HIGH PERFORMANCE MAGAZINE CERTIFICATION TEST NO. 3: PLANNING AND RESULTS

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28th DDESB Seminar
Omni Rosen Hotel
Orlando, FL
18-20 August 1998

ABSTRACT

The Naval Facilities Engineering Service Center (NFESC) is developing a new ordnance storage magazine, the High Performance Magazine (HPM). The HPM is a partially buried, earth-bermed, 2-story, box-shaped structure. The most important factor in the improved performance of the HPM is the reduction in the Maximum Credible Event (MCE) to a detonation, explosion, or fire involving a small fraction of the total quantity of explosives stored in the HPM. This performance is achieved by utilizing nonpropagation walls (NPW) and pit covers to segregate the ordnance and to prevent sympathetic reaction to closed storage cells. The HPM reduces by at least 80 percent the land encumbered by Explosives Safety Quantity-Distance (ESQD) arcs designed to protect people and property from effects of an accidental explosion.

The HPM Certification Test No. 3 was conducted on 24 October 1996 at the Cactus Flat Test Range, China Lake, CA for the following critical transport sympathetic detonation hazard scenario:

- Simultaneous detonations of a 26,000-lb donor of Mk82 bombs in an open 38'-6" x 20' x 15'-6" (LxWxH) storage cell, a 4,000-lb donor of Mk84 bombs located above the aisle transfer wall, and a 30,000-lb donor of Mk82 bombs located in the SRA

- Critical acceptors consisted of thick-case bombs and projectiles and thin-case torpedo warheads and mines placed in three adjacent storage cells

All acceptor ordnance was recovered and accounted for. As predicted, the thin-case acceptors suffered more extensive damage than the thick-case acceptors. Many of these acceptors cracked open and their explosive contents reacted by burning, but not detonating. However, during the post detonation fires that lasted for more than 23 minutes, three acceptors (i.e., a Mk55 mine, Mk82 bomb, and M107 projectile) did deflagrate. The test results certified the explosives safety performance of the HPM to prevent sympathetic detonation.

INTRODUCTION

Background

The conceptual design of the current (April 1997) HPM prototype is shown in Figures 1, 2, and 3. The HPM is a partially buried, earth-bermed, 2-story, box-shaped structure. Story-1 is partially buried and earth-bermed along all four sides of the concrete structure, to an elevation slightly above the maximum possible elevation of stored ordnance. Story-2 is a conventional, prefabricated building with no earth cover. The second story protects personnel and ordnance handling equipment inside the magazine for local weather conditions. The earth berm serves as a barricade designed to prevent sympathetic detonation between adjacent magazines from fragments and debris. The earth berm also serves to direct blast overpressures and debris upward. The Entrance Area provides the path for vehicle access to the SRA. The vehicle entrance will accommodate a fully loaded truck. The SRA is used to load and unload conveyance vehicles. The vehicle is parked in the vehicle pit, which will accommodate a flatbed truck. A side-loading dock and rear-loading dock allow storage and retrieval of ordnance in side-loaded and rear-loaded covered conveyance vehicles, using a forklift truck located on the loading dock. Also, the side- and rear-loading docks plus the staging dock allow prestaging of ordnance before arrival of the transport vehicle. The weapons storage areas are located at both ends of the box structure. Each storage area consists of two storage pits, each 82'-0" x 20'-0" x 15'-6" (LxWxH). The storage pits provide protected space to store containerized and palletized ordnance. The storage pits are separated by a 9'-0" wide storage transfer aisle, for unobstructed transport of ordnance between storage pits and the SRA. A relocatable, modular, nonpropagation cell wall (5'-8" total thickness) may be added to a storage pit to subdivide a storage pit into two storage cells. Each storage pit has a cover, consisting of ten pit covers.

The HPM reduces the land area encumbered by Explosives Safety Quantity-Distance (ESQD) arcs by at least 80 percent; allows noncompatible ordnance to be stored in the same magazine, thereby reducing the number of magazines needed to store a fixed inventory of ordnance; requires a smaller work crew and less equipment and time to store and retrieve ordnance; provides the equivalent of a barricaded siding for temporary storage of ordnance loaded vehicles; improves storage efficiency, selectability, and versatility; and accommodates a broad spectrum of ordnance types (missiles, mines, torpedoes, bombs, bullets and projectiles), ordnance sizes (containerized missiles and palletized conventional ordnance), and hazard classes of Navy ordnance. In general, the HPM provides a better balance between operational requirements, explosives safety regulations, and economic considerations.

The most important factor in the improved explosives safety performance of the HPM is the reduction in the Maximum Credible Event (MCE) to a small fraction of the total quantity of explosives stored in the HPM. For example, the explosive storage capacity of the HPM is 300,000 pounds net explosive weight (NEW), but the MCE is no more than 60,000 pounds NEW (total NEW in an open storage cell plus the SRA). This performance is achieved by utilizing nonpropagation walls (NPW) and pit covers to segregate the ordnance and to prevent propagation of a detonation between storage and transfer areas.

The NFESC has concluded that the HPM is a feasible concept based on results from computer code analysis of MCE detonations and fires inside the HPM, and from explosive tests involving MCE detonations in small-scale and full-scale structures. In FY93, the NFESC conducted two full-scale explosive tests of storage cells which served to demonstrate the explosives safety performance of the

HPM. These tests demonstrated that the nonpropagation cell walls prevented sympathetic detonation (SD) to Mk82 bombs and M107-155mm projectiles from Mk82 bombs stored in an adjacent cell. The nonpropagation walls were designed using preliminary SD threshold criteria developed from the test and analysis of thick-case weapons. The tests also verified the procedure for calculating loads, nonpropagation wall response and acceptor ordnance response. In FY95, NFESC conducted HPM Certification Test No. 1 (CT1) which showed nonpropagation walls prevent SD of thin-case and thick-case acceptors located in the storage area. The donor in CT1 included 144 Mk82 bombs with a total NEW of 30,000 lb located in a closed storage cell. In FY96, HPM CT2 confirmed that a 12"-thick lightweight concrete pit cover would stop primary fragments from a Mk84 bomb (Reference 1).

Objectives

Primary Objective. The primary objective of the HPM CT3 is to certify that the HPM prototype aisle walls, cell walls, and storage pit covers will prevent sympathetic detonation from multiple donors located in an open storage cell, the SRA, and above the transport aisle to the critical acceptors in adjacent storage cells. Certification of the nonpropagation aisle and cell wall designs requires the following:

- Relative deformation of thick-case acceptors (i.e., bombs and projectiles) shall not exceed a change in diameter/original diameter ($\Delta D/D$) of 0.25

- Explosive fill of thick-case acceptors shall not promptly react (i.e., during initial MCE detonation)

- Explosive fill of thin-case acceptors (i.e., mines and torpedo warheads) may burn but shall not detonate

Secondary Objective. External pressure and debris data will be gathered to help validate prediction methods for safe pressure and debris distances from accidental detonations. Since the CT3 structure represents the current HPM prototype design, the data will be used to empirically derive safe distance criteria for the prototype HPM.

Scope

To certify nonpropagation, CT3 is an explosive test of the internal nonpropagation transfer aisle walls, cell walls, and storage pit covers for the following critical transport sympathetic detonation hazard scenario:

- Simultaneous detonation of a 26,000-lb donor of Mk82 bombs in an open 38'-6" x 20' x 15'-6" (LxWxH) storage cell, 4,000-lb donor of Mk84 bombs located above the aisle transfer wall, and a 30,000-lb donor of Mk82 bombs located in the SRA (These donor charge weights are nominal NEW)

- Critical acceptors from HPM Storage Groups 4 (i.e., thick-case bombs and projectiles) and 8 (i.e., thin-case torpedo warheads and mines) will be placed in 3 adjacent storage cells

The test setup (including details of the test site, test structure, ordnance configuration, and data acquisition) are described in the next section.

TEST SETUP

Test Site

HPM CT3 was conducted at the Cactus Flat Test Range, China Lake, CA by the Naval Air Warfare Center (NAWC). The site layout is shown in Figure 4. A 400-ft radius was cleared around the CT3 structure to facilitate construction. Soil within this area was used to berm the structure. Three 10-ft wide strips were cleared of vegetation and leveled (with a blade) to a range of about 2,000 ft from the structure for three pressure gauge lines opposite the front wall (0°), side wall (90°), and back wall (180°).

Test Structure

The current HPM prototype is a two-story structure with an earth-bermed, reinforced concrete, box structure for the first story and a conventional, prefabricated, metal structure for the second story. The critical interior nonpropagation walls and floor plan of the CT3 structure are representative of the prototype concept. The prototype design is inexpensive and quickly vents gas pressure to reduce internal loads and debris throw distance.

External Structure. The CT3 structure is a full-scale representation of the Entrance Area, SRA, and Left Storage Area of the HPM prototype as shown in Figure 5. The CT3 structure does not include the Right Storage Area. The plan view and cross-sections of the external envelope of the CT3 structure are shown in Figures 6 through 8. The CT3 structure was designed by SOH&A Structural Engineers, San Francisco, from an NFESC Basis of Design (Reference 2). Design details can be obtained from the final SOH&A drawings and specifications (Reference 3).

The floor plan of Story-1 is shown in Figure 6. The exterior walls of the Entrance Area and SRA, plus the structure floor and foundation are normal weight reinforced concrete. The exterior walls around the storage area and the transport aisle walls are lightweight structural concrete. The gross internal volume of the structure is 133'-0" x 52'-0" x 28'-3" (LxWxH). The top of the earth berm is 3'-0" above the storage area height. An exterior photograph of the completed structure is shown in Figure 9.

Nonpropagation Walls. The internal aisle and cell walls of the CT3 structure plus the storage area exterior walls must prevent propagation of a detonation from the donors to the adjacent acceptor cells. The prototype storage transfer aisle wall and cell wall that divide the CT3 storage area into one donor cell (D3) and three acceptor cells (A1, A2, and A3) are shown in Figure 6. Also shown on this figure is the SRA transfer aisle wall which separates the donor (D1), located in the

SRA, from the storage area.

The cell wall consists of precast, wire mesh reinforced, hollow CBC blocks which were stacked and then filled on-site with a heavy granular fill. CBC is a lightweight (60 pcf) “Chemically Bonded Ceramic” with a compression strength, f'_c, of 2500 psi and a strain capacity (at nearly constant crushing strength of f'_c) of about 60%. The crushable shock-absorbing CBC reduces kinetic energy, absorbs strain energy, and provides thermal insulation to mitigate acceptor loads from the design hazard scenarios. The CBC had previously been developed by CEMCOM Research Associates, Inc. to U.S. Navy specifications and characterized in Reference 4 for the HPM nonpropagation walls. The material properties of the CBC are summarized below:

Material Parameter	Value
Density, g	58-62 pcf
Porosity	50%
Compressive Strength, f'_c	2500 psi
Dynamic Strain Capacity*	60%
Splitting Tensile Strength	250 psi
Rebar Bond Strength	600 psi
Elastic Modulus, E	800,000 psi

* Occurs at nearly constant crushing strength of f'_c

The CBC blocks have 18"-thick walls parallel to the acceptors and thin structural webs in the depth of the wall. A granular fill is used to reduce the kinetic energy of the wall on impact with the acceptor. The cross-section (5'-8" total thickness) of the cell wall is 3' of CBC and 2'-8" of granular fill. In the HPM prototype and in CT3, the cell walls are filled with steel grit (SAE size S170; density = 285 pcf ± 10 pcf) to a height of 10' and with sand above 10'. This cell wall design was used previously in the successful HPM CT1 in which the acceptor ordnance was also oriented perpendicular to the wall.

