosions and their effects. The committee compiled statistics concerning explosions ranging in size from very small amounts of explosives to nearly a million pounds. Additionally, it looked at the manufacture, storage, and transportation of explosives domestically and abroad over a period of nearly 50 years. All recommended distances were for barricaded magazines. The barricades could be natural or artificial but needed to screen the magazine from other buildings, railways, and highways. The committee recommended that distances between non-barricaded magazines and buildings, railways, and highways be doubled (Assheton and Coy 1919).

The most important feature in establishing the distances between magazines and inhabited buildings was the distance at which “substantial structural damage” occurred on buildings in the vicinity. Substantial structural damage was based on two basic requirements: first, that the resulting damage to the property could not be readily repaired, and second, that risk to life and limb was caused by damage to an integral portion of the building. Minor damage, such as the breaking of window glass or falling plaster, was not considered in establishing the distance table. Possible damage due to flying missiles was also not factored into the table. In determining the recommended distances, the structural strength of the building before the explosion was not evaluated. The recommended distances between barricaded magazines and inhabited buildings ranged from 15 feet for magazines storing 1,000 to 5,000 blasting caps to 2,705 feet for structures storing 475,000 to 500,000 pounds of other explosives (Assheton and Coy 1919).

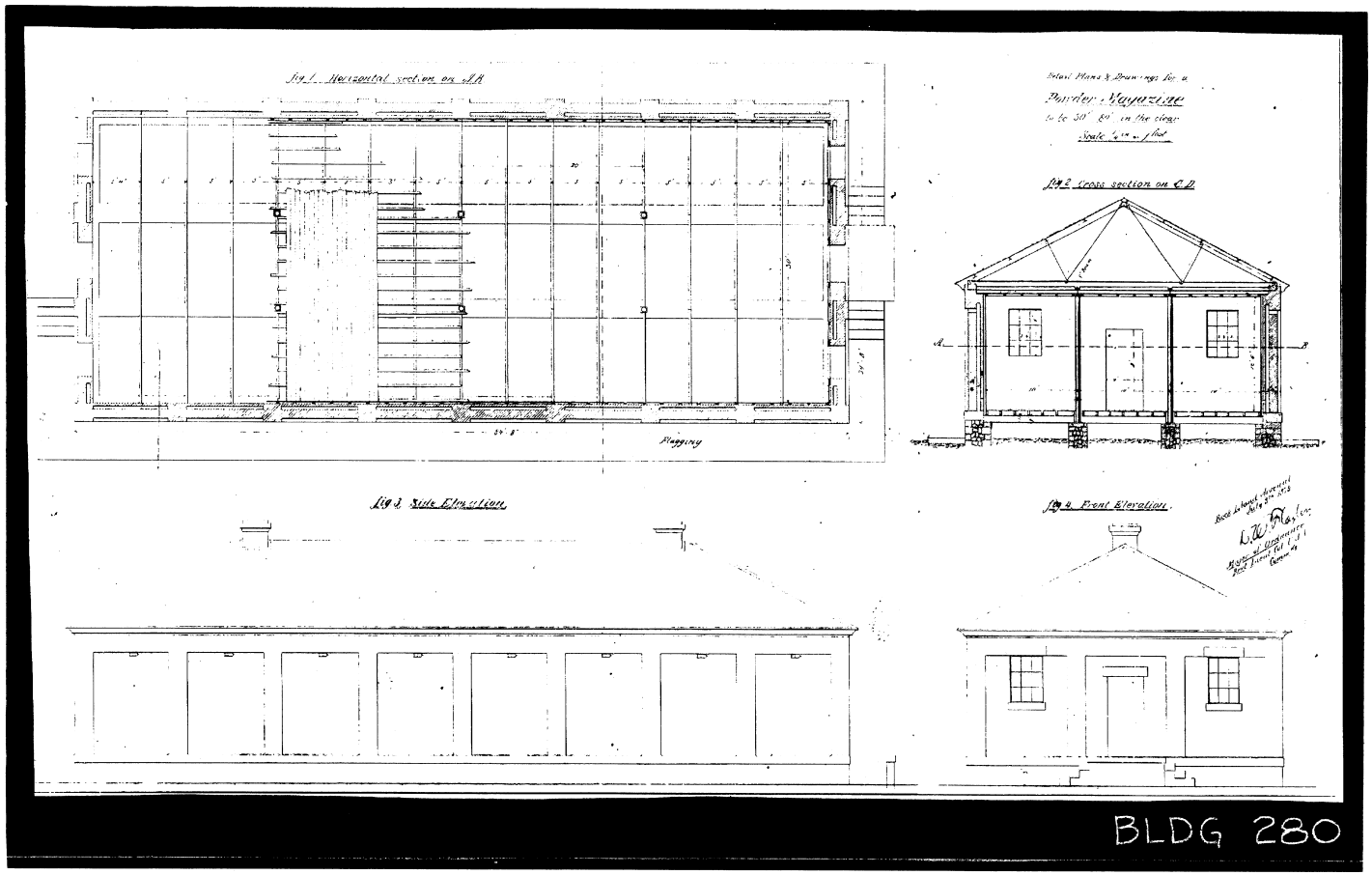


Figure 5. Detail plans and drawing for Powder Magazine (Building 280) at Rock Island Ordnance Center.

Figure 6. Powder Magazine (Building 280) at Rock Island Ordnance Center.

The committee encountered difficulty in establishing distance tables between barricaded magazines and public railways due to a lack of data concerning explosions involving passenger trains. As such, they concluded that distances between magazines and railroads should be established by using 60 percent of the distance between magazines and inhabited buildings. This conclusion was based on comparing the relative smaller size of railroad cars that would be exposed to concussion and the greater strength of the railroad cars to resist the concussion. Additionally, the committee believed that trains, which were only temporarily in the presence of magazines due to their transient nature, required less distance than buildings, which were constantly at risk because of their stationary nature. As such, the distance table called for distances between magazines and barricaded public railways of only 10 feet for those structures storing 1,000 to 5,000 blasting caps, but ranged to 1,620 feet for magazines storing 475,000 to 500,000 pounds of other explosives (Assheton and Coy 1919).

To reduce the risk of danger to persons traveling along public highways, the committee studied over 100 explosions, involving nearly 350 people. Of the total number of explosions studied, nearly 60 explosions contained accounts of about 150 people who were exposed to the direct effects of the explosions by being in the open. In determining the distance table for public highways, the committee used the resistance of the human body to an explosive wave. The committee looked at the amount of explosives involved in the various explosions, the distance at which the persons in the open were located at the time of explosion, and the effect on the person(s), which ranged from being killed to being merely "stunned." The results of the study determined that barricaded magazines containing 1,000 to 5,000 blasting caps should be located at least 5 feet from a public highway. The distance widened to a maximum of 810 feet for magazines containing 475,000 to 500,000 pounds of other explosives (Assheton and Coy 1919).

The Great War

The distance tables were developed by and for private explosives manufacturers. At the time, the federal government and the Army were not as concerned due to the lack of military need. Following the end of the Spanish-American War in 1900, the Army was engaged in peacetime activities until the 1916 Mexican Expedition. However, this was quickly followed by the declaration of war with Germany on 6 April 1917. Because of the relative inactivity of the previous nearly two decades, the Army was not prepared in terms of ordnance or other supplies to outfit the needed troops. The lack of physical plants and the introduction of new warfare methods and technology prevented the rapid manufacture of scarce war materiel. Compounding the problem was the lack of a widespread industrial base in the United States from which the tools of war could be obtained. Although certain private American firms had been providing the Allies with munitions since the beginning of the war in 1914, there was little excess capacity to supply American troops in 1917. As such, to supply the United States troops, agreements were made with Allied nations to provide certain equipment and supplies until American shops could be brought into production. Due to the use of French-made metric weapons early in the American involvement in World War I, artillery and ammunition had to be interchangeable between American and French equipment.

At the beginning of America's involvement in the Great War, the Ordnance Department had 11 arsenals in operation. These consisted of arsenals at Augusta, Georgia; Benicia, California; Frankford, Pennsylvania; New York, Picatinny and Raritan, New Jersey; Rock Island, Illinois; San Antonio, Texas; Springfield, Massachusetts; Watertown, Massachusetts, and Watervliet, New York. The Army also conducted proving ground activities at Sandy Hook, New Jersey. It quickly became apparent that these facilities were not able to handle the demands of a full-scale, modern war. Because the proving ground at Sandy Hook was located away from the coast and did not have direct rail connections, the Ordnance Department purchased 35,000 acres near Aberdeen, Maryland, for a new proving ground. The first test shot was fired on 2 January 1918 at the Aberdeen Proving Ground. Initially, the Aberdeen Proving Ground mission was acceptance testing of field artillery, trench mortars, antiaircraft guns, ammunition, and

railway artillery. Due to the great demand, two additional proving grounds were quickly established at Erie, Ohio, and Savanna, Illinois.

During the war, the Ordnance Department also greatly expanded the nation's arms, ammunition and explosives manufacturing capabilities. The government had responsibility for the construction of many new facilities, but it also relied on private firms to meet the demand. By the end of the war, America had become so proficient in the production of smokeless powder and high explosives that the munitions debts to other Allied countries were paid using these materials. In 1918, there were 92 plants engaged in the manufacture of powder and high explosives in the United States. The government constructed sixteen of the 92 plants. Additionally, there were 93 loading plants in operation. New Army depots were established at Aberdeen, Maryland; Neville Island, Pennsylvania; Tullytown, Pennsylvania; and at the Old Hickory Powder Plant, Tennessee. While manufacturing facilities were made available at the Rochester Arms and Gun Plant, an additional facility was constructed at Erie, Ohio. The success of the artillery in World War I was credited in part to the Ordnance Department's constant and continuous provision of ammunition.

As the manufacturing of ammunition and explosives escalated, the need for storage facilities also rose, and as the war progressed, the Ordnance Department acquired land at various depots to build 625 magazines. Various types of magazines were designed to store ammunition, smokeless powder, primers and fuses, or high explosives. An example of a magazine built during this period was Magazine L-13 at the Rock Island Arsenal. This magazine was one of seven similar structures built at the arsenal. Magazine L-13 measured 30-by-20 feet and stood 8 feet 6 inches tall. It had 600 total square feet. The magazine had a concrete foundation on bearing rock and walls of tile and steel under a stucco finish. The floor was concrete and the flat roof was pitch and gravel. The structure was designed with two globe vents and sat on a 5-foot surrounding concrete slab apron (Figure 7).

World War I ended on 11 November 1918. The Ordnance Department at that time consisted of two services—the Manufacturing Service and the Field Service—and controlled 10 arsenals, one armory, one storage depot, two supply depots, one Howitzer plant, one arms and gun plant, three proving grounds, one powder plant, and 11 general ordnance depots. To the Manufacturing Service were assigned the Frankford, Picatinny, Watervliet, and Rock Island arsenals; the Chicago Storage Depot; the Erie Howitzer Plant; the Rochester Arms and Gun Plant; and the Springfield Armory. The Field Service received responsibility for the Amatol, New Jersey; Augusta, Georgia; Benicia, California; Raritan, New Jersey; San Antonio, Texas; and Tullytown, Pennsylvania arsenals; the Aberdeen, Maryland; and Neville Island, Pennsylvania supply depots; the Aberdeen, Maryland; Erie, Ohio; and Savanna, Illinois proving grounds; the Old Hickory Powder Plant, Tennessee; and the Charleston, South Carolina; Curtis Bay, Maryland; Delaware, New Jersey; Middletown, Pennsylvania; Morgan, New Jersey; Perriman, New Jersey; Pig Point, Virginia; Seven Pines, Virginia; Sparta, Wisconsin; Wingate, New Mexico; and Woodberry, New Jersey general ordnance depots.

With the end of the war, overseas shipments of ammunition and explosives were discontinued. As production was at full capacity right up to the end of the war, materiel quickly began piling up in warehouses and on docks. Combined with the large shipments of ordnance returning from overseas and the impending demobilization, the government had a huge inventory of ordnance materiel worth more than one billion dollars. However, the government did not have sufficient storage facilities available.

Overall, there were three basic categories of ammunition and explosives storage structures by World War I. The most prevalent category of magazine was aboveground magazines. Usually rectangular in shape, these structures had either gabled or flat roofs. The structures were constructed using masonry (often tile) or corrugated asbestos on a wood frame, or using ordinary wood-framed construction. The floors were at-grade or at railroad car-floor level.

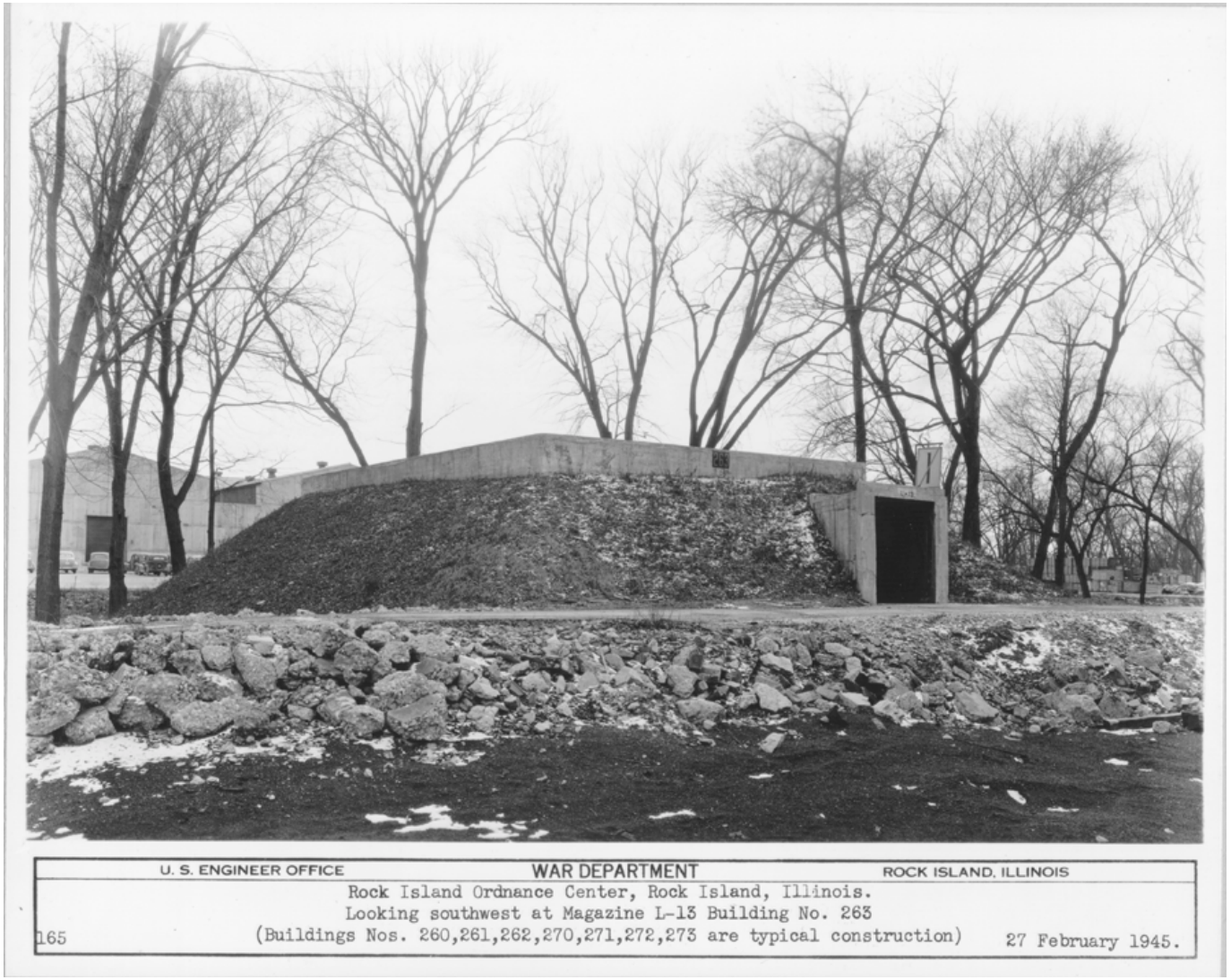


Figure 7. Magazine L-13 at Rock Island Ordnance Center.

Occasionally, separate barricades were erected around the magazines so that safety distances could be reduced. Another type of storage structure was the casemate magazine. These magazines were masonry vaults that were fortified, sometimes in hills. Casemate magazines were used only at coastal artillery installations. The final category of storage resource in use by World War I was a dump. Consisting of open stacks of ammunition, this category of storage was seldom used except in wartime.

Part of the problem in storing the surplus ammunition after World War I was the different requirements needed for the six classes of ammunition. Each class of ammunition was stored in a prescribed type of aboveground magazine based on its explosives potential. The first class included finished ammunition and loaded components. The second class was composed of smokeless powder used in bulk and in the form of separate ready-made propelling charges. Fuses and primers made up the third class of ammunition, while the fourth class consisted of high explosives such as T.N.T., picric acid, explosive D, and tetryl. Sodium nitrate and inert components such as empty shells, boosters, and metallic components of fuses comprised Class Five. The sixth class of ammunition consisted of small arms ammunition.

Class One ammunition was stored in standard ammunition magazines. The principal characteristics of this type of ammunition were great weight and moderate sensitivity. Overall, shells below six inches were not subject to mass detonation. Although it was possible for shells of six inches and larger caliber shells to detonate en masse, it was unlikely unless there were a fire. Typically, the standard ammunition magazines measured approximately 50-by-20 feet. The magazines were spaced 300 feet to 400 feet apart. The structures were of hollow tile construction. The concrete floors had a permissible floor load of at least 1,000 pounds per square foot. Due to the tonnage of ammunition and the weight of an individual shell or package, standard-gauge railroad tracks were always provided to these magazines. The standard ammunition magazine presented a fireproof exterior and was constructed so that in the event of an explosion, the walls and roof would break up into small fragments. As such, there was no danger of large masses of debris being thrown any appreciable distance (Reed 1995:40).

Smokeless powder, Class Two ammunition, was assigned to magazines of lighter construction than standard ammunition magazines. Although smokeless powder was not explosive, if it was ignited it burned with an extremely intense heat. A typical smokeless powder magazine measured about 32-by-96 feet. The usual capacity of this type of magazine was 500,000 pounds of powder, although the actual capacity was limited only by the necessity for limiting losses in case of fire. Smokeless powder magazines were located 300 feet apart. They were constructed with asbestos siding and gypsum slab roofs. This type of magazine had wooden floors. Due to the 300-foot spacing between magazines and the fireproof exterior of the magazines, the threat of fire spreading from one magazine to another was limited (Reed 1995:40).

Fuses and primers were also stored in magazines measuring 32-by-96 feet. The distinguishing characteristics of Class Three ammunition were great sensitivity, high cost, and the fact that the destruction of a comparatively small amount in bulk would render useless a relatively large amount of other components. Similar to smokeless powder magazines, Class Three magazines had hollow tile walls, gypsum slab roofs, and wooden floors. Again, these magazines were spaced 300 feet apart. Due to the characteristics of this type of ammunition, the magazines were comparatively small and the exterior was thoroughly protected against sparks or fire (Reed 1995:40).

Class Four ammunition, high explosives, was consigned to magazines constructed with hollow tile walls and gypsum slab roofs. Typically measuring 26-by-42 feet, these magazines were designed with a capacity of 250,000 pounds of explosives. Complying with the American Table of Distances, high explosives magazines were spaced 800 feet apart. Class Four ammunition was comparatively sensitive. If ignited, it was likely that most of the explosives would detonate. Thus, the hollow tile and gypsum slab construction was necessary to prevent damage from heavy missiles (Reed 1995:40–41).

Class Five ammunition did not require specialized magazines. Sodium nitrate was very soluble in water. It was an oxidizing material rather than an explosive, and it would not burn unless mixed with a combustible material. It was permissible to store sodium nitrate in a concrete trench. The sodium nitrate was simply dumped into the trench, rolled, and then covered with a waterproofing pitch compound (Reed 1995:41).

Small arms ammunition, Class Six, also did not demand storage in magazines because of its stable nature. This class of ammunition included pistol and small arms ammunition, tracer ammunition, incendiary ammunition, armor-piercing ammunition, and trench mortar ammunition. Standard warehouse spaces were constructed for Class Six ammunition in sections of 100-by-160 feet. These warehouses usually had brick walls, wood roofs, and concrete floors. A brick firewall was placed between adjoining sections of these structures (Reed 1995:41).

Following the end of World War I, storage structures were erected at the Aberdeen, Maryland; Erie, Ohio; and Savanna, Illinois proving grounds. Additionally, new ammunition storage depots were constructed and commercial space was leased. However, due to the great quantity of munitions left over from the war, all storage facilities were overburdened. This situation continued as America embraced a policy of isolationism and funding for war-related activities decreased.

The Lake Denmark Disaster

The Army was not the only military branch burdened with a surplus of World War I ordnance. The Navy also had a surplus of munitions inadequately stored at various installations. In 1926, this dangerous situation finally erupted at the Naval Ammunition Depot, located at Lake Denmark, New Jersey. The Naval Ammunition Depot was constructed on land transferred from the Army's Picatinny Arsenal, New Jersey, in 1891. Originally comprising 315 acres, by 1926 the Naval Ammunition Depot included over 200 resources. One-quarter of these were explosives magazines designed for the storage of high explosives, projectiles, black powder, and smokeless powder.

Temporary Magazine Number 8, located in the northeast quadrant of the depot, which was adjacent to the Army's Picatinny Arsenal, was a typical, aboveground, 150-by-200-foot clay tile, storage structure. Like most ammunition storage structures in the decade after World War I, Magazine Number 8 was overloaded with leftover ordnance. Prior to 10 July 1926, the depot's safety record was without incident. On that Saturday, however, lightning struck Magazine Number 8 at 5:15 p.m. during a severe electrical storm. Thick black smoke immediately began issuing from the magazine, prompting the depot's fire alarm to be sounded. Within minutes, the emergency fire fighting team arrived onsite and began to apply a stream of water.

At 5:20 p.m., Magazine Number 8 exploded, rocking both the depot and the adjacent arsenal. Only a crater remained where once the magazine had stood, while embers and missiles catapulted for a distance of over one mile. As a result, two more major explosions detonated in nearby Magazine Number 9 and Shell House Number 22. The direct effect of the blasts caused the complete total annihilation of structures within a radius of 2,700 feet and damaged buildings up to 8,700 feet away. Nineteen people died and over 50 were injured. The damage to munitions and other stores exceeded $40,000,000 *(Army Ordnance* 1945:426; Reed 1995:41).

The Naval Depot and the adjacent Picatinny Arsenal were immediately treated as crime scenes. Blast damage was extensively photographed and documented to ascertain the effects of the blasts on buildings and structures in hopes that scientific study would produce findings that would prevent future disasters (Reed 1995:41).

While the military community was bent on fact finding, the American public was horrified at the extent of the disaster. An editorial published in the *Engineering News Record* summarizes the public view and calls for an official inquiry:

> Of the whole series of major accidents that the Navy has experienced in recent years, none has so closely involved the personal interest of the

> citizen as this one. It has brought sharply to consciousness the danger of destruction and sudden death inherent in great stores of high explosives, and simultaneously has awakened a general conviction that if means can be found to minimize this danger they should be used, whatever the cost. Lightning, if that is what set off the initial blast at the arsenal, is not yet subject to human control, and despite the most elaborate protective devices a powderhouse may be struck as readily as a farmhouse. Even without reckoning the chance of ignition through other causes, then, any powder store is the potential seat of an explosion. But the greatness of the danger grows rapidly with the amount of the explosive and its concentration in unisolated groups; and so also it can be limited by storing smaller quantities and subdividing and isolating them. . . . It is sure to be of wide public interest, for it is as much the public's as the Navy's problem how to maintain adequate supplies of necessary explosives and yet keep the inevitable hazard down to a minimum. The inquiry should also furnish better knowledge than has yet been available as to the width of the danger zone surrounding a store of high explosives [Reed 1995:42, as quoted from *Engineering News Record* 1926, Vol. 97(4):125–126].

The Navy appointed a Court of Inquiry on 14 July 1926, headed by Rear Admiral Robert E. Coontz, U.S.N. The court was charged with rendering an opinion on the cause of the disaster and making recommendations that might prevent future disasters of this type. The court examined the damages to the depot, the loss of life, and the causes of the explosions (*Army Ordnance* 1945:426).

The Court of Inquiry, however, did not satisfy everyone. On 22 December 1927, Congress approved the First Deficiency Act, Fiscal Year 1928, which included a provision that a joint Army-Navy board survey the conditions of ammunition storage. The board, composed of officers appointed by the Secretary of War and the Secretary of the Navy, was to pay special attention to ordnance facilities that, due to their proximity to populous communities and industrial areas might "constitute a menace to life and property." The results of the survey were to include recommendations concerning any needed changes to storage facilities, including location and the feasibility of the joint use of the installations by the Army and Navy (Joint Army and Navy Board 1928:1).

