TNT EQUIVALENCE OF SELECTED U. S. ARMY GUN PROPELLANTS

presented by

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ABSTRACT

Tests have been conducted to determine the TNT equivalency of selected U.S. Army gun propellants. These tests examined M1, M6, and M30A1 propellants. The tests utilized relatively large stacks of material (Net Explosive Weight on the order of 2000 pounds). The tests were conducted by placing the material inside a heavy-walled concrete pipe (simulating magazine-type confinement) and attempting to detonate one or more of the items. Airblast was measured outside the structure. Equivalent yield and TNT equivalency were determined from the airblast. All three materials exhibited energetic reactions which approached a detonation and gave yield approximately that of an equal weight of TNT.

INTRODUCTION

Current Army procedures[1,2] require that the TNT equivalence of propellants be taken as 100%, if the actual value is unknown. If it can be shown that when stack size and confinement concerns have been adequately addressed that this is not the case and that the TNT equivalence is something less than 100%, then savings could occur. These savings could manifest themselves in any of several ways: (1) reduced quantity-distance requirements for a given load of material, (2) increased amounts of material of a given quantity-distance range, and (3) possible relaxations of the rules for mixed storage (mixing of various hazard division materials) of items.

Several previous TNT equivalence studies such as those reported in References 3 and 4 have not addressed the effects of confinement nor mode of initiation. Generally, these efforts have concentrated on the determination of equivalences for single items or small groups of items without regard to confinement effects.

Any tests which are performed for the determination of the TNT equivalence of gun propellants should address, as a minimum, these factors: (1) the type of propellant (including composition and configuration), (2) the type of initiation stimulus, and (3) the effects of confinement. When these factors are taken into account, the results can be applied to a variety of storage situations. A question that has arisen several times during hazard classification discussions is the following: Should a TNT equivalence which is based on single item, or a small number of items, detonated in the open be applied to storage situations

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in which there is massive confinement--both from the numbers of rounds involved and from the structure in which the rounds are stored?

After discussions within the hazard classification and user communities, the U. S. Army through the Project Manager for Ammunition Logistics (PM-AMMOLOG) and the SAFELOAD Program decided to initiate an effort to examine this problem for selected propellant types. After a review of the proposals which had been submitted, the Dahlgren Division of the Naval Surface Warfare Center was selected to conduct this effort. The remainder of this paper describes the results of this effort.

SELECTION OF TEST ITEMS

For the first phase of the testing effort, it was decided to concentrate on 155 mm gun systems. The M107 projectile (DODIC D544), containing 15.4 pounds of Composition B explosive, constitutes the bulk of the high explosive (HE) rounds within this system. Likewise, within the Army stockpile system, two propellant series make up the bulk of the propellants used: (1) The M119 series (DODIC D533), containing M6 propellant, represents 43% of the 155 mm propellant stockpile and (2) the M4 series (DODIC D541), containing M1 propellant, represents 37% of the 155 mm propellant stockpile. This is further reflected in the ammunition load-outs aboard Army prepositioning ships. These two series represent over 71% (by weight) of the propellant carried by these ships.

For these reasons, it was decided that the first portion of the testing program would concentrate on these two propellant series: M119 and M4. The results, however, should be applicable to other propellant series which utilize these same propellants. As the fielding effort was being prepared, funding became available to add an additional propellant series to the program. The M203 series containing M30A1 propellant was selected and added. Each of these propellant series uses a multi-perforated grain. All three of the propellant series selected for testing are shipped/stored in metal shipping containers. Table 1 presents more detailed information about each of the test items.

TEST PROCEDURE

The tests were designed to examine worst-case conditions of both confinement (structural as well as inertial) and method of initiation and to determine equivalences under such conditions. These equivalences should, then, be applicable to conditions of lesser severity.

<u>CONTAINMENT STRUCTURE</u>. All of the tests were fired in disposable containment structures which were supposed to mimic the structural confinement provided by above-ground storage magazines. Each structure was a section of large diameter concrete pipe with a concrete lid. This pipe had an inner diameter of 84 and was 72 tall. One end of the pipe was buried approximately 6 into the ground. The wall-thickness of this pipe was 8. Each structure weighed approximately 14,500 pounds and was closed with a 4-inch thick (nominal) slab of lightly-reinforced concrete, weighing approximately 2900 pounds. This structure is shown schematically in Figure 1, while Figure 2 provides a photograph of one of the

structures prior to testing.

STORAGE SCENARIOS. Two types of storage were examined--Pure propellant and Mixed storage. In the Pure propellant case, only containers of propellant were placed in the containment structure for testing. Under Mixed storage, Composition B-loaded, M107 projectiles were used to replace approximately half of the propellant cans. Composition B-loaded projectiles were used instead of TNT-loaded rounds because of their slightly higher TNT equivalence (1.1 versus 1.0), as well as their demonstrated increase in fragmentation performance. This increased performance was chosen to maximize initiation stimuli and potential reaction yields. Relatively large Net Explosive Weights were chosen to provide inertial confinement.

INITIATION PROCEDURE. Two different initiation schemes were used, depending upon the storage type--Pure or Mixed.

For Pure storage situations, several containers were opened, exposing the propellant grains. High explosive was then placed in direct contact with the propellant Seven separate containers, distributed throughout the stack, were primed--each with approximately 5-pounds of Composition C4 plastic explosive. All of the Composition C4 was detonated simultaneously.

For the Mixed storage, six separate projectiles were primed with Composition C4 (approximately 0.75-pounds in the nose well of each each projectile). All six of the primed projectiles were detonated simultaneously. Because of the arrangement of projectiles within the containment structure, this initiation scheme was expected to cause sympathetic detonation of all of the projectiles within the stack.

REFERENCE EXPLOSIVES. TNT was used as the reference explosive. It was cast into cylinders with a nominal length-to-diameter ratio (l/d) of 3:1. The nominal weight of each standard charge was 1000 pounds. A Composition C4 booster was placed on the top of each of these charges and initiated.

TEST INFORMATION

Each combination of propellant type and storage mode is referred to as a Test Configuration. In addition, the TNT charges are referred to as a Standard configuration. Table 2 presents the Test Configurations investigated during this test program. Also given in this table is the firing sequence and the Net Explosive Weights (NEWs) for each of the components involved.

Figure 3 is a sketch of a Pure propellant configuration; Figure 4 shows a similar sketch for a Mixed configuration, while Figure 5 presents a sketch of the TNT Standard configuration. Figures 6,7, and 8 are photographs corresponding to a portion of each of these configurations. The witness plate shown in Figures 3-5 was 1-inch thick and was included on every test. The post-test condition of this plate was useful in determining the severity of the reaction which has occurred.

The tests were conducted by the U.S. Army Waterways Experiment Station (USA WES). The test site was at the Utah Test and Training Range (UTTR), outside Salt Lake City, Utah. Airblast was measured along two gauge lines, located 90° apart, on each test. There were six transducers along each gauge line. WES provided and recorded all airblast instrumentation. They also provided personnel for the actual conduct of the test. Finally, they provided both summary tables and digitized pressure-time traces for each transducer for each shot.

RESULTS AND INTERPRETATION

Based on the on-site observations, it was felt that each test resulted in a reaction that could not be distinguished from a detonation. The ground under the structure was severely cratered and the structure, itself, was destroyed. The only portions of the structure that were recovered were small chunks that were found several hundred meters from the ground zero area.

The witness plates, however, told another story. On the four tests of Configuration 4A (all projectiles) and the TNT Standard, the plates were shattered. For the Mixed storage tests, the portions of the plate beneath the projectiles were either shattered or punched through. The portion under the propellant canisters was simply bowed. For the Pure propellant tests, the witness plates were simply bowed. These observations indicate that in all likelihood the propellant was not undergoing a detonation, but a somewhat less severe reaction.

The Peak Pressure and Positive Impulse recorded on this test program are plotted in Figures 9-16. Also shown on each Figure are least-squares curve fits through the data. These curve fits will be used in a subsequent section to determine the TNT equivalent weight for each material.

TNT EQUIVALENT WEIGHT ANALYSIS

The equivalent weight of a particular energetic material is the weight of some assumed standard explosive (like TNT) required to produce a selected shockwave parameter of equal magnitude to that produced by a unit weight of the test material in question. A given material will have several equivalent weights, depending on the shockwave parameter selected; i.e., it will have
an equivalent weight based on pressure, impulse, etc. The equivalent weight for any given parameter may vary as a function of the distance from the charge. For many purposes, it is sufficient to cite a single number--averaged over some range of pressure or distance.

The basic tenets of similitude imply that comparisons be made between charges of the same shape, confinement, and geometry of interest. The results of such a comparison represent a true measure of the explosive performance.

Using the least squares curve fits shown in Figures 9-16, equivalent weights based on peak pressure and positive impulse have been calculated. The results are shown in Figures 17 and 18. Table 3 presents equivalent weights averaged over a pressure range of 2-100 kPa for each configuration.

YIELD ANALYSIS

Utilizing techniques developed and defined in the analysis of nuclear blast yields, an absolute yield in megacalories can be determined for any pressure-distance curve. These concepts have been refined and incorporated into Porzels Unified Theory of Explosions.[5] Although the technique was developed for spherical or hemispherical detonations, it has been successfully applied to cylindrical data as well.[3,6] These results are also shown in Table 3. Not surprisingly, they do not differ significantly from the results obtained from an equivalent weight analysis.