The SRA and storage transfer aisle walls use a lightweight, structural concrete (80 pcf) with a compression strength, f'_c, of 2500 psi and a strain capacity (at nearly constant crushing strength of f'_c) of about 45%. The lightweight concrete reduces kinetic energy, absorbs strain energy, and provides thermal insulation to mitigate acceptor loads from the design hazard scenarios. A sand fill is used to reduce the kinetic energy of these walls on impact with the acceptor. The cross-section (15'-0" total thickness) of the SRA transfer aisle wall is 3'-0" of lightweight concrete and 12'-0" of sand. The cross-section (12'-0" total thickness) of the storage transfer aisle wall is 3'-0" of lightweight concrete and 9'-0" of sand. The HPM CT1 aisle wall was so successful, the aisle wall for CT3 was redesigned to use lightweight concrete (vs. CBC) and sand (vs. steel grit). The overall cross-section was increased, but total wall cost will be much less. A photograph of a portion of the transfer aisle walls is shown in Figure 10.

The storage area exterior walls, designed to resist the lateral earth loads, also use this lightweight concrete. These walls are a minimum of 14" thick with 12" of cover on the interior face to reduce impact loads to the acceptors.

Pit Cover. The pit cover is primarily required in the HPM to prevent SD of ordnance in adjacent storage cells during aisle transport and temporary ordnance storage. It is not feasible to design the pit covers to remain intact after an accidental detonation. Therefore, the pit covers are designed to remain in place only long enough to stop fragments from the aisle transport donor. Consequently, the pit covers must be constructed in a way that ensures that SD is prevented when the pit cover impacts acceptor ordnance. The pit cover has been designed, based on finite element and hydrocode analysis, and test data from HPM CT2 The selected pit cover is 12" of lightweight reinforced concrete with a 3/16" steel cover plate. This cross-section stopped fragments from a Mk84 bomb (HPM CT2) and analytically kept critical acceptor response well below the design threshold levels (e.g., relative case deformations < 25 percent, and explosive fill pressures < 4.0 kbar for thick-case acceptors) for the HPM (Reference 5). A photograph of a pit cover being placed over a storage cell is shown in Figure 11.

Donor Ordnance

HPM CT3 is an explosive certification test of the internal nonpropagation transfer aisle walls, cell walls, and storage pit covers for the critical transport sympathetic detonation hazard scenario. This scenario represents a worst case situation involving simultaneous detonation of multiple donors located in an open storage cell, SRA, and above the transport aisle. In case of an accident at any one of these three locations, line of sight fragments may cause SD of ordnance at the other two locations. The overall donor stowage plan for CT3 is shown in Figure 12 and listed below and in Table 1:

- **Donor D1.** 150 Mk82 bombs (26 pallets) with a total NEW (Net Explosive Weight) of 28,800 lb located in the SRA

- **Donor D2.** 4 Mk84 bombs (2 pallets) with a total NEW of 3,780 lb located above the storage transfer aisle wall

- **Donor D3.** 138 Mk82 bombs (23 pallets) with a total NEW of 26,496 lb located in a 38'-6" x 20'-0" x 15'-6" (LxWxH) storage cell

To ensure complete and prompt detonation, every other bomb was primed. The bombs of Donor D1 were located on the vehicle parking pad and on the loading docks to each side of the parking pad and were oriented parallel to the SRA transfer aisle wall. The bombs of Donors D2 and D3 were oriented parallel to the storage transfer aisle wall. The high charge weight (D3 = 26,496 lb) in a relatively small, open storage cell produces near critical design aisle and cell wall loads, while the aisle transport donor (D2) causes the highest fragment and blast pressures on a pit cover.

Acceptor Ordnance

Worst Case Acceptors. The worst case acceptor ordnance from all the HPM Storage Groups (SG's) were tested in CT3. The worst case acceptors come from SG 4 (thick-case bombs and projectiles) and SG 8 (thin-case mines, torpedoes and missiles). The worst case SG 4 acceptors to be tested were the general purpose Mk82 and Mk83 bombs, and the M107-155mm projectile. The worst case SG 8 acceptors to be tested were the Mk107 warhead for the Mk46 torpedo, Mk103 warhead for the Mk48 torpedo, Mk55 mine, and the WAU-17 Sparrow warhead. They were stowed in the orientation consistent with the HPM stowage plans (e.g., the Mk series bombs were stored parallel to the storage transfer aisle wall and perpendicular to the cell wall).

Acceptor Stowage Plans. The overall acceptor stowage plan for CT3 is shown in Figure 12 and listed in Table 1. The exact HPM stowage plan spacings could not be maintained in Cells A1 and A3 because these cells contained ordnance from both SG4 and SG8. However, the spacing of acceptors in Cell A2 from nonpropagation walls was the same as in the HPM stowage plan. All acceptors were exposed to a significant threat from the donor ordnance.

- **Cell A1.** Acceptor Cell A1 is literally surrounded by donor ordnance. This cell tested SG 4 acceptors (Mk82 bombs and M107-155mm projectiles) and SG 8 acceptors (Mk55 mines, Mk103 & Mk107 torpedo warheads, and WAU-17 Sparrow warheads) opposite the SRA transfer aisle wall from Donor D1, beneath the pit cover from Donor D2, and opposite the cell wall from Donor D3. Most acceptors were oriented perpendicular to these walls. The M107-155mm projectiles and Mk103 torpedo warheads, which are stored vertically, are parallel to all walls. Since the loading environment behind a cell wall is greater than behind the aisle walls (and the M107-155mm projectile is parallel to both), this cell is considered the more critical location for the projectiles. Acceptor A1 is exposed to a greater threat than the other two acceptors. A photograph of the ordnance in Cell A1 is shown in Figure 13.

- **Cell A2.** Acceptor Cell A2 is the least threatened of the acceptors. This cell tested SG 4 acceptors (Mk82 bombs) and SG 8 acceptors (WAU-17 Sparrow warheads) opposite the SRA transfer aisle wall from Donor D1, beneath the pit cover from Donor D2, and opposite the storage transfer aisle wall from Donor D3. Acceptor loads from these walls are not expected to be critical. Primary damage to the acceptors will be caused by the pit cover impact from Donor D2. All acceptors were oriented parallel to the storage transfer aisle wall. A photograph of the ordnance in Cell A2 is shown in Figure 14.

- **Cell A3.** Acceptor Cell A3 is significantly threatened by Donor D3. This cell tested SG 4 acceptors (Mk82 and Mk83 bombs) and SG 8 acceptors (Mk55 mines, Mk103 & Mk107 torpedo warheads, and WAU-17 Sparrow warheads) opposite the storage transfer aisle wall from Donor D3. All acceptors were oriented parallel to the aisle wall as would be expected in a prototype HPM. The acceptors in this cell will provide a good evaluation of the effectiveness of the redesigned storage transfer aisle wall. A photograph of the ordnance in Cell A3 is shown in Figure 15.

Data Acquisition

Acceptor Response: Measured. The primary post-test response analysis was made by visual inspection and measurement of acceptor deformations. The measured deformations were compared with predictions and the design criteria allowables.

Acceptor Response: Sympathetic Reaction Determination. For each acceptor ordnance not recovered intact, a determination of reaction occurrence was made. If a reaction occurred it was further characterized as a burn, explosion, or detonation. Reactions were evaluated by the condition of the acceptor casing (crushed, scorched, and presence and pattern of case fragments), floor cratering in the CT3 structure, exterior wall response of the CT3 structure (including fragment damage and patterns), and the presence of unburned explosives. External pressure readings were evaluated for indications of independent (in time) detonations, uneven pressure vs. range along the three gage lines (located at 90° intervals), and for greater pressure than expected from the three multiple donors alone.

Airblast. Three lines of side-on self-contained HDAS[1] pressure gages were installed by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) to measure the airblast pressure versus range and azimuth. Since the test setup was not symmetrical, gages were placed on three gage lines as shown in Figure 4 and described below:

- 0° Line (opposite the front wall of the CT3 structure)
- 90° Line (opposite the side wall of the CT3 structure)
- 180° Line (opposite the back wall of the CT3 structure)

Four gages were located on each line at ranges that provided an accurate relationship for establishing the safe Inhabited Building Distance (i.e., 1.2 psi range). The following table shows the gage locations on each line in relationship to the outside face of the CT3 structure's exterior walls:

Gage No.	Location	
	Azimuth (Degree)	Range from Wall R_z (ft)
F-1	Front (0°)	757
F-2		1148
F-3		1539
F-4		1930

[1]Hardened Data Acquisition System

Gage No.	Location	
	Azimuth (Degree)	Range from Wall R_z (ft)
S-1 S-2 S-3 S-4	Side (90°)	742 1133 1524 1915
B-1 B-2 B-3 B-4	Back (180°)	757 1148 1539 1930

These distances are the actual values at the test site altitude of 5,000 ft above sea level. The values will later be adjusted to sea level conditions. At each measurement location, an instrumentation package, containing a HDAS canister and a Kulite XT190 airblast gage, was installed. Data was recorded at 125 kHz and recording time was 920 msec, including the pre-trigger data.

Debris Recovery. Debris was recovered and characterized by Bakhtar Associates with assistance from a small NAWC crew under the supervision of the Site Coordinator. The pick-up zones and procedures outlined in this section were chosen to determine the safe debris distance criteria (for the test conditions) and to validate prediction procedures. The safe debris range is defined as the distance beyond which the hazardous debris density is less than 1 per 600 ft^2 [Note: hazardous debris = debris weighing at least 134 grams (2-in. diameter concrete sphere or 1-in. diameter steel sphere)]. After a post-test visual inspection of the debris distribution, the three 10° areas (as shown in Figure 4) emanating from the CT3 structure in the 0° (front/north), 90° (side/east), and 180° (back/south) azimuths were chosen for debris recovery. The collection zones extended out to 3,000 ft for the 0° azimuth, and 2,000 ft for both the 90° and 180° azimuths.

Post-test access was controlled by the Site Coordinator. When access was allowed, area sweep teams flagged debris locations within the 10° zones. Reflector teams marked the debris locations (with a mirror) for surveying the range and azimuth. The reflector team also indicated the debris type (concrete, steel rebar, or CBC) to the recorder. The automated mapping technique developed for the Air Force, Explosion Hazard Reduction Program - EHR, was employed for debris recovery and mapping. The analysis of the field data, debris density and hazard criterion, was performed based on the methodology proposed in Reference 6.