The results of the official inquiry, titled *Report of the Joint Army and Navy Board Convened to Make a Survey of Points of Storage of Ammunition in Compliance with a Provision of the First Deficiency Act, Fiscal Year 1928*, were completed by 3 March 1928. The document was divided into three main sections. The first section consisted of a preliminary statement that noted the most stringent laws in the country concerning explosives belonged to the state of New Jersey. These laws, which incorporated the American Table of Distances, were adopted by the joint board in establishing its standard of safety. The second section of the report listed the procedures by which the study was made. The third discussed the individual ordnance facilities directed by the Army and Navy and provided suggestions to mitigate possible hazards (Joint Army and Navy Board 1928).

The study noted that after World War I, enormous quantities of ammunition destined for France piled up on the Atlantic seaboard and were eventually diverted to the nearest depot. This action dangerously overloaded the depots. Although all ammunition considered not essential for future use was accordingly disposed of, this still left many depots overextended. The study stipulated that no problems had occurred where the ordnance was properly stored and that steps could be taken to appease further concerns. The joint board proposed an overall solution of redistribution and rearrangement of the ammunition and the establishment of a permanent joint Army-Navy Ammunition Storage Board to serve in an advisory capacity to the Secretary of War and the Secretary of the Navy. Today, this board is known as the Defense Ammunition Safety Board. It provides oversight of explosives and chemical agents at military facilities (Reed 1995:42; Thomson and Mayo 1960).

The joint board also made specific recommendations that would profoundly alter the way the American military stored munitions in the future. The board recommended that cast TNT in bombs, depth charges, mines or other similar containers should be segregated from all other explosives stores; that all metallic parts of magazines and their contents should be grounded; that magazine personnel should be instructed to avoid fighting heavy fires in

explosives magazines; that magazines, shell houses, and containers should be made as nonflammable as possible and of construction that would eliminate forming heavy missiles in case of explosion; that dwellings should be located clear of probable injury due to explosions; that ammunition depots should be supplied with improved fire alarm and fire fighting equipment and additional roads to fight fires; that distances between magazines be made "adequate" with the use of barricades and subsurface storage in future construction; that a table of distances be developed that would serve as a future guide; that Lake Denmark should be rebuilt; and that Congress provide two new ammunition depots of at least 100 square miles for the storage of high explosives with one to be located within 1,000 miles from the Pacific Coast and the other within 1,000 miles from the Atlantic Coast (Joint Army and Navy Board 1928).

While the Navy was investigating the Lake Denmark explosion through a Court of Inquiry, the Army also appointed its own board to examine the Lake Denmark explosion and to make recommendations on rebuilding Picatinny Arsenal. The 1926 explosion gave the Army the unprecedented opportunity to assess the damage and effects of large detonations of munitions in storage. The Army board advised that, in addition to rebuilding Picatinny Arsenal, the installation be enlarged to allow for the consolidation of the Army's ordnance activities in northern New Jersey (Joint Army and Navy Board 1928).

Between 1927 and 1931, Picatinny Arsenal was essentially rebuilt at a cost of 2.3 million dollars. As safe handling of explosives was a top priority, the redesigned arsenal included the division of the arsenal into zones based on function or activity. The four zones consisted of a powder and explosives production and handling zone; powder and explosives storage zone; powder and explosives testing zone; and non-hazardous manufacturing and administration and research offices. However, the magazine area of the installation remained essentially unchanged with the use of aboveground magazines. Recommendations concerning safety procedures were adopted and several new sand-filled, wooden bunkers were constructed in the magazine area. Overall, the amount of ammunition stored was reduced, and additional land area was purchased to ensure adequate quantity-distance spacing (Nolte et al. 1998:25).

In 1928, the Army's Ordnance Department issued a new set of standards for the storage of explosives and ammunition. The new standards dictated that explosives and ammunition in quantity be stored only in specially designed structures developed in response to the class of materiel being stored. Interestingly, the 1928 standards do not mention the use of igloo magazines, which were already in use by the Navy. Igloo magazines would subsequently replace the 1928 magazines, although they do not appear in the Army Ordnance Safety Manual until 1941.

In 1931, the Ordnance Department issued another safety manual that detailed five types of ammunition and explosives storage structures. Each magazine had size and distance requirements appropriate to the type of munitions stored in it. All five structures were apparently un-barricaded. The use of barricades would have presumably reduced the needed distance between magazines (U.S. Army 1931).

Explosives magazines were to measure approximately 26-by-42 feet and be spaced 400 to 800 feet apart. These magazines were originally designed to store up to 250,000 pounds of bulk explosives, including black powder, TNT, tetryl, and explosive D. However, to allow for ample aisle space for inspection and shipping and to have piles of convenient height, these magazines were usually limited to 100,000 pounds. Explosives magazines were to be constructed with concrete foundations, hollow tile or brick walls, and wood floors. The flat roof was to have wooden roof trusses and gypsum blocks or slabs covered with fire-resistant built-up roofing (U.S. Army 1931).

Smokeless powder magazines, measuring 32-by-96 feet, were to be spaced 300 feet apart and were designed to store smokeless powder in boxes or propellant charges. The construction of smokeless powder magazines varied considerably from other standard magazines because smokeless powder required good protection from moisture and high temperature and was a significant fire hazard. These magazines were built of frame construction on

concrete or wooden piers. Outside walls that extended to the ground level were of corrugated sheet asbestos. The floor, ceiling, and inner walls of smokeless powder magazines were carefully built to avoid cracks and crevices. Using a roof similar to that of explosives magazines, smokeless powder magazines had ventilators in the roof as well as below the floor in the outside walls. There were also air passages between the inner walls and floors. The capacity of smokeless powder magazines was originally set at 500,000 pounds of powder in boxes. The amount of powder stored in the form of propelling charges was less (U.S. Army 1931).

Primer and fuses magazines were to be the same size as smokeless powder magazines and located the same distance apart. The design of primer and fuses magazines was similar to that of explosives magazines. However, these magazines were to contain primers, primer detonators, adapters, boosters, and fuses. The capacity of these magazines was not detailed because of the danger of losing all of one type of component if stored in one magazine (U.S. Army 1931).

Ammunition magazines, much larger than the three previous types of magazines, were to be nearly 50 feet wide and 220 feet long. These magazines were to be spaced 300 feet apart when constructed in groups. Separate loading shell and shrapnel were to be stored in ammunition magazines. The ammunition magazines were to have solid concrete foundations and floors. Walls were to be of hollow tile or brick. A peaked roof of gypsum blocks or slabs covered with fire-resistant built-up roof was to rest on wooden roof trusses supported on concrete or brick pilasters. Ventilators were to be placed in the roof with openings in the sidewalls that could be opened and closed to regulate airflow. The capacity of ammunition magazines was not defined because of regulations that limited the number of shells to a pile and distances between piles (U.S. Army 1931).

The fifth type of storage structure was the warehouse. Built similarly to commercial warehouses, these structures had solid concrete foundations and floors. Constructed in sections of about 160 feet in width by 100 feet in length, each warehouse had brick or tile walls, as well as interior firewalls separating the sections and sprinkler systems. Warehouses were used for the storage of small arms ammunition, sodium nitrate, and other non-explosive materiel (U.S. Army 1931).

In addition to the design, maintenance, and repair of ammunition and explosives storage structures, the Ordnance Department also dictated specific guidelines in the storing of ammunition and explosives. Generally, these guidelines followed the joint Army-Navy board's findings. The first guideline mandated that magazines should be remote from inhabited buildings and conform to Ordnance Department quantity-distance tables. The magazines were to be arranged so that similar risks were grouped together. Railroads in magazine areas were to have a classification yard for incoming and outgoing shipments. Additionally, magazine areas were to have a main-line railroad track to each row of magazines with a spur at each magazine to allow railroad cars to be loaded and unloaded without blocking the main track. Adequate drainage in magazines was to be provided to reduce moisture that deteriorated ammunition. Good roads for fire fighting and security purposes were to be built. Magazines were to be constructed of materials that would not form missiles or firebrands in case of explosion. Additionally, magazines were to be fireproof and to be designed staunch, low, and narrow to withstand blast pressures from adjacent magazines. The size of magazines was to be determined by the quantity-distance tables, although ample space for aisles to allow ease in inspection and shipping was to be provided. All magazines were to have a loading platform with the floor at railroad car-floor height. If a wooden floor was used, it should be of narrow tongue-and-groove material, blind-nailed, to avoid cracks and crevice where spilled explosives could lodge. Magazine doors were to be placed opposite of the prevailing winds and were to tightly fit in order to seal the opening. Magazines were to be constructed to eliminate the accumulation of explosive dust and were to be provided with ventilators to regulate the temperature. Finally, magazines were to be adequately grounded (U.S. Army 1931:22–26).

Development of the Igloo Magazine

The most notable consequence of the Lake Denmark explosion was the development of a new type of standard ammunition magazine. This new magazine became widely known as the "igloo" due to the general impression that the structure resembled traditional Eskimo dwellings (Abate 1998:359). The igloo magazine was a low, barrel-arched structure constructed of reinforced concrete and covered with earth. The use of the barrel-arch design directed the force of an explosion up instead of out, while the berming of earth upon the structure dampened the force of a potential explosion. Although the floor of the magazine was at or above natural grade, the magazine was considered underground because of the earthen berm on three sides of the structure. The amount of explosives materiel stored in each igloo magazine was limited, and a minimum distance of 400 feet between magazines was specified.

The antecedents of the igloo design are sketchy. The new design was possibly developed simultaneously in several places. For example, the barrel-vaulted German *munitionshaus* was being constructed by the 1930s and possibly before. Further, although the igloo magazine was only widely adopted by the Navy following the Lake Denmark explosion, the basic design elements of earth-covered concrete magazines had existed in the United States almost a decade earlier. As early as 1918, earth-covered concrete magazines with concrete blast walls were constructed at the Lake Denmark Naval Depot. The primary difference between these magazines and igloo magazines was that the 1918 magazines had a flat concrete roof instead of the concrete arch (Fine and Remington 1972; Reed 1995:46).

The arch design had a distinct advantage over flat-roof construction in the event of an explosion. The thick haunches of the concrete arch and the thicker earth covering along the sides would laterally confine the contents of the igloo magazine. Thus, contents would be vented upward through the thinner crown and earth covering at the top of the magazine. This, in turn, would reduce the radius of possible sympathetic detonation. The flat-roofed concrete magazine, on the other hand, would vent evenly upward, not just along a narrow ridge at the arch. Therefore, large portions of the contents and the magazine itself would be randomly discharged, increasing the risk of sympathetic explosions in nearby magazines. Overall, concrete-arched magazines had to be designed to deaden only the loads of the arch and covering itself, while flat-topped magazines had to also take into account blast pressures (Explosives Safety Board 1997).

It has been theorized that the form for the igloo magazine is a copy of a similar form found in the wood-and-steel Nissen Bow hut of the British that developed into the World War II steel Quonset hut of the Americans (Reed 1995). It is more likely, however, that the unique barrel-vaulted, concrete, arch design was introduced at that time due to the practical realities of engineering blast design rather than visual similarity with other forms. As effectively tested by both the Navy and the Army, the design of the igloo magazine was successful in mitigating possible damage to nearby structures and buildings, which, following the Lake Denmark explosion was the major concern.

The many advantages of the igloo magazine over traditional magazines ultimately led to its preference for use as an explosives magazine. The thermal insulation qualities of concrete and earth covering eliminated the extreme high temperatures that were common in aboveground magazines and that accelerated the deterioration of smokeless powder and other munitions. The earth-cover of the igloo magazines also facilitated camouflage of these critical resources. Because the design of the igloo magazine reduced the risk of sympathetic detonation as well as the radius of structural damage and the range of missiles, the igloo magazines were deemed less hazardous to their environs than other aboveground magazines, particularly un-barricaded aboveground magazines. Igloo magazines also did not require separate barricades, thus substantially reducing land area requirements. Additionally, because of the inherent barricaded nature of igloo magazines, distances between magazines, and distances between magazines and inhabited buildings, could be halved. As igloos were supposed to be missile-proof and resistant to structural damage caused by an explosion at an adjacent magazine, explosives subject to detonation by missiles or by structural damage did not need to be separated from missile-forming and mass-

detonating ammunition by inhabited building distance. This allowed additional saving in land requirements and increased flexibility and efficiency in space utilization. Overall, the possibility of propagation of an explosion from magazine to magazine was reduced to practically zero with the use of the igloo magazine.

In July 1928, the Navy's Bureau of Ordnance began testing the newly designed reinforced concrete igloo magazines at Indian Head, Maryland. The experiment, conducted by the Naval Powder Factory, proved the safety of the magazine. Four miniature test models measuring six feet square were loaded with 3,300 pounds of TNT. The models were spaced 25 feet apart. As the object of the test was to see if hot fragments from an initial explosion would trigger secondary explosions, the central magazine was detonated. The central magazine was destroyed, and the concussion caused two other magazines to collapse. The collapsed magazines, however, did not explode, proving the safety of the igloo design (*Army Ordnance* 1928:127–128).

The Navy began constructing igloo magazines at the Yorktown Naval Depot, Virginia, in 1928. A 1928 article on naval construction activities in *Engineering News Record* described the magazine as a semi cylindrical structure of reinforced concrete and covered with earth except on the end walls, which were protected by barricades of earth faced with creosoted wood (*Engineering News Record* 1928:112). As built, the Yorktown magazine was 40 feet in length and 10 feet in height at the crown of the arch. Each magazine had the capacity to store 140,000 pounds of explosives. They were laid out in groups of seven with 500 feet between each magazine and 1,900 feet between groups. The design of the magazine was attributed to Captain E. R. Gaylor, Civil Engineers Corps, U.S.N., under Rear Admiral L. E. Gregory, Civil Engineers Corps, U.S.N., Chief of the Bureau of Yards and Docks (Reed 1995:43).

The article in *Engineering News Record* notes that:

> The outstanding feature of the new design is that the magazines will be sunk into the ground and bulwarked at each end, that in case of an accident, the explosive force would be directed upward instead of horizontally [Reed 1995:43, as quoted from *Engineering News Record* 1928, Vol. 101(3):112].

Additionally, the new design featured a complex system of lightning protection that included lightning rods and steel reinforcing rods, closely set and welded in the arch. All of the reinforcing steel and other metal parts were electrically connected to a copper girdle circling the entire structure and embedded in its footing (Cotter 1930; Fine and Remington 1972; see also Reed 1995:43).

A plan for a magazine, titled "Magazine Plan Elevation and Section," Yards and Docks Drawing Number 104260, has been located on file at Yorktown Naval Weapons Center, Virginia. The plan, dated 15 July 1927, indicated that N. M. Smith was the project manager. Smith was actually Commander N. M. Smith, Civil Engineer Corps, Bureau of Yards and Docks, U.S.N., and a member of the joint Army-Navy board that investigated ammunition storage conditions. The designer of the plan is noted simply as "J.M." A companion sheet to the plan with an analysis of stresses indicates the full name of the designer was Mr. J. M. Michaelson.

Drawings 104260 and 104261 provide a plan, elevation, section, and details of an early barricaded igloo. The elevation shows a 40-foot-long structure. Measuring 11.8 feet in total height, the crown of the arch was 10 feet covered with fill on three elevations. A waterproof membrane capped with a layer of sand shows under the fill but was not described. Vertical steel rods were placed within the concrete arch and two ventilators are in place. A sloped barricade facing the entry wall has protective planking on its top and its vertical face. The head wall is composed of a concrete section fronting the arch; the wing sections were shown as being wood. Double metal doors on the head wall offered access to the interior. Anchors were attached to the back of the head wall wings. The end wall was covered with fill, only one ventilator pipe being visible. The interior plan was open. The concrete floors were gently sloped to the edge gutters that lined each long parallel wall. The arch and the floor were not attached. The half section shows the concrete footing, it's size, and setting in gravel (Figures 8 and 9).

Naval Ammunition Depot, Hawthorne, Nevada

The first entirely modern ammunition depot to house twentieth-century explosives and propellants was the Naval Ammunition Depot at Hawthorne, Nevada.[2] Built by the Navy, the depot was located in an isolated area of the Nevada desert but was still within 1,000 miles of major Pacific coastal ports. Initial construction began in July 1928 and was completed in 1931.

The design of the individual magazines at Hawthorne was almost identical to the structures constructed at Yorktown, VA, in 1928. The typical magazine had a capacity of 143,000 pounds and measured 40 feet 4 inches long and 25 feet wide. The maximum height at the center of the arch roof was 20 feet. The top and sides of the magazine were completely covered with earth except in front where the depressed roadway gave access to the door. All reinforcing steel and other metal parts on the magazines were electrically connected to a copper girdle circling the entire structure and embedded in the footing. Opposite the depressed door was an earth barricade (Figure 10).

The initial magazine area at Hawthorne contained 84 high explosives magazines and two fuse and detonator storage magazines. Concern for safety governed magazine layout and individual magazine design at Hawthorne. The magazines were split into groups of seven with each group forming an approximate hexagon with one building at each angle of the perimeter and one in the center. The magazines in each group were separated center to center by 600 feet of space. This spacing was believed to be adequate to prevent induced or sympathetic explosions within the magazine group. The maximum probable loss within the group was determined to be only the explosives stored in one magazine, which amounted to 143,000 pounds. This equaled only 1.19 percent of the total explosives stored on the facility.

Each group was further spaced 3,000 feet center-to-center from adjacent groups. This distance was believed sufficient to prevent damage from extending from one group to another in the unlikely event that all seven magazines in one group detonated. As such, the maximum loss possible was held to the amount of explosives stored in one group, equaling about 1 million pounds or 8.33 percent of the entire installation's storage capacity.

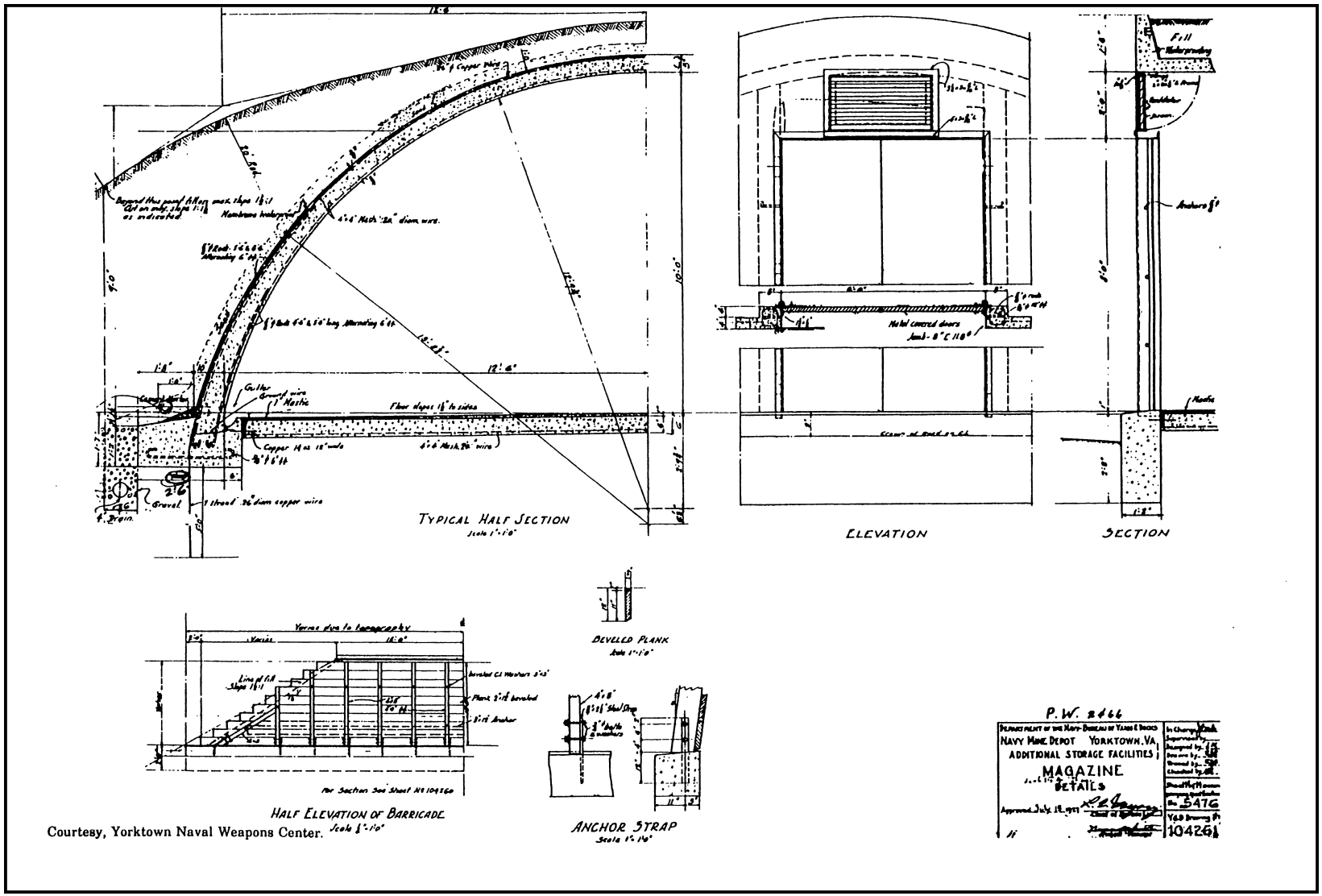
By the outbreak of World War II in Europe in the fall of 1939, the Navy still had only limited capacity for storing munitions. The Naval Ammunition Depot at Hawthorne remained the Navy's only inland depot until after America's entrance into World War II. As such, considerable construction activity occurred at Hawthorne between 1935 and 1945. A total of 1,751 magazines was erected by the Navy at Hawthorne. Nearly two-thirds of these were conventional 25-by-80-foot, single-arch, high-explosives storage igloos. Other magazines constructed at Hawthorne included the triple-barrel-vault, high-explosives magazines in which each vault measured 25-by-80 feet; the 50-by-100-foot rectangular box, high-explosives magazines; the 25-by-20-foot single-arch, fuse and detonator igloos; and the 100-by-50-foot smokeless powder magazines. All of the magazines were laid out for safety according to standard quantity and distance formulas. With the exception of the four, brick, smokeless powder magazines, all magazines were constructed of reinforced concrete (Figure 11 and 12).

Overall, the magazine design and layout at Hawthorne would serve the Navy and the Army as a paradigm for future construction of military ammunition storage facilities and establish the earth-covered igloo as the primary means for safe ammunition and explosives storage for the twentieth century.

Igloos and the Army

Although the Army rebuilt Picatinny Depot without using the newly developed igloo magazines, the Army's Ordnance Department was aware of the Navy's work with the new design. Three years after the Lake Denmark incident, the Ordnance Department undertook

[2] In 1977, the Naval Ammunition Depot at Hawthorne, Nevada, was transferred to the Army and the name was changed to Hawthorne Army Ammunition Plant.



Courtesy, Yorktown Naval Weapons Center.

Figure 8. Magazine details for Drawing 104261.

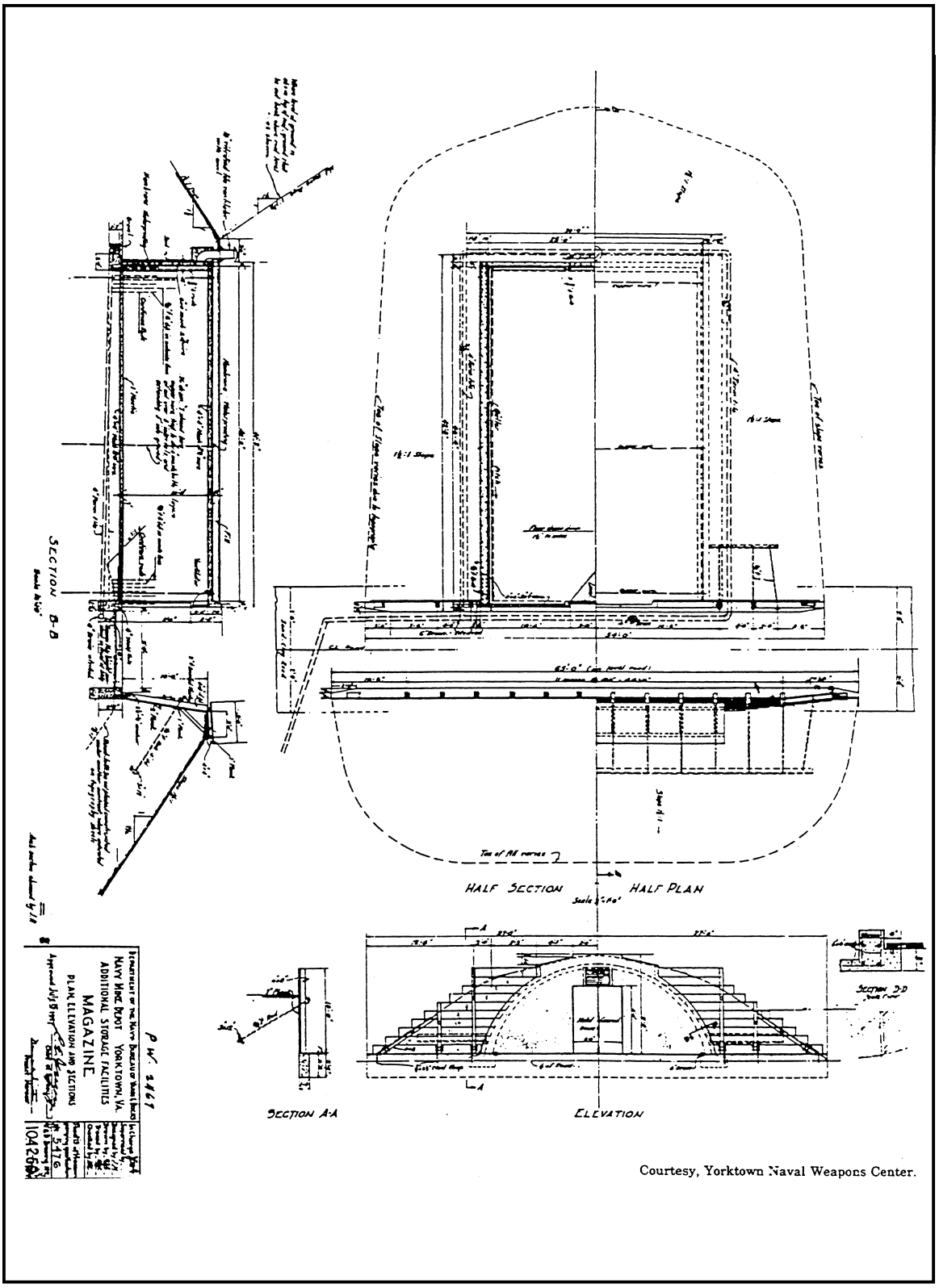


Figure 9. Magazine plan, elevations, and sections for Drawing 104260.

