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DETERMINATION OF MINIMUM NON-PROPAGATION DISTANCE OF 8-INCH M106 HE PROJECTILES

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JUNE 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
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DOVER, NEW JERSEY

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DETERMINATION OF MINIMUM NON-PROPAGATION DISTANCE OF 8-INCH M106 HE PROJECTILES

William Stirrat

June 1979

The last sentence in the Abstract, DD Form 1473, Block 20, should be changed to read as follows:

> The test results indicated that the minimum non-propagation distance for 8-inch M106 HE projectiles is 0.30 meter (1 foot) provided that aluminum shielding rods 7.6 centimeters (3.0 inches) in diameter and the same height as the projectiles are positioned vertically, in a straight line, between adjacent projectiles.

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This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Minimum non-propagation distance
8-inch M106 HE Projectile
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of tests ~~were~~ (was) conducted to establish the minimum non-propagation distance between 8-inch M106 HE projectiles loaded with 16.7 kilograms (38.8 pounds) of Composition B. Each projectile was supported above the ground surface by low density concrete blocks. This effort was in direct support of the modernization of the Iowa Army Ammunition Plant, Burlington, Iowa, but it is applicable to other similar facilities. The test results indicated that the minimum non-propagation distance for 8-inch M106 HE projectiles is 0.30 meter (over)

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20. Abstract (continued)

(1 foot) provided that aluminum shielding rods 7.6 centimeters (30 inches) in diameter and the height of the projectiles are positioned vertically in a straight line between adjacent projectiles.

ACKNOWLEDGEMENTS

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SUMMARY

The safe separation distance testing of the 8-inch M106 HE Projectile loaded with 16.7 kilograms (38.8 pounds) of Compositon B was requested by the Project Manager for Munition Production Base Modernization and Expansion, specifically in support of the Iowa AAP. After a review of the Load-Assemble-Pack operations at Iowa AAP, it was determined that exploratory tests be conducted with projectiles positioned in a vertical base-up position configuration, supported above the ground surface by low density concrete blocks. A program to determine the minimum non-propagation safe separation distance was drafted by ARRADCOM and initiated at the Tooele Army Depot, Utah, and the final tests were implemented at the National Space Technology Laboratories (NSTL) Station, Mississippi. The tests performed under the auspices of this program simulated the actual (LAP) plant operational conditions.

The Test Program was conducted in three phases: an Exploratory Test Program divided into two phases, namely, (1) unshielded exploratory tests and (2) shielded exploratory tests and a third phase, Test Phase 3, Shielded Confirmatory Tests.

After the non-propagation safe separation distance of 4.30 meters (14.0 feet) determined in Test Phase 1 was found to be incompatible with normal belt conveyor speeds at the loading plants, a second phase, Test Phase 2, was conducted employing aluminum as well as steel shielding rods 7.60 centimeters (3.0 inches) in diameter positioned vertically in a straight line half way between the donor and acceptor projectiles. The shielding rods were welded to a base plate 44.12 centimeters (18.0 inches) by 1.27 centimeters (0.5 inch) thick. The configuration utilized in this phase of the test program was 76.2 centimeters (30.0 inches) above the ground surface to simulate the approximate height of the LAP conveyor system. With the adequate number of shielded exploratory tests conducted during Test Phase 2, the non-propagation safe separation distance of 0.30 meter (1.0 foot) with 7.60-centimeter (3.0-inch) diameter shielding rods were selected for the shielded confirmatory tests, Test Phase 3 of this Test Program.

A total of 25 shielded confirmatory tests were performed at a safe separation distance of 0.30 meter (1.0 foot), employing 7.60-centimeter (3.0-inch) diameter aluminum rods located half way between the donor and acceptor projectiles. There was no evidence of propagation of detonation to adjacent projectiles by a donor initiation nor fire propagation between donor and

acceptor units. These tests established an upper limit of 7.11 percent probability of propagation of an explosive incident at the 95 percent confidence level.