COMPARISON WITH OTHER DATA

In 1979, Reeves[7] conducted a series of complete round pallet tests of 155 mm ammunition. The complete round pallet under test contained 16 projectiles and 4 propelling charges, containing M1 propellant. The objective of his tests were to determine the contribution of the propelling charges to blast overpressures when the HE projectiles on the complete round pallet detonate en masse and to expand the data base that can be used to resolve similar problems analytically. All of his tests were conducted using M107 projectiles and M4A2 propelling charges (DODIC D 541). One, four, and eight pallet arrays were tested. The conclusion of these tests were that the propelling charges contribution to the blast overpressure can be equated to TNT, on an equal weight basis (100% equivalence), when assessing the storage hazards associated with the use of the pallet.

Propelling Charges (DODIC D533 and D541) were included in large quantities in the Maritime Prepositioning Ship (MPS) Test conducted in 1990[8]. Based on the airblast data obtained on this test, the estimated TNT equivalence of both of these items was no more than 50%. It must be remembered, however, that the detonation sources on these tests were not in intimate contact with the projectiles. They were, at best, in adjacent containers. Perhaps, this difference in the initiation mode can explain the apparent difference in the TNT equivalence.

SUMMARY

Based on the analysis of the airblast data presented above, it is evident that all of the propellants tested reacted quickly enough to contribute to the airblast. Further, based on the airblast, the reaction was indistinguishable from a detonation.

Generally, the average equivalent weights based on peak pressure and positive impulse were quite similar, with the largest difference being about 30%. For the configurations containing M1 and M6 propellant, the Mixed situations seemed to give higher equivalences--indicating that there may be an effect due to the size of the booster. In the Mixed mode, the initiation of the six primed projectiles causes the remainder of the projectiles to sympathetically detonate--effectively increasing the size of the booster. The reverse appears to be true for the M30A1 propellant--the Pure configuration gives the higher equivalent weight. Why this should be is not known at this time.

For purposes of hazard classification and entry of the information derived from these tests into the Joint Hazard Classification System, all three of the items tested: M1, M6, and M30A1 (all in the multi-perf grain configuration) should be considered to have a TNT equivalence of 100%.

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2. U.S. Army Explosives Safety Program, AR 385-64, 13 August 1993.

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6. Swisdak, M. M. and Rye, K. W., Hazard Division 1.2 Tests--Instrumentation Results and Interpretation, NSWCDD/TR-93/218, December 1993.

7. Reeves, H. J., Hazard Classification Tests of Complete Round 155 mm Pallets, ARBRL-MR-02924, May 1979.

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TABLE 1. TEST ITEM INFORMATION

SERIES	DODIC	ENERGETIC MATERIAL	ENERGETIC MATERIAL WEIGHT (pounds)	CONTAINER DESIGNATION	CONTAINER WEIGHT (pounds)
M4	D541	M1 propellant (multi-perf grain)	13.4	M13	30.5
M119	D533	M6 propellant (multi-perf grain)	20.5	PA37A1	70
M203	D532	M30A1 propellant (multi-perf grain)	28	PA103	20
M107	D544	Composition B explosive	15.4	none	75*

*Case Weight

TABLE 1. TEST ITEM INFORMATION

TABLE 2. TEST SEQUENCE AND ADDITIONAL INFORMATION

CONFIGURATION NUMBER	SHOT NUMBERS	ENERGETIC MATERIAL	NUMBER OF PROJECTILES	NUMBER OF PROPELLANT CANS	NEW (PROPELLANT) (pounds)	NEW (PROJECTILES) (pounds)	NEW (BOOSTER) (pounds)	TOTAL NEW (pounds)
4	1,3	M6, C4	0	114	2337.0	0.0	46.9	2383.9
10	2,4	M1, C4	0	138	1849.0	0.0	46.9	1895.9
6	5,7	M6, COMP B C4	56	58	1189.0	862.4	6.0	2057.4
12	6,8	M1, COMP B C4	68	70	938.0	1047.2	6.0	1991.2
4A	9,10	COMP B, C4	114	0	0.0	1755.6	6.0	1761.6
STANDARD	11,12	TNT, C4	0	0	1000*	0.0	13.4	1013.4
4B	13,15	M30A1, C4	0	106	2964.0	0.0	46.9	3010.9
6A	14,16	M30A1, COMP B C4	56	58	1508.0	862.4	6.0	2376.4

*TNT standard

TABLE 2. TEST SEQUENCE AND ADDITIONAL INFORMATION

TABLE 3. EQUIVALENT WEIGHT/YIELD SUMMARY

	PROPELLANT TYPE					
	M6		M1		M30A1	
	Pure	Mixed*	Pure	Mixed*	Pure	Mixed*
PRESSURE	0.70	0.93	0.82	1.31	1.81	1.06
IMPULSE	0.63	1.20	0.75	1.06	1.41	1.31
UTE-YIELD	0.73	1.11	0.85	1.63	2.01	1.50

(note: all values averaged over the pressure range of 2-100 kPa)

