1. GENERAL

a. PURPOSE/OBJECTIVE

The definitive drawings provide criteria and guidance for the planning, siting, design and construction of an underground ammunition storage facility. It was developed with particular consideration of the hazardous effects of an accidental detonation of the explosive contents of the storage chambers, and includes design features whose purpose is to contain or mitigate those effects.

b. APPLICABILITY

The definitive drawings were developed for use within continental United States (CONUS) and outside continental United States (OCONUS). For CONUS, the definitive drawings will be used as presented in conjunction with the DOD 6055.9-STD safety criteria. For OCONUS application, the definitive drawings may be modified to meet more safety-stringent host nation operational, engineering and safety requirements.

c. REFERENCE DOCUMENTS

Department of Defense (DOD)
DOD 6055.9-STD, DOD Ammunition and Explosives Safety Standards, Oct. 1992 (latest version).

2. DEFINITIONS

a. Underground Ammunition Storage Facility. An underground ammunition storage facility is a storage site located entirely below the natural ground surface (as opposed to "earth-covered" magazines). The facility is normally excavated in a solid, competent rock, and consists of one or more storage chambers that are accessed through one or more entrance passages. The principal components of an underground storage facility are defined in the glossary.

b. GLOSSARY

1). Adit - an underground passage with an entrance/exit at only one end.

2). Chamber Entrance Tunnel - a tunnel providing access into a storage chamber, either directly from the entrance portal (for a small facility) or from the storage access tunnel of a large facility.

3). Chamber Storage Site - an excavated chamber or series of excavated chambers especially suited to the storage of ammunition and explosives. A natural cavern may be subdivided or otherwise structurally modified for use as a chamber storage site.

4). Closure Block, High Pressure - a protective construction feature consisting of a massive concrete and steel block, located just inside a storage chamber, designed to seal the chamber entrance tunnel to an underground storage chamber in the event of an explosion within the chamber. MAGAE blocks are passive closures that are driven by the blast wave from a normally open to a closed position. KLOTZ blocks are active closures, operated by a hydraulic system to move from a normally closed to an open position (for access).

5). Connected-Chamber Storage Site - a chamber storage site consisting of two or more chambers connected by tunnels. Such chambers may be at the ends of branch tunnels off a main passageway.

6). Constrictions - short lengths of tunnel whose cross sectional areas are reduced to one-half or less of the normal tunnel cross section.

7). Debris (or Fragments) - any solid particle thrown by an explosion or other strong energetic reaction. For aboveground detonations, debris refers to secondary fragments, which have ballistic trajectories. For detonations in underground storage facilities, debris refers to both primary and secondary fragments, which may be transported by a strong flow of detonation gasses.

8). Debris Trap - a protective construction feature in an underground storage facility which is designed to capture fragments and debris. This is usually accomplished by relying on the inertia of the material to separate it from the detonation gas stream.

9). Entrance/Exit Tunnel - the tunnel providing access from a portal to the interior of an underground facility.

10). Expansion Chamber - a protective construction feature in an underground storage facility which is designed to reduce the airblast shock and overpressure exiting the facility by increasing the total volume of the complex. It may also function as an operating area within the underground facility, as well as a debris trap.

11). Loading Density - quantity of explosives per unit volume of storage chamber, usually expressed as kilograms per cubic meter (kg/m^3). (Note: Current U.S. safety standards (Reference 1.c. above) uses English units; i.e. pounds per cubic foot (lbs/ft^3)). As applied to underground storage facilities, there are two types of loading densities used in Quantity-Distance (QD) calculations:

a) The chamber loading density is based on the NEQ (or NEW, in english units) within an individual storage chamber and the volume of the chamber (V_{CH}). See Table 9-20 of reference, DOD 6055.9-STD.

b) The calculation of airblast peak pressures and IBD's for explosions in underground storage facilities is based on the shock-engulfed volume (V_E) of the facility. This is the total volume filled by the expanding gases at the time the blast front reaches the point of interest (e.g., the entrance to an adjacent chamber). It includes volumes in any direction that the gases can enter, to a distance from the explosion source that equals the distance from the source to the point of interest. The total loading density for a given chamber is the NEQ for that chamber divided by V_E.

12). Loading/Unloading Chamber - an interior chamber (or room) connected to the portal by an entrance/exit tunnel, where munitions are loaded on/unloaded from transport trucks and carried from/to the storage chamber by MHE.

13). Material Handling Equipment (MHE) - forklifts, dollies and other equipment used to transport munitions within the underground facility.

14). NEQ - net explosive quantity expressed in kilograms. (NEW - net explosive weight expressed in pounds).

15). Portal - an outside opening into an adit or tunnel.

16). Portal Structure - normally a reinforced concrete framework designed to provide structural support or stability to a portal.

17). Protective Construction - construction designed to protect assets or resources from damage or destruction. Protective construction with respect to underground munitions storage facilities includes:

a) Above Ground - structures designed to resist the effects of airblast and fragment/debris hazards.

b) Underground - tunnel/chamber support systems designed to resist crushing and prevent rock spall to protect stored munition assets from damage or accidental initiation and high-strength chamber doors designed to resist blast, thermal and fragment/debris loads produced by accidental detonations in adjacent storage chambers.