Photographic. Photographic coverage was provided by NAWC, China Lake. Coverage included:

- Pre-test and post-test photographs and video tape (including construction)

- Four video cameras during the test

TEST RESULTS

HPM CT3 was conducted on 24 October 1996. All 288 Mk82 and 4 Mk84 donor bombs were successfully detonated and the CT3 structure was destroyed. A 4-shot sequence of far-range photographs of the detonation is shown in Figure 16.

A chronological list of the major events following the detonation are summarized below:

Time	Event
T_D	Detonation of donor explosives inside test structure.
T_D + 5 sec	Several pieces of broken & burning explosives debris are observed being thrown out of structure.
T_D + 20 sec	Several fires involving burning explosives are observed within and outside the structure.
T_D + 2 min	Fires can be clearly seen on the berm behind Cell A3 [Mk107 torpedo warhead (#1) from Cell A3] and behind Structure [Mk107 torpedo warhead (#2) from Cell A3]. These fires diminish and eventually burn out when the explosives are consumed.
T_D + 10 min 31 sec	1st late-time reaction occurs in Cell A1. Large fire erupts in Cell A1 [Mk55 mine (#2) and Mk107 torpedo warhead (#5)].
T_D + 15 min 28 sec	2nd late-time reaction occurs in Cell A1. Flash of light and small bang are observed. Possibly the Mk55 mine (#2) popped open and then continued to burn until T_D + 16 min 57 sec.
T_D + 16 min 57 sec	3rd late-time reaction occurs in Cell A1, shortly preceded (about 5 sec) by an increase in the intensity of fire. Significant explosives event occurs in Cell A1. Identified as deflagration of Mk55 mine (#3) from Cell A1 and possibly the M107-155mm projectile (#8) from Cell A1.
T_D + 22 min 55 sec	4th late-time reaction occurs in Cell A1 preceded by a very small amount of burning. Smaller explosives event occurs in Cell A1. Firing officer observes a Mk82 bomb being thrown from structure. Identified as a very low-order reaction (pressure rupture of case) of Mk82 bomb (#13) from Cell A1.
T_D + 22 min 59 sec	Mk82 bomb strikes ground outside structure and kicks up small cloud of dust.

The list is based on analyses of the video tapes and direct on-site observations by NFESC, NAWC, and ISA personnel. Low resolution images captured from these tapes are shown in Figures 17 and 18. Figure 17 shows the white smoke from the early-time (T_D + 20 sec) burning explosives which eventually burned out when the explosives were consumed. Figure 18 shows the 3rd late-time reaction in Cell A1 at T_D + 16 min 57 sec.

Photographs taken the next day of the exterior CT3 site are shown in Figure 19. None of the 2nd story structure remained. Closer views of the interior damage to the CT3 structure are shown in Figures 20, 21, and 22. The exterior concrete walls of Cell D3 were destroyed and small pieces of concrete were thrown outside the structure. The exterior walls of the SRA and the three acceptor cells were rotated outward against the soil berm. The following internal nonpropagation walls were destroyed and completely missing:

- SRA transfer aisle wall between D1 and Cells A1/A2
- Cell wall between D3 and Cell A1
- Storage transfer aisle wall between D3 and Cell A3

The storage transfer aisle wall between Cells A1 and A2, where donor D2 was located, was crushed downward and broken.

Almost all of the acceptor ordnance (except some ordnance from Cells A1 and A3) was found within or nearby the original boundary of the CT3 structure. The following two acceptors from Cell A1 were thrown outside the structure during the 3rd and 4th late-time reactions (i.e., deflagrations):

- Mk55 mine. Pieces found at 125' and 550' from structure along 90° azimuth
- Mk82 bomb. Bomb found at 200' from structure along 135° azimuth

Airblast Data

Reference 7 contains the digitized external pressure data recorded at the test site altitude of 5,000' above sea level. Impulses were obtained by numerically integrating the data. A 9500 Hz low-pass filter was applied to the pressure data. The data are referenced to a common zero time (Time of Detonation) and are displayed with time in milliseconds on the abscissa and the data output on the ordinate. A typical data record is shown in Figure 23.

The values of the measured peak pressures at altitude are listed in Table 2. These peaks are not the initial spikes seen on some of the waveforms, which is an overshoot associated with quick rise times for this type of gage, but rather interpretations of the actual peaks based on the intersection of an exponential curve drawn through the waveform and the vertical rise at the waveform arrival. However, in order to compare this data with the results from analytical prediction models, the data was converted to sea level conditions using a computational procedure outlined in Reference 7. These adjusted measured peak pressures and their ranges are listed in Table 3.

For comparison purposes, the measured CT3 pressures will be compared with the following best-fit equations determined for the airblast data from previous earth-covered magazine tests:

- Front (0°): $p_o = 799.43Z^{[-2.1850+(0.09419)(\ln Z)]}$
- Side (90°): $p_o = 70.711Z^{[-0.70889-(0.12311)(\ln Z)]}$

where,

Z = scaled range from magazine wall $R/W^{1/3}$, $ft/lb^{1/3}$
W = net weight of explosives stored in magazine, lb

In both of these two directions, the safe inhabited building distance, IBD, was established as $35W^{1/3}$ for earth-covered magazines. Because the HPM does not have the unbermed frontwall of an earth-covered magazine, the measured peak pressures to the back of the HPM will be compared to the earth-covered magazine equation for the side direction. The predicted peak pressures based on these earth-covered magazine tests are listed in Table 3 for all the pressure gage stations at sea level conditions. These predictions are plotted versus scaled range as single solid lines in Figures 24 and 25. The measured external peak pressures listed in Table 3 are also plotted in these figures, and are within the lower and upper bounds (see dashed lines) of the data scatter for these best-fit equations. Thus, the safe IBD for the HPM is also established as $35W^{1/3}$.

Debris Data

Figure 26 represents the overall debris distribution in polar coordinates around the center of the CT3 structure within the three 10° sectors surveyed. From this figure, it can be seen that ranges for hazardous distances are slightly greater in the front (0°) direction, along the entrance to the structure. Also, debris distribution is fairly uniform around the 0°, 90°, and 180° azimuths.

The U.S. DOD and Navy Explosives Safety Standards (References 8 & 9) criterion for debris hazard range is the farthest distance to a debris density of one hazardous particle per 600 ft^2. All the debris recovered within the three 10° sectors are considered lethal and hazardous. The technique proposed by Jacobs is used for analysis and interpretation of the hazardous debris density. The Jacob's method is illustrated in Figure 27. According to the Jacob's method, a sector of the annulus of length "***d***" (100' in this analysis) was moved away from ground zero (GZ) in increments of "***i***" (20' in this analysis). The analysis was started at distance "***a***", representing the inner border in the closed-in region where 100% debris recovery was initiated. For each increment, the area of the sector was calculated, the number of debris in the sector was counted, and the number of debris per 600 ft^2 was determined. This process was continued until the farthest debris (distance "***b***") was included in the debris-distance calculations. The distance from GZ to the center of the sector of the annulus is the distance reported for the hazardous debris density. An example of the debris areal distributions for CT3, as collected in the front sector, is listed in Table 4. The debris densities for all three directions are graphically shown in Figures 28, 29, and 30. In order to determine the quantity-distance (Q-D) a curve fitting technique based on an exponential function with a generalized form given by:

$$f(x) = a e^{bx}$$

was used. For such statistical analysis, values of constants are calculated so that the sum of the square of the errors given by $[g(x_i) - \ln(y_i)]^2$ is minimized. The statistical fit for each set of data from the three sectors are shown by the inserted equation f(x) in Figures 28, 29, and 30. From these equations, the Q-D values defining the hazard criterion in the three debris recovery sectors were calculated as:

- Front Sector (0°): D = 1,337.6'
- Side Sector (90°): D = 1,108.3'
- Back Sector (180°): D = 1,145.0'

These distances are less than the distances determined for any other experimentally tested earth-covered magazine. Thus, the previously established safe debris distance of 1250' for earth-covered magazines can also be used for the HPM.

Acceptor Response

The detailed results of acceptor response are reported in a separate seminar paper authored by Carl Halsey from NAWC. As expected, the thick-case acceptors suffered minimal initial impact crushing (e.g., measured maximum 16% deformation in one bomb vs. 25% threshold for causing detonation). As previously reported, the expected burning of some thin-case acceptors caused three late-time low-order reactions of a Mk55 mine, M107-155mm projectile, and Mk82 bomb. However, no sympathetic detonation of any acceptors occurred.

REFERENCES

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3. NAVFAC Drawing Nos. 6438714 - 6438730. Certification Test Structure No. 3, High Performance Magazine, by SOH & Associates, Structural Engineers, San Francisco, CA, 30 October 1995.

4. CEMCOM Contract Report submitted to Naval Facilities Engineering Service Center. Development of Structural Shock Absorbing Cement Based Materials for Magazine Construction, by Claudio Herzfeld and Sean Wise, CEMCOM Research Associates, Inc., Baltimore, MD, January 1995.

5. "High Performance Magazine Acceptor Threshold Criteria”, by James E. Tancreto, Michael Swisdak, and Javier Malvar. Twenty-Sixth DoD Explosives Safety Seminar Proceedings, Miami, FL, 16-18 August 1994.

6. "Determining Hazardous Fragment Separation Distance", by Edward M. Jacobs and Joseph Jenus. Twenty-Sixth DoD Explosives Safety Seminar Proceedings, Miami, FL, 16-18 August

1994.

7. Naval Facilities Engineering Service Center. Site Specific Report SSR-Draft-SHR: Test Report for High Performance Magazine Certification Test No. 3, by Robert N. Murtha, James E. Tancreto, and Kevin P Hager, Port Hueneme, CA.

8. DOD 6055.9-STD: Ammunition and Explosives Safety Standards.

9. NAVSEA OP 5 Volume 1: Ammunition and Explosives Ashore Safety Regulations for Handling, Storing, Production, Renovation and Shipping, 6th Revision, 1 March 1995.

Table 1. Donor and acceptor stowage plan.

Location	Donor/Acceptor							Total NEW (lb)
	Item	Explosive Type	HPM SG[a]	Number of Storage Units[b]	Total Number of Weapons	NEW per Weapon (lb)	NEW (lb)	
Donor D1	Mk82 bomb	Tritonal	4	26	150	192	28,800	28,800
Donor D2	Mk84 bomb	Tritonal	4	2	4	945	3,780	3,780
Donor D3	Mk82 bomb	Tritonal	4	23	138	192	26,496	26,496
Acceptor A1	Mk55 mine Mk103 torpedo WH Mk107 torpedo WH Mk82 bomb M107 155mm projectile	HBX-1 H6 PBXN-103 H6 Comp B	8 8 8 4 4	3 1 5 4 1	3 4 5 24 8	1,292 96 665 192 10	3,876 384 3,325 4,608 80	12,273
Acceptor A2	WAU-17 Sparrow WH Mk82 bomb	PBXN-103 H6	8 4	1 3	2 18	25 192	50 3,456	3,506
Acceptor A3	Mk55 mine Mk103 torpedo WH Mk107 torpedo WH WAU-17 Sparrow WH Mk82 bomb Mk83 bomb	HBX-1 H6 PBXN-103 PBXN-103 H6 H6	8 8 8 8 4 4	2 1 4 2 4 4	2 4 4 4 24 12	1,292 96 665 25 192 445	2,584 384 2,660 100 4,608 5,340	15,676

[a] High Performance Magazine Storage Group
[b] Pallets or containers

Total Donor NEW = 59,076 lb
Total Acceptor NEW = 31,455 lb

Table 2. Measured peak pressure at altitude (z = 5,000 ft).