* with M107 155 mm projectiles

TABLE 3. EQUIVALENT WEIGHT/YIELD SUMMARY

FIGURE 1. CONTAINMENT STRUCTURE

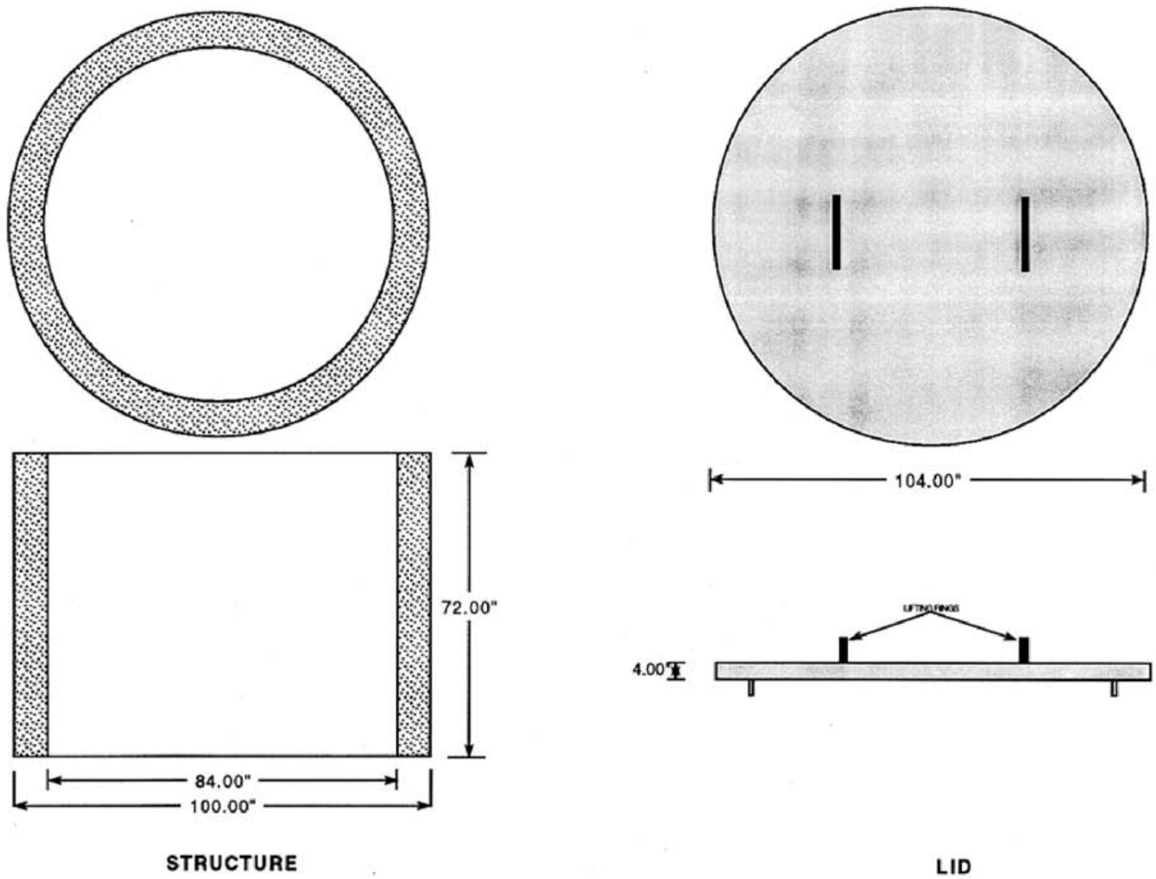

FIGURE 1.   CONTAINMENT STRUCTURE

FIGURE 2. EXPENDABLE CONTAINMENT STRUCTURE

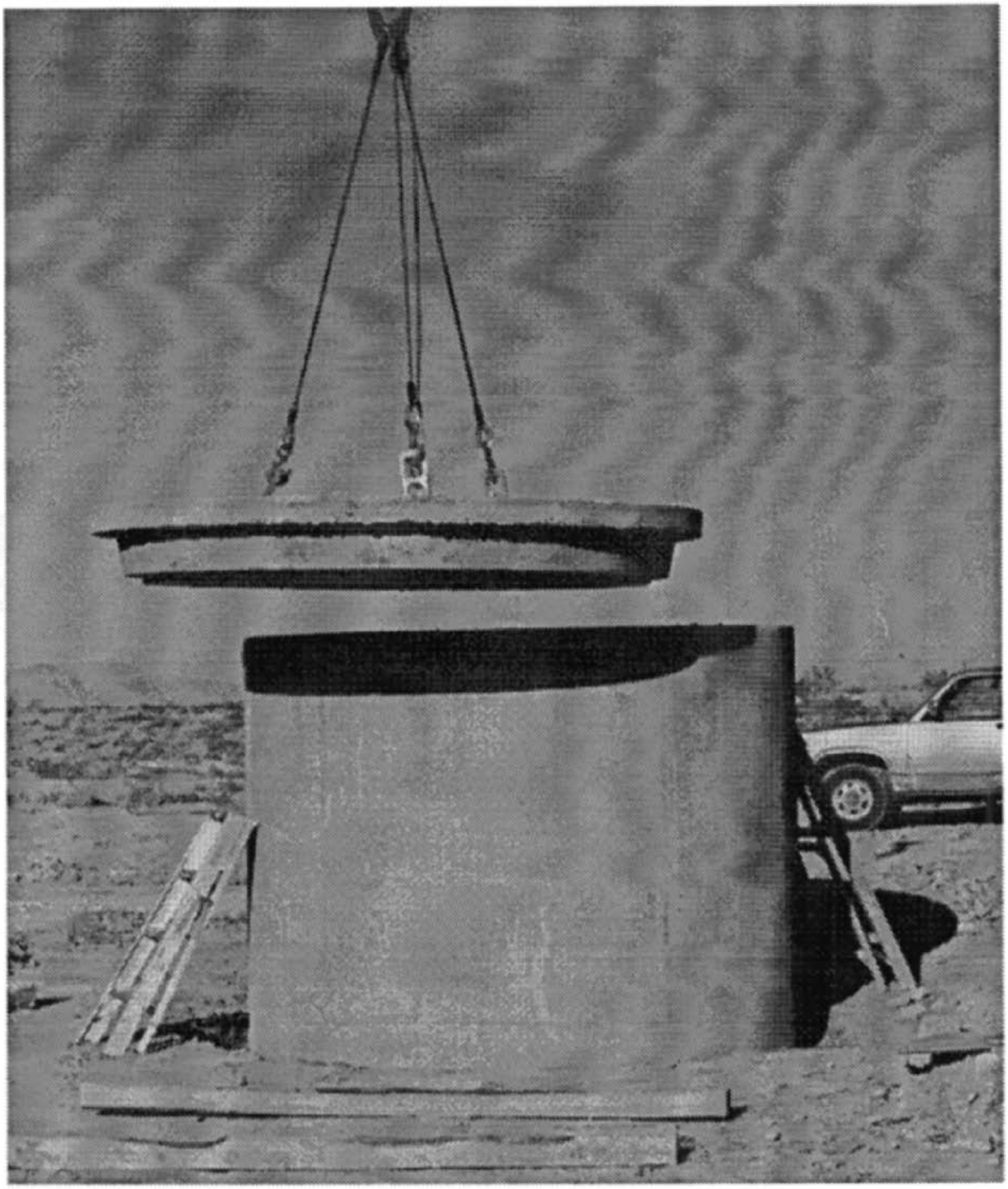

FIGURE 2. EXPENDABLE CONTAINMENT STRUCTURE