INTRODUCTION

Background

At the present time, an Army-wide modernization program is underway to upgrade existing and to develop new explosive manufacturing and Load-Assemble-Pack (LAP) facilities. This effort will enable the U.S. Army to achieve increased production cost effectiveness with improved safety as well as to be able to provide manufacturing facilities for new weaponry with existing facilities. As an integral part of this program, the Manufacturing Technology Division, Large Caliber Weapon Systems Laboratory, ARRADCOM, Dover, New Jersey, is engaged in the continuous development of safety criteria as an activity entitled "Safety Engineering in Support of Ammunition Plants" which includes safe separation distance studies of munition end-items as well as in-process explosive materials. These criteria will be utilized as part of the basis for the design of all explosive production installations due for modernization and will be available for reference purposes to privately owned and operated (POPO) plants engaged in ordinance manufacturing operations.

The activities covered in this report provide safety data to specifically support modernization activities in the 8-inch M106 HE projectile LAP areas at Iowa AAP, Burlington, Iowa; but it is also applicable to other similar LAP facilities. A test program was implemented to simulate the Iowa LAP facilities utilizing 8-inch M106 HE Projectiles.

Objective

The primary objective of this report was to determine experimentally the safe non-propagation separation distance between single 8-inch M106 HE Projectiles transported on a conveyor belt system between LAP operations.

The Test Program consisted of three phases. The first and second phases involved exploratory testing to determine through a series of trial and error tests the minimum non-propagative safe separation distance for 8-inch M106 HE Projectiles. A third sequential test phase, the confirmatory test phase, was implemented to establish statistical confidence in the test results.

Criteria

The testing was conducted in such a manner as to simulate as accurately as possible the actual plant conditions. The only acceptable criteria for determining the safe separation distance was the non-propagation of the donor unit to the acceptor units. Note that the safe separation distances were measured edge-to-edge, not centerline-to-centerline, between two adjacent projectiles.

TEST CONFIGURATION

General

Testing of the 8-inch M106 HE Projectile to determine the appropriate self non-propagating separation distance between donor and acceptor units was initiated in 1973 at Tooele Army Depot, Utah; however, the test program was not completed until July 1978 due to the low priority given to this study. The final tests were conducted by the ARRADCOM Resident Operations Office at the National Space Technology Laboratories (NSTL) Station, Mississippi.

This test program consisted of three distinct test phases: the exploratory test phase consisting of two test phases, namely, (1) unshielded exploratory testing and (2) shielded exploratory testing and (3) a shielded confirmatory test phase. These test phases were implemented in order to firmly establish the minimum safe non-propagative separation distance between 8-inch M106 HE Projectiles that would be compatible with existing LAP operations.

Test Specimen

The test specimen was the 8-inch M106 HE Projectile, unfuzed, with the lifting plug, spacer, supplementary charge and liner removed from the projectile's nose cavity (see Figure 1). The projectile was loaded with 16.7 kilograms (38.8 pounds) of Composition B. These test specimens, having a deep fuze cavity, consisted of a hollow steel forging with a boat-tail base, a streamlined ogive, and a gliding metal rotating band. A base cover was welded to the projectile base as an added protection against the entrance of hot gases from the propelling charge during ballistic firing. The projectiles were 79.83 centimeters (31.43 inches) in length, as tested, without either lifting plug or fuze, and had a maximum diameter at the rotating band of 21.03 centimeters (8.28 inches). The loaded projectile's overall weight varied from 86.80 to 92.70 kilograms (191.40 to 204.30 pounds).

Test Arrangements

Each test set-up utilized one donor specimen and two acceptor specimens contained in a simulated conveyor system arranged in a straight line. The center specimen served as the donor, while the two specimens at the extremities served as the acceptors. This arrangement produced two acceptor test results for each test donor detonated. The separation distance between donor and acceptor units varied from test to test, but always the same distance from donor to both acceptor units was maintained within any given test.