Gage No.	Location		Peak Pressure p_z (psi)
	Azimuth (Degree)	Range from Wall R_z (ft)	
F-1 F-2 F-3 F-4	Front (0°)	757 1148 1539 1930	3.15 1.70 1.21 ----
S-1 S-2 S-3 S-4	Side (90°)	742 1133 1524 1915	2.40 1.30 1.04 ----
B-1 B-2 B-3 B-4	Back (180°)	757 1148 1539 1930	2.90 ---- ---- ----

Table 3. Peak pressures adjusted for sea level (Nominal 60,000 lb TNT).

Gage No.	Adjusted Range from Wall R_o (ft)	Adjusted Scaled Range from Wall Z_o (ft)	Measured Adjusted Peak Pressure p_o (psi)	Predicted Peak Pressure p_o (psi)
F-1 F-2 F-3 F-4	712.3 1080.3 1448.2 1816.1	18.20 27.60 36.99 46.39	3.79 2.04 1.45 ----	3.12 1.60 1.02 0.73
S-1 S-2 S-3 S-4	698.2 1066.2 1434.1 1802.0	17.84 27.24 36.63 46.03	2.88 1.56 1.26 ----	3.30 1.77 1.12 0.77
B-1 B-2 B-3 B-4	712.3 1080.3 1448.2 1816.1	18.20 27.60 36.99 46.39	3.49 ---- ---- ----	3.21 1.74 1.10 0.76

Table 4. Debris density in front recovery sector.

Zone No.	Range (ft)		Number of Debris, N	Area Covered (ft^2)	Debris Density (per 600 ft^2)
	Near to Far	To Center			
1	800-900	850	135	14,835	5.460
2	820-920	870	161	15,184	6.362
3	840-940	890	156	15,533	6.026
4	860-960	910	163	15,882	6.158
5	880-980	930	152	16,232	5.619
6	900-1000	950	148	16,581	5.356
7	920-1020	970	122	16,930	4.324
8	940-1040	990	123	17,279	4.271
9	960-1060	1010	110	17,628	3.744
10	980-1080	1030	100	17,977	3.338
11	1000-1100	1050	92	18,326	3.012
12	1020-1120	1070	90	18,675	2.892
13	1040-1140	1090	86	19,024	2.712
14	1060-1160	1110	75	19,373	2.323
15	1080-1180	1130	73	19,722	2.221
16	1100-1200	1150	66	20,071	1.973
17	1120-1220	1170	63	20,420	1.851
18	1140-1240	1190	56	20,769	1.618
19	1160-1260	1210	56	21,118	1.591
20	1180-1280	1230	54	21,468	1.509
21	1200-1300	1250	47	21,817	1.293
22	1220-1320	1270	49	22,166	1.326
23	1240-1340	1290	43	22,515	1.146
24	1260-1360	1310	40	22,864	1.050
25	1280-1380	1330	32	23,213	0.827

Zone No.	Range (ft)		Number of Debris, N	Area Covered (ft^2)	Debris Density (per 600 ft^2)
	Near to Far	To Center			
26	1300-1400	1350	28	23,562	0.713
27	1320-1420	1370	24	23,911	0.602
28	1340-1440	1390	28	24,260	0.693
29	1360-1460	1410	27	24,609	0.658
30	1380-1480	1430	35	24,958	0.841
31	1400-1500	1450	38	25,307	0.901
32	1420-1520	1470	44	25,656	1.029
33	1440-1540	1490	39	26,005	0.900
34	1460-1560	1510	45	26,354	1.025
35	1480-1580	1530	42	26,704	0.944
36	1500-1600	1550	42	27,053	0.932
37	1520-1620	1570	31	27,402	0.679
38	1540-1640	1590	28	27,751	0.605
39	1560-1660	1610	19	28,100	0.406
40	1580-1680	1630	15	28,449	0.316
41	1600-1700	1650	12	28,798	0.250
42	1620-1720	1670	10	29,147	0.206
43	1640-1740	1690	11	29,496	0.224
44	1660-1760	1710	11	29,845	0.221
45	1680-1780	1730	9	30,194	0.179
46	1700-1800	1750	7	30,543	0.138
47	1720-1820	1770	7	30,892	0.136
48	1740-1840	1790	6	31,241	0.115
49	1760-1860	1810	5	31,590	0.095
50	1780-1880	1830	3	31,940	0.056
51	1800-1900	1850	5	32,289	0.093

Zone No.	Range (ft)		Number of Debris, N	Area Covered (ft^2)	Debris Density (per 600 ft^2)
	Near to Far	To Center			
52	1820-1920	1870	5	32,638	0.092
53	1840-1940	1890	6	32,987	0.109

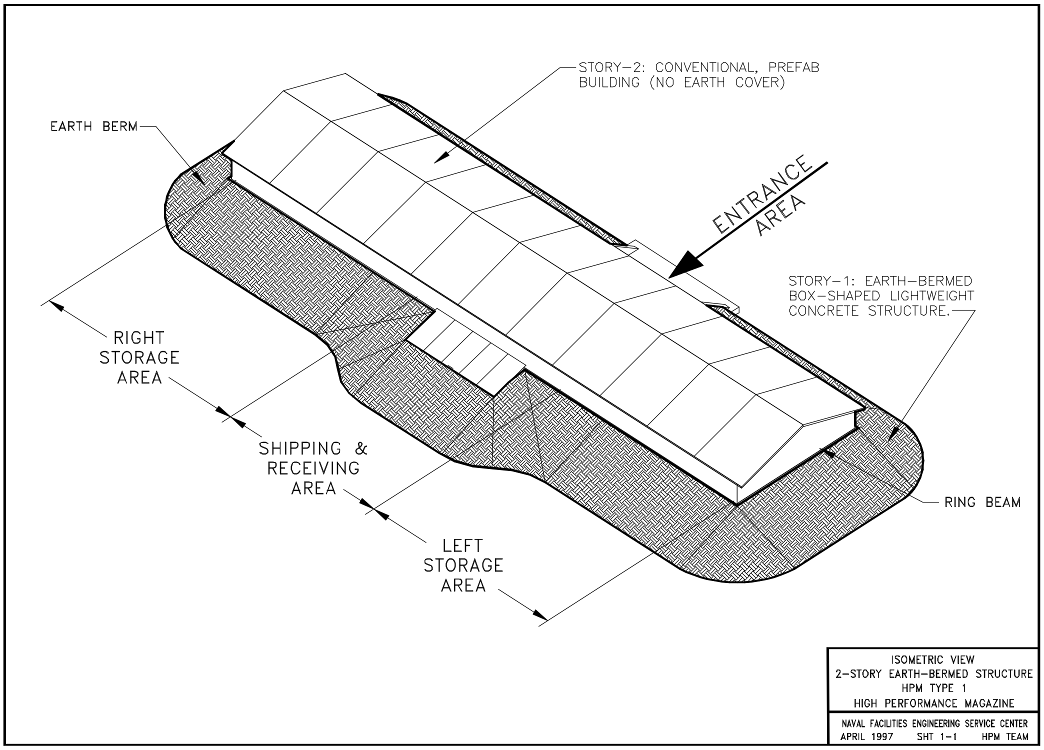


Figure 1. High Performance Magazine: Isometric view of magazine.

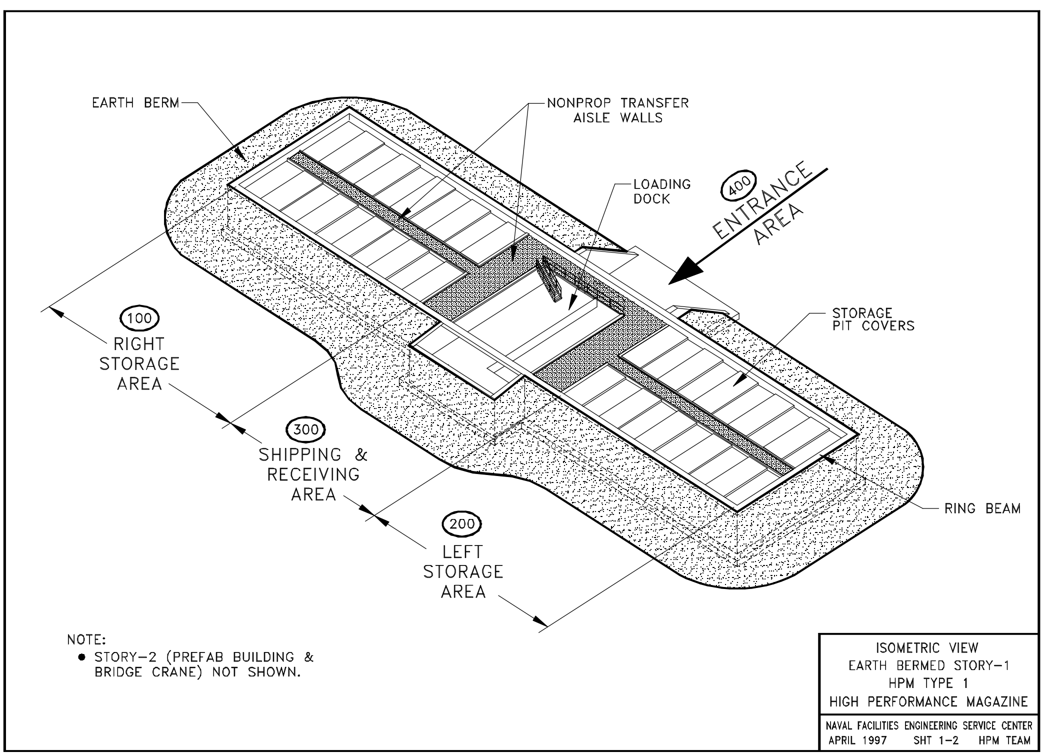


Figure 2. High Performance Magazine: Isometric view of Story-1.