FIGURE 3. "PURE" CONFIGURATION

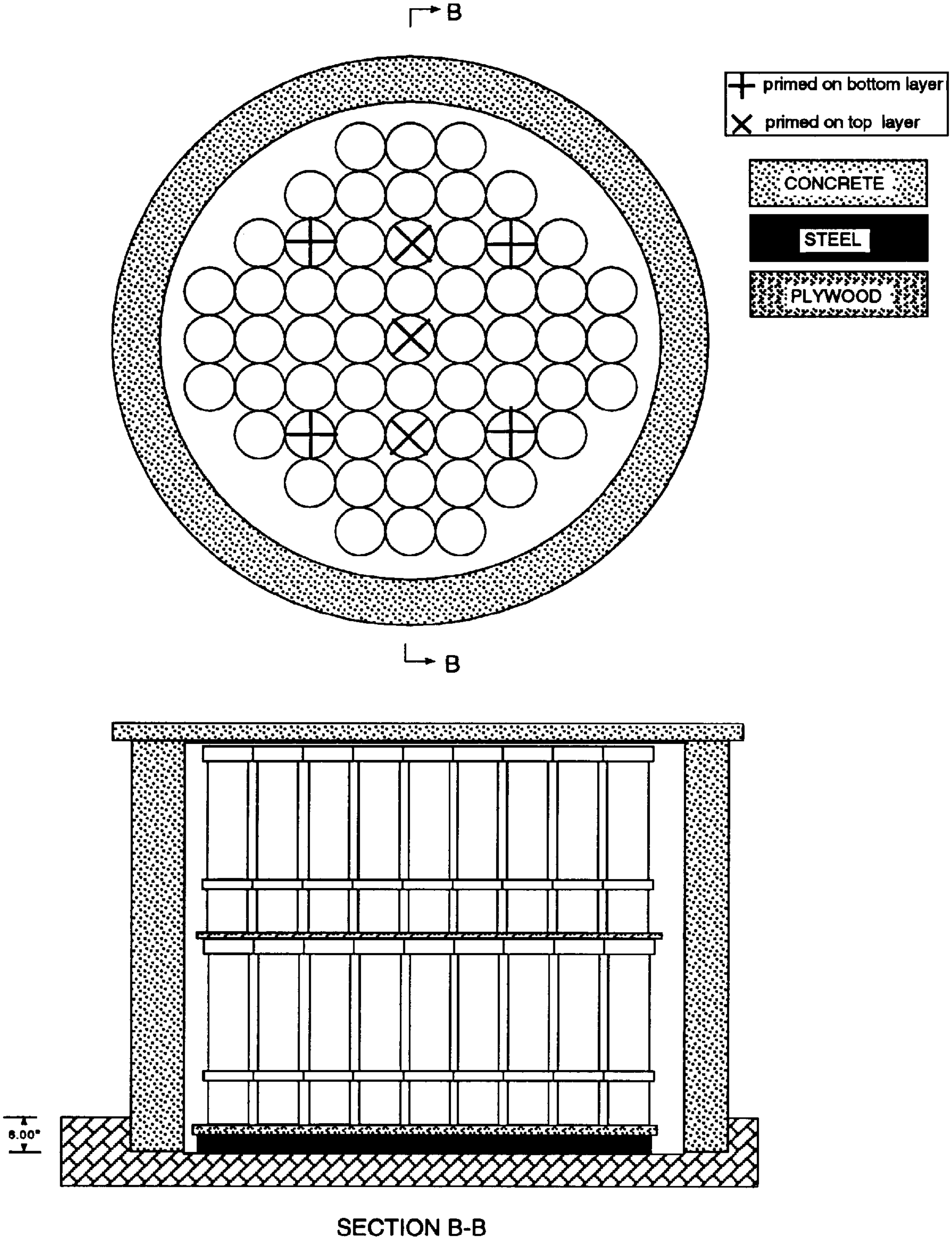

FIGURE 3. "PURE" CONFIGURATION

FIGURE 4. “MIXED” CONFIGURATION

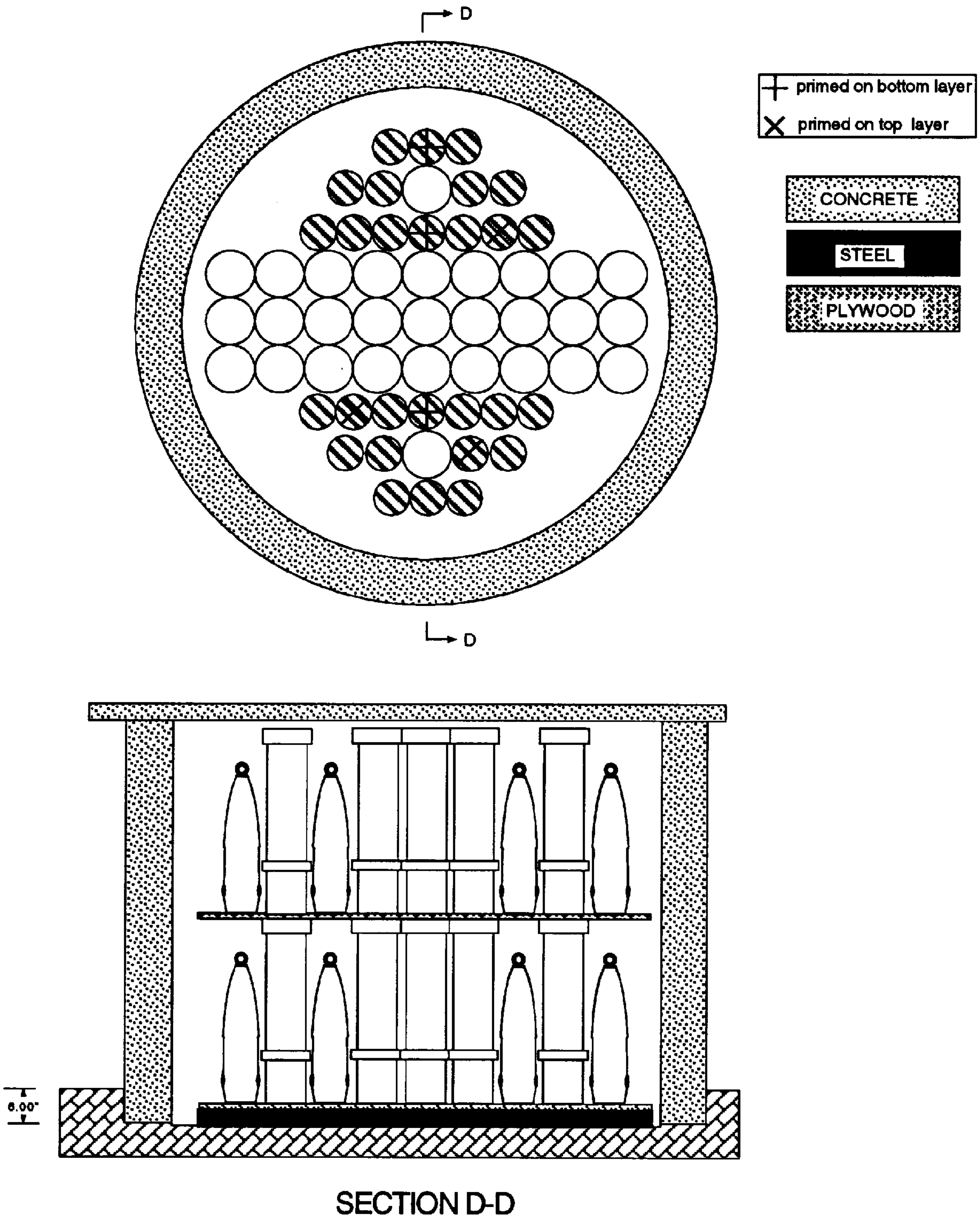

FIGURE 4. "MIXED" CONFIGURATION

FIGURE 5. COMPARISON STANDARD

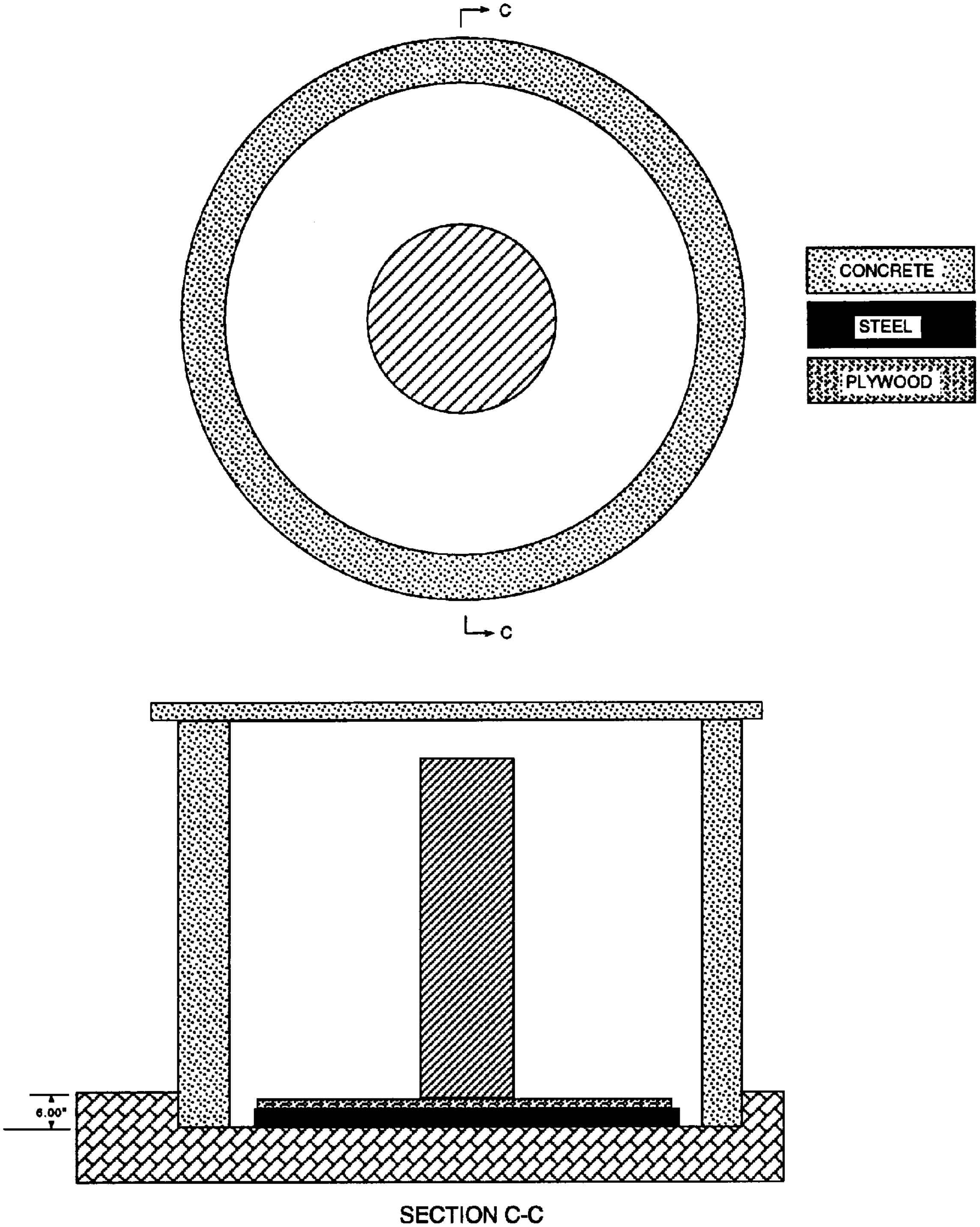

FIGURE 5. COMPARISON STANDARD