The exploratory test phase consisted of two test phases. First, an unshielded test array, with three projectiles arranged in the vertical nose-up position on a pine board in a straight line as shown in Figure 2. The projectiles were supported by low density concrete blocks approximately 76.20 centimeters (30 inches) above the existing terrain in order to simulate the LAP conveyor system. The distances, measured edge-to-edge on the projectile bodies, ranged from 1.83 to 4.27 meters (6 to 14 feet). The second test phase, utilizing a test array similar to the first, except that shielding rods were positioned vertically at the half way distance between donor and acceptors (see Figure 3). This was implemented to establish a safe separation non-propagating distance betweeen 8-inch M106 HE Projectiles which would be compatible with existing LAP facilities. The rods were solid metal bars, 76.20 centimeters (30 inches) in height, of varying diameters and constructed of either steel or aluminum. The shields used during the second test phase were welded to a base plate 44.12 centimeters (18 inches) wide by 1.27 centimeters (0.5 inch) thick. The donor, shield and acceptors were supported by low density concrete blocks approximately 76.20 centimers (30 inches) above the ground surface. The test distances, measured edge-to-edge on the projectile bodies, ranged from 0.15 to 1.83 meters (0.50 to 6.0 feet).

The confirmatory test phase (Phase 3) consisted of a series of 25 tests, utilizing the test array of the second sequential test phase of the exploratory investigations, where a 7.62-centimeter (3.0-inch) diameter aluminum rod was used as the shield positioned half way between the donor and acceptor units (see Figure 4).

Method of Initiation

The donor projectile (initiated sample) was primed with approximately 0.12 kilogram (4 ounces) of Composition C-4 explosive in the fuze well cavity and electrically initiated by an engineer's special J-2 blasting cap. This method of initiation insured that the donor projectile always detonated high order.

TEST RESULTS

General

As previously stated, the simulated detonation propagation tests on 8-inch M106 HE Projectiles filled with 16.70 kilograms (38.80 pounds) of Composition B were grouped into two phases. The results of exploratory tests are detailed below. Also described are the results of the confirmatory tests.

Results of Individual Test Phases

Unshielded Exploratory Tests (Phase 1)

Thirteen projectile exploratory tests were conducted at Tooele Army Depot, Utah, during the months of May and June 1973. The results of these tests are shown in Table 1. The separation distances used in the exploratory testing of this phase ranged from 0.61 meter (2.0 feet) to a maximum of 4.30 meters (14.0 feet) and a high order detonation occurred at the 1.85-meter (6.0-foot) point. At distances from 0.61 meter (2.0 feet) to 3.05 meters (10 feet), the acceptor projectiles were observed to have either excessive fragment damage and penetrations or were broken up by the donor blast detonation. Therefore, a spacing of 4.30 meters (14.0 feet) was selected as the minimum non-propagative safe separation distance for unshielded confirmatory testing.

Shielded Exploratory Tests (Phase 2)

The separation distances used in the exploratory testing of this program phase ranged from 0.15 meter (0.5 foot) to 1.85 meters (6.0 feet) with a total of 19 exploratory tests (Nos. 1 to 19 inclusive) being conducted prior to establishing a separation distance for the confirmatory tests. Propagation Tests Nos. 1 through 15 inclusive were conducted during the months of July and August 1973 at Tooele Army Depot, Utah. After a long delay, the propagation tests were resumed during the months of June and July 1978 at the National Space Technology Laboratories (NSTL) Station, Mississippi (Tests Nos. 16 to 19 inclusive). The test data is presented in its entirety in Table 2, Tests Nos. 1 to 19 inclusive. High and low order detonations occurred only at the 0.15-meter (0.50-foot) point. In all other cases, only minor fragment damage or projectile body cracking (Figures 5 and 6) was observed for 7.60-centimeter (3.0-inch) diameter aluminum shielding rods spaced at the half way separation distance; however, slightly more damage (projectile body breakup) was observed with the use of 7.60-centimeter (3.0-inch) steel shielding rods. Hence, a spacing of 0.30 meter (1.0 foot) with 7.60-centimeter (3.0-inch) diameter aluminum shielding rods was selected as the minimum non-propagation safe separation distance for the Third Phase of the Test Program, Shielded Confirmatory Tests (see Figure 7).