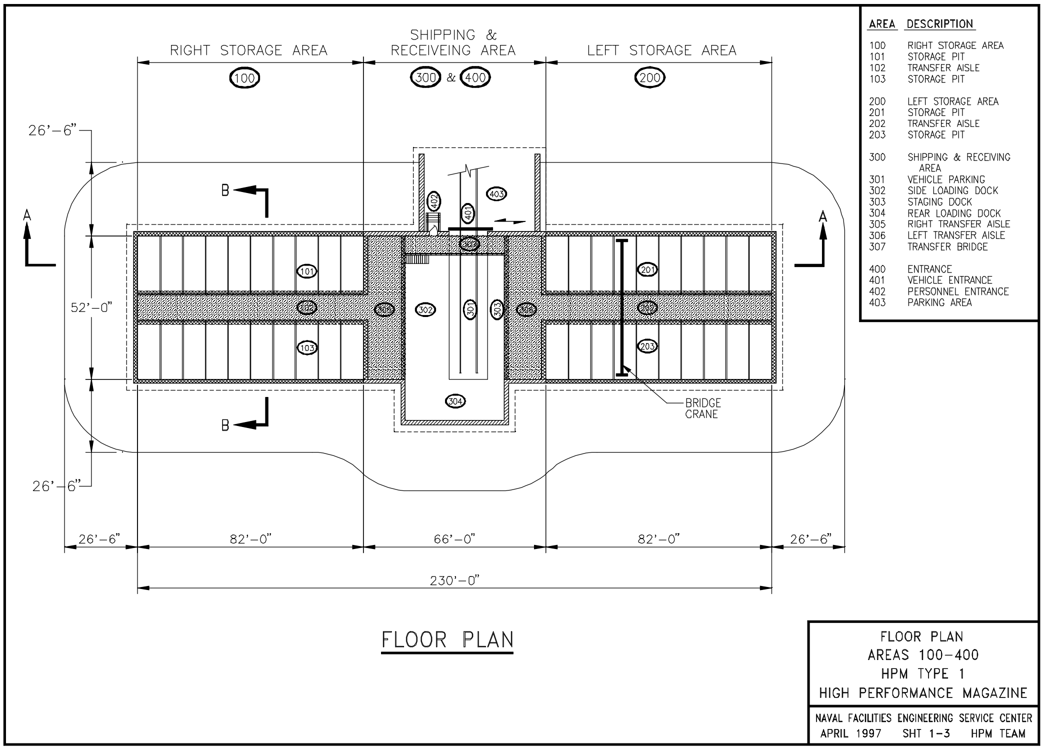


Figure 3. High Performance Magazine: Floor plan.

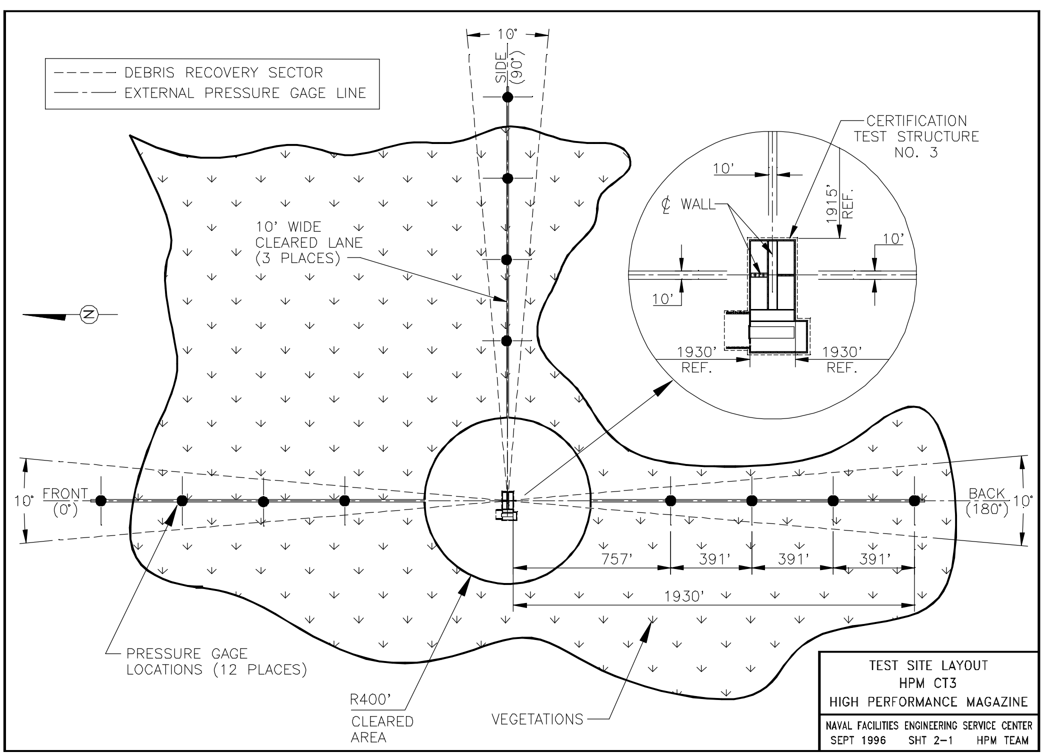


Figure 4. Test site layout.

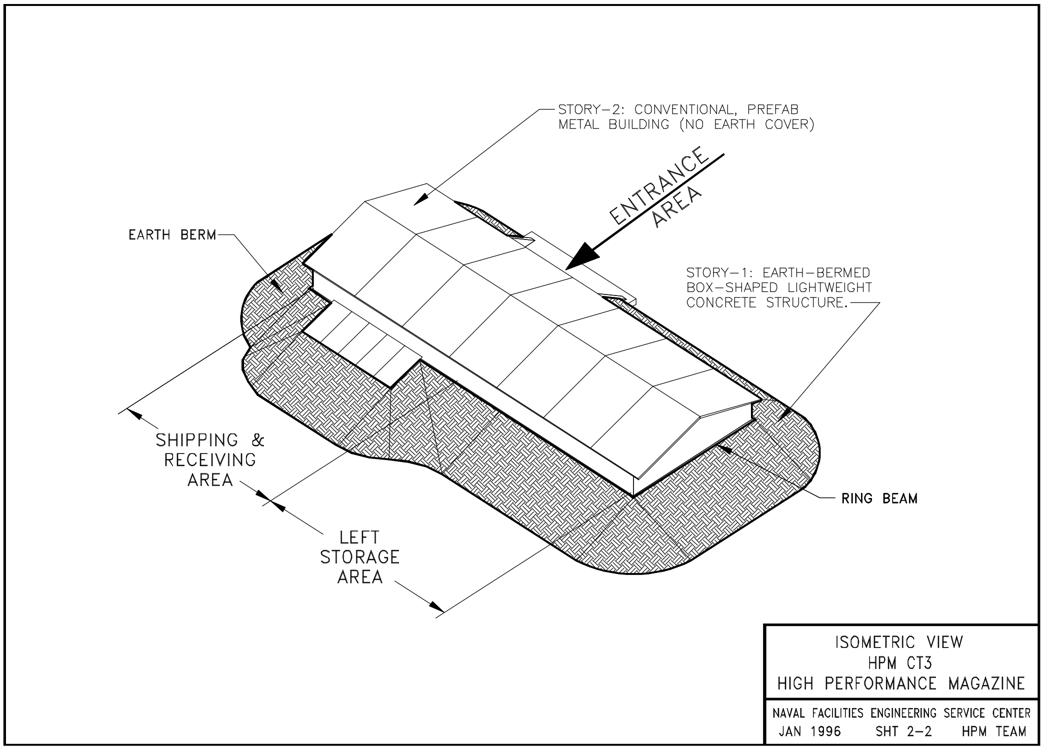


Figure 5. CT3 structure.

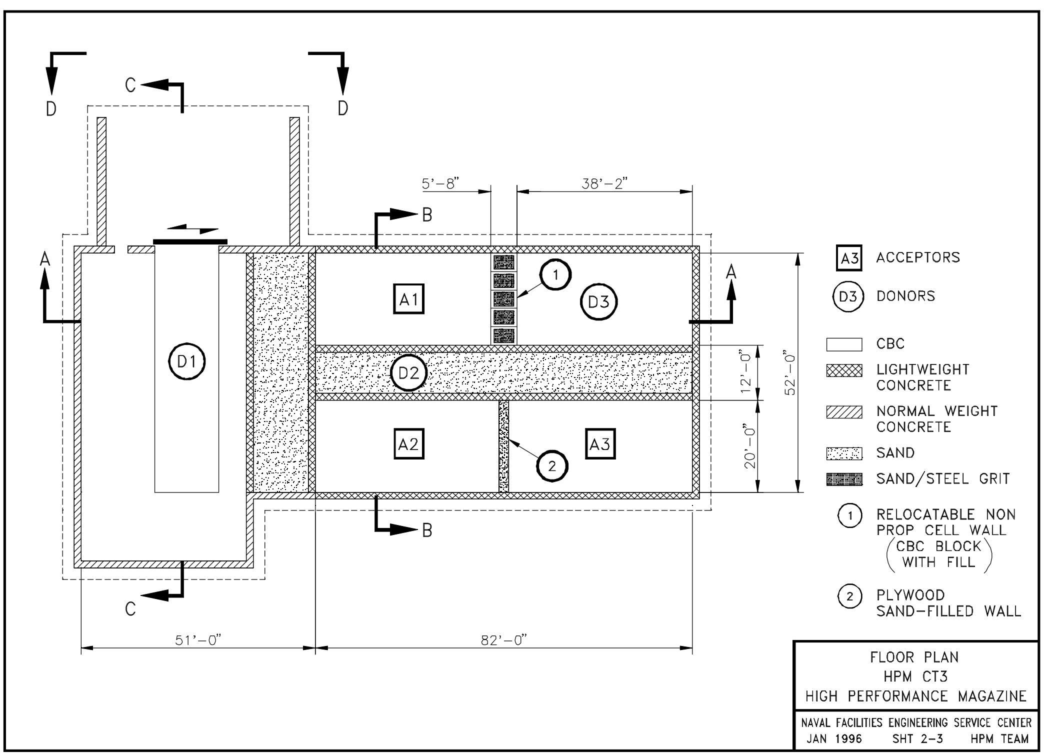


Figure 6. CT3 structure: Floor plan.

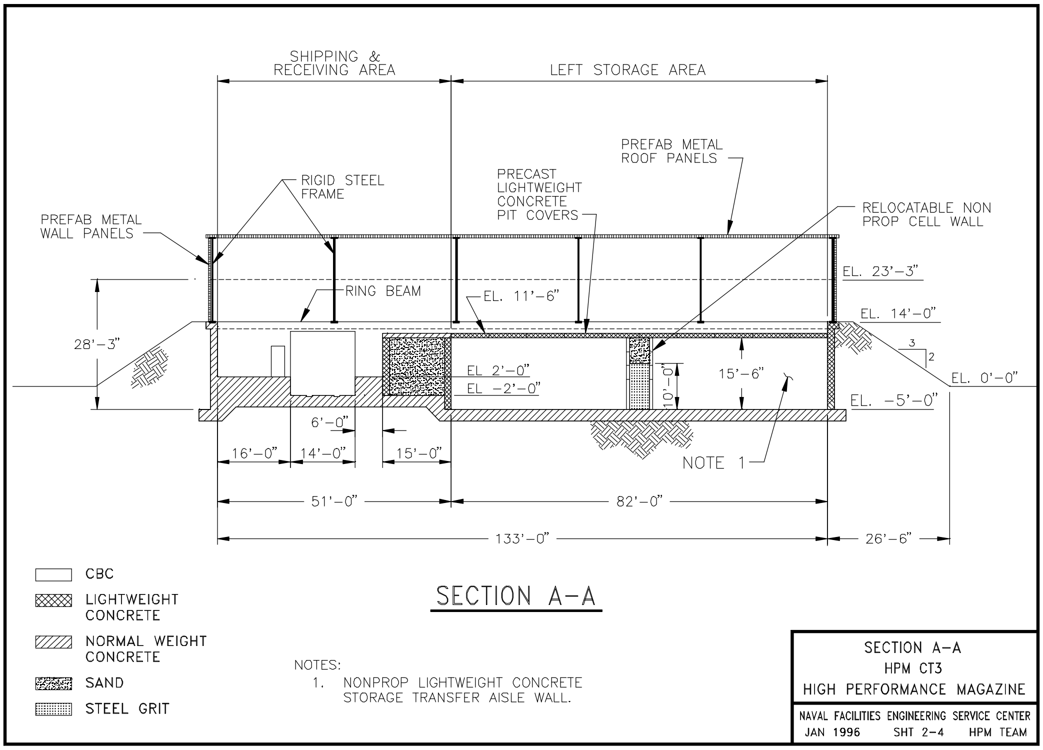


Figure 7. CT3 structure: Section A-A.