FIGURE 6. "PURE" PROPELLANT CONFIGURATION

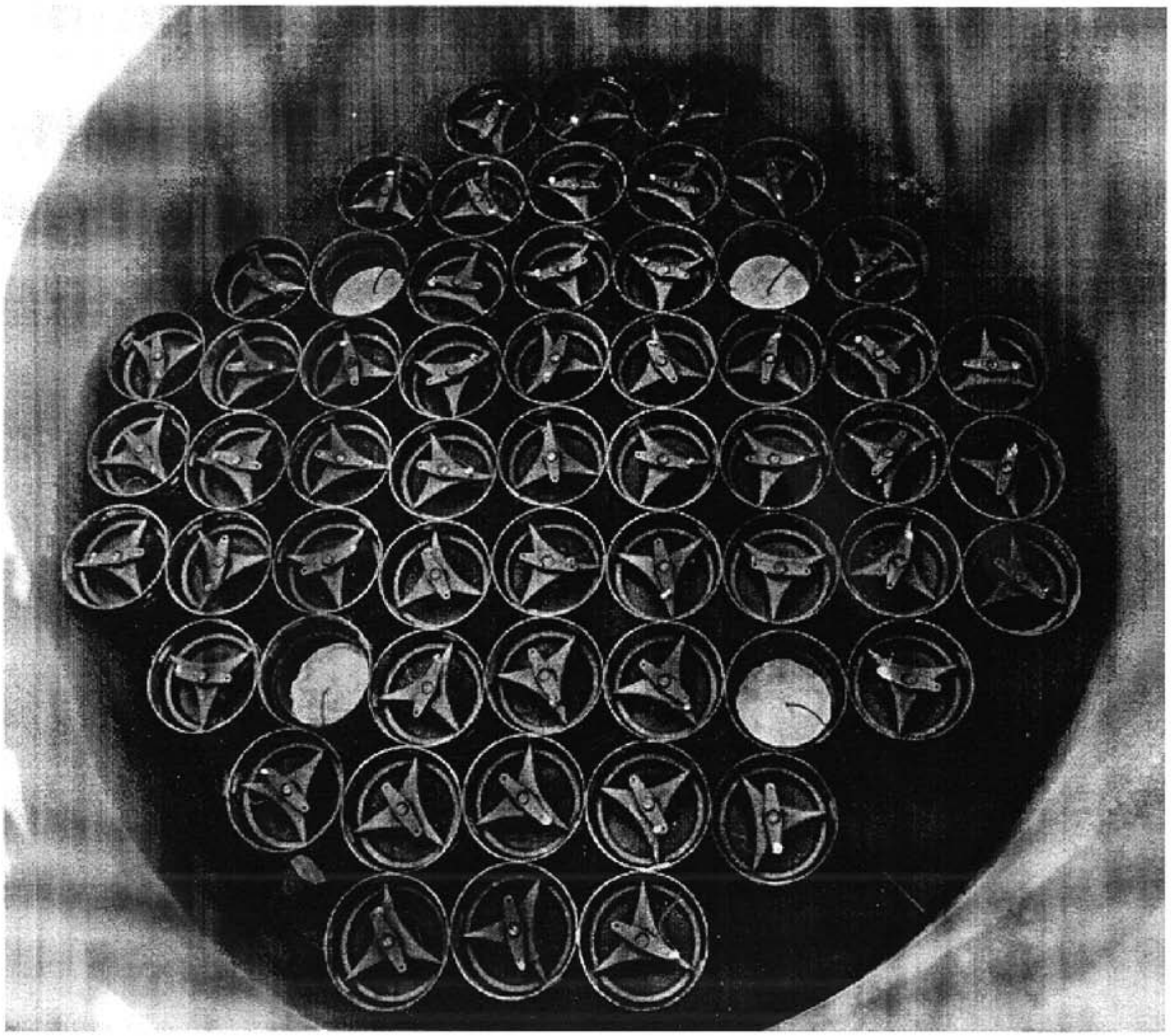

FIGURE 6. "PURE" PROPELLANT CONFIGURATION

FIGURE 7. "MIXED" PROPELLANT/PROJECTILE CONFIGURATION

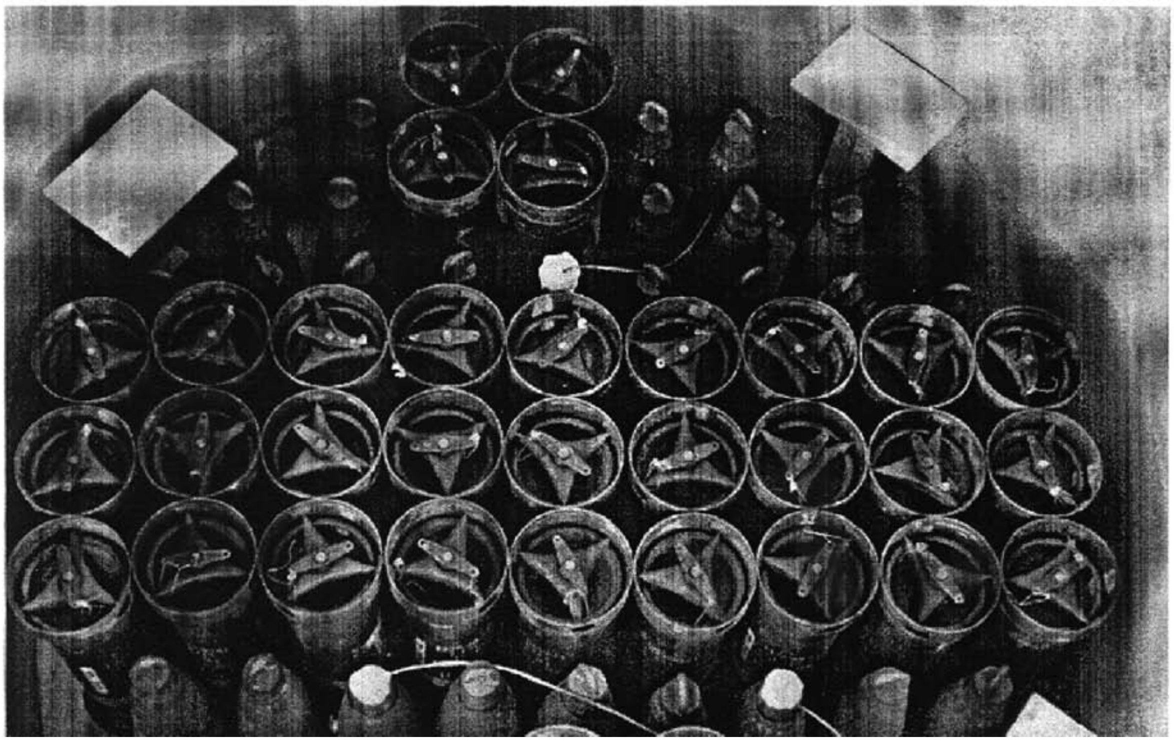

FIGURE 8. TNT STANDARD

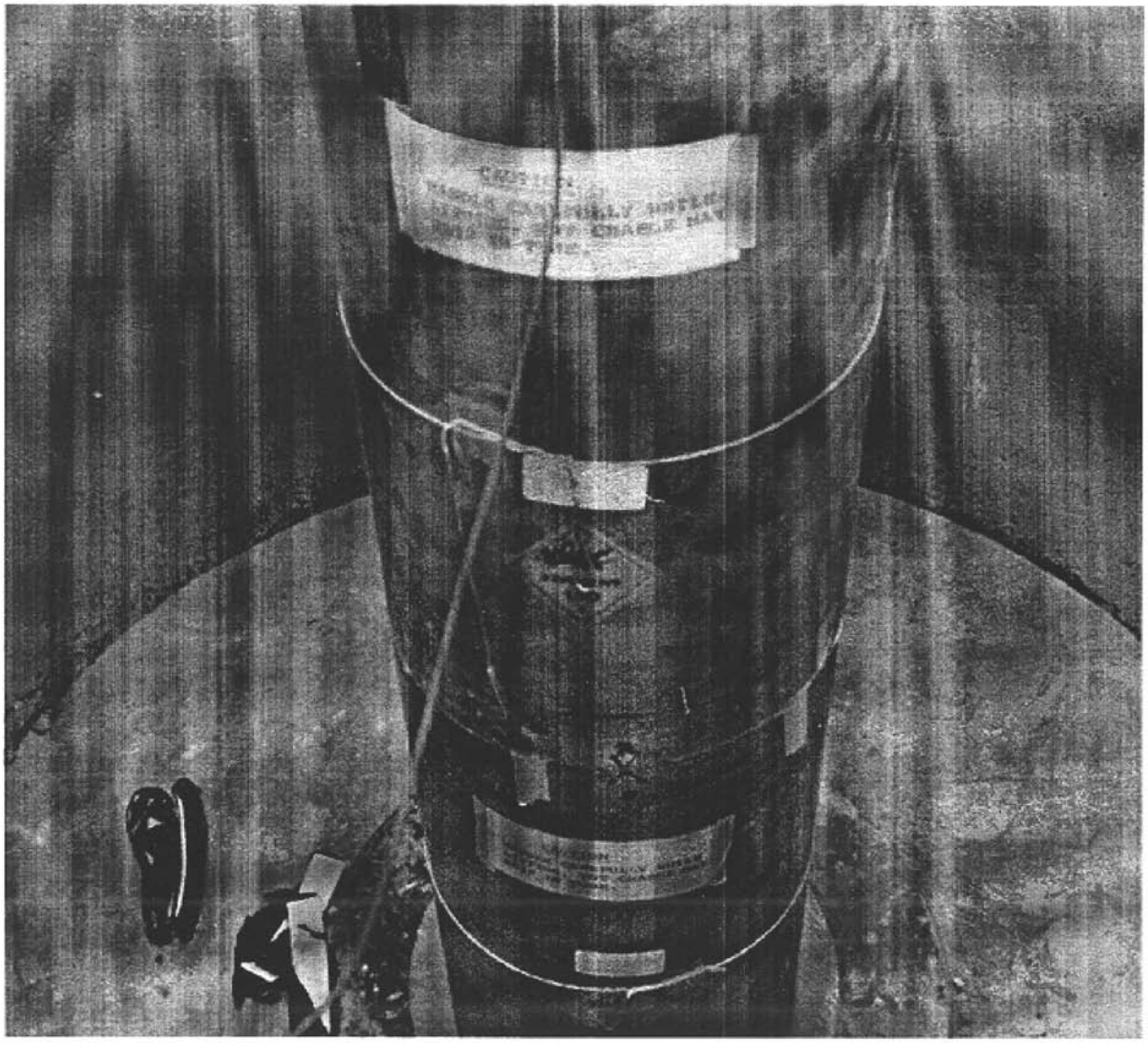

FIGURE 8. TNT STANDARD