18). Rock Strength - Strong, moderately strong, and weak rock are designations which provide a general classification of rock types for siting underground storage facilities. Classification of a rock body into one of these three rankings is based on the rock impedance factor:

$$\text{rock impedance factor} = \rho \times c \times 10^{-6}$$

where

γ = rock density, kg/m^3

g = gravitational force, 9.76 m/sec^2

ρ = mass density of the rock, γ/g $kg\text{-}sec^2/m^4$

c = seismic velocity of the rock, m/sec

The rock impedance value will be 1.15 or greater for strong rock; between 1.15 and 0.75 for moderately strong rock; and less than 0.75 for weak rock.

Values of these parameters can usually be estimated based on examinations of exposed rock outcrops or core samples from an exploratory drill hole. For the detailed design of an underground storage facility (maximum span width, rock reinforcement, etc.), standard engineering classification systems for rock excavations should be used.

19). Single-chamber Storage Site - a storage chamber with its own access to the natural ground surface, not connected to any other storage chamber.

20). Spall - Spall refers to pieces of a material (and the process by which they are formed) that are broken loose from the surface of a parent body by tensile forces that are created when a compression shock wave travels through the body and reflects from the surface. For underground storage, spall normally refers to the rock broken loose from the wall of an acceptor chamber by the shock wave transmitted through the rock from an explosion in a nearby donor chamber.

21). Storage Access Tunnel - a tunnel providing access to the entrance tunnels of multiple storage chambers from another interior location, such as a loading/unloading chamber.

22). Tunnel (Chamber) Support System - construction work performed to ensure the structural stability of a tunnel or chamber, particularly the ceiling. Typical support systems (in order of increasing degrees of support provided) include:

a) Wire Mesh - a steel mesh (usually "chain link" fencing mesh) fastened to the rock surface by short rock bolts or other means to prevent the fall of small, loose pieces of rock.

b) Shotcrete - cement sprayed over the rock surface.

c) Steel Sets - steel beams assembled into an arch shape conforming to the cross-section of a tunnel, typically spaced at one to three-meter intervals along the tunnel length. Wooden timber (lagging) may be placed between adjacent steel sets to hold back loosened pieces of rock.

d) Rockbolts - long steel rods inserted into holes drilled into the rock, connecting a steel plate (bolted onto the end of the rod) at the rock surface to an anchor point in stable rock one to five meters from the rock surface.

e) Concrete liners - reinforced concrete cast between formwork and the rock walls and ceiling of a tunnel or chamber. In rare cases, precast sections of concrete may be assembled to form a liner.

23). Tunnel - an underground passage with an entrance/exit at each end.

3. PLANNING GUIDANCE

Each underground ammunition storage facility should be designed on an individual basis, because of the wide variety of requirements or site conditions that may exist. In general, the development of a design should include the following steps:

a. Establish the storage requirement. The storage requirement refers to the hazard classification and quantity of ammunition and/or explosives that must be stored, and the associated material volume (including packaging) and net explosive quantity (NEQ). These requirements should cover the expected useful life of the facility, including possible changes in the mission of the operating organization.

b. Define the operating requirements. Like the storage requirements, operating requirements will be closely related to the mission of the operating organization, e.g., a depot, training installation, forward operating base, etc. The requirements may include the volume and rate of storage turnover, frequency of ammunition inspection or rehabilitation, rapid deployment of combat support material, size of ammunition containers, e.g. especially large rocket/missile containers such as MLRS pods, and the types of equipment (primarily MHE)

c. Site Selection. Selection of a specific site for the facility will depend on the availability and location of an area with the geology and topographic features required for the underground construction. Other factors will include the land use plan for a military installation, proximity to inhabited areas on or off the base, accessibility from existing roads, distance to transshipment or usage locations (e.g., firing ranges at training installations, etc).

d. Quantity-Distance (QD) Assessment. The hazard distances are based on the quantity of explosives and take into account any mitigation or suppression of the explosion effects. The minimum acceptable QD for the hazards produced by an accidental explosion within the facility should be established based on the site's proximity to inhabited buildings, public traffic routes (PTR's), airstrips, etc.

e. Site Investigation. A geotechnical subsurface investigation of the proposed site must be performed to determine the site topography, geologic structure, groundwater conditions, presence of jointing planes, cracks and fissures, and the physical properties of the material to be excavated. The results of the geological investigations will be the basis for selection of the excavation and construction methods, for selection and design of any tunnel support systems, and for provisions to be made when particular problems are expected.

f. Facility Design. After it has been determined that the site itself meets the engineering, operational and safety requirements for the facility, engineering drawings for the layout and construction of the facility can be developed. The design shall be based on applicable design standards and definitive drawings for underground storage facilities that have been approved by service and DOD safety agencies. Variances to the standard designs may be made as necessary to tailor the facility on a site-specific basis, within the limits established by the appropriate safety regulations and approved design guidelines.

US Army Corps of Engineers

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