- Shielded Confirmatory Tests (Phase 3)

The final confirmatory tests were performed at a safe separation distance of 0.30 meter (1.0 foot) between the donor and acceptor projectiles. The test configuration employed consisted of aluminum shielding rods, 7.60 centimeters (3.0 inches) in diameter, the height of the projectiles, positioned vertically in a straight line half way between the donor and acceptor projectiles. A total of 25 tests were conducted (Tests Nos. 20 through 44) with no propagation of the donor detonation to the acceptor projectiles (see Table 3). Also there was no evidence of acceptor projectile composition burning in any of the confirmatory tests conducted.

Summary of Test Results

Phase 1 of the initial exploratory test phases utilized a configuration of unshielded projectiles positioned vertically in a straight line which established a safe separation distance of 4.30 meters (14.0 feet). However, this phase of the Test Program was discontinued because the selected safe separation distance was found to be incompatible with normal belt conveyor speeds at the Iowa AAP (LAP) facilities and other similar loading plants.

The second exploratory test phase, Phase 2, utilized 7.60-centimeter (3.0-inch) diameter aluminum bars (Tests No. 1 through 5 and 16 through 19) and 7.60-centimeter (3.0-inch) diameter steel bars (Tests Nos. 5 through 15) as shields positioned vertically in a straight line half way between the donor and acceptor projectiles (see Table 2). In the initial steel versus aluminum shield tests, there was a definite trend of producing greater projectile damage with the steel shielding bars than with the aluminum. Evidently, the steel transmitted the blast impact effects, while the softer aluminum tended to absorb them (see Figures 8 and 9). Hence, a safe separation distance of 0.30 meter (1.0 foot) with a 7.60-centimeter (3.0-inch) diameter aluminum shielding rod was selected for the confirmatory tests, Phase 3, of the Test Program. The confirmatory test results clearly showed that no propagation of detonations occurred at the established safe separation distance. The established safe separation distance for the test configuration of Test Phase 3, utilizing aluminum shielding rods, was 0.30 meter (1.0 foot).

Analysis of Test Results

Variations in manufacturing tolerances, materials, wear, etc., require that statistical reasoning be enlisted in the interpretation of the test data. The actual probability of the propagation of an explosive incident is a function of the number of propagation occurrences in a particular test phase as related to the total number of tests conducted (see Appendix for statistical theory).

In Test Phase 3, the shielded confirmatory test phase of this study, there was a total of 50 observations recorded at the 0.30-meter (1-foot) safe separation distance resulting in an upper limit of 7.11 percent probability of propagation of an explosive incident at the 95 percent confidence level.

These values are equivalent to stating that in a large number of tests, 95 out of a 100 times, the probability of an explosive event will be less than, or equal to, the stated values. These values indicate the quality of the tests and the reliance that can be placed upon the conclusions drawn from the testing (see Figure 10).

CONCLUSIONS

It may be concluded from the test results of Test Phase 3, shielded confirmatory testing with aluminum shielding rods 7.60 centimeters (3.0 inches) in diameter and positioned vertically in a straight line half way between the donor and acceptor projectiles on a conveyor system at existing loading plants, that if a separation distance of 0.30 meter (1.0 foot) is maintained between 8-inch M106 HE Projectiles, the probability of a detonation of the adjacent acceptor projectile by a donor initiation is 7.11 percent at the 95 percent confidence level. This conclusion is based upon a statistical population of 50 acceptor projectiles at a 0.30-meter (1.0-foot) safe separation distance (see Table 3, Test Nos. 20 through 44). None of the projectiles burned at the established minimum non-propagation safe separation distance.