Figure 10. Magazine 56-AT-2 at Hawthorne Naval Ammunition Depot.

Figure 11. Triple Arch Magazine at Hawthorne Naval Ammunition Depot.

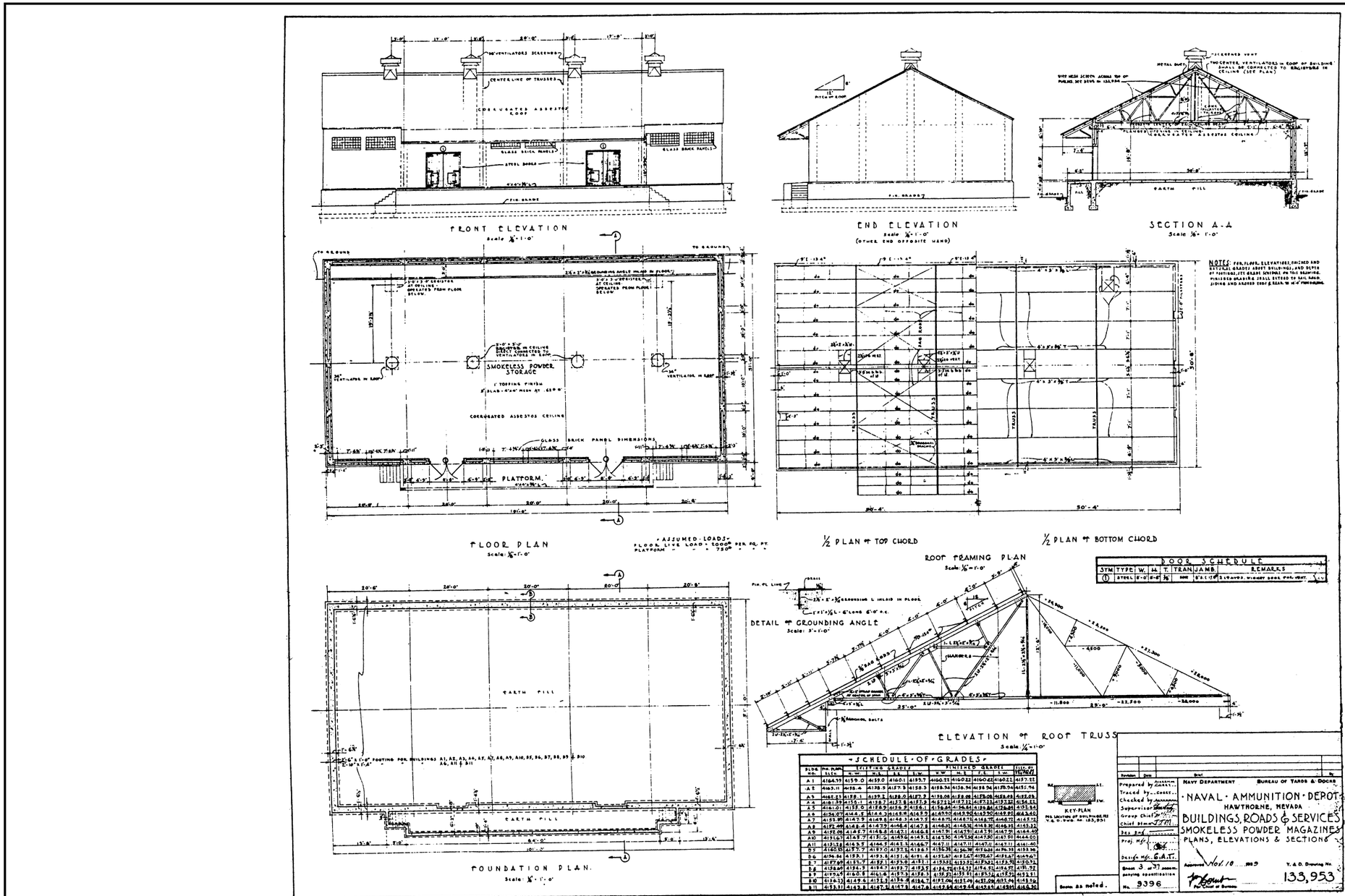


Figure 12. Plans, elevations, and sections for Smokeless Powder Magazine at Hawthorne Naval Ammunition Depot.

expansion of the Savanna Ordnance Depot, Illinois, as a result of the findings of the 1928 joint Army-Navy board investigating ordnance storage. The Savanna depot was particularly well suited for the storage of high explosives, and the joint board recommended that the facility be expanded to accommodate ammunition from the east coast depots where ammunition storage had become too concentrated.

In early 1929, the Ordnance Department constructed 24 earth-covered magazines at Savanna. The first Army standard-type igloo, commonly known as the "Old Savanna" type, was based on Office of the Quartermaster General drawings 6579–160, –160; changed to 652–311, –312 (Ordnance No. 19–2–93,04, Magazine Type 30), dated 19 July 1928. The "Standard Underground Magazine" measured 25 feet wide and 40 feet 4 inches long with a 10-foot crown inside. The magazine's concrete arch was 5 inches thick at the crown and 10 inches thick at the sides. The crown was covered with one foot of earth. The front wall was 4 inches thick, while the rear wall was 6 inches. The magazine's concrete had wire mesh reinforcements in the arch and walls. The single entry, a steel-clad, double, wooden door, measured 6-by-8 feet. The magazine did not have a platform or apron. The full timber net headwall fronted directly onto the road, with an optional timber-revetted barricade across the road. The structure was vented with louvers and was fully grounded (Figure 13).

The 24 magazines at the Savanna Army Depot were constructed in parallel rows. This was considered safe since the basic design of the igloo directed explosions upward rather than outward. As found by the Navy at Indian Head, Maryland, the design of the igloo prevented detonation of adjacent magazines in the event of an explosion. In addition to constructing the Old Savanna type magazine at the Savanna depot, the Army also built them at the Delaware Arsenal, New Jersey; Benicia Arsenal, California; and Aberdeen Proving Ground, Maryland (Figure 14).

In addition to the Old Savanna type igloo, the Army developed two other igloo-type designs in the 1930s. The design of the "Old Line" type was based on the Old Savanna type with some modifications. The plans for the Old Line type magazines were dated 20 June 1933 and labeled Office of the Quartermaster General drawings 652–295 through 296 (Ordnance No. 19–2–107–108, Magazine Type 41). Old Line-type magazines measured 25 feet wide and 40 feet 4 inches long with a 10-foot inside crown. The concrete arch was 5 inches thick at the crown and 10 inches thick along the sides. An exterior monorail was added, and the exterior door was changed from wood to steel plate. The timbered headwall was specified as concrete and 6 inches thick. Earth-cover at the crown was increased to 2 feet, and a sand cushion over a waterproofing membrane was specified. The Army constructed Old Line-type igloos at Savanna Army Depot, Illinois; Delaware Depot, New Jersey; Benicia Arsenal, California; and Aberdeen Proving Ground, Maryland.

The "Old Depot" magazine type was derived from the design of the Old Line magazine type in two lengths, 40 feet and 60 feet. The plans for the 40-foot magazine, known as Type A, were dated 9 December 1935 as Office of the Quartermaster General drawing 652–317 through 320 (Ordnance drawing 19–2–121 through 130, Magazine Type 45). The plans for the 60-foot magazine, known as Type B, were dated 23 July 1937 as Office of the Quartermaster General drawing 652–326 through 331 (Ordnance drawing 19–2–125 through 130, Magazine Type 49). The Old Depot type magazine increased the width of the magazine to 25 feet 6 inches and raised the crown height to 12 feet 9 inches. The thickness of the crown was also increased to 6 inches. The monorail was put only on the inside on pilasters projecting from the back and end walls. The single door increased to 4 feet in width. The concrete reinforcement changed from wire mesh to rebar. The Old Depot-type magazine was constructed at Camp Stanley, Texas; Ogden Depot, Utah; and other pre-World War II depots and stations (Figures 15 and 16).

Preparing for War

Following World War I, American citizens and politicians generally embraced a policy of isolationism. However, certain lessons learned during World War I made a sufficient impression for Congress to instigate some new policies. The National Defense Act, passed by Congress in 1920, reorganized the War Department and,

importantly, mandated that the Assistant Secretary of War organize all military procurement. The latter mandate was important because it would prevent the type of rivalry between military branches for supplies that occurred during World War I. As a consequence of the act, the Planning Branch, Office of the Assistant Secretary of War, was established. The Planning Branch was charged with both procurement and industrial mobilization planning. In 1922, the Planning Branch established the Army and Navy Munitions Board to coordinate Army and Navy planning. Along with the Planning Branch and the Army and Navy Munitions Board, the Office of the Chief of Ordnance and the Manufacturing Service of the Ordnance Department worked together in procurement planning during the interwar years. The planning provided by these groups during the 1920s and 1930s allowed for the successful rearmament of the United States military prior to and during World War II (Kane 1995:14, 19).

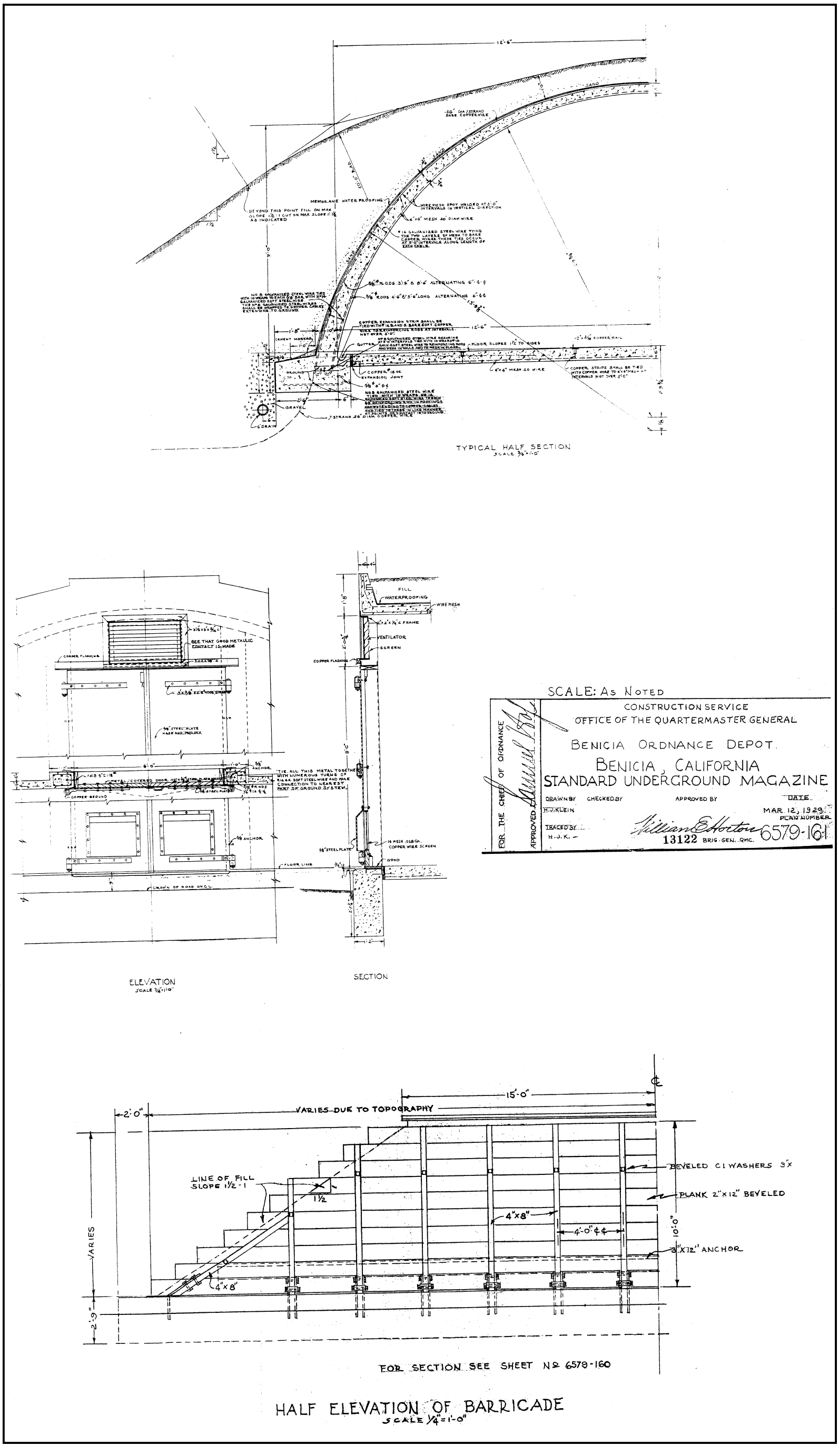
However, Congress also passed certain measures to limit the possibility of American participation in another world war. This culminated with the passage of several neutrality acts in the mid-1930s that restricted contact with warring nations. Additionally during the 1920s and early 1930s, Congress slashed the budgets of all military agencies. Economic conditions were so tough that many older officers took pay cuts so that younger officers could remain on staff. The Great Depression of the 1930s further reduced the budgets and abilities of the military. Military agencies, such as the Ordnance Department, did benefit slightly from New Deal-era work programs such as the Civil Works Authority, Public Works Administration, and Works Progress Administration. These agencies primarily provided labor to help in the maintenance and repair of existing facilities (Kane 1995:26–27).

By 1936, the possibility of war in Europe was an increasing reality. In response to this and despite the isolationist policies of the previous years, Congress started increasing military appropriations. By 1938, with isolationism seriously beginning to fall from favor, Congress gave sufficient monies to the Ordnance Department to permit an increased level of planning, as well as equipment purchases for powder, small arms ammunition, and loading-and-packing installations. Additionally, beginning in 1938, the Allied powers were allowed to place orders for munitions with American companies using a loophole in the neutrality legislation. This loophole allowed warring nations to purchase supplies by paying cash on delivery and transporting the goods on their own ships (Kane 1995:28–29).

On 1 September 1939, war was formally declared in Europe. Seven days later, President Franklin D. Roosevelt proclaimed a state of limited national emergency. Between September 1939 and June 1940, Congress and the President strove to help the Allied powers in various ways. In June 1940, Congress passed the first national defense appropriations act and instituted the Protective Mobilization Program. Critically, the Protective Mobilization Program included a munitions building program that provided for the manufacture of materiel sufficient to supply 1.2 million ground troops. Additionally, the program called for procurement of long-lead-time supplies sufficient to supply a force of 2 million—the production of 18,000 airplanes and the productive capacity to supply a force of more than 2 million on combat status. Together, this provided a major step in the mobilization of the United States Army (Kane 1995:29–30).

Army Depot System

As part of the mobilization efforts for World War II, the Army instigated an extensive network of depots for the sole purpose of receiving, storing, and issuing general military supplies. The Ordnance Department, Quartermaster Corps, and Air Corps operated the most extensive depot systems. The Signal Corps, Corps of Engineers, and Chemical Warfare Service also operated smaller logistical systems. Ordnance Department depots were unique among the service depots. While other depots primarily consisted of facilities for the storage of inert materiel, the primary mission of ordnance depots was the storage and distribution



TYPICAL HALF SECTION
SCALE 3/8"=1'-0"

ELEVATION
SCALE 3/4"=1'-0"

SECTION

SCALE: As Noted

CONSTRUCTION SERVICE
OFFICE OF THE QUARTERMASTER GENERAL

BENICIA ORDNANCE DEPOT.

BENICIA, CALIFORNIA
STANDARD UNDERGROUND MAGAZINE

DRAWN BY	CHECKED BY	APPROVED BY	DATE
H.J. KLEIN			MAR 12, 1929
TRACED BY H.J.K.			PLAN NUMBER 6579-161

APPROVED FOR THE CHIEF OF ORDNANCE
William E. Horton
13122 BRIG. GEN., QMC.

HALF ELEVATION OF BARRICADE
SCALE 1/4"=1'-0"

Figure 13. Plans for standard underground magazine constructed at Benicia Ordnance Depot.

Figure 14. Standard underground magazine at Savanna Army Depot.

of explosives materiel and represented the single largest concentration of ammunition magazines.[3]

In the 1920s and 1930s, the Army did not have large numbers of depots, reflecting the small size of the military during this period. In the interwar years, depots were divided into reserve, intermediate, and area facilities. Reserve facilities held large amounts of supplies for indefinite periods of time. They were intended to provide needed materiel during national emergencies. Intermediate and area depots were constructed to store three months' worth of supplies for the military posts within their jurisdiction. Intermediate depots served strictly for storage. Area depots were used only for distribution. By World War II, the functions of intermediate and area depots were combined. Each Army post also had depot facilities that were intended to store one month's worth of supplies.

During the interwar years, the Ordnance Department maintained reserve depots at Curtis Bay, Maryland; Delaware, New Jersey; Raritan, New Jersey; Nansemond, Virginia; Savanna, Illinois; Wingate, New Mexico; and Ogden, Utah. These reserve depots were mainly responsible for maintaining surplus World War I materiel. Intermediate depots were maintained at Augusta, Georgia; Benicia, California; Rock Island, Illinois; and San Antonio, Texas, to serve Army organizations within their respective areas.

Little was done during the interwar years to address the potential future depot needs of the military. Though the Army conducted studies of existing facilities that highlighted inadequacies

[3] Other services built ordnance depots that eventually came under Army control. These include the Hawthorne, Nevada, and McAlester, Oklahoma, army ammunition plants and the several former Chemical Warfare Service depots. Hawthorne and McAlester were navy ammunition depots that were transferred to the Army in 1977. Chemical ordnance depots were established near three of the Chemical Warfare Service arsenals at Edgewood, Maryland; Huntsville, Alabama; and Pine Bluff, Arkansas.

of the current system, no action was taken. For example, the Ordnance Department noted in 1937 that, ideally, 25 percent of ordnance depot capacity within the United States should be concentrated along the eastern seaboard, 60 percent should be situated in the continental interior, and the remaining 15 percent in the West. When war erupted in Europe in 1939, Ordnance Department planners studied their distribution of depots and found that 65 percent of available storage space was in the East, 27 percent in the Midwest, and seven percent in the West. Little was done to prepare for the needs anticipated by planners until mid-1940 when the Protective Mobilization Plan was assembled and funded by Congress.

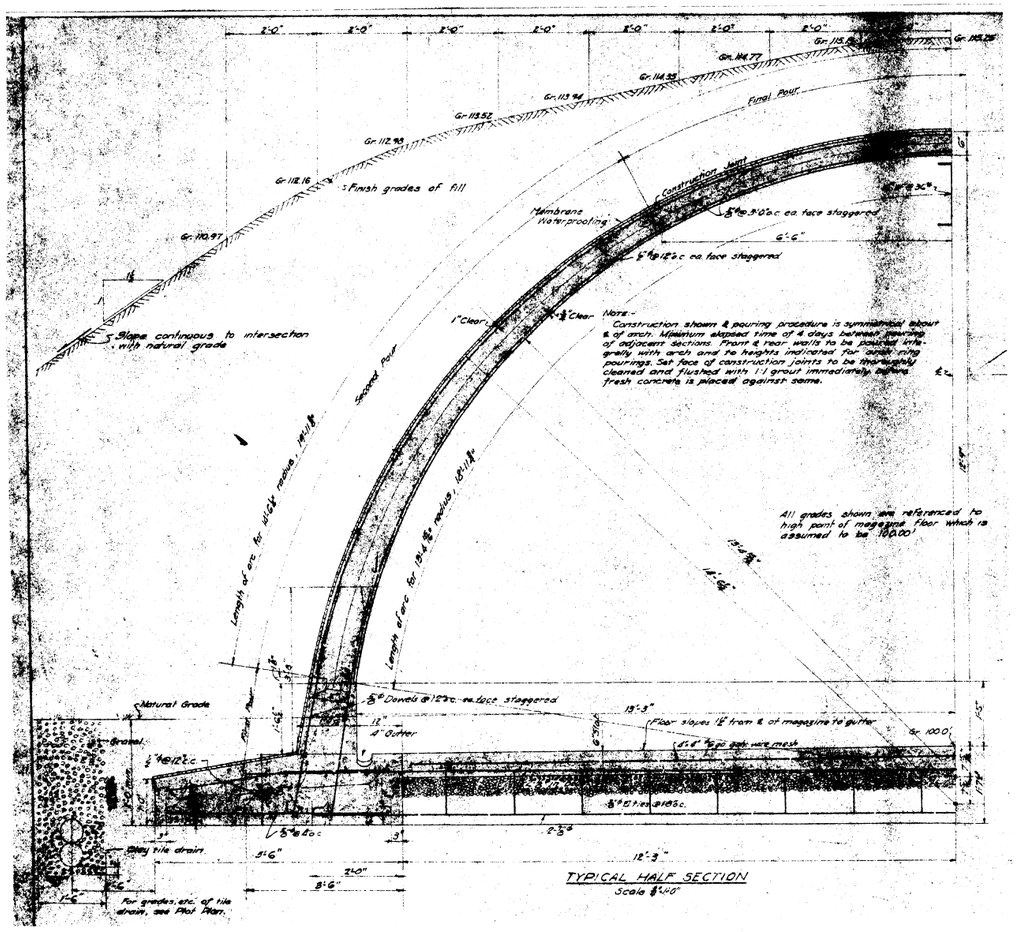
When Congress enacted the Protective Mobilization Plan of 1940, Ordnance Department planners moved to correct the problems identified in 1939 concerning the national distribution of ordnance storage facilities. The Army also was rapidly establishing new ordnance works and plants, which resulted in the expansion of the depot system to accommodate the influx of materiel from the new plants.[4] New ordnance depots were established along the Atlantic, Gulf, and Pacific coasts. By 1942, the Ordnance Department had developed an extensive system of ordnance depots, supplemented by general supply depots, back-up storage facilities, war aid depots, holding points, and motor bases to ensure adequate supplies of ordnance and to repair equipment (Figure 17).

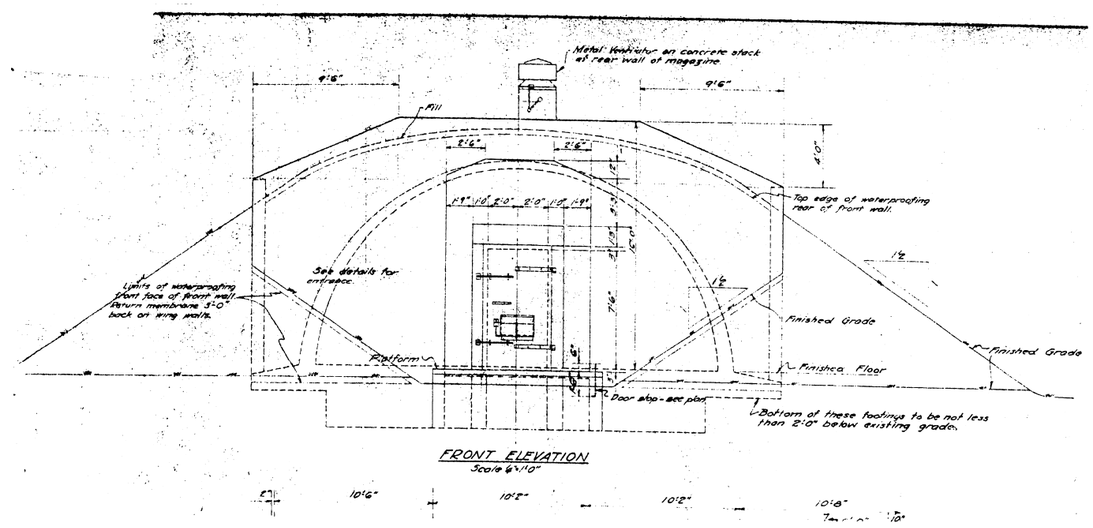
Immediately after passage of the protective mobilization legislation, the Ordnance Department established four new depots. These consisted of Anniston Ordnance Depot in Anniston, Alabama; Portage Ordnance Depot, located contiguous to the Ravenna Ordnance Plant in Ravenna, Ohio; Umatilla Ordnance Depot in Umatilla, Oregon; and Fort Wingate Ordnance Depot, located within the boundaries of Fort Wingate, New Mexico. Before construction of these four facilities was complete, Ordnance Department officials recognized that more storage capacity was required, and construction was begun on four more depot facilities: Milan Ordnance Depot in Milan, Tennessee; Red River Ordnance Depot in Texarkana, Texas; San Jacinto Ordnance Depot in San Jacinto, Texas; and Seneca Ordnance Depot in Seneca, New York. All eight depots were classed as "Class A" depots, and the Ordnance Department intended to retain these installations after the war. Thus, it was preferred that buildings and structures constructed at these facilities use permanent construction materials such as brick and stone.