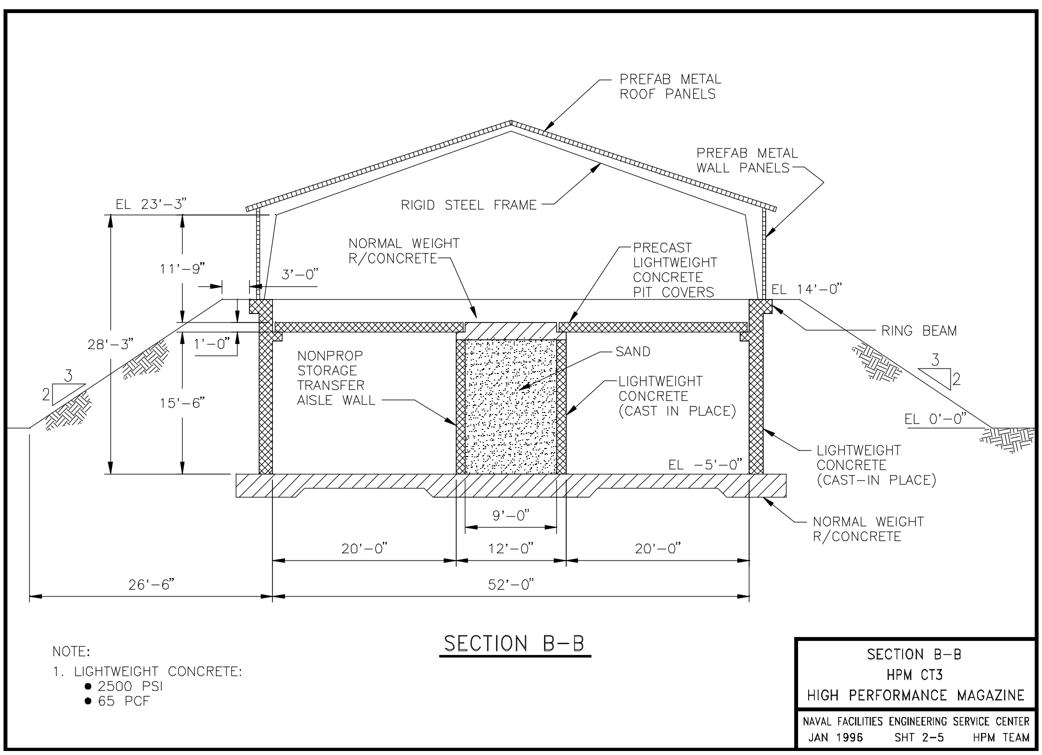


Figure 8. CT3 structure: Section B-B.

Figure 9. Exterior view of CT3 structure.

Figure 10. Portion of transfer aisle walls.

Figure 11. Pit cover.

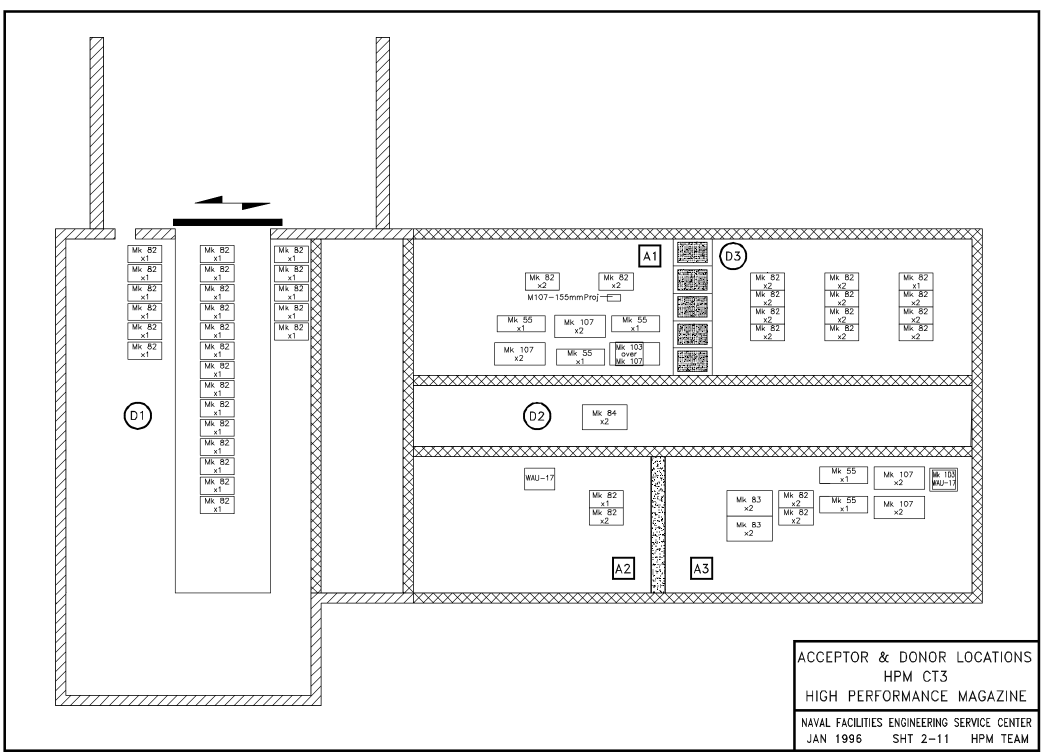


Figure 12. Acceptor and donor locations.

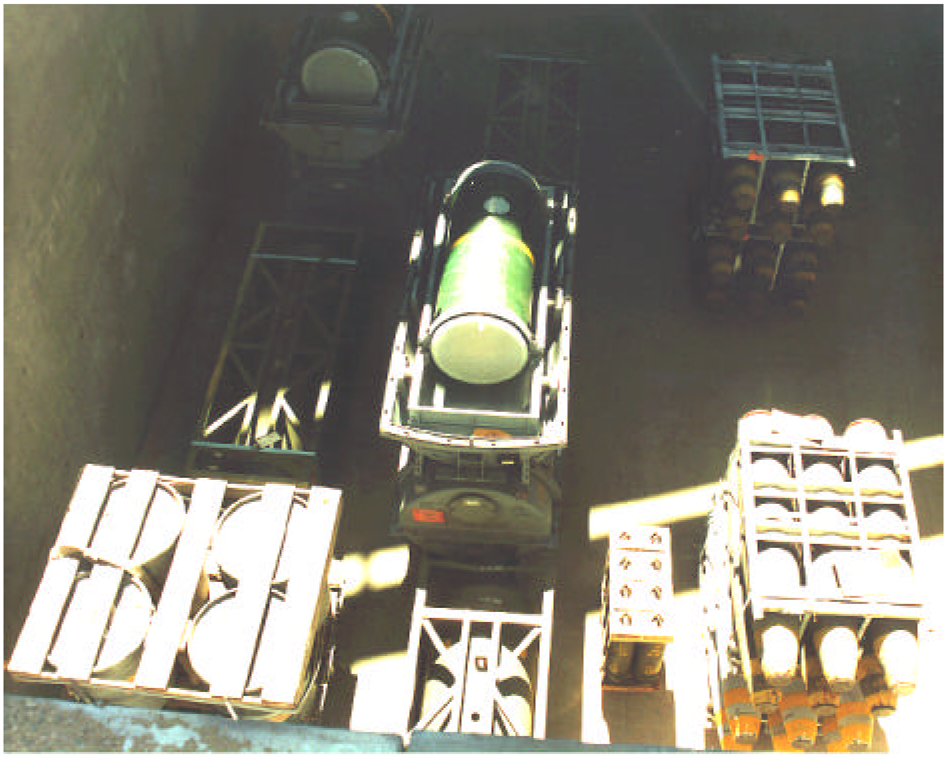


Figure 13. Acceptor ordnance inside Cell A1.

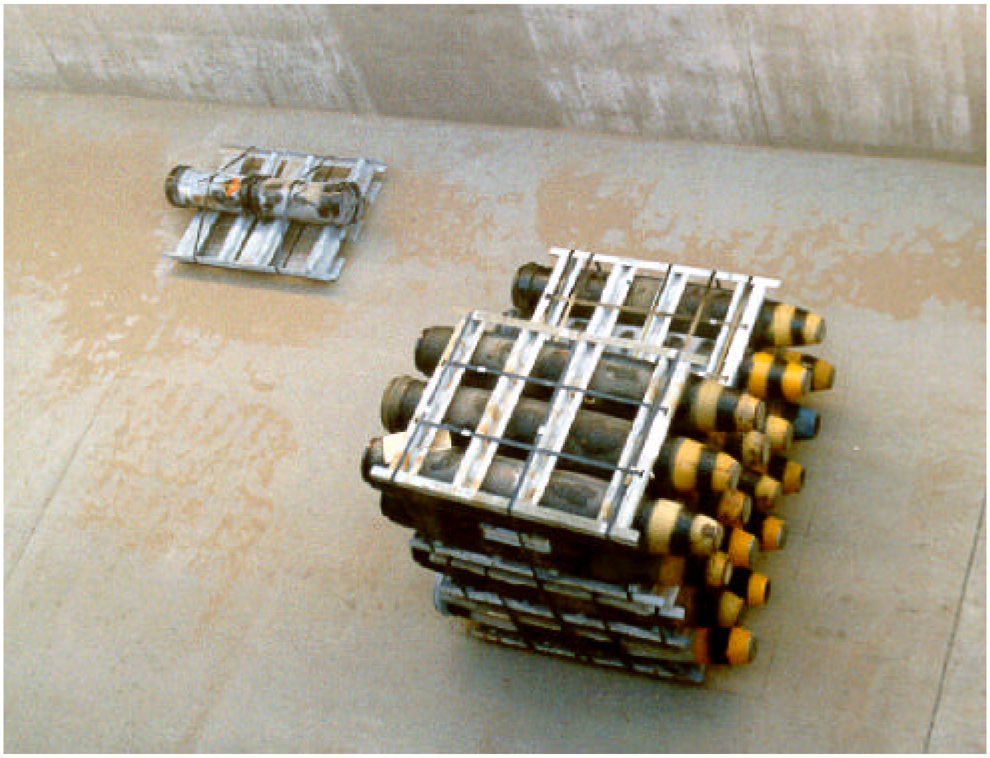


Figure 14. Acceptor ordnance inside Cell A2.

Figure 15. Acceptor ordnance inside Cell A3.

Figure 16a. CT3 site: Detonation sequence photographs.