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Table 1

8-inch M106 HE Projectile unshielded exploratory tests (Phase 1)

Test No.	Acceptor Distance Meters	(Feet)	Results
1 L	0.61	(2.0)	*NDP, broken projectile
R	0.61	(2.0)	NDP, broken projectile
2 L	0.91	(3.0)	NDP, broken projectile
R	0.91	(3.0)	NDP, broken projectile
3 L	0.91	(3.0)	NDP, broken projectile
R	0.91	(3.0)	NDP, broken projectile, composition burning
4 L	1.22	(4.0)	NDP, broken projectile
R	1.22	(4.0)	NDP, broken projectile
5 L	1.22	(4.0)	NDP, broken projectile, composition burning
R	1.22	(4.0)	NDP, broken projectile
6 L	1.56	(5.0)	NDP
R	1.56	(5.0)	NDP
7 L	1.56	(5.0)	NDP, broken projectile
R	1.56	(5.0)	NDP, broken projectile
8 L	1.85	(6.0)	NDP
R	1.85	(6.0)	NDP
9 L	1.85	(6.0)	NDP, cracked projectile, composition burning
R	1.85	(6.0)	NDP
10 L	1.85	(6.0)	NDP, cracked projectile
R	1.85	(6.0)	**HOD

* NDP - No Detonation Propagation
** HOD - High Order Detonation

Table 1

8-inch M106 HE Projectile unshielded exploratory tests (Phase 1) (concluded)

Test No.	Acceptor Distance Meters	(Feet)	Results
11 L	2.45	(8.0)	*NDP, broken projectile
R	2.45	(8.0)	NDP, excessive fragment damage
12 L	3.05	(10.0)	NDP, excessive fragment damage
R	3.05	(10.0)	NDP, cracked projectile
13 L	4.30	(14.0)	NDP
R	4.30	(14.0)	NDP

* NDP - No Detonation Propagation

Table 2

8-inch M106 HE Projectile shielded exploratory tests (Phase 2)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
1 L	0.61	(2.0)	Alum	7.6	(3.0)	*NDP	-	-	-
R	0.61	(2.0)	Alum	7.6	(3.0)	NDP, cracked body	-	-	-
2 L	0.61	(2.0)	Alum	7.6	(3.0)	NDP	-	-	-
R	0.61	(2.0)	Alum	7.6	(3.0)	NDP	-	-	-
3 L	0.61	(2.0)	Alum	7.6	(3.0)	NDP, cracked body	-	-	-
R	0.61	(2.0)	Alum	7.6	(3.0)	NDP	-	-	-
4 L	0.82	(2.7)	Alum	7.6	(3.0)	NDP	-	-	-
R	0.82	(2.7)	Alum	7.6	(3.0)	NDP	-	-	-
5 L	0.82	(2.7)	Alum	7.6	(3.0)	NDP	-	-	-
R	0.82	(2.7)	Alum	7.6	(3.0)	NDP	-	-	-
6 L	0.61	(2.0)	Steel	7.6	(3.0)	NDP	-	-	-
R	0.61	(2.0)	Steel	7.6	(3.0)	NDP	-	-	-
7 L	0.61	(2.0)	Steel	7.6	(3.0)	NDP	-	-	-
R	0.61	(2.0)	Steel	7.6	(3.0)	NDP, cracked body	-	-	-

* NDP - No Detonation Propagation

Table 2

8-inch M106 HE Projectile shielded exploratory tests (Phase 2)
(continued)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
8 L	0.61	(2.0)	Steel	7.6	(3.0)	*NDP, cracked body	-	-	-
R	0.61	(2.0)	Steel	7.6	(3.0)	NDP	-	-	-
9 L	0.82	(2.7)	Steel	7.6	(3.0)	NDP	-	-	-
R	0.82	(2.7)	Steel	7.6	(3.0)	NDP	-	-	-
10 L	0.82	(2.7)	Steel	7.6	(3.0)	NDP	-	-	-
R	0.82	(2.7)	Steel	7.6	(3.0)	NDP	-	-	-
11 L	0.61	(2.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
R	0.61	(2.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
12 L	0.91	(3.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
R	0.91	(3.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
13 L	1.22	(4.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
R	1.22	(4.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-
14 L	1.56	(5.0)	Steel	7.6	(3.0)	NDP	-	-	-
R	1.56	(5.0)	Steel	7.6	(3.0)	NDP, broken projectile	-	-	-