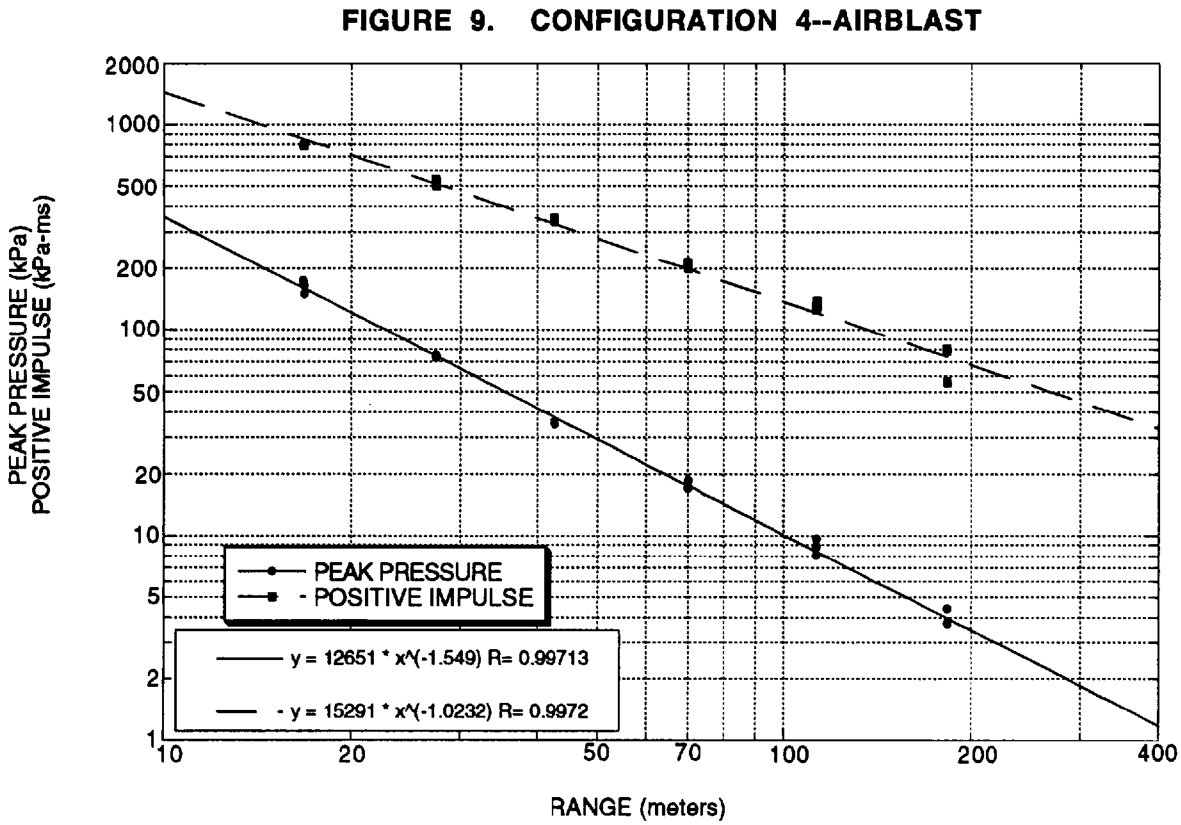

FIGURE 9. CONFIGURATION 4 - AIRBLAST

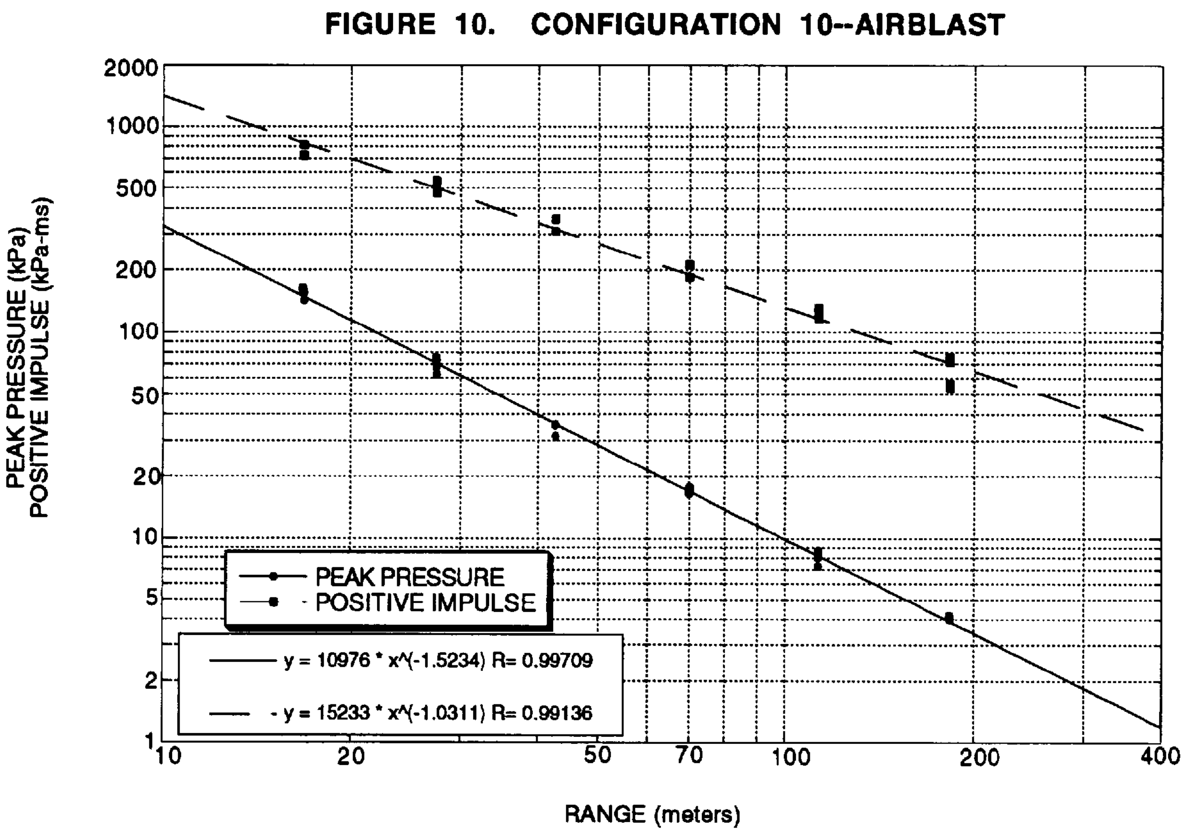

FIGURE 10. CONFIGURATION 10 - AIRBLAST

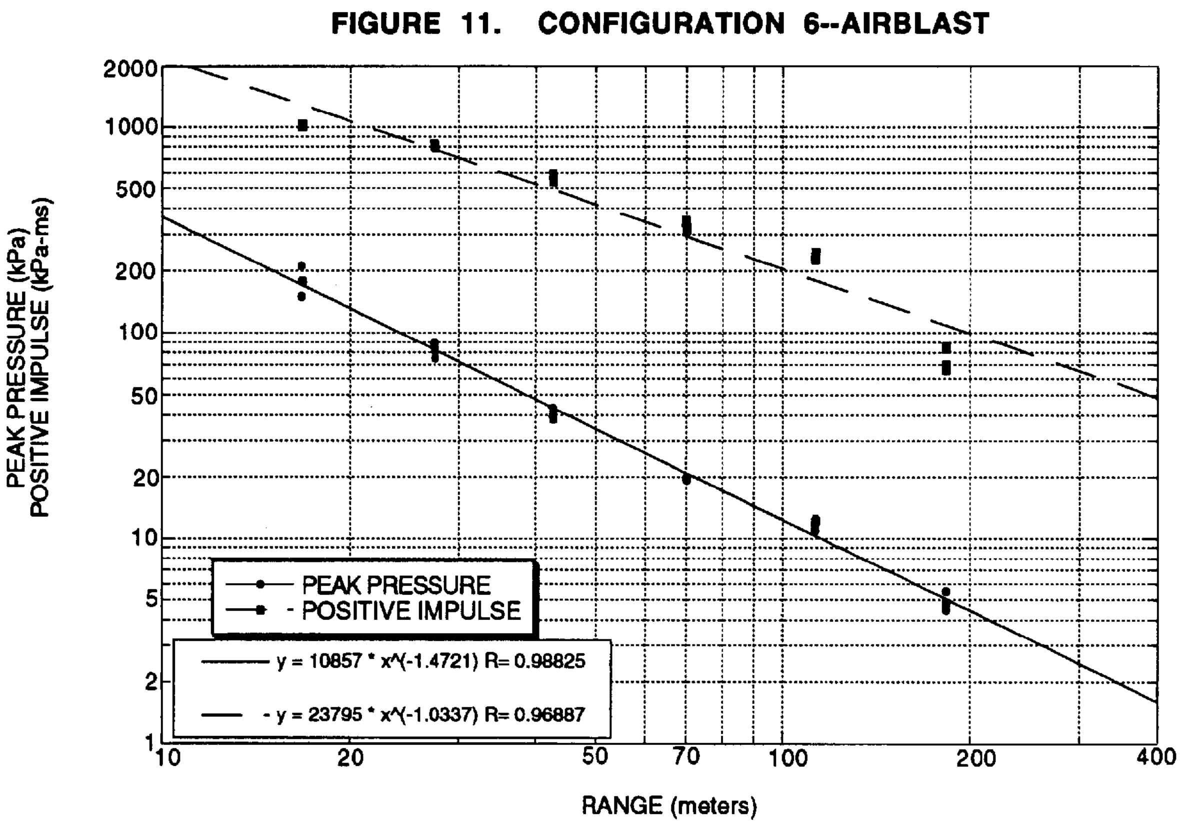

FIGURE 11. CONFIGURATION 6 - AIRBLAST

FIGURE 12. CONFIGURATION 12--AIRBLAST

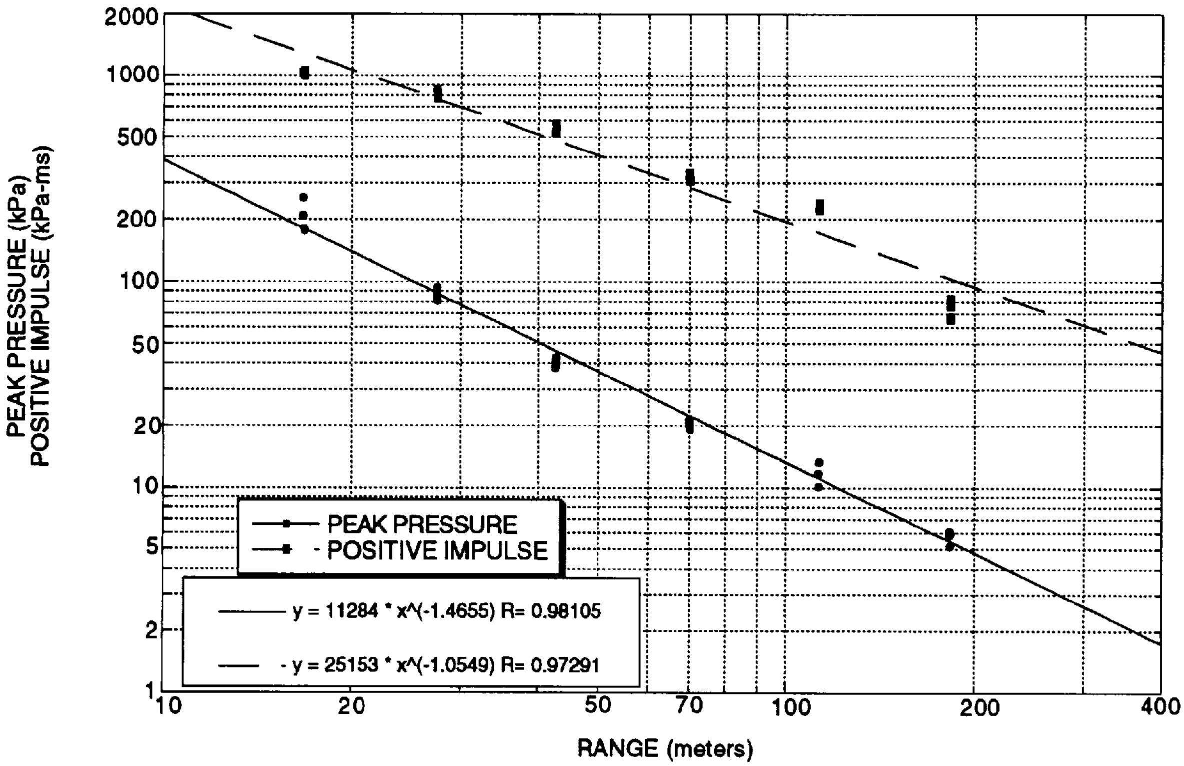