Following the declaration of war by the United States in 1941, the Ordnance Department undertook construction of a second wave of eight depots. These depots were classed as "Class B" depots. As such, the explosives storage areas were built using permanent construction materials, while the administration and other non-explosives storage structures were constructed utilizing temporary mobilization building plans and materials when possible. The eight depots constructed in the second wave included Blue Grass Ordnance Depot in Lexington, Kentucky; Letterkenny Ordnance Depot in Letterkenny, Pennsylvania; Pueblo Ordnance Depot in Pueblo, Colorado; Sierra Ordnance Depot near Herlong, California; and Tooele Ordnance Depot near Tooele, Utah.

The first four "Class A" Ordnance depots were located roughly within the four corners of the United States, in accordance with plans for defending the United States from potential foreign attacks. As the mobilization program continued to swell the size of the Army and its air component, the need for more depots and a more diverse geographic distribution was recognized. Whenever feasible, the Ordnance Department located its depots near loading plants to reduce transportation costs. Two extant examples of this practice are the Portage Ordnance Depot, Ohio, which became part of the Ravenna Army Ammunition Plant, and Milan Ordnance Depot, Tennessee, which became part

[4] In addition to the ordnance depots, the Army authorized the construction of 77 government-owned, contractor-operated (GOCO) ordnance plants during the World War II-era. These plants also included extensive ammunition and explosives storage areas. The majority of these areas are identical to those found at ordnance depots. Kane (1995) presents an excellent historic context concerning the development and operation of the GOCO ordnance plants. Because of the similarity in the ammunition and explosives storage areas in these plants and ordnance depots as well as the existence of the GOCO historic context, the plants are not discussed in this report.





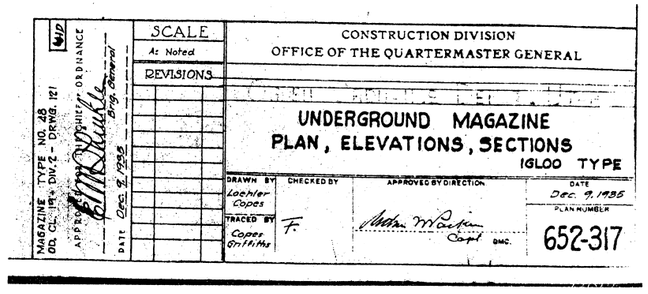
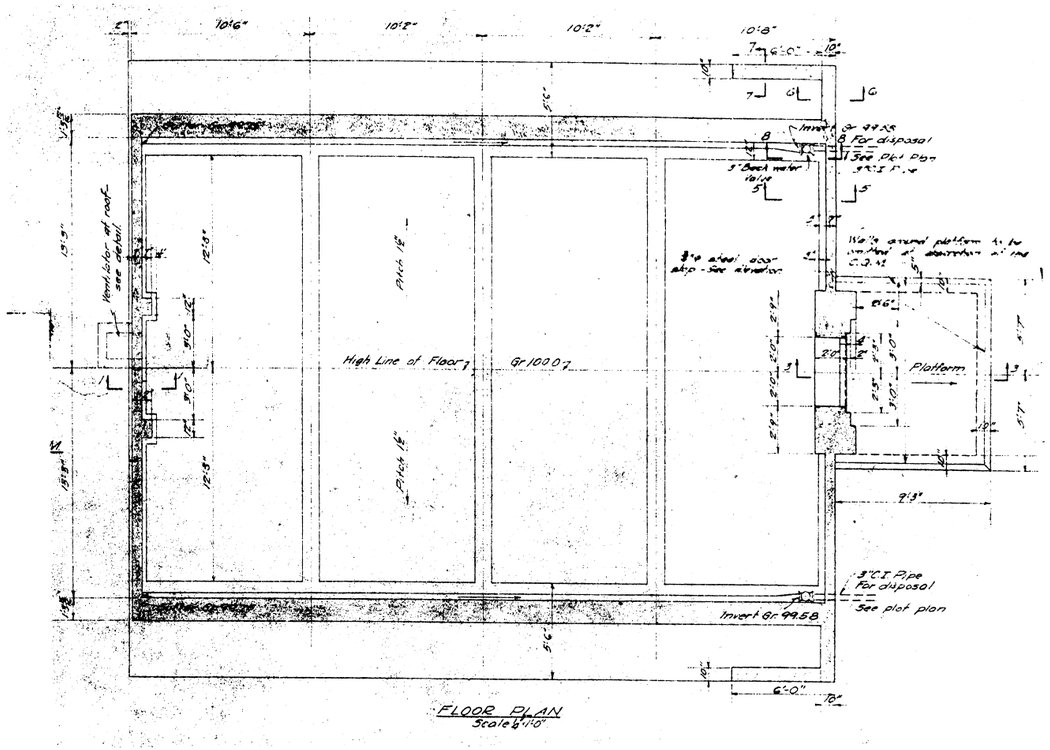


Figure 15. Typical half section and front elevation for underground magazine, Drawing 652-317.



MAGAZINE TYPE NO. 28 ORD. CL. 14 - DIV. 2 - ORD. 12	SCALE: As Noted	CONSTRUCTION DIVISION OFFICE OF THE QUARTERMASTER GENERAL
APPROVED: Brig. General, ORDNANCE OFFICE	REVISIONS	UNDERGROUND MAGAZINE PLAN, ELEVATIONS, SECTIONS IGLOO TYPE
DATE: Dec. 9, 1936	DRAWN BY: Lochler Copes; CHECKED BY: F.; APPROVED BY DIRECTION: Nathan McClain Capt. QMC; DATE: Dec. 9, 1936	
	TRACED BY: Copes Griffiths	PLAN NUMBER: 652-317

Figure 16. Floor plan and longitudinal section for underground magazine, Drawing 652-317.

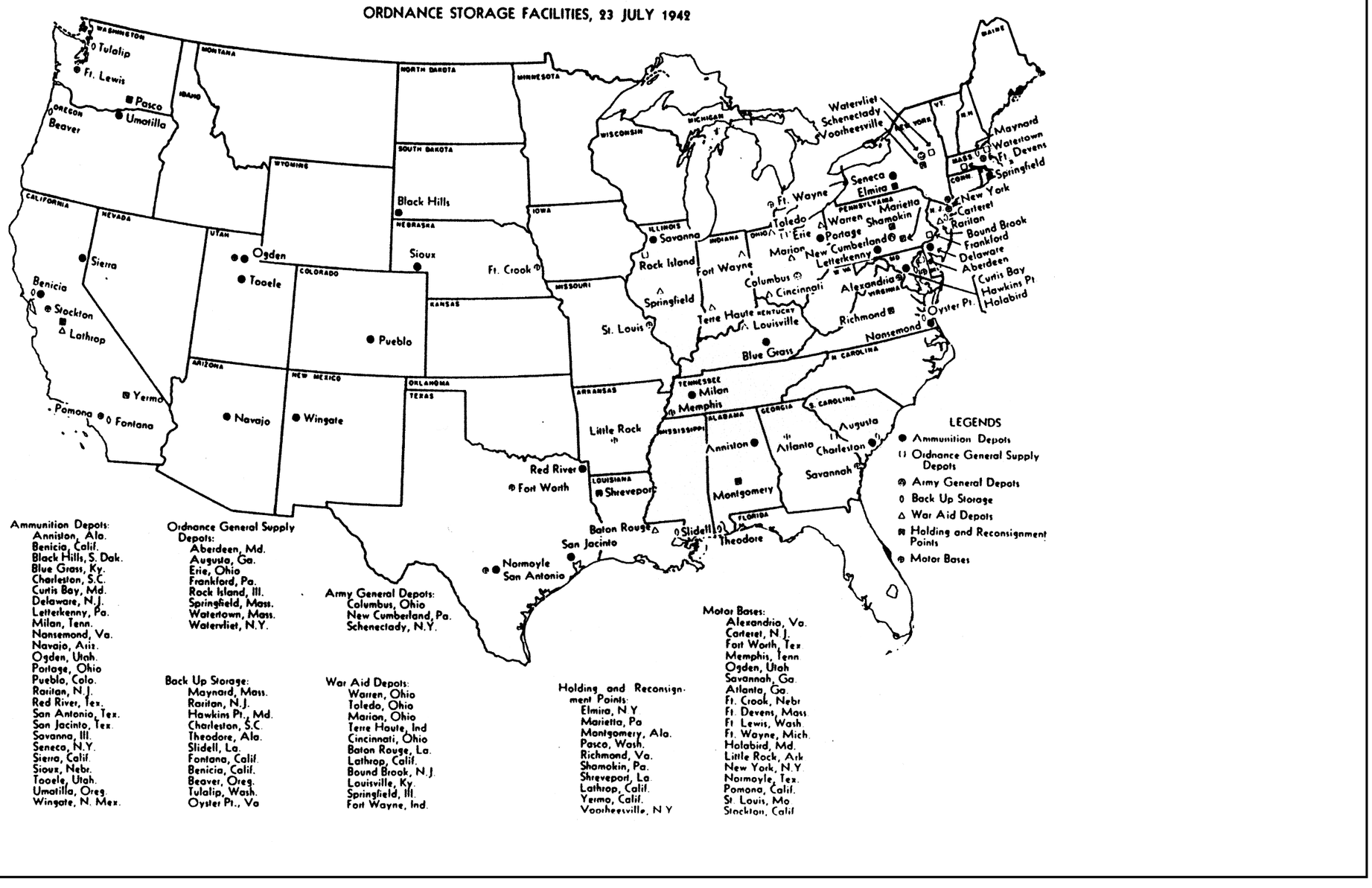


Figure 17. Location of ordnance storage facilities in 1942 (from Thomson and Mayo 1960).

of the Milan Army Ammunition Plant. As American forces began to be transferred overseas, the Ordnance Department began to build more depots near the coasts to support movement of ammunition to port facilities.

In addition to ammunition and explosives storage, Ordnance Department depots also received, stored, and issued a wide variety of other materiel. Traditionally, the Ordnance Department was responsible for weapons, tanks, and similar items in addition to ammunition. After August 1942, its responsibilities expanded to include motor vehicle inventory, maintenance, distribution, and repair. Ordnance depots, therefore, included general storage facilities in addition to explosives storage facilities.

Architectural Design and Layout of Ordnance Depots

The architectural design of World War II-era ordnance depots exhibits the characteristics of standard, utilitarian, World War II mobilization construction. Like most other ordnance facilities, ordnance depots were separated into functionally distinct areas: administration, inert storage, and explosives storage. Some depots also incorporated repair and maintenance facilities or training facilities. Most depots utilized standardized plan types established by the Ordnance Department in the construction of buildings and structures.

Both the layout and infrastructure associated with ordnance depots developed out of the need to ensure safety and to facilitate transportation of volatile munitions. Safety regulations concerning ammunition storage defined the minimum distance between munitions storage structures, the maximum number of structures allowed in a group, and the minimum distances between munitions storage groups. As a result, ordnance depots required vast tracts of land, typically occupying between 10,000 and 20,000 acres of land.

The development of road and railway systems was fundamental to the transport of munitions; thus, ordnance depots were frequently located near railroad lines where railway spurs could easily connect ammunition storage magazines to the main rail line. The existence of railroads was often one of the key factors in determining the location of an ordnance depot. The site for Seneca Army Depot, for example, was selected on the basis that the area was rural (thus, requiring that a fewer number of people be dislocated), relatively flat, and that two lines of the Lehigh Valley Railroad ran along the western and eastern boundaries of the site. Savanna Army Depot was bounded on the northeast by the Burlington Railroad. Ravenna Ordnance Plant was conveniently located in an area graced by three railroad lines (Walsh 1995:19). Throughout the nation, ordnance depots were constructed, in part, with rail transportation for munitions in mind. The existence of such features greatly influenced the layout of each depot as the ammunition storage area was typically located in an area bordering the main rail line (see Kane 1995:89).

Railroad tracks within the boundaries of ordnance depots were laid close to the doors of igloo magazines to enable the loading and unloading of munitions into railroad cars. Railroad lines also facilitated movement of munitions from production areas to storage areas. Ravenna Ordnance Plant, for example, maintained 130 miles of railroad track within its boundaries (Walsh 1995:34).

The vast majority of structures constructed at ordnance depots reflected the installation's primary mission, ordnance storage. Two types of ordnance storage magazines were erected: standardized, aboveground, structural clay tile magazines; and standardized, earth-bermed, concrete igloo magazines. Aboveground storage magazines were used to store explosives with a relatively low volatility, mainly raw explosives materiel and smokeless powder. Some loaded projectiles were stored in these magazines also. The aboveground magazines were steel-frame, one-story structures constructed on a concrete platform foundation and sheltered by a gabled roof. Walls were clad in 8-inch structural clay tile. Magazine sizes varied from 8-by-8 feet to multiple-bay structures spanning 51 feet in width. Reinforced steel doors provided access to the interior. Entrances were limited to only one side of the structure. The larger magazines featured concrete loading docks. Some aboveground magazines incorporated overhanging eaves to shelter the loading platform.

Although the design of igloo magazines was modified to suit differing needs and budgetary concerns, utilized standard plan types were utilized. All igloo storage magazines were 26 feet wide and were constructed in lengths of 40, 60 or 80 feet. These explosives magazines were to be spaced a minimum of 400 feet apart and were to be grouped in clusters of no more than 100, with at least 1,400 feet separating igloo clusters. Extensive road and rail networks were constructed to link the storage areas at each depot.

The igloo was preferred by the joint Army-Navy Ammunition Storage Board and the Ordnance Safety Board for all types of ammunition storage except small arms. In January 1941, the Ordnance Department required that igloos be used in all future depot construction. However, with the construction of large depots looming, reducing construction costs became a significant issue. Additionally, building material shortages that affected other aspects of the mobilization program also affected explosives storage construction. Unlike other mobilization programs, though, safety considerations prohibited the construction of igloos using temporary construction materials such as wood. However, modifications to the igloo design were made to assuage the material shortages and slash construction costs (Thomson and Mayo 1991:368; see also Reed 1995:46).

To meet the escalating demand for ammunition and explosives storage structures in 1941, temporary igloo magazines were authorized for use. These magazines were constructed of steel and covered with earth. By varying the number of sections built, temporary igloo magazines were constructed in various sizes. These magazines were adopted for emergency use during the war and were predominantly built on Army forts (U.S. Army 1941:31).

The concerns regarding building material shortages prompted the design and use of three alternative igloo types—the Triple-Barrel Vault, the Huntsville magazine, and the Corbetta Beehive magazine. All three were designed specifically to reduce the amount of materials required for construction. In addition, two new igloo designs were introduced during the World War II era. Both designs were considered to be improvements over those igloos constructed in the interwar era. The new igloo types became known as the "New Depot" and the "Army Standard Igloo."

Colonel Hugh J. Casey was appointed construction officer in charge of directing the redesign project for igloos. Eventually, Casey adopted an idea proposed by Colonel Edwin V. Dunstan, which eliminated the tie beams by reinforcing the concrete slab floor to take the thrust of the arch. By adopting these changes, an estimated $800 to $2,000 per igloo was saved (Fine and Remington 1989:334). Even with reductions of that nature, an average 50-foot igloo used the following quantities of materials: 160 cubic yards of concrete, 7,641 pounds of reinforcing steel, 4,323 pounds of reinforcing mesh, 240 pounds of copper, and an estimated 1,500 man-hours (MacLeay 1942:75; see also Reed 1995:46).

Many additional alternative designs were introduced to reduce the amount of material necessary in explosives magazine construction. One variation of the igloo design was the triple-barrel vault, which was composed of three hemispheres that shared common walls, foundations, and loading docks. In this design, three rectangular structures spaced approximately 12 feet apart were interconnected by a common concrete wall and loading platform. Each unit measured 26 feet 6 inches wide and 80 feet long. The concrete walls were 12 inches thick at the base and tapered to 6 inches near the peak. A set of double metal doors was centered on each vault.

In 1941, construction duties for the Army were transferred from the Quartermaster to the Corps of Engineers. By 1942, the Army had developed four basic designs of earth-covered magazines constructed during World War II. The first two designs were improvements over the igloo designs of the interwar years. The latter two designs were the direct result of attempts to cope with construction material shortages, primarily steel.

The first was the "New Depot" type. Based on the Old Depot type magazine, the New Depot magazines were constructed using Office of the Quartermaster General drawings 652–340 through 349, dated 27 September 1940, tracings lost and superseded by Office of the

Quartermaster General drawings 652–377 through 392, dated 30 October 1940. This new igloo design offered three standard lengths: 40 feet 4 inches, 60 feet 8 inches, and 81 feet. In this design, monorails and pilasters were deleted. This changed the square footage to 1,003, 1,528 and 2,147 respectively. The vents were deleted from the design but restored in a 1941 revision. The New Depot type magazines were constructed at the new Ordnance Department depots of Anniston Ordnance Depot, Alabama; Portage Ordnance Depot, Ohio; Umatilla Ordnance Depot, Oregon; Fort Wingate Ordnance Depot, New Mexico; Milan Ordnance Depot, Tennessee; Red River Ordnance Depot, Texas; San Jacinto Ordnance Depot, Texas; and Seneca Ordnance Depot, New York (Figure 18).

The second igloo design was the Army Standard Igloo magazine. These magazines were constructed at Ordnance Department Field Service depots and at line stations. The design of Army Standard Igloo magazines typically featured fully reinforced arch and walls, a full concrete headwall, and vents. Concrete doors were added as an alternative. The front wall increased to 10 inches in thickness, and the sand fill was deleted. The magazines were constructed using Corps of Engineers drawings 652–686 through 693, dated 27 December 1941, revised 4 March 1942 (Underground Magazine-Igloo Type O).

The Huntsville magazine was the third derivative igloo design used by the Army during World War II. This type of alternative magazine was the result of the effort to conserve critical materials, primarily steel. Reinforcing in the concrete was reduced. The headwalls were stubbed (earth fill spilled around the front corners). The door was changed to a 6-foot, double sheet of steel. The thickness of the front wall was decreased to 8 inches. Huntsville type magazines were constructed under Corps of Engineers drawings 652–1012,–1014,–1013, dated 29 April 1942 (Magazine Type A-O). Huntsville magazines were built at ordnance industrial installations and elsewhere.

The fourth alternative design was the Corbetta Beehive. Designed in 1941 by the Corbetta Construction Company of New York City, this structure consisted of an at-grade floor, elliptical dome-shaped (an oblate hemispheroid), earth-covered magazine with a 6-foot, double sheet, steel door. The first sample magazine was completed by mid-January 1942. By 1943, more than 2,000 of these magazines had been built (*Engineering News Record* 1943:95). The advantage of the Corbetta Beehive magazine was that it equaled the standard igloo magazine in structural strength but required only one-half the steel, one-third the copper and two-thirds the concrete used in the standard type igloo. The Corbetta Beehive was executed in single units or triple units with footprints of 44 feet 7 inches or 52 feet. These magazines were constructed under Corps of Engineers drawings 652–1000 through 1010, dated 19 February and 23 March 1942 (Underground Magazines 52 feet 0 inches and 44 feet 7 inches Corbetta Beehive Types). The first Corbetta Beehive magazines were constructed at Curtis Bay Ordnance Depot, Maryland. They were also constructed at the Sioux Ordnance Depot, Nebraska; Susquehanna, Maryland; the Naval Ammunition Depot at McAlester, Oklahoma; and other various ordnance industrial installations (Figures 19 and 20).

The Richmond Magazine, though not an alternative igloo design, is commonly mistaken for one. It is not earth-covered and, thus, does not meet the definition of an Army igloo. This magazine has massive side and rear walls banked with earth and a wood-framed, gabled roof with roll roofing. The front wall is wood-framed with asbestos shingles. The Richmond Magazine was constructed as a wartime substitute and has never been classified as an igloo for quantity distance purposes. Richmond Magazines were constructed at Savanna Army Depot and various ordnance industrial installations (Figures 21 and 22).

An example of the construction activities undertaken at the ordnance depots during the war was the building of 700 igloos at the Anniston, Alabama ammunition depot in 1941. The magazines were constructed under the direction of Lt. Col. Edmund Randall, constructing quartermaster. Local firms from Mobile and Birmingham handled the design of the magazines, while firms from Mobile and Montgomery handled the contracting. As described in the *Engineering News Record* these storage structures were

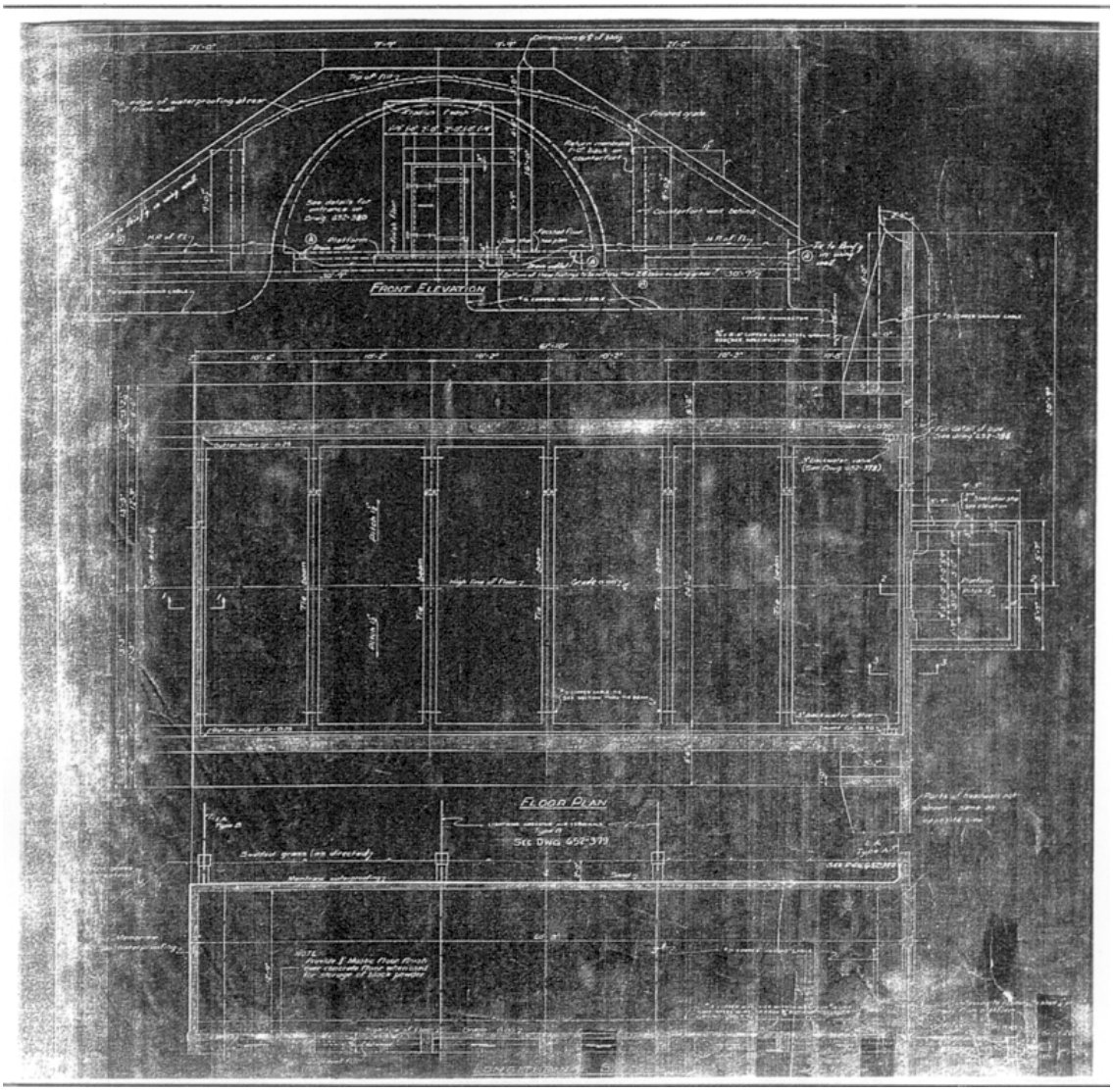


Figure 18. Floor plan and front elevation for underground magazine, Drawing 652–383.