* NDP - No Detonation Propagation

Table 2

8-inch M106 HE Projectile shielded exploratory tests (Phase 2)
(concluded)

Test No.		Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
15	L	1.85	(6.0)	Steel	7.6	(3.0)	*NDP,	-	-	-
	R	1.85	(6.0)	Steel	7.6	(3.0)	NDP, cracked projectile	-	-	-
16	L	1.22	(4.0)	Alum	7.6	(3.0)	NDP	0	6.4	(21)
	R	0.61	(2.0)	Alum	7.6	(3.0)	NDP	0	27.0	(87)
17	L	0.61	(2.0)	Alum	7.6	(3.0)	NDP	0	24.0	(78)
	R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	25.5	(84)
18	L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	121.0	(396)
	R	0.15	(0.5)	Alum	7.6	(3.0)	**HOD	-	-	-
19	L	0.23	(0.8)	Alum	7.6	(3.0)	NDP	0	87.5	(285)
	R	0.15	(0.5)	Alum	7.6	(3.0)	***LOD	-	-	-

* NDP - No Detonation Propagation
** HOD - High Order Detonation
*** LOD - Low Order Detonation

Table 3

8-inch M106 HE Projectile shielded confirmatory tests (Phase 3)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
20 L	0.30	(1.0)	Alum	7.6	(3.0)	*NDP	0	42.5	(137)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	25.5	(84)
21 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	34.5	(112)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	35.5	(115)
22 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	29.5	(96)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	25.0	(81)
23 L	0.30	(1.7)	Alum	7.6	(3.0)	NDP	0	55.0	(180)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	38.7	(126)
24 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	44.5	(144)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	29.5	(96)
25 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	39.5	(129)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	49.5	(162)
26 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	42.5	(139)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	23.0	(75)

* NDP - No Detonation Propagation

Table 3

8-inch M106 Projectile shielded confirmatory tests (Phase 3)
(continued)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
27 L	0.30	(1.0)	Alum	7.6	(3.0)	*NDP	0	38.7	(126)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	61.0	(195)
28 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	41.0	(132)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	39.5	(129)
29 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	43.0	(141)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	58.0	(189)
30 L	0.30	(1.7)	Alum	7.6	(3.0)	NDP	0	45.5	(147)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	22.0	(78)
31 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	33.5	(108)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	27.5	(90)
32 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	35.0	(114)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	22.5	(72)
33 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	44.5	(144)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	10.2	(33)

* NDP - No Detonation Propagation

Table 3

8-inch M106 HE Projectile shielded confirmatory tests (Phase 3)
(continued)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
34 L	0.30	(1.0)	Alum	7.6	(3.0)	*NDP	0	39.5	(129)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	50.5	(162)
35 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	63.0	(201)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	35.0	(114)
36 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	32.5	(105)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	45.0	(147)
37 L	0.30	(1.7)	Alum	7.6	(3.0)	NDP	0	34.5	(111)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	11.3	(36)
38 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	46.0	(150)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	37.0	(120)
39 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	24.5	(80)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	57.0	(182)
40 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	68.0	(210)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	38.5	(123)

* NDP - No Detonation Propagation

Table 3

8-inch M106 HE Projectile shielded confirmatory tests (Phase 3)
(concluded)

Test No.	Acceptor Distance Meters	(Feet)	Shielding Rod Mat'l	Cm	(In)	Results	% Burn Comp	Acceptor Distance Thrown Meters	(Feet)
41 L	0.30	(1.0)	Alum	7.6	(3.0)	*NDP	0	32.5	(105)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	84.0	(237)
42 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	82.5	(234)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	57.5	(186)
43 L	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	31.5	(101)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	63.0	(201)
44 L	0.30	(1.7)	Alum	7.6	(3.0)	NDP	0	34.5	(111)
R	0.30	(1.0)	Alum	7.6	(3.0)	NDP	0	43.5	(141)