FIGURE 12. CONFIGURATION 12 - AIRBLAST

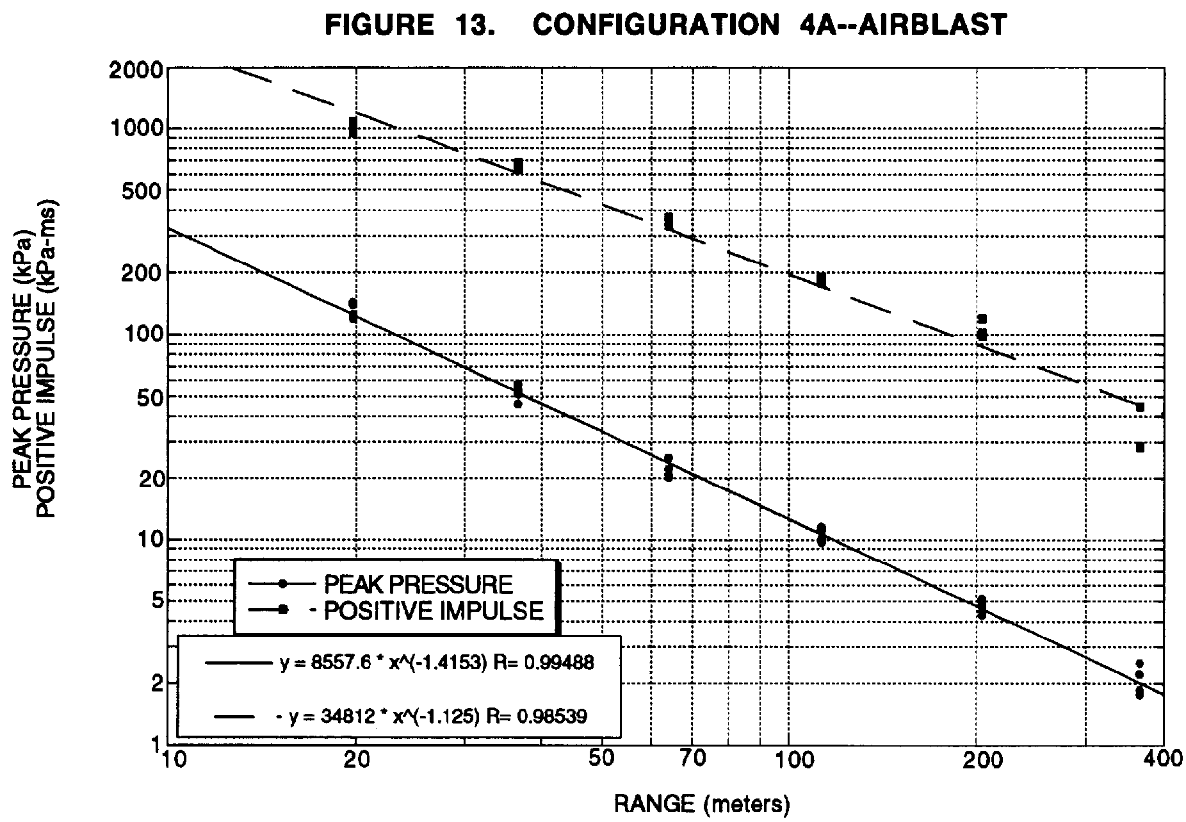

FIGURE 13. CONFIGURATION 4A - AIRBLAST

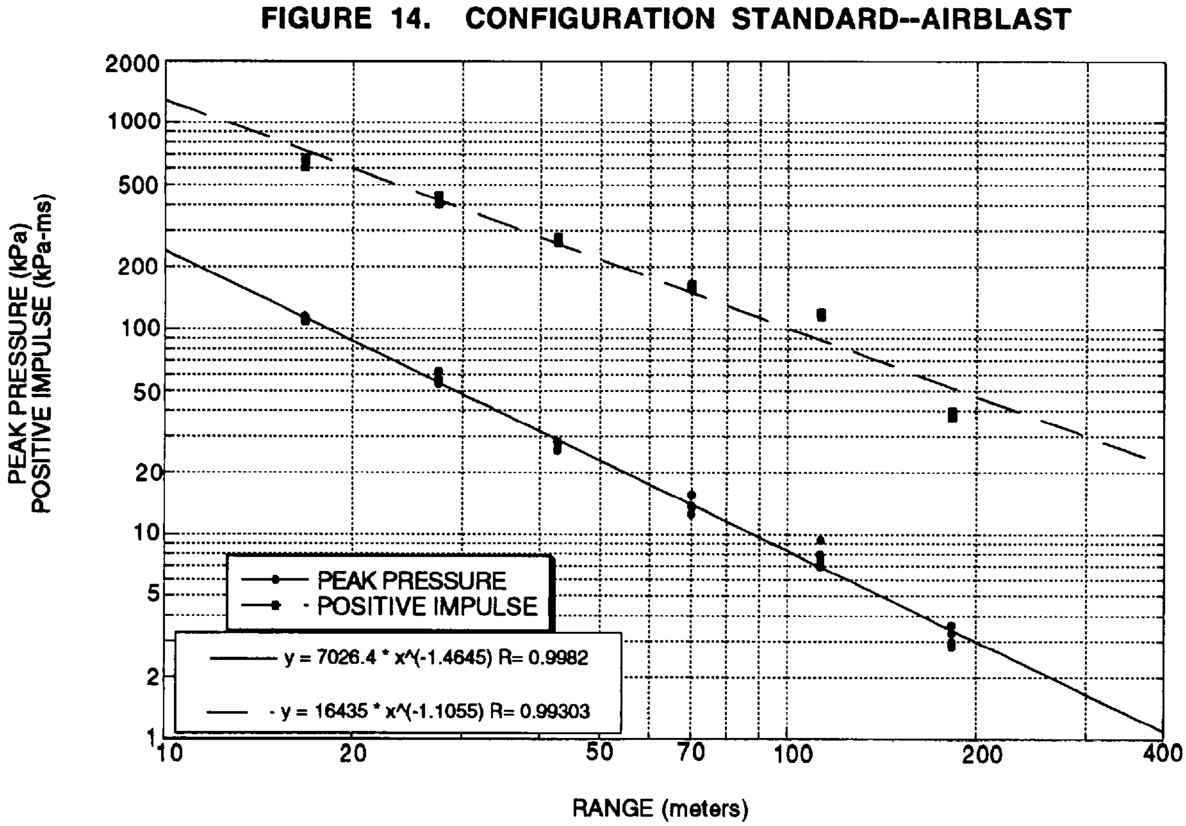

FIGURE 14. CONFIGURATION STANDARD - AIRBLAST

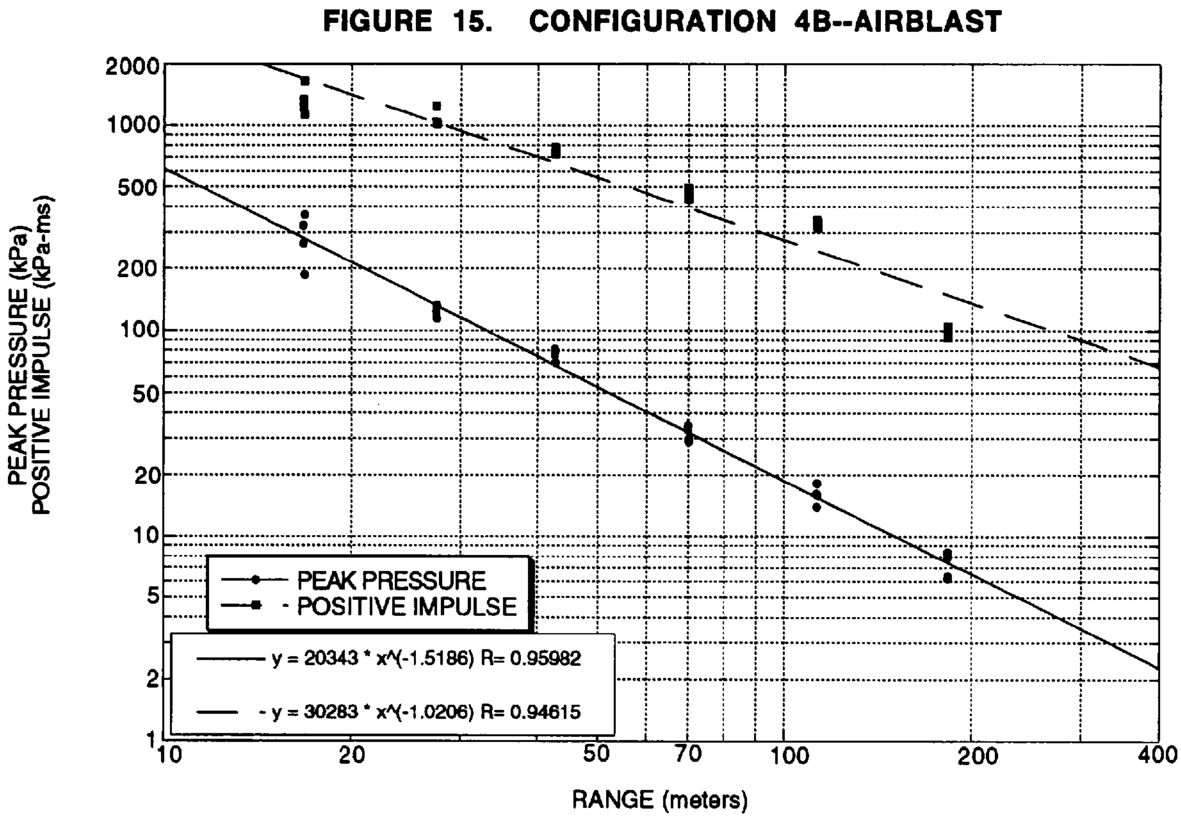

FIGURE 15. CONFIGURATION 4B - AIRBLAST