> . . . not a true igloo shape, being rather half a barrel arch supported on spread footings carried down to firm subsoil. The floor of each structure, 26 feet 6 inches by 60 feet 8 inches, is placed separately from the exterior frame and rests directly on the ground. The igloo's rear wall is merely a "barrel head" while the front is a counterforted retaining wall. Access is through a vault type door in the front wall [*Engineering News Record* 1941a:4].

In addition to having a multiple-ply waterproofing, these concrete magazines were to have a minimum of two feet of earth over the top and rear. The protection of the magazines depended largely on the use of wide distances between the structures. The magazines were to be located 450 feet apart. As such, construction was spread over approximately 14,000 acres of land. Over 110 miles of arterial, secondary, and access roads were constructed as part of the project. Materiel was to be trucked from a central terminal area to the magazines. Additionally, a new spur to existing railroad tracks was constructed to move the ammunition and explosives in and out of the depot (*Engineering News Record* 1941a:4).

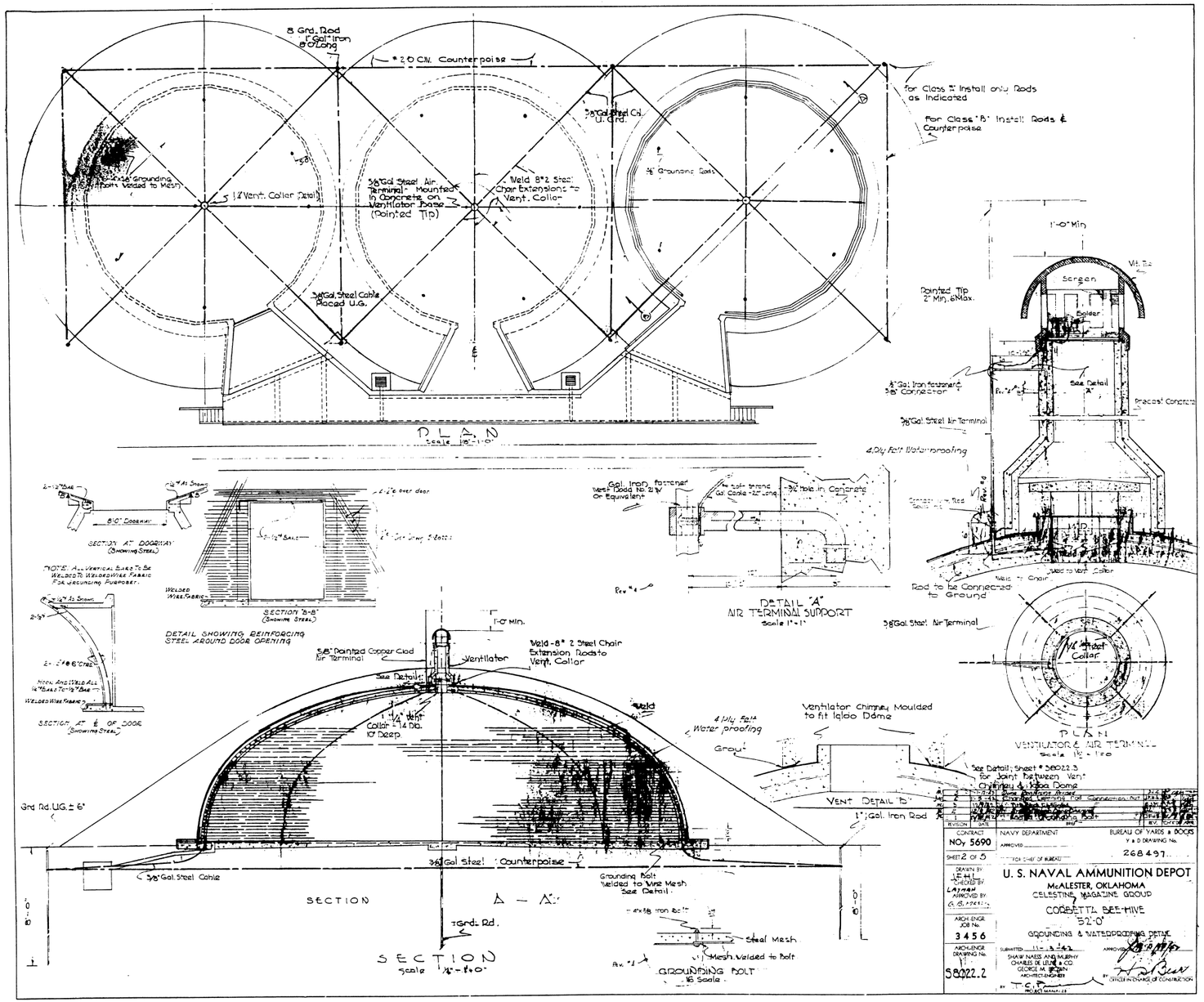


Figure 19. Drawings for Corbetta Beehive.

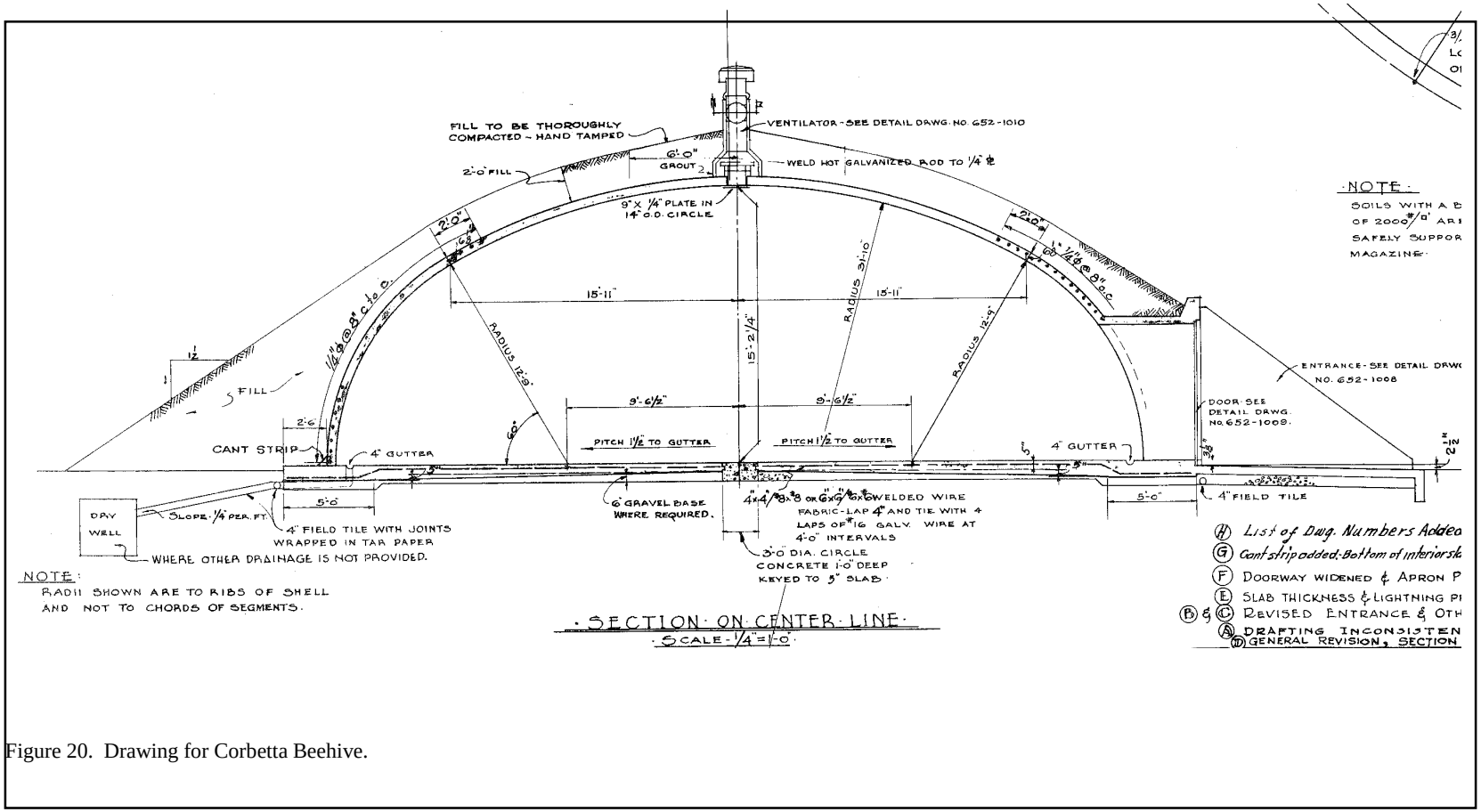


Figure 20. Drawing for Corbetta Beehive.

In September 1941, the War Department announced that Army contractors were establishing a record in the construction of igloos and storage warehouses. At that time, the contractor at the Umatilla, Oregon ordnance depot held the lead with 14 igloos being constructed in one day and 74 in a week. The first claim for a record had come from the Anniston, Alabama, ordnance depot, which had completed eight igloos in one day. But that record was soon superseded by the contractor at the Fort Wingate, New Mexico, ordnance depot who built nine igloos in a single day (*Engineering News Record* 1941b:13).

By December 1942, the ordnance depot system possessed more storage space than all of the commercial warehouses in the United States combined (Table 3). Over the course of World War II, over 10,000 ammunition and explosives storage structures were built by the Army at ordnance depots. This space was critical to the success of the Army during the war because safe storage of munitions was just as essential to the munitions production process as was the actual manufacture of munitions themselves.

Post-World War II Ammunition Storage Facilities

Following the Lake Denmark explosion in 1926, the primary concern in ammunition storage facilities for the next several decades was that of safety. Underground igloos had been specifically planned with catastrophic events in mind. Their shape and construction were designed to direct an explosion upward instead of outward, thereby reducing the chance that adjacent storage facilities or nearby buildings would be impacted. Underground ammunition storage facilities have changed little, though they have undergone modifications. By the late 1950s, Black and Veatch Consulting Engineers had designed a Stradley Magazine (Drawing Number 33–15–58) for the storage of special weapons (Figure 23).

In 1981, the U.S. Army Construction Engineering Research Lab (CERL), anticipating the construction of 1,700 new ammunition storage magazines over the next five years, published the results of its study on the functional requirements for ammunition storage facilities. While safety was still an important criterion, the authors found that other considerations, mainly the need to improve space efficiency, were equally important. The four standard magazine designs in use at that time were all earth-covered arches—circular and oval. The oval arch, while similar to the circular arch magazines, had been an improvement over the circular design. Both, however, used reinforced concrete or corrugated steel arch barrels (Howdyshell 1981:5–6).

The CERL report noted several inherent problems with the circular and oval designs. Both the reinforced concrete and corrugated steel leaked moisture through bolt holes, lap joints, or cracks in the concrete arches. The repair of such leaks was expensive. Condensation was also problematic in earth-covered igloos and even more difficult to control than leaks. In addition to these issues, it was noted that the doors of many older magazines were too small for forklifts to maneuver and that the igloos lacked hard surfaces just outside of the doorway that would facilitate loading and unloading of ammunitions and explosives. Another important drawback to the circular magazines was their lack of straight, vertical walls that were necessary for maximum space efficiency. An arch shape reduces the amount of storage space available (Howdyshell 1981:6–7).

Concerned with both cost and space efficiency, the Army would turn, once again, to the Navy for ideas on ammunition storage. Intrigued by a rectangular earth-covered, flat-roofed structure designed by the Navy, CERL noted that it had performed well in large-scale explosives model tests. Its rectangular shape would allow greater efficiency in storage, which would, in turn, reduce the number of buildings required and the amount of real estate needed. As an added benefit, precast concrete could be used for the roof and front wall, reducing the need for form work, which was expensive and time-consuming (Howdyshell 1981:9).

While a new design was under consideration, the existing magazines continued to serve the Army. In some cases, underground magazines were modified to accommodate new needs in ammunition storage. Pine Bluff Arsenal, for example, fit underground magazines with refrigerators for storing chemicals used in

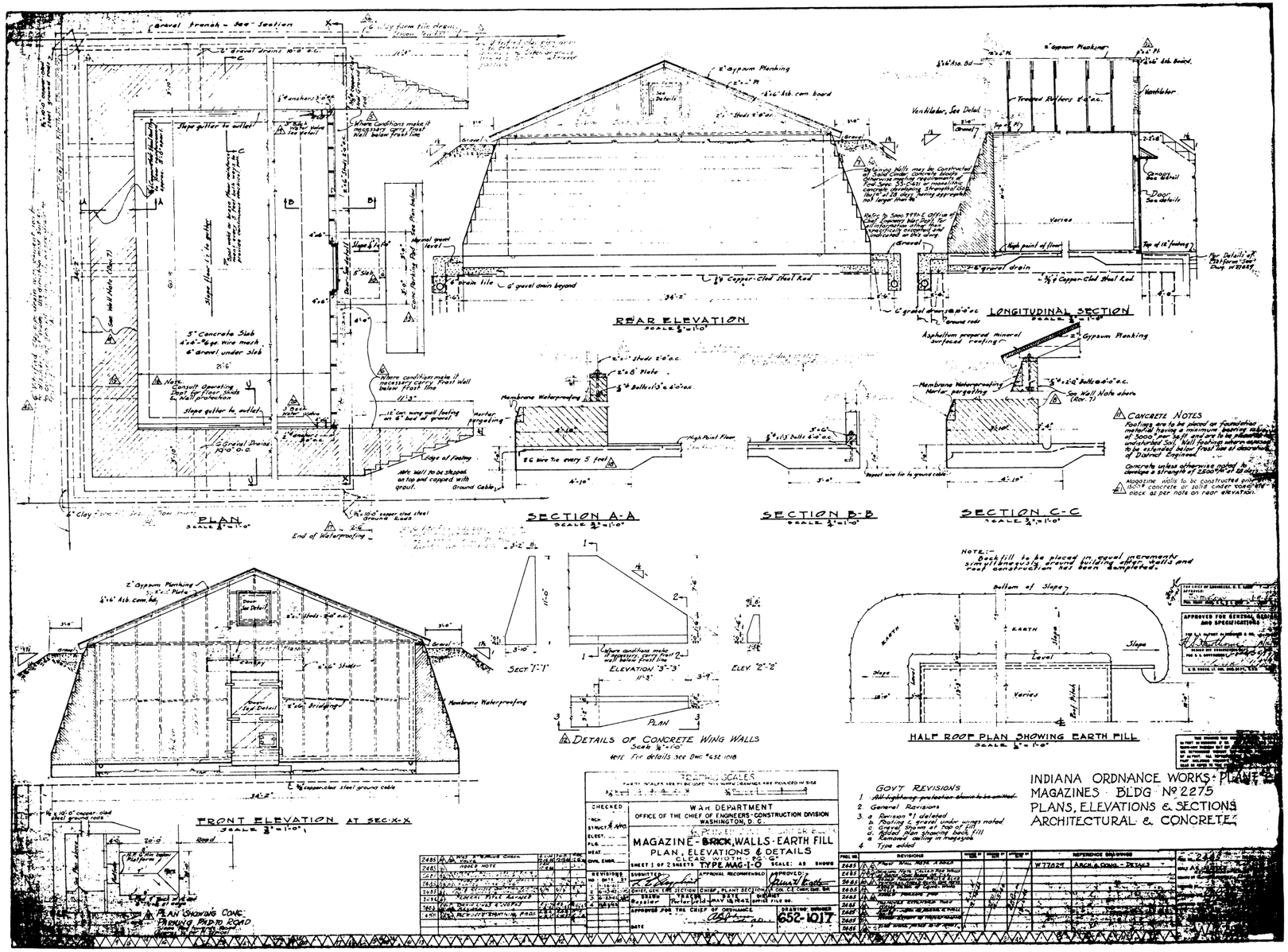


Figure 21. Front and rear elevations for Richmond Magazine.

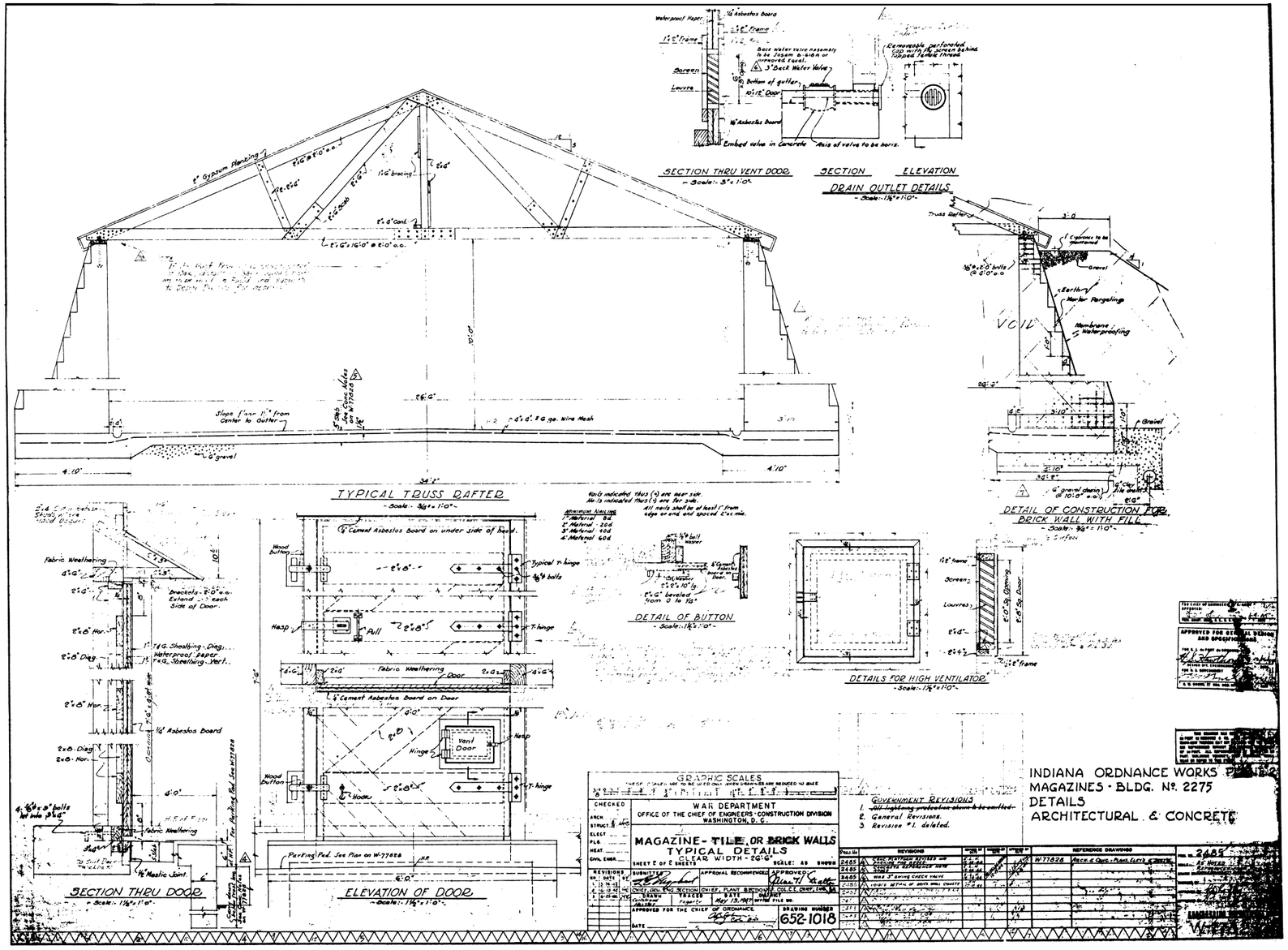


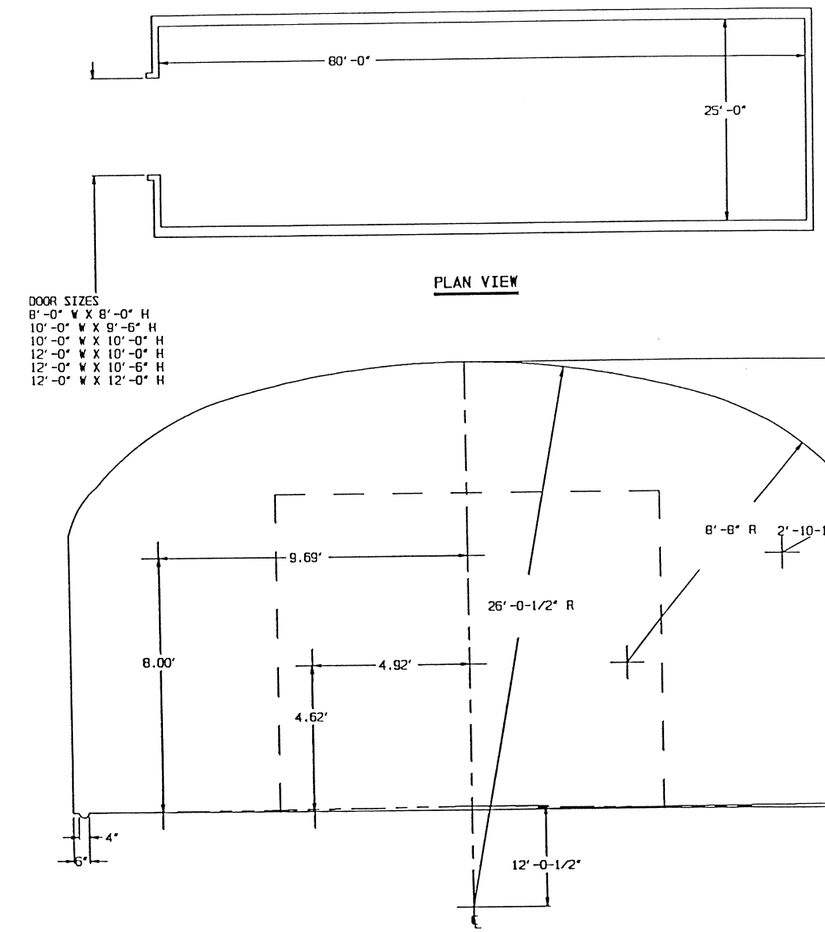
Figure 22. Typical details for Richmond Magazine.

Table 3
Reinforced-Concrete Underground Magazines Constructed During World War II and Initial Mobilization Effort

		Standard Type		Huntsville Type			Corbetta Beehive	
Ordnance Depot	Construction Started	60'	80'	40'	60'	80'	44'7"	52'
Umatilla OR	8 February 1941	642	358	2	—	—	—	—
Wingate NM	24 February 1941	550	100	2	—	—	—	—
Anniston AL	19 March 1941	200	600	2	—	—	—	—
Portage-Ravenna OH	19 March 1941	354	100	2	—	—	—	—
Milan TN	25 June 1941	600	100	2	—	—	—	—
San Jacinto TX*	1 July 1941	146	54	2	—	—	—	—
Seneca NY	9 July 1941	400	100	2	—	—	—	—
Red River TX	4 August 1941	300	400	2	—	—	—	—
Letterkenny PA	26 February 1942	200	600	2	—	—	—	—
Pueblo CO	4 March 1942	—	—	2	200	600	—	—
Sierra CA	4 March 1942	200	600	2	—	—	—	—
Black Hills* SD	25 March 1942	—	—	2	200	600	—	—
Blue Grass KY	27 March 1942	—	—	2	200	600	—	—
Navajo AZ	2 April 1942	—	—	2	200	600	—	—
Tooele UT	7 April 1942	—	—	2	200	600	—	—
Sioux* NE	15 April 1942	—	—	—	—	—	202	600

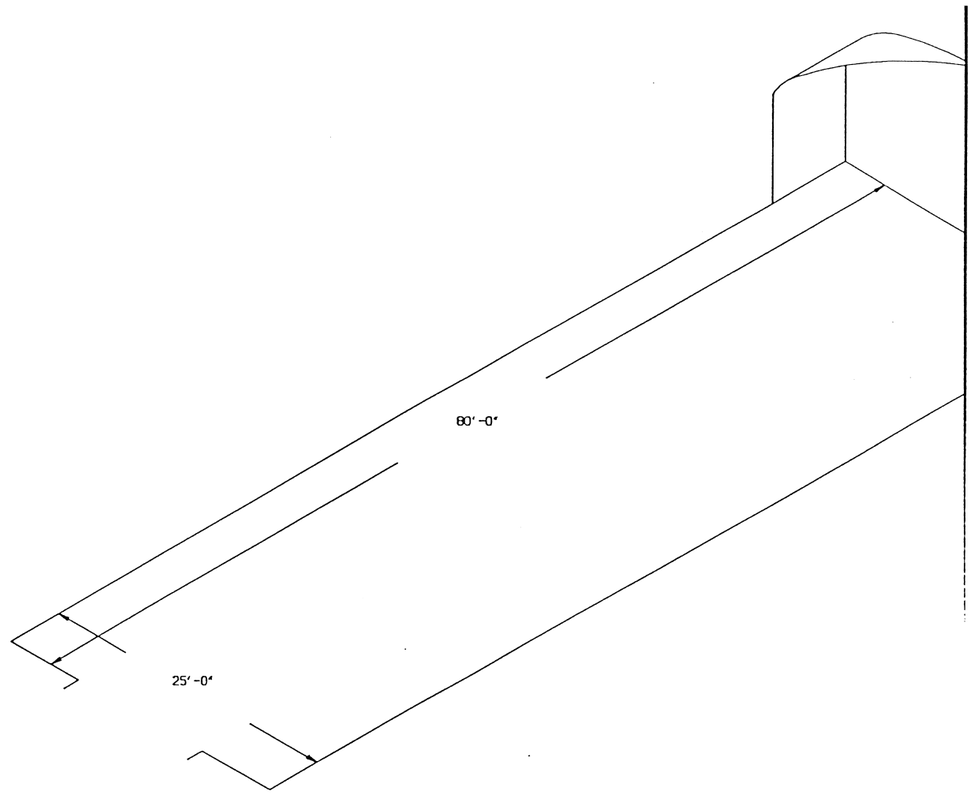
* These facilities are no longer within the federal government real property inventory.

biological warfare (Figure 24). As of 1993, 39 Army installations were equipped with a variety of ammunition storage magazines (Table 4). The magazines are broken down into nine types recognized by Industrial Operations Command (IOC): igloos/arch earth-covered magazines, Stradley magazines, rectangular earth-covered magazines, Corbettas, Richmonds, miscellaneous earth-covered magazines, magazines used specifically for chemicals and special weapons, standard aboveground magazines, and miscellaneous aboveground magazines. Table 5 provides a listing of ammunition and explosives storage buildings by Major Command (MACOM).