* NDP - No Detonation Propagation

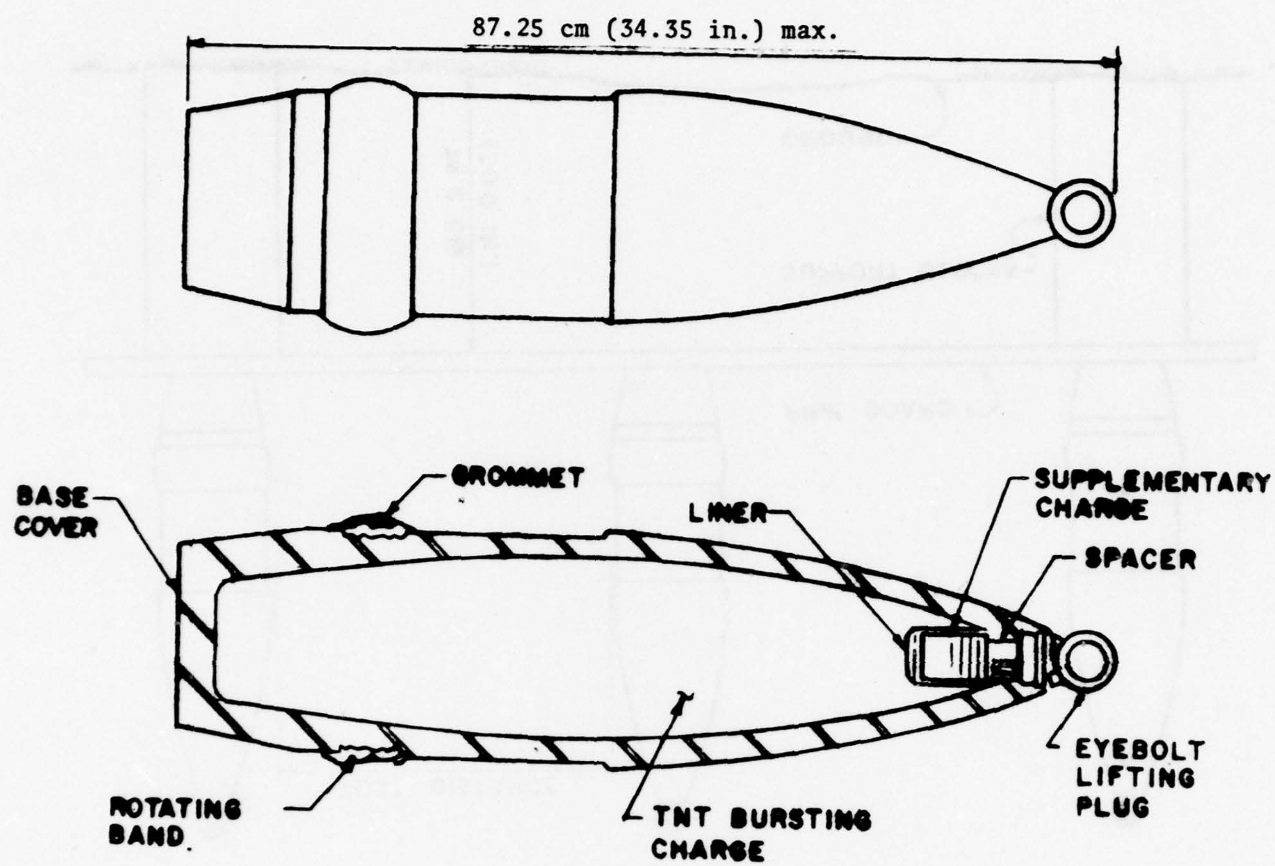

Fig 1 8-inch M106 HE Projectile