Figure 16b. CT3 site: Detonation sequence photographs.

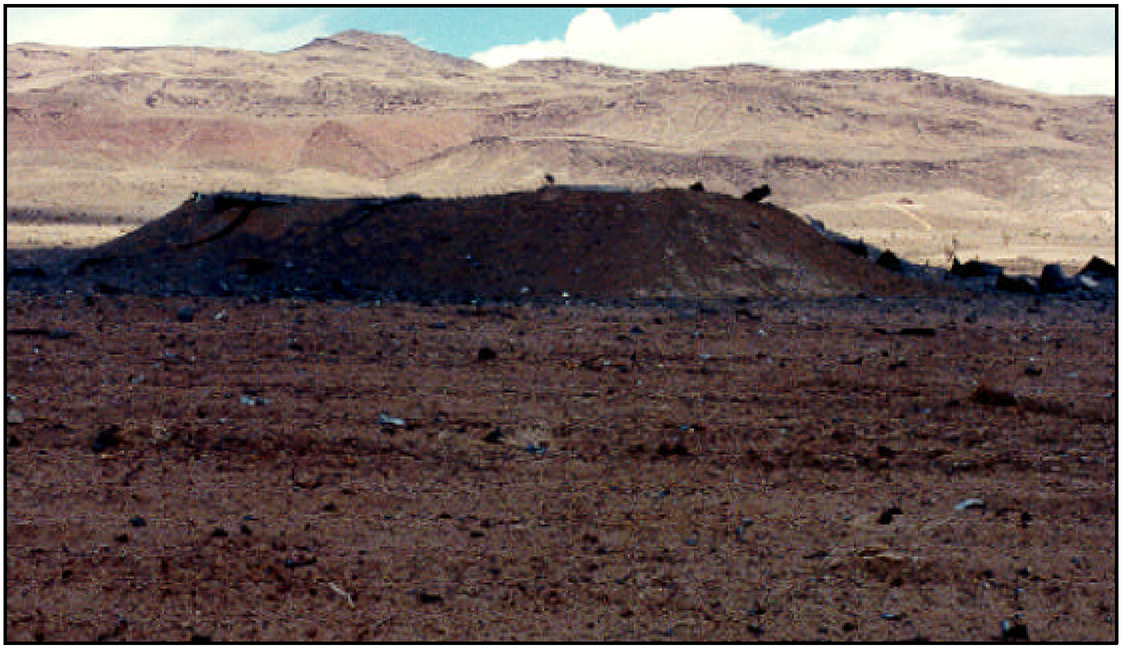
Figure 17. CT3 site: Video image at T_D +20 sec.

Figure 18. CT3 site: Video image at T_D +16 min 57 sec.

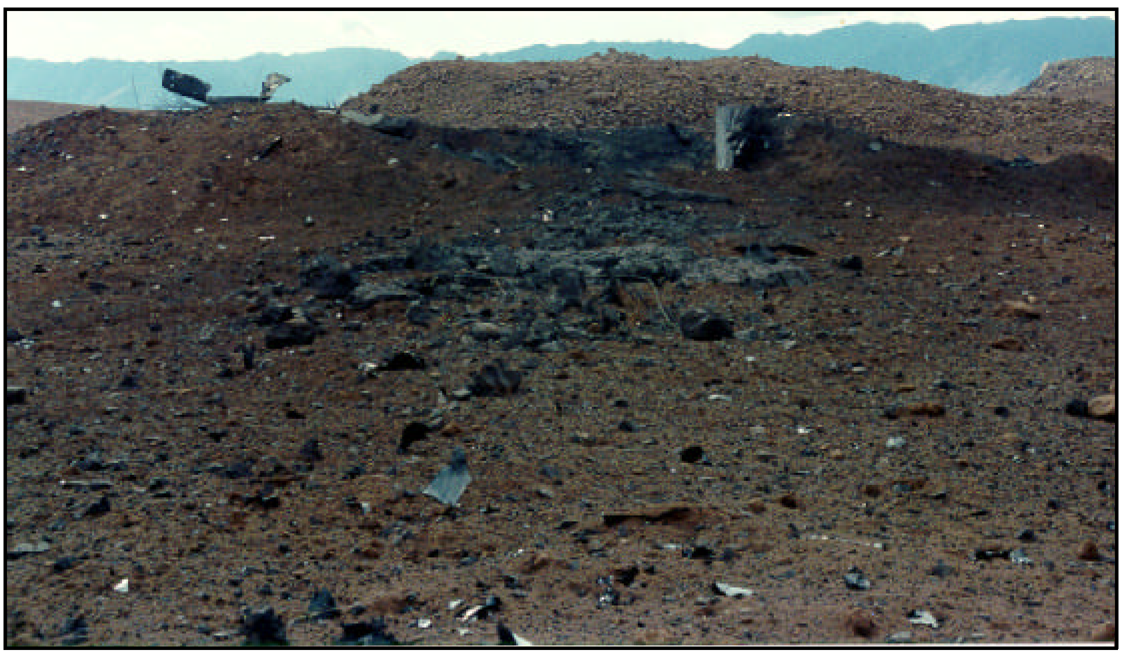
Front (0°)

Side (90°)

Figure 19a. Post-test views of CT3 structure.



Back (180°)



Side (270°)

Figure 19b. Post-test views of CT3 structure.

Figure 20. View of CT3 structure: SRA.

Figure 21. View of CT3 structure: Cell A3.

Figure 22. View of CT3 structure: Cells A1 and D3

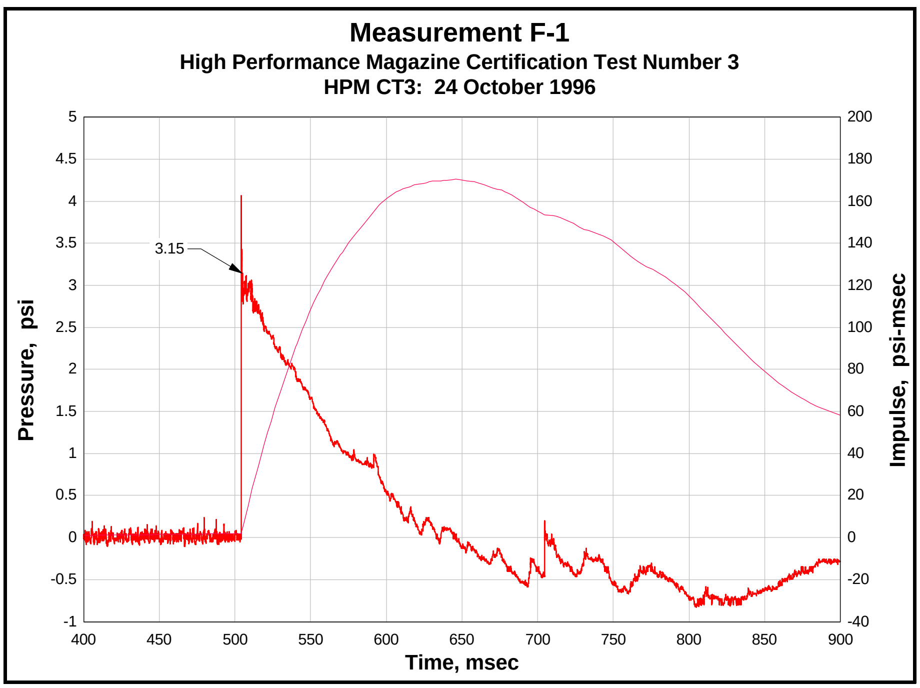


Figure 23. External airblast pressure measurement F-1.

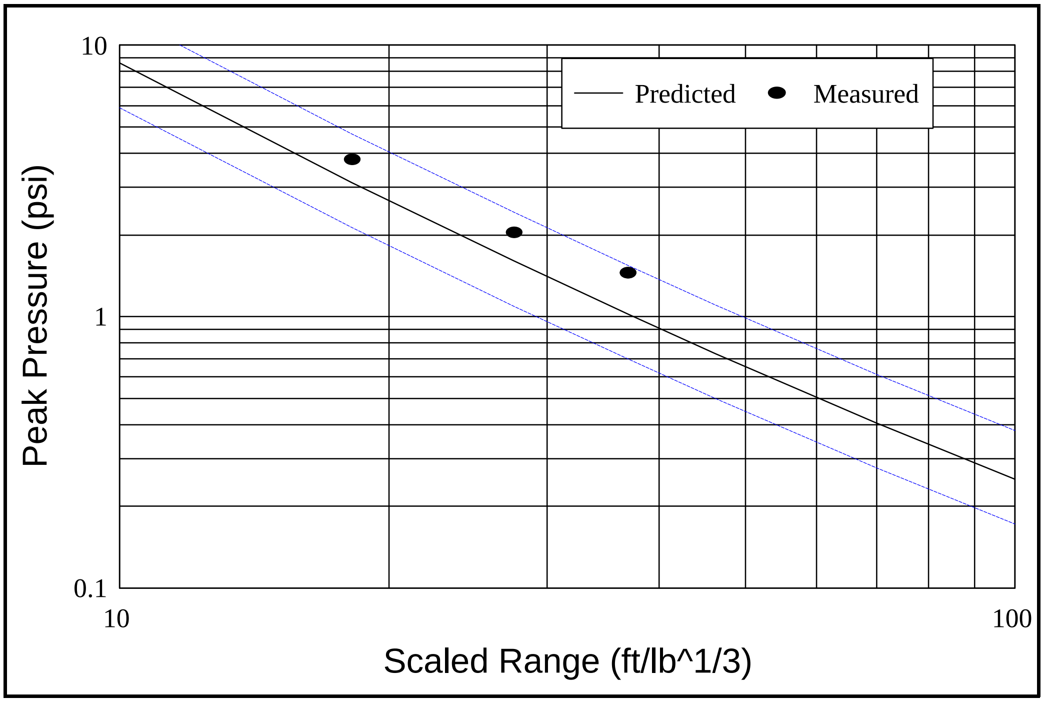


Figure 24. Measured vs. predicted peak external pressures: Front.