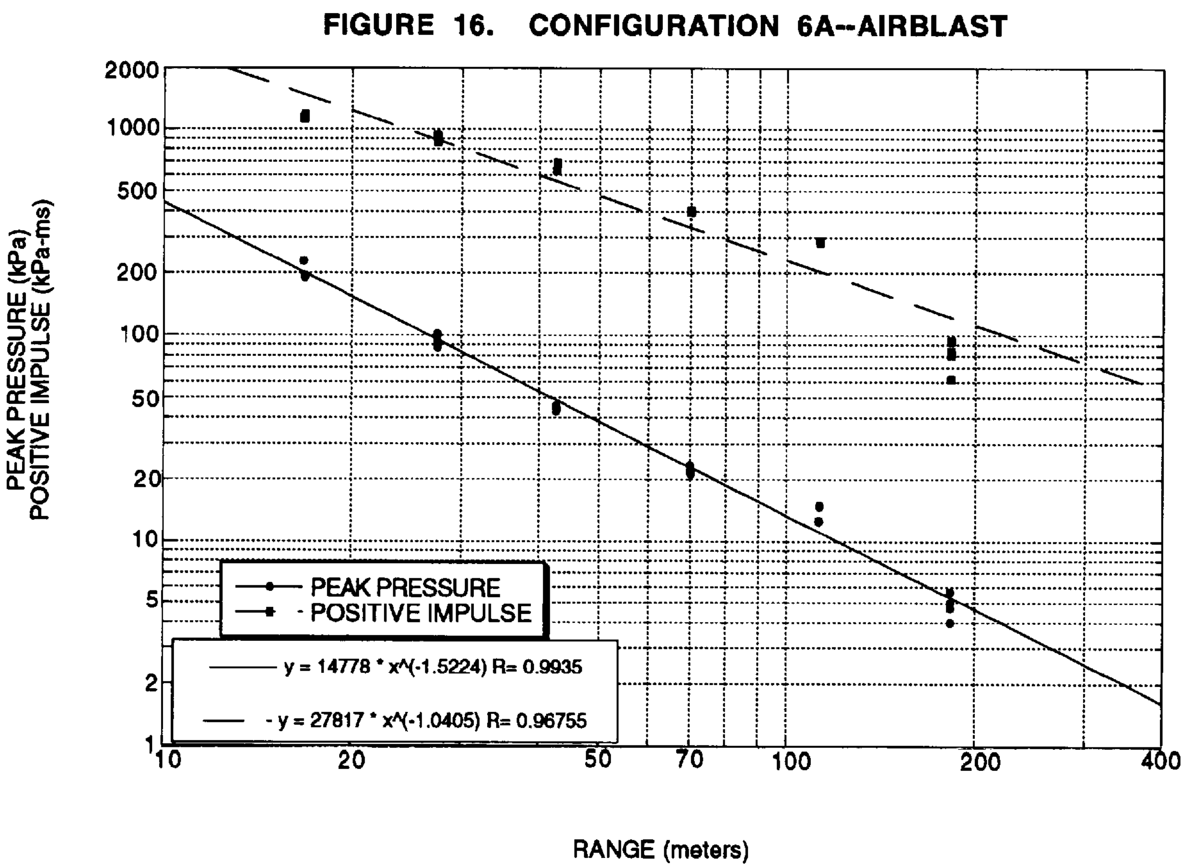

FIGURE 16. CONFIGURATION 6A - AIRBLAST

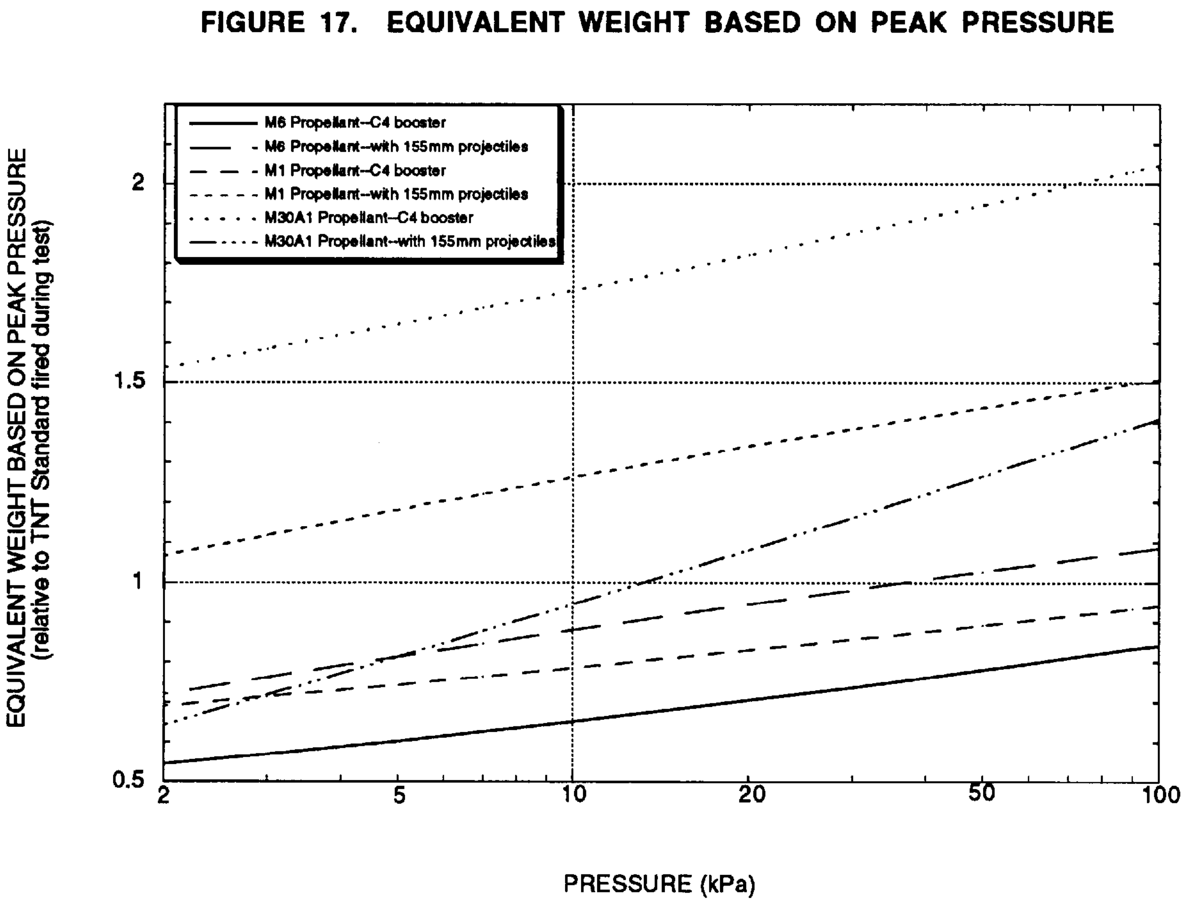

FIGURE 17. EQUIVALENT WEIGHT BASED ON PEAK PRESSURE

FIGURE 18. EQUIVALENT WEIGHT BASED ON POSITIVE IMPULSE

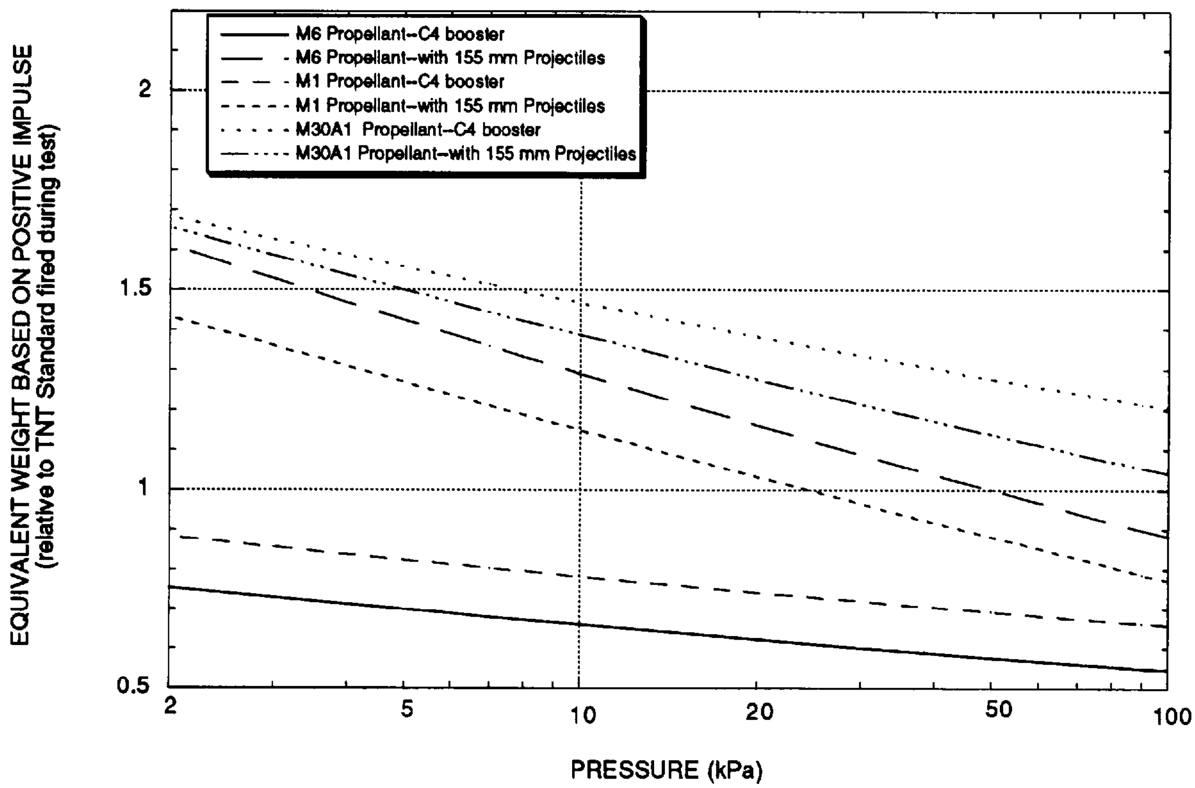

FIGURE 18. EQUIVALENT WEIGHT BASED ON POSITIVE IMPULSE