PLAN VIEW

SECTION



ISOMETRIC VIEW

CONSTRUCTION DRAWINGS

DRAWINGS CITED IN DOD STD 6055.9,
CHAPTER 5, 15 JANUARY 1992.
MAGAZINES APPROVED FOR
UP TO 500,000 LBS NEW.

OCE NO. 33-15-58
OCE NO. 33-15-61
OCE NO. 33-15-74

80'-0" L X 25'-0" W X 14'-0" H STRADLEY MAGAZINE

80'-0" L X 25'-0" W X 14'-0" H STRADLEY MAGAZINE

Figure 23. Drawings for Stradley Magazine (from Industrial Operations Command 1993).

Figure 24. Igloo at Pine Bluff Arsenal that has been modified with refrigeration for biological weapons storage.

Table 4
Types of Magazines Associated with Army Installations

Army Installation	Igloo/Arch Earth-Covered	Stradley	Rectangular Earth-Covered	Corbetta	Richmond	Misc. Earth-Covered	Chemical & Special Weapons	Standard Above-ground	Misc. Above-ground
Anniston A.D., AL	646	478	—	—	—	—	155	6	5
Badger A.A.P., WI	—	—	—	—	25	—	—	—	98
Coosa River S.A., AL	136	—	—	—	—	—	—	—	—
Cornhusker A.A.P., NE	—	—	—	—	219				
Crane A.A.A., IN	1,108	—	467	—	—	3	—	—	—
Dugway P.G., UT	11	—	—	—	—	—	—	—	15
Fort Wingate A.D.A., NM	731	—	—	—	—	—	—	12	—
Hawthorne A.A.P., NV	1,786	—	332	—	—	13	—	—	98
Holston A.A.P., TN	—	—	—	130	—	—	—	—	8
Indiana A.A.P., IN	173	—	—	—	—	—	—	—	117
Iowa A.A.P., IA	271	—	—	—	—	4	—	16	—
Joliet A.A.P., IL	395	—	—	—	—	—	—	34	—
Kansas A.A.P., KS	183	—	—	—	—	4	—	25	—
Lake City A.A.P., MO	5	—	—	—	—	6	—	—	24
Letterkenny A.D., PA	902	—	—	—	—	—	—	10	—
Lexington-Bluegrass A.D., KY	853	—	—	—	—	—	49	12	—
Lone Star A.A.P., TX	196	—	—	—	—	4	—	38	—
Longhorn A.A.P., TX	—	—	—	—	58	—	—	—	5
Louisiana A.A.P., LA	141	25	—	—	—	—	—	—	—
McAlester A.A.P., OK	1,280	—	323	660	—	—	—	—	163
Milan A.A.P., TN	871	—	—	—	—	4	—	22	—
Mississippi A.A.P., MS	—	—	—	—	—	42	—	—	1
Navajo A.D.A., AZ	779	—	—	—	—	—	—	12	—
Newport A.D.A., IN	2	—	—	—	52	—	—	—	—
Picatinny Arsenal, NJ	—	—	—	—	—	32	—	—	135
Pine Bluff Arsenal, AR	175	—	—	—	—	1	86	25	54
Pueblo A.D.A., CO	921	—	—	—	—	—	—	—	—
Radford A.A.P., VA	89	—	—	—	59	—	—	—	62
Ravenna A.A.P., OH	691	—	—	—	—	—	—	25	47
Red River A.D., TX	702	—	—	—	—	—	—	17	—
Redstone Arsenal, AL	413	—	—	—	—	—	—	—	49
Rocky Mountain Arsenal, CO	10	—	—	—	—	—	—	—	29
Savanna A.D.A., IL	429	8	—	—	—	—	—	100	56
Seneca A.D., NY	455	—	—	—	—	—	64	8	—
Sierra A.D., CA	749	—	—	—	—	—	50	12	—
Sunflower A.A.P., KS	—	—	—	—	—	—	—	—	95
Tooele A.D., UT	902	—	—	—	—	—	239	12	—
Umatilla A.D.A., OR	1,001	—	—	—	—	—	—	14	—
Volunteer A.A.P., TN	100	—	—	100	—	—	—	—	—

A.A.A. = Army Ammunition Activity
A.A.P. = Army Ammunition Plant
A.D. = Army Depot
A.D.A. = Army Depot Activity
S.A. = Storage Annex

Table 5
Number of Ammunition/Explosives Storage Buildings by MACOM

MACOM	No. of Ammunition/Explosives Storage Buildings	No. of Buildings Over 50 Years	No. of Historical* Buildings
HQDA	25,841	19,873	27
AMC	21,496	19,151	5
EUSA	197	0	0
FORSCOM	556	45	1
MDW	39	12	4
MEDCOM	12	8	5
MTMC	1	0	0
NG	299	162	0
SMDC	18	3	0
TRADOC	400	152	11
USACE	114	0	0
USARC	219	92	1
USAREUR	2,036	49	0
USARPAC	324	80	0
USARSO	119	112	0
USMA	11	7	0

*Historical in this list means designated as historical in the IFS database (information entered by installation real property managers)
Information is based on 4th quarter, FY99 data

PLANNING-LEVEL SURVEY

As indicated in Table 5, the HQDA real property inventory in the fourth quarter of FY99 revealed the presence of 25,841 ammunition storage facilities throughout the MACOMs. The majority of these (21,496) are the property of Army Materiel Command. The distribution of the various types of magazines among the AMC installations is noted in Table 4 of this document.

Examples of storage facilities date from the late eighteenth century and include structures built in the 1940s during World War II. Magazines for the storage of ammunition and explosives can be classified into two broad categories—aboveground magazines and underground igloo magazines. Both broad types exhibit variations that developed out of the necessity to (1) store different types of ammunition or explosives, (2) contend with shortages of construction material, (3) reduce costs, (4) reduce amount of land required, or (5) reduce safety hazards.

ABOVEGROUND MAGAZINES

Aboveground magazines built during the late eighteenth to early twentieth centuries follow no standardized plans. They vary in size, shape, construction material, and architectural/ engineering features. Early aboveground magazines were constructed of wood, brick, and stone. Some of the early magazines include the Hessian Powder Magazine, Carlisle, Pennsylvania; the magazine at Fort Towson, Oklahoma; the West Magazine at Watervliet Arsenal, New York; the principal magazine at Frankford Arsenal, Pennsylvania; the magazine at Rock Island Arsenal, Illinois; Picatinny Powder Depot, Picatinny Arsenal, New Jersey; the magazine at Fort D. A. Russell in Wyoming; and the ammunition building at Fort Sam Houston, Texas (see Figures 1, 2, 3, 5, and 6).

By the time World War I occurred, most aboveground magazines were rectangular in shape with gabled or flat roofs. The construction material most often used was masonry (often tile) or corrugated asbestos on a wooden frame. Some magazines, however, were of ordinary wood-framed construction. Floors were located at grade or at railroad car-floor level, and safety distances were sometimes reduced by installing a separate barricade. An example of a magazine built during this time period is that of L-13, Building 263, at Rock Island Arsenal (see Figure 7).

By the end of World War I, ammunition and explosives were stored in standardized magazines that varied in construction materials, spacing, and size, in accordance with the classification of ammunition or explosives being stored (Figure 25; Table 6). Finished ammunition and loaded components (Class I) were stored in magazines measuring 50-by-20 feet and spaced 300 to 400 feet apart. Structures were of hollow tile with concrete floors. Because of the tonnage of ammunition and weight of an individual shell or package, standard gauge railroad tracks ran to the magazines. These magazines had fireproof exteriors and were constructed so that in the event of an explosion, the walls and roof would break up into small fragments.

Smokeless powder (Class II) was stored in magazines of lighter construction than those for Class I. Smokeless powder magazines typically measured 32-by-96 feet and were spaced 300 feet apart. These magazines were constructed of asbestos siding and had gypsum slab roofs with wooden floors. Class III ammunition—fuses and primers—were also stored in magazines of 32-by-96 feet and were spaced 300 feet apart. Magazines had hollow tile walls, gypsum slab roofs, and wooden floors. High explosives (Class IV) were stored in smaller magazines measuring 26-by-42 feet and spaced 800 feet apart. These magazines were also constructed with hollow tile and had gypsum slab roofs.

The 1931 Ordnance Department Safety Manual that detailed the specifications for aboveground magazines varied somewhat from the previous specifications. Most obvious were the modifications that would reduce safety hazards. Storage facilities for high explosives (Class IV type) now measured 26-by-42 feet and were spaced 400 to 800 feet apart. At the same time, the facilities for finished ammunition and loaded

components (Class I) became much larger and were spaced 300 feet apart (see Table 6). The construction of smokeless powder magazines (Class II) varied from other standard magazines because smokeless powder required protection from moisture and high temperatures. Magazines were built of frame construction on concrete or wooden piers. Outside walls, which extended to the ground level, were of corrugated sheet asbestos. The floor, ceiling, and inner walls were carefully built to avoid cracks and crevices; the roof was similar to that of explosives magazines. Smokeless powder magazines also had ventilators in the roof, as well as below the floor in the outside walls. There were also air passages between the inner walls and floors. Smokeless powder magazines retained the same measurements as before (Figure 26; see Table 6).

In general, all magazines were to be adequately grounded and fireproof, have ventilators to regulate temperatures, have loading platforms with the floor at railroad car-floor height, have adequate drainage, and have tightly fitting doors placed opposite of the prevailing winds.

In addition to the specifications regarding the actual buildings, the surrounding landscape was to have a mainline railroad track to each row of magazines with a spur at each magazine to allow railroad cars to be loaded and unloaded without blocking the main track. Well-maintained roads were to be present to facilitate fighting fires if necessary and to enhance security.

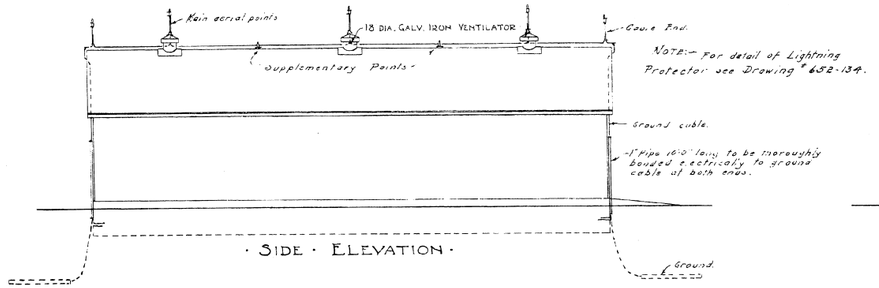
During World War II and the mobilization effort leading up to the war, the Army continued to build aboveground storage facilities, though underground igloos were preferred for all types of ammunition and explosives storage. World War II aboveground magazines built during this era were used to store explosives with relatively low volatility. The magazines were steel-frame, one-story structures constructed on a concrete platform foundation and sheltered by a gabled roof. Walls were clad in 8-inch structural clay tile. Magazine sizes varied from 8-by-8 feet to multiple bay structures spanning 51 feet. Reinforced steel doors provided access to the interior, and entrances were limited to only one side of the structure. The larger magazines featured concrete loading docks. Some aboveground magazines incorporated overhanging eaves to shelter the loading platform (Figure 27).

IGLOO MAGAZINES

Soon after the Lake Denmark disaster of 1926, underground igloos became the preferred design for ammunition and explosives storage. The Navy was the first to install a group of this design in 1928 at the Yorktown Naval Depot, Virginia. The Army quickly followed suit in 1929 when 24 igloos were built at Savanna Army Depot (see Figure 14).

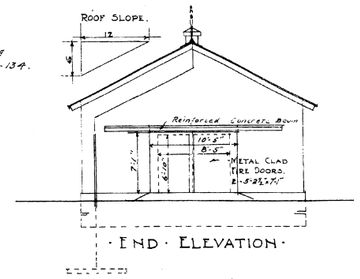
The first magazines built by the Army are now referred to as the Old Savanna type. These igloos were based on Office of the Quartermaster General drawings 6579–160,–160; changed to 652–311,–312 (Ordnance No. 19–2–93,04, Magazine Type 30), dated 19 July 1928. They measured 25 feet wide and 40 feet 4 inches long with a 10-foot crown inside. The magazine's concrete arch was 5 inches thick at the crown and 10 inches thick at the sides; the crown was covered with one foot of earth. The front wall was 4 inches thick, while the rear wall measured 6 inches. The magazine's concrete had wire mesh reinforcements in the arch and walls. The only entry, a steel-clad, double, wooden door, measured 6-by-8 feet. The magazine did not have a platform or apron. The full timber net headwall fronted directly onto the road, with an optional timber-revetted barricade across the road. The structure was vented with louvers and it was fully grounded. In addition to the igloos constructed at Savanna, Old Savanna igloos are found at Delaware, Benicia, and Aberdeen (see Figure 13).

In the 1930s, a new plan for igloos, similar to the Old Savanna type, was introduced. Plans for the Old Line-type igloo were dated 20 June 1933 and were identified as Office of the Quartermaster General drawings 652–295 through 296. These magazines measured 25 feet wide and 40 feet 4 inches long, with a 10-foot inside crown. The concrete arch was 5 inches thick at the crown and 10 inches thick along the sides. An exterior monorail was added, and the exterior wooden door was changed to steel plate. The timbered headwall was composed of six-inch-thick concrete. The earth covering at the crown was increased to two feet and a sand cushion

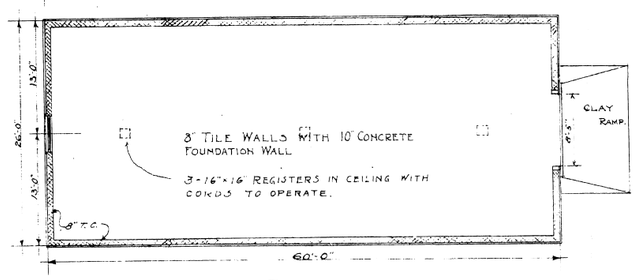


· SIDE · ELEVATION ·

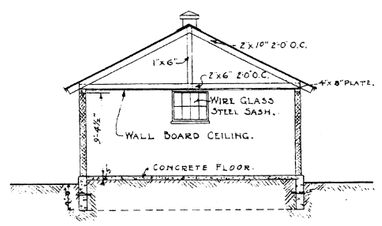
NOTE:— For detail of Lightning Protector see Drawing # 652-134.



· END · ELEVATION ·

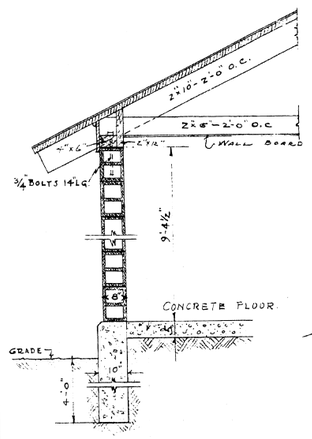


· PLAN ·
SCALE 1/8" = 1'-0".

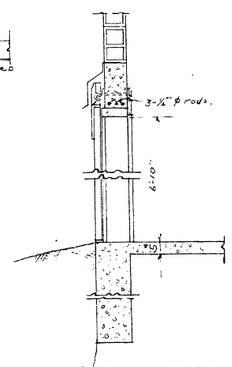


· SECTION ·

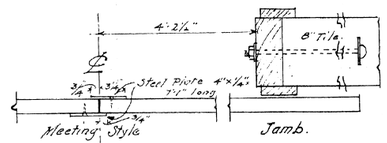
KEY
Indicates Concrete.
" Tile.



· WALL SECTION ·
Scale ½"=1'-0".



SECTION THRO. DOOR.
Scale: ½"=1'-0".



FIREPROOF DOORS
Scale: 1½"=1'-0"

-NOTES-

LINTELS OF REINFORCED CONCRETE OVER DOOR AND WINDOW.
SILLS OF CEMENT POURED IN PLACE
DOOR JAMBS 5"x 8" WITH 3-¾" ANCHOR BOLTS ANCHORED IN THE TILE. TILE AT DOOR TO BE FILLED WITH CONCRETE.
METAL CLAD FIRE DOORS 1¾"x x 7'-1", CUT FROM DOORS TO BE SHIPPED TO JOB FROM SEVEN PINES GEN. ORD. DEPOT.
FLOOR LEVEL AT CENTER OF BUILDING TO BE SAME AS TOP OF ADJACENT RAIL OR ADJUSTED TO ALLOW DRAINAGE FROM ALL SIDES

97

APPROVED FOR THE CHIEF OF ORDNANCE BY Thas R Baxter CAPT. O.D. U.S.A.

CONSTRUCTION SERVICE Q.M.C.-U.S.A.—WASHINGTON, D. C.
· SAVANNA · PROVING · GROUNDS ·
· SAVANNA · ILLINOIS ·
· STANDARD · MAGAZINE · FOR · HIGH · EXPLOSIVES ·
JOB No. 6379. DATE JULY 24, 1920.
PLAN No. 119. APPROVED BY Jell Whistler Capt Ord Dept Exec. Officer

DATE	REVISIONS	ACPT BY	APPROVED

DRAWN BY	CHECKED BY	ACCEPTED BY	PLAN NUMBER
TRACED BY			119.

Figure 25. Plans and elevations for standardized aboveground magazine for high explosives.

Table 6
Summary Characteristics of Aboveground Magazines

	Post-World War I Building			1931 Building		
Class*	Dimensions	Placement	Description	Dimensions	Placement	Description
I	50-x-20 ft	300–400 ft apart	Hollow tile construction; concrete floors; standard gauge railroad tracks	50-x-220 ft	400–800 ft apart	Concrete foundations and floors; brick or hollow tile walls and interior firewalls; peaked roof of gypsum blocks on slabs covered with fire-resistant, built-up roofing rested on wooden roof trusses supported on concrete or brick pilasters
II	32-x-96 ft	300 ft apart	Asbestos siding and gypsum slab roofs; wooden floors	32-x-96 ft	300 ft apart	Frame construction on concrete or wood piers; corrugated sheet asbestos siding; roof ventilators; ventilators below the floor on the outside wall
III	32-x-96 ft	300 ft apart	Hollow tile walls; gypsum slab roofs; wooden floors	32-x-96 ft	300–400 ft apart	Concrete foundation; brick or hollow tile walls; wooden floors; flat roof, wooden trusses; gypsum block or slabs with fire-resistant built-up roofing
IV	26-x-42 ft	800 ft apart	Hollow tile walls; gypsum tile roofs	26-x-42 ft	300 ft apart	Concrete foundation; brick or hollow tile walls; flat roof, wooden trusses; wooden floors; gypsum blocks or slabs covered with fire-resistant, built-up roofing
V	—	—	Concrete trench; did not require magazine	—	—	—
VI (Ware-houses)	100-x-160-ft sections		Did not require magazine. Brick walls; brick firewall between adjoining sections; wooden roofs; concrete floor	100-x-160-ft sections		Concrete foundations and floors; brick or tile walls; interior firewalls; sprinkler systems

* Class I—finished ammunition and loaded components
Class II—smokeless powder
Class III—ammunition, fuses and primers
Class IV—high explosives
Class V—sodium nitrate and inert components
Class VI—small arms ammunition

over a waterproofing membrane was specified for this design. Old Line-type igloos were built at Savanna, Illinois, Delaware, New Jersey, Benicia, California, and Aberdeen, Maryland.

Evolving in the 1930s from the Old Line type was the Old Depot-type igloo, which was constructed in 40-foot and 60-foot lengths. Plans for the 40-foot magazine were known as Type A and were dated 9 December 1935 as Office of the Quartermaster General drawing 652–317 through 320 (Ordnance drawing 19–2–121 through 130, Magazine Type 45). Plans for the 60-foot magazine, Type B, were dated 23 July 1937 as Office of the Quartermaster General drawing 652–326 through 331 (Ordnance drawing 19–2–125 through 130, Magazine Type 49; see Figures 15 and 16).

The Old Depot type increased the width of the magazine to 25 feet 6 inches and raised the crown height to 12 feet 9 inches. The thickness of the crown was also increased to 6 inches. The monorail was put only on the inside on pilasters projecting from the back and end walls. The single door increased to 4 feet in width. The concrete reinforcement changed from wire mesh to rebar. Old Depot magazines were constructed at Camp Stanley, Texas; Ogden, Utah; and other pre-World War II depots and stations.

Although Hawthorne was a naval depot when igloos were constructed there during the 1930s, the facility is now an Army depot. The igloos built during the 1930s were almost identical to those at Yorktown. Typical magazines measured 40 feet 4 inches long and 25 feet wide. The maximum height at the center of the arch roof was 20 feet. The top and sides of the magazine were completely covered with earth except in front where the depressed roadway gave access to the door. All reinforcing steel and other metal parts on the magazines were electrically connected to a copper girdle circling the entire structure and embedded in the footing. Opposite the depressed door was an earth barricade.

Igloos were constructed in groups of seven with each group forming an approximate hexagon with one building at each angle of the perimeter and one in the center. Magazines in each group were separated center to center by 600 feet of space. Each group was further spaced 3,000 feet center to center from adjacent groups.

The igloo was preferred by the joint Army-Navy Ammunition Storage Board and the Ordnance Safety Board for all types of ammunition storage except small arms. In January 1941, the Ordnance Department required that igloos be used in all future depot construction. But with heavy construction activity to commence, there was a need to reduce costs. Additionally, the Army had to contend with construction material shortages. Thus, modifications to the standard igloo design were made to assuage these material shortages and to slash construction costs. All igloo storage magazines were 26 feet in width and were constructed in lengths of 40, 60 or 80 feet, and were to be spaced at least 400 feet apart. They were to be grouped in clusters of no more than 100 and to have at least 1,400 feet separating igloo clusters. Extensive road and rail networks were constructed to link the storage areas at each depot.

By 1942, the Army had developed a standardized plan for igloos—the Army Standard Igloo Magazine or Type 49 (Figures 28 and 29). Variations of this design included the Triple-Barrel Vault (Figure 30), the New Depot, and the Huntsville.

The Corbetta Beehive (see Figures 19 and 20) was designed in 1941 by the Corbetta Construction Company of New York City. This structure consisted of an at-grade floor, elliptical dome-shaped (an oblate hemispheroid), earth-covered magazine with a double sheet, steel door. The advantage of the Corbetta Beehive was that it equaled the standard igloo magazine in structural strength but required only one-half the steel, one-third the copper, and two-thirds the concrete used in the standard-type igloo. Corbetta Beehives were constructed at the Army installations at Curtis Bay (the first Beehives to be constructed), Maryland; Holston, Tennessee; Sioux (no longer in federal real property inventory), Nebraska; and McAlester, Oklahoma.