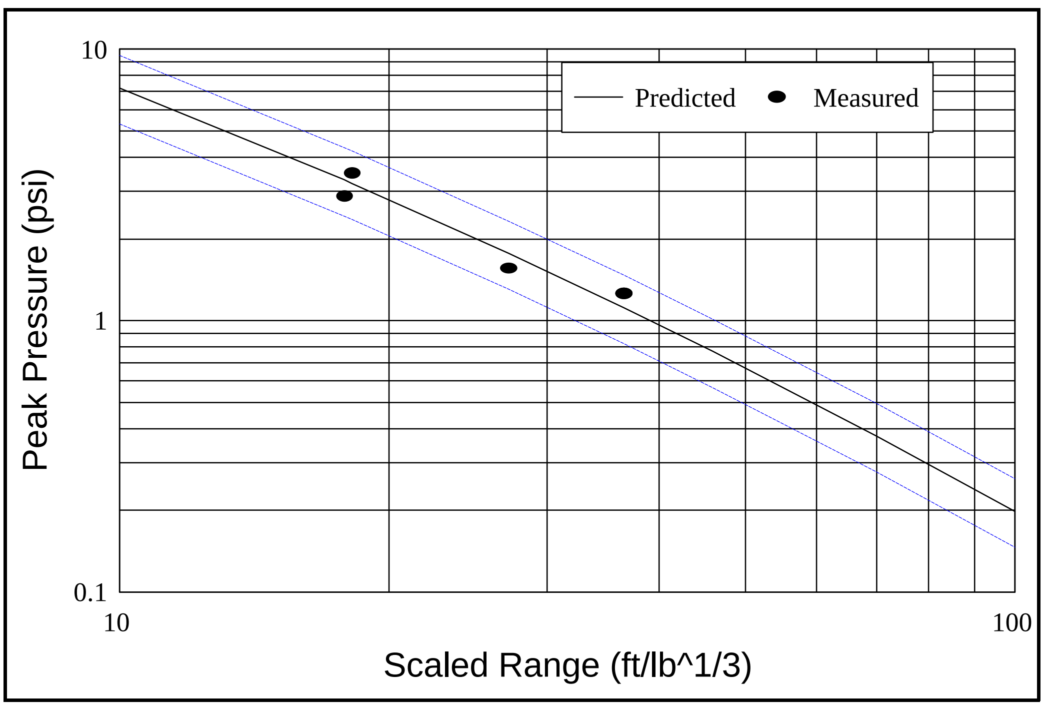


Figure 25. Measured vs. predicted peak external pressures: Side & Back.

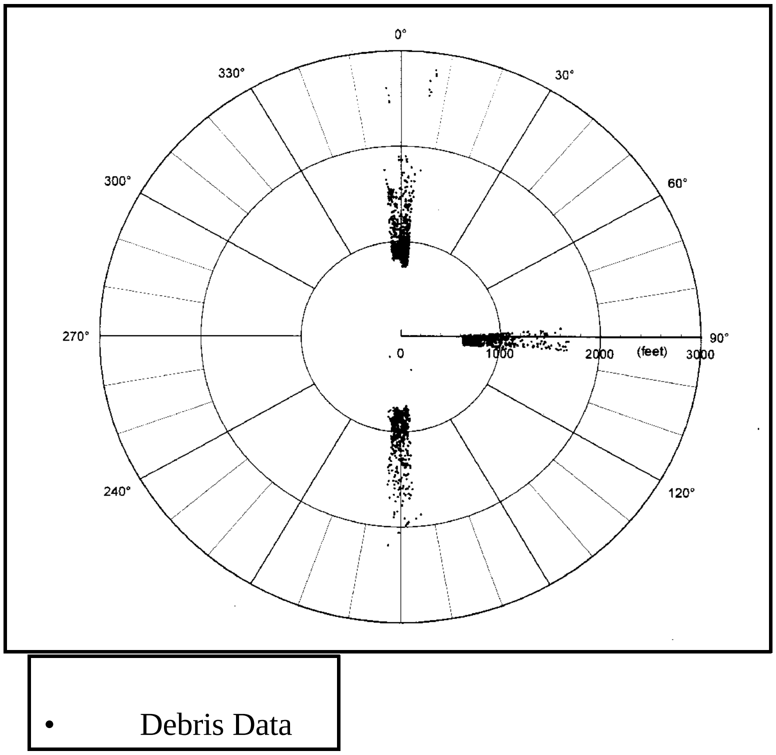


Figure 26. Polar plot of hazardous debris locations.

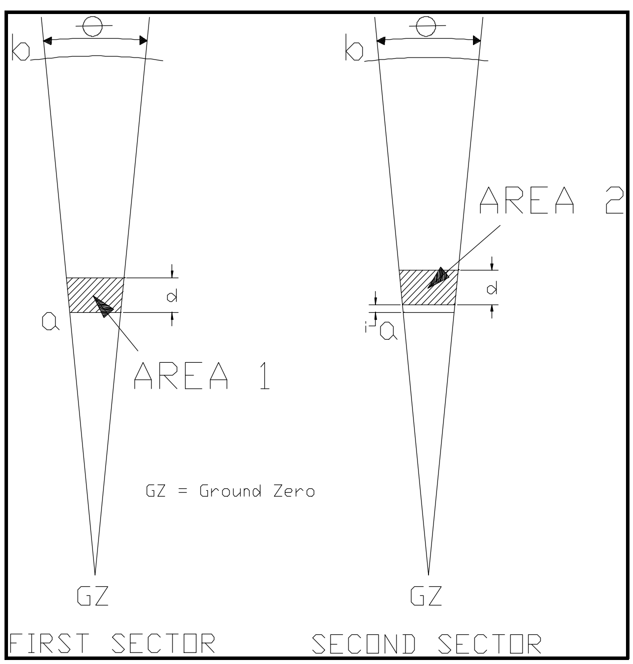


Figure 27. Schematic representation of Jacobs' Method.

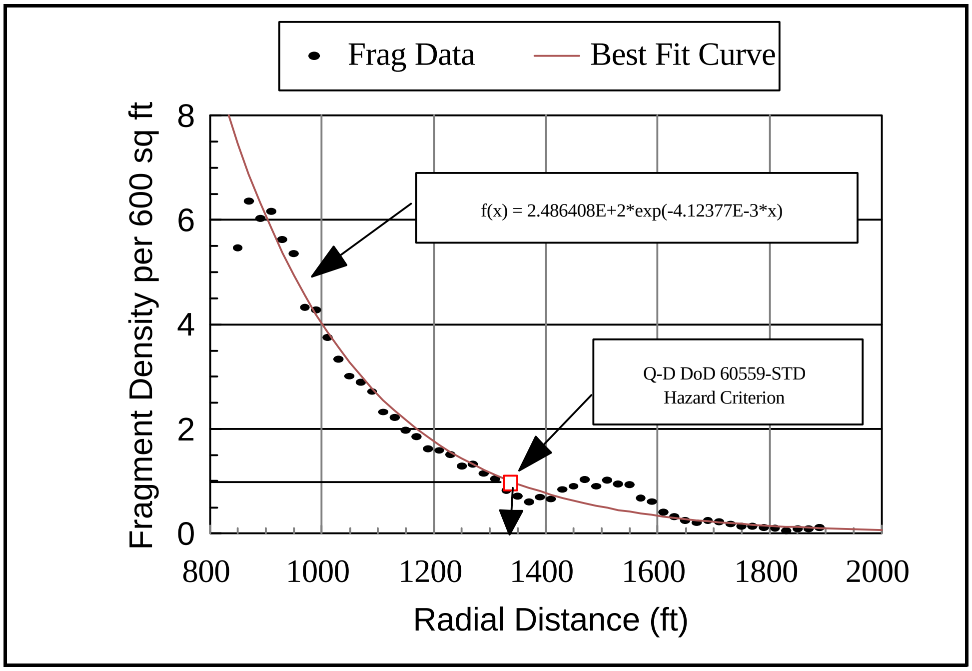


Figure 28. Debris areal number density distribution: Front sector.

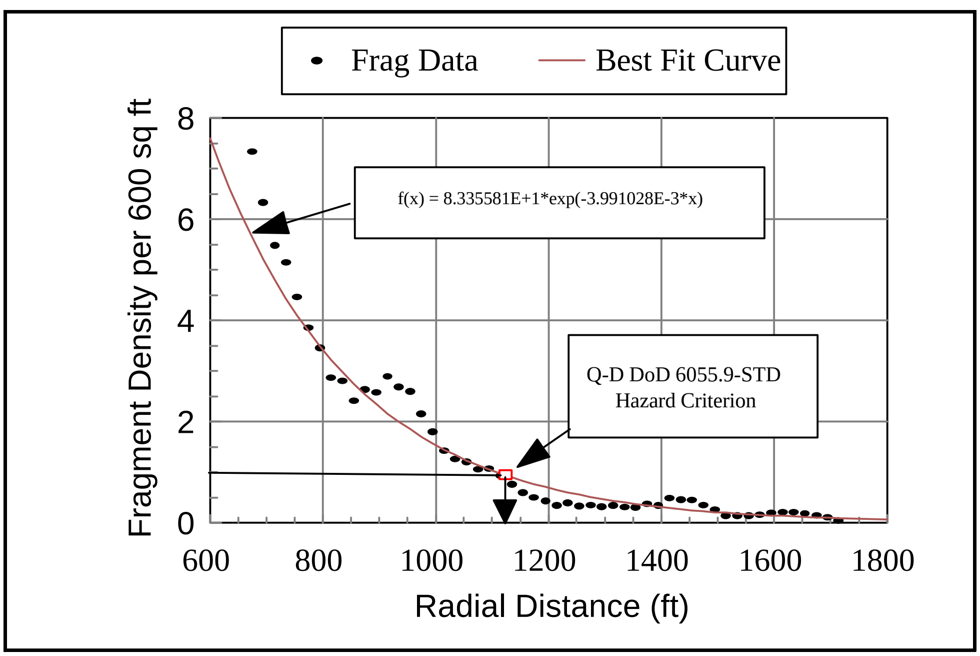


Figure 29. Debris areal number density distribution: Side sector.

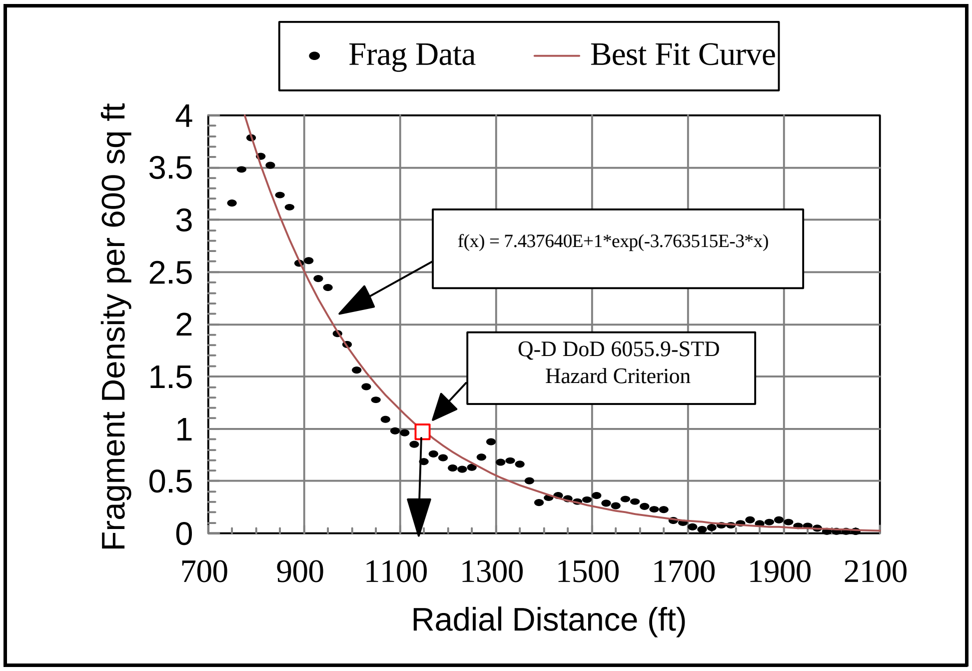


Figure 30. Debris areal number density distribution: Back sector.