Although Richmond Magazines (see Figure 21 and 22) are often mistaken for underground igloos because of the banked earth at their side and rear walls, they were constructed as a wartime substitute and have never been classified as igloos for quantity distance purposes. Richmond Magazines have a wood-framed, gabled roof with roll roofing, and the front wall is wood-framed with asbestos

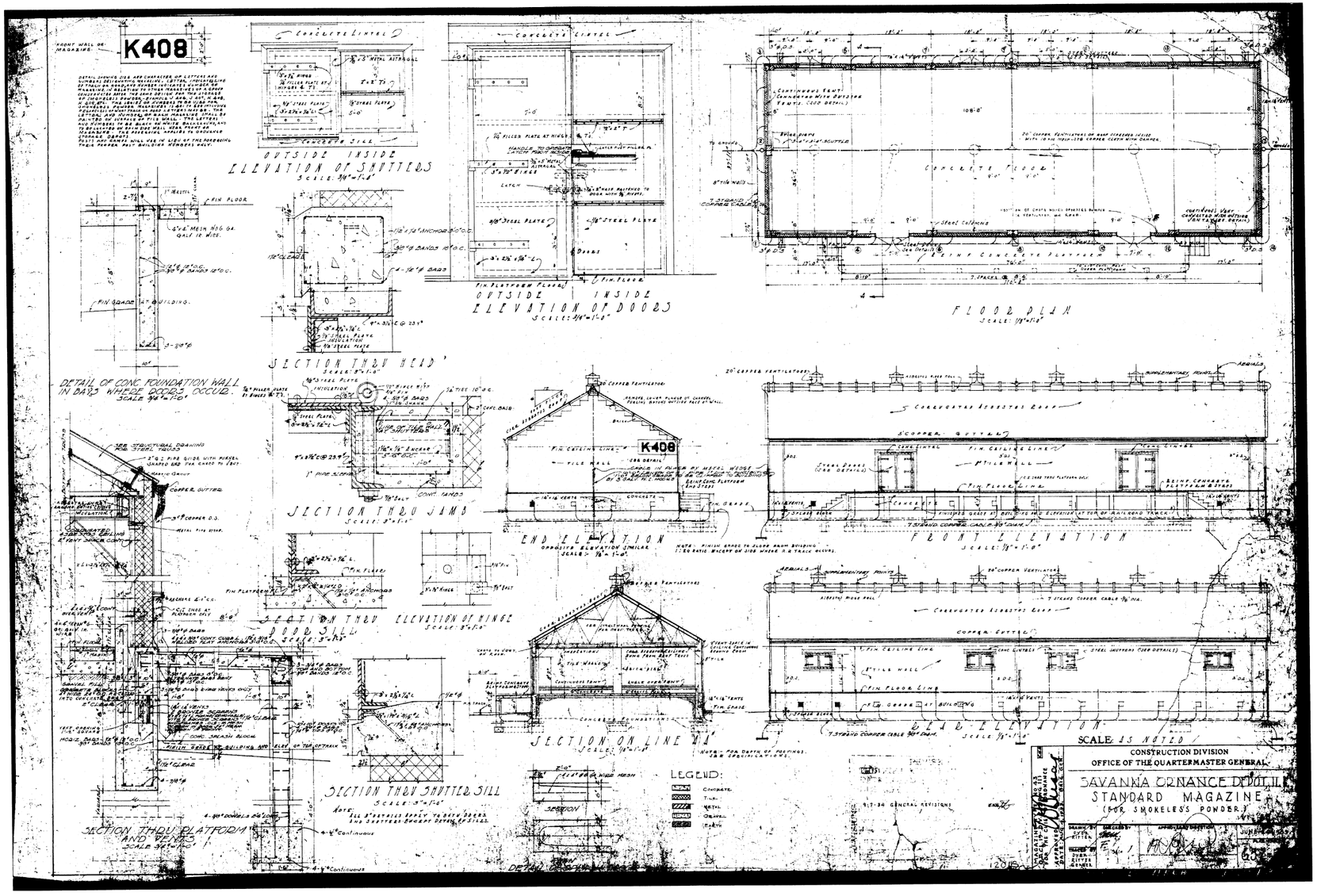


Figure 26. Plans and elevations for standardized aboveground magazine for smokeless powder.

Figure 27. Hollow clay tile aboveground magazine.

shingles. The retaining walls are concrete cinder block or poured concrete. Richmond Magazines were constructed at the Badger, Wisconsin; Cornhusker, Nebraska; Longhorn, Texas; Newport, Indiana; Radford, Virginia; and Savanna, Illinois Army installations.

With the development of the atomic bomb during World War II and the escalation of the Cold War in the 1950s, the Stradley Magazine was designed for the storage of special weapons. The construction of Stradley Magazines was limited to Anniston Army Depot, Alabama; Louisiana Army Ammunition Plant, Louisiana; and Savanna Army Depot, Illinois; however, there are examples of Army Standard Igloos that were converted to a Stradley design through the reconstruction of the front wall (Figure 31).

SUMMARY OF TYPES OF AMMUNITION STORAGE MAGAZINES

As real estate properties, ammunition storage magazines are classified into one of two basic category groups—421, "Ammunition Storage, Depot and Arsenal" and 422, "Ammunition Storage, Installation and Ready Issue." Included within category group 420 are the following types of property: (1) Explosive Transfer Depot Level—F421 04; (2) Stradley, Non-atomic Blast Resistant, Depot Level—F421 07; (3) Fuse and Detonator Magazine, Depot Level—F421 10; (4) High Explosive Magazine, Depot Level—F421 20; (5) Smokeless Powder Magazine, Depot Level—F421 50; (6) Special Weapons Magazine, Depot Level—F421 60; (7) Guided Missile Magazine, Depot Level—F421 70; (8) Igloo Storage, Depot Level F421 80; (9) Ammunition Storehouse, Depot Level—F421 81; (10) Small Arms Ammunition Magazine, Depot Level—F421 82; (11) General Purpose Magazine, Depot Level—421 83; and (12) Ammunition Hut, Depot Level—F421 84.

Property types found within category 422 include: (1) Fuse and Detonator Magazine, Installation—F422 10; (2) High Explosive Magazine, Installation—F422 15; (3) Small Arms Ammunition and Pyrotechnics Magazine,

Installation—F422 30; (4) Ammunition Storehouse, Installation—F422 31; (5) Ready Magazine, Installation—F422 35; (6) Fixed Ammunition Magazine, Installation—F422 40; (7) Special Weapons Magazine, Installation—F422 50; (8) Igloo Storage, Installation—F422 80; (9) Ammunition Hut, Installation—F422 81; (10) General Purpose Magazine, Installation—F422 83; and (11) Unit Small Arms Ammunition Storage, Installation—F422 85.

While the real property classification system is useful for real estate inventory and building management, it is not useful in dealing with such properties as cultural resources. Therefore, ammunition storage magazines have been classified into two broad categories—aboveground magazines and underground igloo magazines—each with subtypes.

The aboveground magazines may be divided into two types on the basis of time period and the presence or absence of standardization. "Early Isolated Magazines" are found singly or in very small groups at Army posts throughout the United States and represent ammunition storage efforts between 1775 and 1918. The primary examples are presented in Table 7. From 1919 to 1945, the design of aboveground magazines became very standardized, according to the classes of ordnance or explosives being stored. Although the size of these structures and their spatial distribution may vary, most (Classes I, III, IV, VI) share a similar design and the use of similar materials (see Table 6). Only the Class II structures, constructed for smokeless powder, exhibit a different design plan and the use of different materials (see Table 6).

The underground igloos, although exhibiting considerable variation, share a very basic design plan—that of a barrel vault. Nevertheless, four subtypes are recognized. The earliest is the Old Savanna or Type 42. The Old Line and Old Depot design plans evolved from this design. As World War II approached, the fourth arched subtype—the Army Standard Igloo or Type 49—became the standard storage magazine for the Army. Variations of this standard design were known as the Triple-Barrel Vault, the New Depot, and the Huntsville. The Corbetta Beehive was unique for its shape and its savings in critical building materials; nevertheless, the circular design was not considered very practical for efficient storage. The Richmond Magazine was a wartime substitute and lacked the arched concrete roof and the concrete front wall. As such, it was not a true igloo.

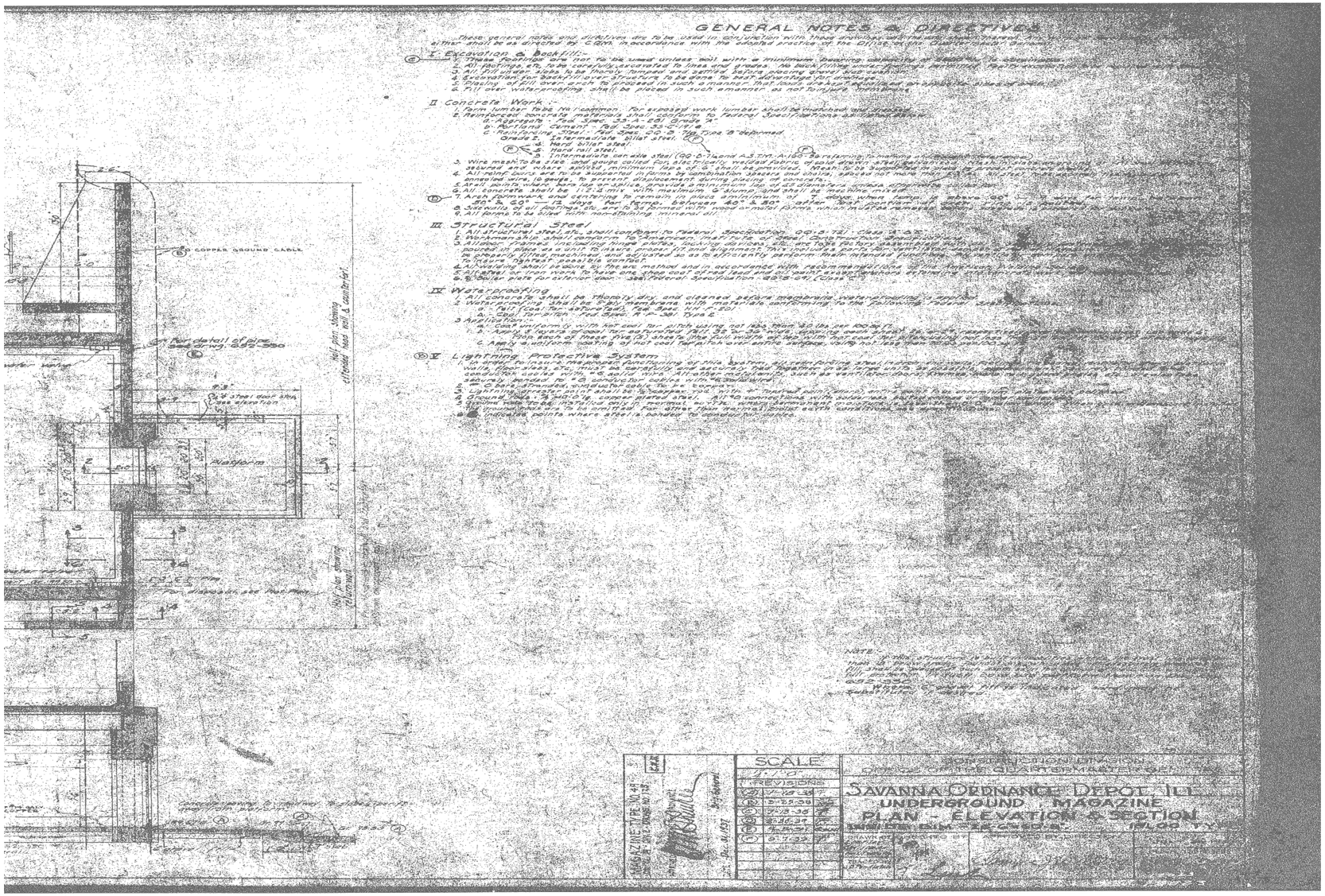


Figure 28. Plans and elevations for Army Standard Igloo (Type 49).

Figure 29. Army Standard Igloo (Type 49).

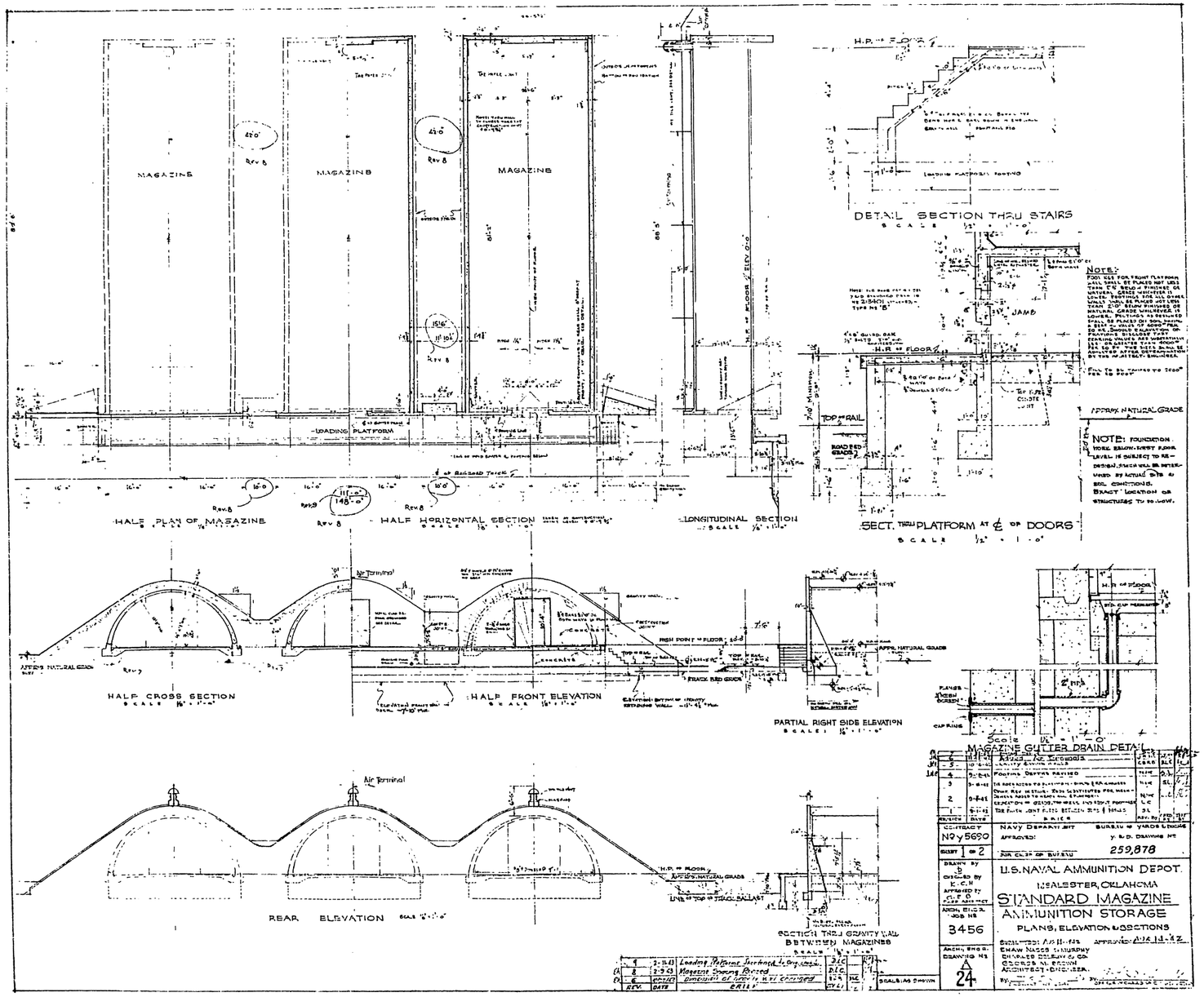


Figure 30. Plans and elevations for Triple-Barrel Vault.

Figure 31. Exterior and interior views of a Stradley Magazine.

Table 7
Classes of Ammunition Storage Magazines within AMC Property Inventory

	Aboveground Magazines		Underground Igloo Magazines
Early Isolated (1775-1918)	Hessian Powder Magazine at Carlisle Barracks PA Fort Sam Houston TX Fort Towson OK West Magazine at Watervliet NY Principal Magazine at Frankford Arsenal PA Rock Island Arsenal IL—1879 Picatinny Powder Depot NJ—1881 Fort D. A. Russell WY Rock Island Arsenal IL—L–13	1929-1940	Old Savanna or Type 42 Old Line Old Depot
Standardized (1919-1945)	Class I, III, IV, VI* Class II	World War II	Army Standard Igloo or Type 49 New Depot Triple-Barrel Vault Huntsville Corbetta Beehive Richmond Magazine

* Class I, II, III, IV, VI = classes of ammunition and ordnance.

GENERAL STATEMENTS OF DESCRIPTION, SIGNIFICANCE, AND REGISTRATION REQUIREMENTS

DESCRIPTION

The history of Army ammunition and explosives storage in the United States dates to the very beginning of our nation's pursuit of independence, when in 1776 the Board of War and Ordnance was created. Part of the board's responsibilities was to make arrangements for the storage and maintenance of arms and ammunition. The earliest facilities constructed for this purpose were aboveground structures. Since no standardized plans were used, these early facilities demonstrate variation in floor plan, design, and construction material. In spite of these variations, however, a concern for safety appears to have been an important consideration in the design, construction, and layout of early magazines.

Although somewhat constrained by the limitations of technology and available building materials, magazines constructed during the late eighteenth, the nineteenth, and the early twentieth centuries were often done so with fire hazards in mind. When possible, magazines were constructed of brick or stone. The West Magazine at Watervliet Arsenal in New York did not contain iron elements so as to avoid attracting lightning, and a stone wall encompassed the magazine to protect it from fire. Structural iron was used to fireproof the principal magazine, built during the Civil War period, at Frankford Arsenal in Philadelphia. In some instances, magazines were located away from other buildings, thus reducing the chance of fire spreading either to or from a store of ammunition. The Hessian Powder Magazine at Carlisle Barracks, Pennsylvania, for example, was located away from other major buildings at the complex, as was West Magazine at Watervliet, New York. However, it should be noted that there was no observed plan for the layout of forts, thus in many cases, ammunition and explosives storage buildings were frequently located on or near the parade ground by the officers' quarters.

Although fire hazard appears to have been the primary concern of those responsible for the design and construction of magazines, other issues were also considered. The Fort Towson magazine, located in Indian Territory, contained dead air space, one-brick wide, that encircled the building. This space probably served as insulation to keep stored ammunition and explosives dry. The building also had a drain installed that is effective even today in keeping the interior dry.

Beginning in 1909, a greater consideration for the layout of ammunition and explosives storage facilities emerged through the concerns expressed by Colonel B. W. Dunn, Chief Inspector of the Bureau of Explosives. Dunn's interest in greater safety led to the issuance of the "American Table of Distances for Inhabited Buildings, Public Railways, and Public Highways" in 1914. By this time, there had evolved three basic types of ammunition and explosives storage facilities. The most prevalent was the aboveground magazine, generally rectangular in shape with a gabled or flat roof. This type was often constructed of masonry (tile) or corrugated asbestos on a wooden frame, though some were constructed of wood. Ammunition and explosives were also stored in casemate-type magazines, which were masonry vaults, or were stockpiled in open dumps; neither of these storage types was as commonly used as the aboveground magazines. The casemates were found only at coastal artillery installations, and dumps were used infrequently except during wartime.

The end of World War I left the Ordnance Department with an overabundance of ammunition and explosives. Classified into six categories, the type of storage facility used to store ammunition and explosives depended upon the classification scheme. Munitions with a high explosive potential were stored in aboveground magazines of various construction material and sizes that were designed and spaced so as to reduce the potential for fire and sympathetic explosions. The less volatile materiel was stored in warehouses or even concrete trenches, as in the case of sodium nitrate.

Although the Ordnance Department had given careful consideration to safety issues, nothing had prepared the department for the full impact and consequences that a major explosion would have upon the loss of life, resources, and materiel. That was to change on 10 July 1926 when lightning struck a temporary magazine at the Naval Ammunition Depot at Lake Denmark, New Jersey. Minutes later, the magazine exploded sending embers and missiles as far as a mile away, leaving nothing but a crater in the magazine's place. Two other nearby structures caught fire and exploded, causing massive damage to both the naval depot and to Picatinny Arsenal, which was located near the naval depot. All totaled, the Lake Denmark disaster, as the tragic event was referred to, cost 19 lives, numerous injuries, and over $40,000,000 worth of damage to munitions and other stores.

Almost immediately, the Navy appointed a Court of Inquiry to study the explosion and to make recommendations. However, there was some dissatisfaction with the Court of Inquiry, prompting Congress to approve a provision for a joint Army-Navy board that would survey the conditions of ammunition and explosives storage. By 3 March 1928 the board had completed its survey and recommendations.

The Lake Denmark disaster revolutionized ammunition and explosives storage. Clearly, the design and construction materials of the aboveground storage magazine that detonated had not sufficiently contained or directed the explosives materiel in a way to curtail the damage incurred, nor had it reduced the chances of sympathetic explosions from occurring. Ironically, the building had been constructed of fireproof material (hollow tile) and was equipped with lightning rods (Reed 1995:41).

Although the new underground igloo design would soon become the most prominent type of ammunition and explosives storage facility in use, the Army's Ordnance Department issued new sets of standards for storing explosives and ammunition in aboveground structures during the first few years following the Lake Denmark incident. The 1931 safety manual issued by the Ordnance Department recognized five types of ammunition and explosives storage structures based on the type of ammunition or explosives to be stored. These structures were (1) explosives magazines; (2) smokeless powder magazines; (3) primer and fuses magazines; (4) ammunition magazines; and (5) warehouses. The manual also issued a number of requirements that dictated the spacing, grouping, and arrangement of magazines.

While new regulations for aboveground storage facilities were under development, a radically new concept in munitions storage was underway as the Navy considered ways to make storage of explosives and ammunition safer. The result was the igloo magazine; a barrel-arched structure built of reinforced concrete and covered with earth. The barrel-arch design would direct the force of an explosion upward instead of outward, and the earth berm would reduce the force of an explosion. The Navy had actually experimented with a similar design in 1918 when an igloo was constructed at the Lake Denmark Naval Depot. This first igloo, however, had a flat concrete roof instead of the concrete arch. Safety tests conducted in 1928 proved barrel-arch igloos with an earth covering to be more effective in reducing the radius of possible sympathetic explosions. In addition to safety, igloos had other advantages as well. Because explosions were directed upward, reducing the potential for sympathetic explosions, the distance between magazines could be reduced, thereby, requiring less land. The earth covering assisted in camouflaging these important resources and also kept inside temperatures down. While the Navy constructed igloos at Yorktown and Hawthorne, the Army installed igloos at Savanna Depot in Illinois. In 1929, 24 igloo magazines were constructed using standardized plans for a type known now as the Old Savanna. During the 1930s, two more versions evolved—the Old Line type and the Old Depot type.

The mobilization effort of World War II induced the Army to instigate an extensive network of depots for receiving, storing, and issuing general military supplies. Ordnance depots were specifically tasked with the storage and distribution of explosives materiel. As part of the mobilization effort, the depot system was expanded to ensure that there was a sufficient amount of ammunition storage. During this active period of construction, both standardized aboveground magazines and standardized underground igloo magazines were constructed. The aboveground magazines were used to store

explosives with relatively low volatility. The Ordnance Department, however, preferred the igloo design; thus in 1941, it required that design to be used in all future depot storage construction, except for the storage of small arms.

The escalating demand for igloos occurred at a time when the country was experiencing a shortage of construction materials due to the war effort. By this time, the Army was using a standardized barrel-arch igloo design, sometimes referred to as the Army Standard Igloo, but also known as Type 49, that offered improvements over the earlier igloos constructed during the interwar period. The Army Standard Igloo had fully reinforced arches and walls, full concrete headwall and vents, and concrete doors. The front wall was increased to 10 inches in thickness, and the sand fill was deleted.

A concerted effort to reduce the amount of building material used in igloo construction led to variations on the basic standard igloo design. One variation, the Triple-Barrel Vault, consisted of three standard igloos built side-by-side so that they shared walls, a foundation, and a loading dock. The Huntsville, another variation, was designed to reduce the amount of steel that was used. Besides these modifications to the standard igloo design, a new alternative design, the Corbetta Beehive, was introduced. The Corbetta Beehive required only half the amount of steel used in the standard igloo and used one-third of the copper and two-thirds of the concrete in standard igloos.

Though technically not an igloo, the Richmond Magazine, built during the World War II era as a substitute, had massive side and rear walls that were banked with earth and a wood-framed, gabled roof with roll roofing. The front wall was wood-framed with asbestos shingles.

While the reduction in construction materials and cost for magazines was an important consideration during World War II, there were other matters to consider that affected the layout of ordnance depots. Safe storage of explosives was still a primary concern, which meant that vast amounts of land were required in order to accommodate distance safety regulations. Ordnance depots had to abide by the safety regulations pertaining to both the distances between magazines as well as distances between storage groups. Explosives storage magazines were to be spaced at least 400 feet apart, grouped in clusters of no more than 100, and have at least 1,400 feet separating igloo clusters. Since the mobilization effort required a large number of magazines to store the huge amounts of ammunition and explosives being produced, ordnance depots typically required 10,000 to 20,000 acres of land. Fundamental to the depot was an extensive system of roads and railways that linked various areas of the depot together and facilitated the movement of munitions into and out of the depot.

The history of ammunition and explosives storage magazines reflects, in part, the military's technological advancements and the nation's wartime activities. Dramatically illustrating this last point is the mobilization effort of World War II whereby the production of explosives storage facilities was so intense that within two years the ordnance depot system contained more storage space than all the commercial warehouses in the U.S. combined. Moreover, an overview of the country's magazines documents the architectural and engineering development of a class of buildings designed for the specific function of storing ammunition and explosives. An inherent aspect of such facilities is the issue of safety and how it has been addressed throughout the Army's history. Ammunition and explosives storage facilities, thus, reflect some of the broader trends in military planning and design.

SIGNIFICANCE

Army ammunition and explosives storage facilities may be eligible for listing in the National Register of Historic Places under Criterion A for properties "associated with events that have made a significant contribution to the broad patterns of our history"; Criterion C because they "embody the distinctive characteristics of a type, period, or method of construction . . . or represent a significant and distinguishable entity whose components may lack individual distinction"; or Criterion D because they "have yielded, or may be likely to yield, information important in . . . history" (U.S. Department of the Interior 1991:2).

The National Register recognizes five basic types of properties—buildings, structures, objects, sites, and districts. Ammunition and explosives storage magazines are an example of a structure that is defined by the National Register Bulletin as "those functional constructions made usually for purposes other than creating human shelter" (U.S. Department of the Interior 1991:4). Since certain types of magazines (e.g., underground igloos) were often grouped together at ordnance depots, the concept of a district is also applicable. A district is defined as a resource that "possesses a significant concentration, linkage, or continuity of sites, buildings, structures, or objects united historically or aesthetically by plan or physical development" (U.S. Department of the Interior 1991:5).

Army ammunition and explosives storage facilities may not be as significant for their architectural characteristics as they are for their engineering attributes and the utilitarian value they held for the military. As storage facilities, they have played an important role in preserving stores of ammunition and making available to military personnel resources critical to the struggle for independence, protection of territory, westward expansion, and international conflict (Criterion A).

While storage facilities may lack prominent or aesthetic architectural features, they do "embody the distinctive characteristics of a type, period, or method of construction" (U.S. Department of the Interior 1991:17; Criterion C). This is particularly applicable to underground storage facilities, or igloos, whose design is associated with a specific event (the Lake Denmark disaster of 1926) in which safety concerns took precedence. Modifications to the basic igloo design include alterations in their size, slight modifications to their shape, and modifications in their construction and the type of building material used. These changes were a result of events associated with World War II when the production (and hence need for storage) of ammunition and explosives was at an all-time high; when material shortages demanded a reduction in the use of certain materials (especially steel) and the use of alternative materials; and when cost effectiveness was an important consideration.

Not only does the design of storage facilities reflect certain time periods and national concerns, the layout of such buildings is also associated with time periods and concerns of national importance (Criterion C). During the eighteenth and nineteenth centuries, the layout of aboveground magazines did not follow a particular pattern, though in some cases, it appears that safety was a consideration. Not until 1914, with the implementation of distance tables was the layout of magazines an associated feature. The impetus behind this new pattern was an increased concern for safety that was magnified even more after the Lake Denmark explosion in 1926.

An important aspect of the groups of ammunition and explosives storage structures is an infrastructure consisting of roads and railroads (Figure 32). Both roads and railroad tracks facilitated the loading and unloading of munitions. Roads were also necessary for maintaining security and for fighting fires.

Administration areas are often associated with the large complex of aboveground and igloo magazines. The administrative buildings do not always reflect the same singular time period as the magazine area. Furthermore, modernization, modifications, and demolition have usually compromised the overall integrity of the administrative area. Therefore, inclusion of the administrative area within a large historic district encompassing the storage areas is not always warranted. However, where the administrative area and the storage area together reflect a singular and cohesive development on the landscape for a particular time period, inclusion of the administration area within the proposed district should be considered.

Ammunition and explosives storage facilities provide valuable information regarding technological advancement and are examples of structures in which architecture, function, and technology all interface (Criterion D). Although simple in design, early aboveground magazines demonstrate the knowledge, existing at the time of their construction, regarding the characteristics of various types of munitions and architectural or engineering features that might protect the munitions themselves and the surrounding environment. As magazines

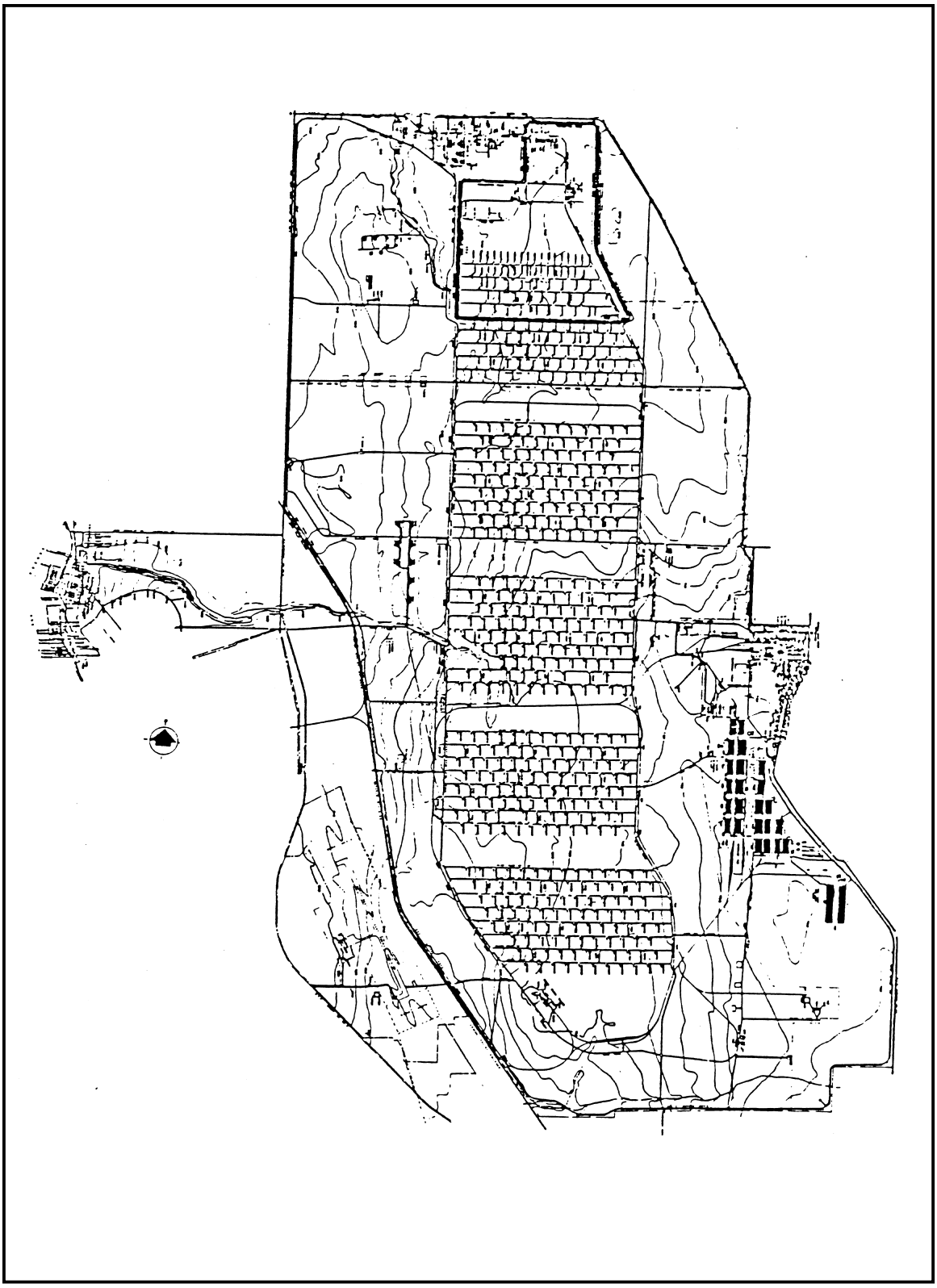


Figure 32. Map of Seneca Depot.

continued to evolve and as technology advanced, the interplay between architecture, engineering, and technology is even more evident—with underground igloos serving as a prime example. With this design, a technological understanding of explosives materiel, combined with architectural and engineering knowledge, produced a structure that greatly reduced the risks associated with storing explosives. As such, underground igloo magazines contribute valuable information pertaining to the safety of the surrounding environment, including human life.

REGISTRATION REQUIREMENTS

Ammunition and explosives storage structures have been key components in the Army's efforts to secure national safety and to achieve governmental objectives. Examples of storage facilities range in age from the late eighteenth century to structures built in the 1940s during World War II. Magazines for the storage of ammunition and explosives can be classified into two broad categories—aboveground magazines and underground barrel-arch igloos. Both broad types exhibit variations that developed out of the necessity to (1) store different types of ammunition or explosives, (2) contend with building material shortages, (3) reduce costs, (4) reduce the amount of land required, or (5) reduce safety hazards.

In considering National Register eligibility of structures, a property must maintain its integrity or, in other words, be able to convey its significance. The National Register defines seven aspects of integrity: (1) location, (2) setting, (3) design, (4) materials, (5) workmanship, (6) feeling, and (7) association. Although not all seven aspects of integrity must be present for the property to be eligible, the property must retain, overall, the defining features and characteristics that were present during the property's period of significance.

Aboveground Magazines

Registration requirements for the two types of aboveground magazines differ due to factors related to temporal period, number of properties, and spatial setting. Given the limited number of representative buildings of the Early Isolated (1875–1918) type, the integrity requirements in relation to design, materials, and workmanship are very high. To demand integrity in relation to setting and association is unrealistic, for most of these isolated examples represent remnants of an earlier phase of the development of the installation. These structures are significant only if they convey the construction and engineering efforts of that era to provide safe storage of munitions and explosives (Criterion C). Consequently, if these structures lack significant modification, retain original materials and the original design plan, each may be considered individually eligible. These structures may be contributing elements to a National Register Historic District if they are part of a larger complex dating to the same time period (Criterion A).

The Standardized Magazines (1919–1945) were designed and constructed to function as part of a much larger complex. Their construction was part of the increasing role of the United States in international politics (Criterion A). Safety concerns dictated the number of individual structures within a cluster and the distances between structures and between the clusters. Efficient handling of the materiel also required the presence of a rail and road infrastructure connecting the entire complex. Eligibility therefore depends on the integrity of setting, location, feeling, and association. These structures would not be considered eligible individually, but would rather be considered as contributing elements to a larger district.

The design of these structures, which differed significantly from the Early Isolated examples, reflects the use of new materials (hollow clay tile) that were fire resistant and would break into small pieces in the event of explosions (Criterion C). Defining characteristics are the hollow clay tile or brick walls and roofing consisting of gypsum blocks or slabs covered with fire-resistant built-up roofing. Alteration of the roof profile, the replacement of doors, the enclosure of loading docks, or the addition of canopies to the exterior would detrimentally impact the integrity of the structure.

Very similar registration requirements would apply to the Class II (smokeless powder) magazines, for the same infrastructure and

spatial elements are relevant. These magazines, however, were built with different materials. The defining characteristics are a frame construction on concrete or wooden piers, corrugated sheet asbestos siding, and ventilators on the roof and on the outside wall. Removal of these features or replacement with dissimilar materials would detrimentally impact the integrity of the structure.

Underground Igloos and Richmond Magazine

Registration requirements for the underground igloos are primarily related to Criterion C or Criterion A, or both. The Old Savanna igloos represent the primary engineering response to the Lake Denmark disaster (Criterion C). The variations of the Army Standard Igloo were built in response to the needs of the United States in its war effort during World War II (Criterion A). The Corbetta Beehive was primarily an engineering solution for the lack of critical resources during the war period (Criteria A and C). The Richmond Magazine, not a true igloo, was a temporary response to storage needs during World War II (Criterion A). The Stradley was designed to meet the stringent requirements of special weapons storage in the 1950s (Criteria A and C).

Setting, location, feeling, and association are the primary issues of integrity related to the underground igloo magazines. The spatial patterning and setting of the igloos were critical elements related to both safety and efficiency (see Figure 32). An integral part of the setting was the rail and road infrastructure that connected the individual structures. Therefore, these structures would not be considered eligible individually; rather, they would be contributing elements of a larger district.

Given the rather simple design of the igloo—a barrel vault constructed of concrete and covered with earth—the integrity of the design, workmanship, and materials is not easily impacted. For example, the replacement of the doors or the replacement or augmentation of the earth fill does not significantly impact the integrity of the igloo. Additions or alterations of the basic design would be the only factors that would detrimentally impact the structure's integrity.

Due to their unique designs, the Corbetta Beehive and the Richmond Magazine storage types exhibit different registration requirements. The circular dome shape of the Corbetta Beehive is its defining characteristic, and as such, represents an engineering solution to the lack of critical resources during World War II. Spatially, the Corbetta Beehives appear either singly or in threesomes. Alterations to the setting, such as the demolition of one or more of the cluster of three, would be detrimental to its integrity. The Richmond Magazine must retain its wood-framed front wall with asbestos shingles, its infrastructure, and wall materials of either concrete block or poured concrete in order to retain its integrity. Alterations to these features may result in loss of integrity and disqualification.

CONCLUSIONS

There are over 20,000 storage magazines at Army installations around the country. While there are some extant examples of early magazine design and construction, virtually all ammunition storage magazines currently in Army use for ammunition and explosives storage were built in response to the World War II mobilization mission; the majority reside at ammunition plants and depots. Mission changes in the post-Cold War era have dictated major changes in the Army's real property inventory, resulting in a continuing reduction of this property type throughout the 1990s. This trend is likely to continue into the next century under Congressional Base Realignment and Closure (BRAC).

Ammunition and explosives storage magazines have significance as historic resources. Magazines have associations with the struggle for independence, protection of territory, westward expansion, and international conflict and therefore may qualify under National Register Criterion A for their association with the broad patterns of American history at a national level. The property type may also be eligible for its unique design and construction values under National Register Criterion C. Because of the massive mobilization effort during World War II, ammunition and explosives storage facilities often form a distinct, cohesive entity that may constitute a historic district or a designed landscape.

The construction of these resources had immediate and long-term impacts, both socially and economically, on the local population. However, the design, construction and operation of ammunition and explosives storage were conceived and executed at a national level with only minor variation for local conditions. The true significance of this property type is derived from its role in protecting and providing materiel critical to national defense at a national scale and should therefore be evaluated under the appropriate national context. However, such property types, in rare instances may have had such an exceptional impact on a State or locality that they could be eligible for the National Register under other State or local themes.

Ammunition magazines consist of a few basic types that are redundant in both design character and general layout when used in multiples (e.g., at depots). Aboveground magazines, designed for particular classes of ammunition are similar in design throughout the twentieth century. Earth covered magazines, or igloos, were developed after the 1926 Lake Denmark disaster and became the standard for the storage of high explosives. Chemical and biological weapons storage was accomplished by altering the basic Army Standard Igloo rather than through the development of a new design. Locks and security measures were added for the storage of chemical weapons, while security and refrigeration were added for the storage of biological weapons. Special weapons storage was also accomplished through modification of the Army Standard Igloo; however, the Stradley Magazine was designed specifically to meet the more stringent requirements for securing nuclear devices in the 1950s.

With only a few basic types and an abundance of examples, the preservation of every magazine or depot would be an unwise use of the limited funds available for cultural resource management. A review of the present-day real property inventory indicates that six geographically dispersed installations contain an array of primary examples of both aboveground and underground magazines with a high degree of integrity: Hawthorne A.A.P., Nevada (early igloo examples), McAlester A.A.P. Oklahoma (Corbetta Beehive igloos), Pine Bluff Arsenal, Arkansas (biological and chemical weapons igloos), Ravenna A.A.P., Ohio (standard World War II igloos and aboveground magazines), Blue Grass Army Depot, Kentucky (standard World War II igloos and aboveground magazines) and Louisiana Army Ammunition Plant (Stradley special weapons igloos). Examples of the early igloo designs are best represented at Aberdeen Proving Ground, Maryland and Camp Stanley, Texas. The Richmond Magazine, not a true igloo, is best represented at Cornhusker A.A.P., Nebraska. It is recommended that primary examples of these classes and subtypes may be eligible for the National Register under this historic context. Extant examples of aboveground magazines dating prior to the end of World War I are extremely limited; consequently, all of the examples listed may be eligible under this context (Table 8).

Potentially eligible aboveground or underground magazines (with the exception of the "Early Isolated" facilities) should focus on districts that encompass a number of similar structures within their original setting. The exact number of structures may be arbitrarily defined; however, the number must be sufficient to reflect the layout and infrastructure related to the function of the complex and the associated safety concerns. The highly redundant nature of these resources, however, and their evaluation within a national context precludes the preservation of all aboveground and underground storage facilities. The previously identified installations are considered to have the best examples of aboveground and underground magazines under this historic context, and are potentially eligible for the National Register. All other installations with ammunition storage facilities contain lesser examples, which may be considered not eligible for the National Register under this context (see Appendix A).

Table 8
Recommended Locations Where Primary Examples of Ammunition and Explosives Storage Facility Classes
May Be Eligible for the National Register

	Aboveground Magazines	Underground Igloo Magazines
Early Isolated (1775-1918)	Hessian Powder Magazine at Carlisle Barracks PA Fort Sam Houston TX Fort Towson OK West Magazine at Watervliet NY Principal Magazine at Frankford Arsenal PA Rock Island Arsenal IL—1879 Picatinny Powder Depot NJ—1881 Fort D. A. Russell WY Rock Island Arsenal IL—L–13	1929-1940 Old Savanna or Type 42 – Aberdeen Proving Ground, MD Old Line – Aberdeen Proving Ground, MD Old Depot – Camp Stanley, TX
Standardized (1919-1945)	Class I, III, IV, VI* – Hawthorne Naval Ammunition Depot, NV McAlester Army Ammunition Plant, OK Pine Bluff Arsenal, AR Ravenna Army Ammunition Plant, OH Lone Star Army Ammunition Plant, TX Class II – Hawthorne Naval Ammunition Depot, NV McAlester Army Ammunition Plant, OK Pine Bluff Arsenal, AR Ravenna Army Ammunition Plant, OH Lone Star Army Ammunition Plant, TX	World War II Army Standard Igloo or Type 49 – Red River Army Depot, TX New Depot – Red River Army Depot, TX Triple-Barrel Vault – Hawthorne Naval Ammunition Depot, NV Huntsville – Blue Grass Army Depot, KY Corbetta Beehive – McAlester Army Ammunition Plant, OK Richmond Magazine – Cornhusker Army Ammunition Plant, NE Chemical and Special Weapons** – Pine Bluff Arsenal, AR Anniston A.D., AL Louisiana A.A.P., LA

* Class I, II, III, IV, VI = classes of ammunition and ordnance.
** Special weapons facilities, such as the Stradley Magazine were developed during the 1950s

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APPENDIX A

CONUS INSTALLATIONS
WITH AMMUNITION STORAGE (FY00)

CONUS Installations with Ammunition Storage (FY00)*
Installations with Potentially Eligible Resources Under this Context

AMC

Aberdeen Proving Ground
Anniston Army Depot
Badger AAP
Blossom Pt. Field Test Facility
Blue Grass Army Depot
Cornhusker AAP
Corpus Christi Army Depot
Defense Dist. Depot, Ogden UT
Deseret Chemical Depot
Hawthorne Army Depot
Holston AAP
Indiana AAP
Iowa AAP
Jefferson Proving Ground
Joliet AAP – Elwood
Kansas AAP
Lake City AAP
Letterkenny Army Depot
Lone Star AAP
Longhorn AAP
Louisiana AAP
McAlester AAP
Milan AAP
Fort Monmouth, Main Post
Newport Chemical Depot
Picatinny Arsenal
Pine Bluff Arsenal
Pueblo Chemical Depot
Radford AAP
Radford AAP New River
Ravenna AAP
Red River Army Depot
Redstone Arsenal
Rock Island Arsenal
Rocky Mountain Arsenal
Savanna Depot Activity
Seneca Army Depot Activity
Sierra Army Depot
Camp Stanley Storage Activity
Sunflower AAP
Tooele Army Depot
Twin Cities AAP
Umatilla Chemical Depot
U.S. Army Garrison Selfridge
Volunteer AAP
Watervliet Arsenal
Fort Wingate Depot Activity

ATEC

Dugway Proving Ground
White Sands Missile Range

FORSCOM

Fort Campbell
Fort Drum
Fort Gillem
Fort McPherson
Hunter Army Airfield
NTC and Fort Irwin
Fort Riley

MDW

Fort Myer
Fort Hamilton
USA Fort Belvoir

MEDCOM

Camp Bullis
Fort Detrick
Fort Sam Houston

NG

ARNG-MTC Fort Pickett
Fort Chaffee
MTA Camp Roberts
MTA Fort Wm. Henry Harrison
NG Hammer Field
NG Hastings MTA
NG Mead MTA
NG New Castle TS Rifle Range
NG Youngstown WETS
Sandstone Armory
TS-AFRC Los Alamitos
TS-Newton Falls (RAAP)

TRADOC

Carlisle Barracks
Fort Benjamin Harrison
Fort Bliss
Fort Bliss AAA Ranges
Fort Benning
Fort Gordon
Fort Huachuca
Fort Jackson
Fort Knox
Fort McClellan
Fort Monroe
Fort Ord
Fort Rucker
Fort Sill

USARC

Camden USAR (OMS)
Fort Devens Training Annex – Sudbury
Fort Dix
Fort McCoy
Fort Sheridan
Parks Reserve Forces TNG Area
USARC Hinghan Cohasset

USMA

West Point Military Reserve

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*Taken from FY00 IFS data – CONUS installation with ammo storage facilities at least 50 years old.

APPENDIX B

AMERICAN TABLE OF DISTANCES

AMERICAN TABLE OF DISTANCES

Blasting and Electric Blasting Caps		Other Explosives		Inhabited Buildings Barricaded*	Public Railway Barricaded*	Public Highway Barricaded*
Number Over	Number Not Over	Pounds Over	Pounds Not Over	(Feet)	(Feet)	(Feet)
1,000	5,000			15	10	5
5,000	10,000			30	20	10
10,000	20,000			60	35	18
20,000	25,000		50	73	45	23
25,000	50,000	50	100	120	70	35
50,000	100,000	100	200	180	110	55
100,000	150,000	200	300	260	155	75
150,000	200,000	300	400	320	190	95
200,000	250,000	400	500	360	215	110
250,000	300,000	500	600	400	240	120
300,000	350,000	600	700	430	260	130
350,000	400,000	700	800	460	275	140
400,000	450,000	800	900	490	295	150
450,000	500,000	900	1,000	510	305	155
500,000	750,000	1,000	1,500	530	320	160
750,000	1,000,000	1,500	2,000	600	360	180
1,000,000	1,500,000	2,000	3,000	650	390	195
1,500,000	2,000,000	3,000	4,000	710	425	210
2,000,000	2,500,000	4,000	5,000	750	450	225
2,500,000	3,000,000	5,000	6,000	780	470	235
3,000,000	3,500,000	6,000	7,000	805	485	245
3,500,000	4,000,000	7,000	8,000	830	500	250
4,000,000	4,500,000	8,000	9,000	850	510	255
4,500,000	5,000,000	9,000	10,000	870	520	260
5,000,000	7,500,000	10,000	15,000	890	535	265
7,500,000	10,000,000	15,000	20,000	975	585	290
10,000,000	12,500,000	20,000	25,000	1,055	635	315
12,500,000	15,000,000	25,000	30,000	1,130	680	340
15,000,000	17,500,000	30,000	35,000	1,205	725	360
17,500,000	20,000,000	35,000	40,000	1,275	765	380
		40,000	45,000	1,340	805	400
		45,000	50,000	1,400	840	420
		50,000	55,000	1,460	875	440
		55,000	60,000	1,515	910	455
		60,000	65,000	1,565	940	470
		65,000	70,000	1,610	970	485
		70,000	75,000	1,655	995	500
		75,000	80,000	1,695	1,020	510
		80,000	85,000	1,730	1,040	520
		85,000	90,000	1,760	1,060	530
		90,000	95,000	1,790	1,075	540
		95,000	100,000	1,815	1,090	545
		100,000	125,000	1,835	1,100	550
		125,000	150,000	1,900	1,140	570
		150,000	175,000	1,965	1,180	590
		175,000	200,000	2,030	1,220	610
		200,000	225,000	2,095	1,260	630
		225,000	250,000	2,155	1,295	650
		250,000	275,000	2,215	1,330	670
		275,000	300,000	2,275	1,365	690
		300,000	325,000	2,335	1,400	705
		325,000	350,000	2,390	1,435	720
		350,000	375,000	2,445	1,470	735
		375,000	400,000	2,500	1,500	750
		400,000	425,000	2,555	1,530	765
		425,000	450,000	2,605	1,560	780
		450,000	475,000	2,655	1,590	795
		475,000	500,000	2,705	1,620	810

*Barricaded, as here used, signifies that the building containing explosives is screened from other buildings, railways, or from highways by either natural or artificial barriers. Where such barriers do not exist, the distances should be doubled.

Source: Report on the Joint Army and Navy Board Convened to Make a Survey of Points of Storage of Ammunition in Compliance with a Provision of the First Deficiency Act, Fiscal Year 1928. On file, U.S. Army Corps of Engineers, Fort Worth District.