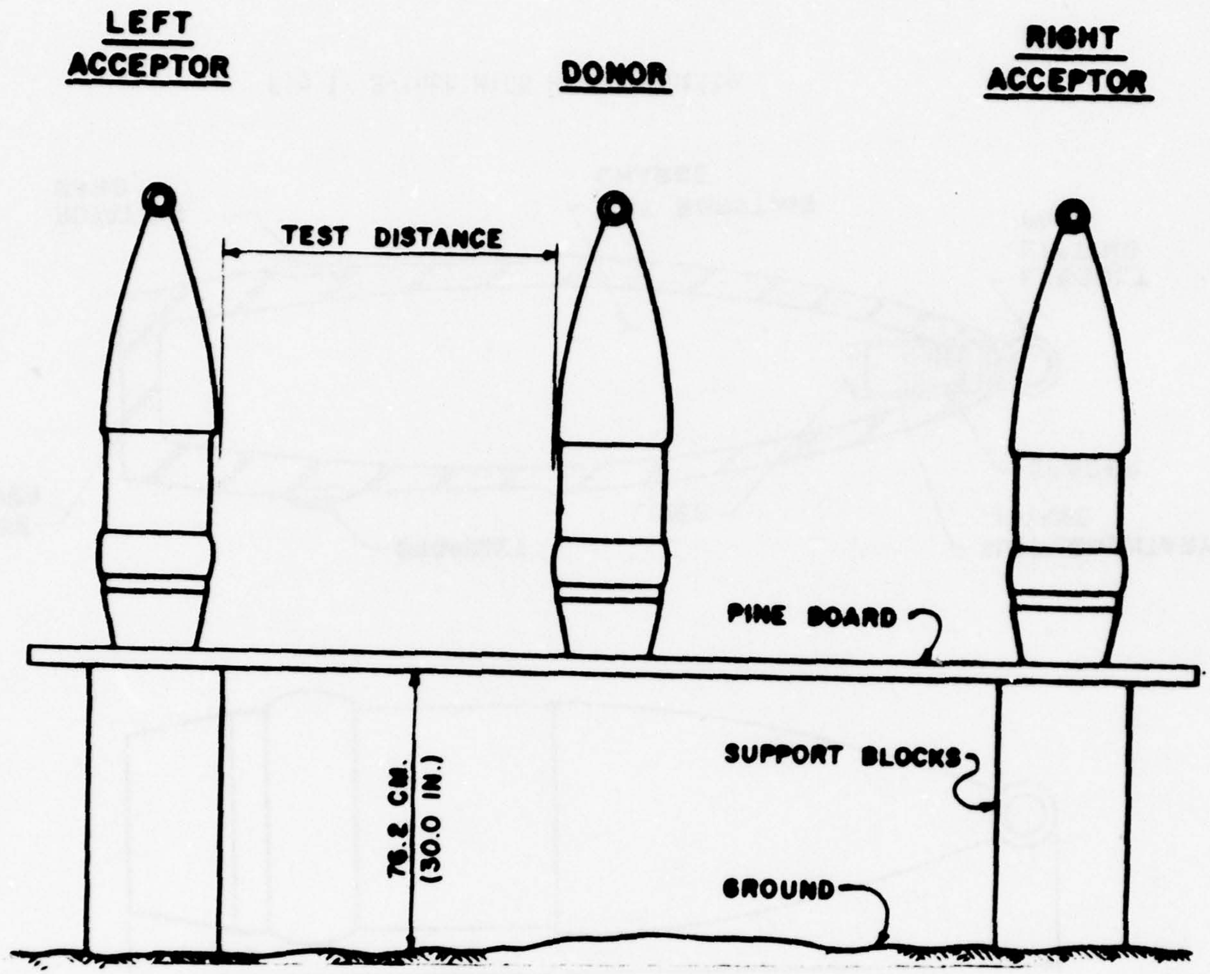

Fig 2 8-inch M106 HE Projectile (unshielded test array)

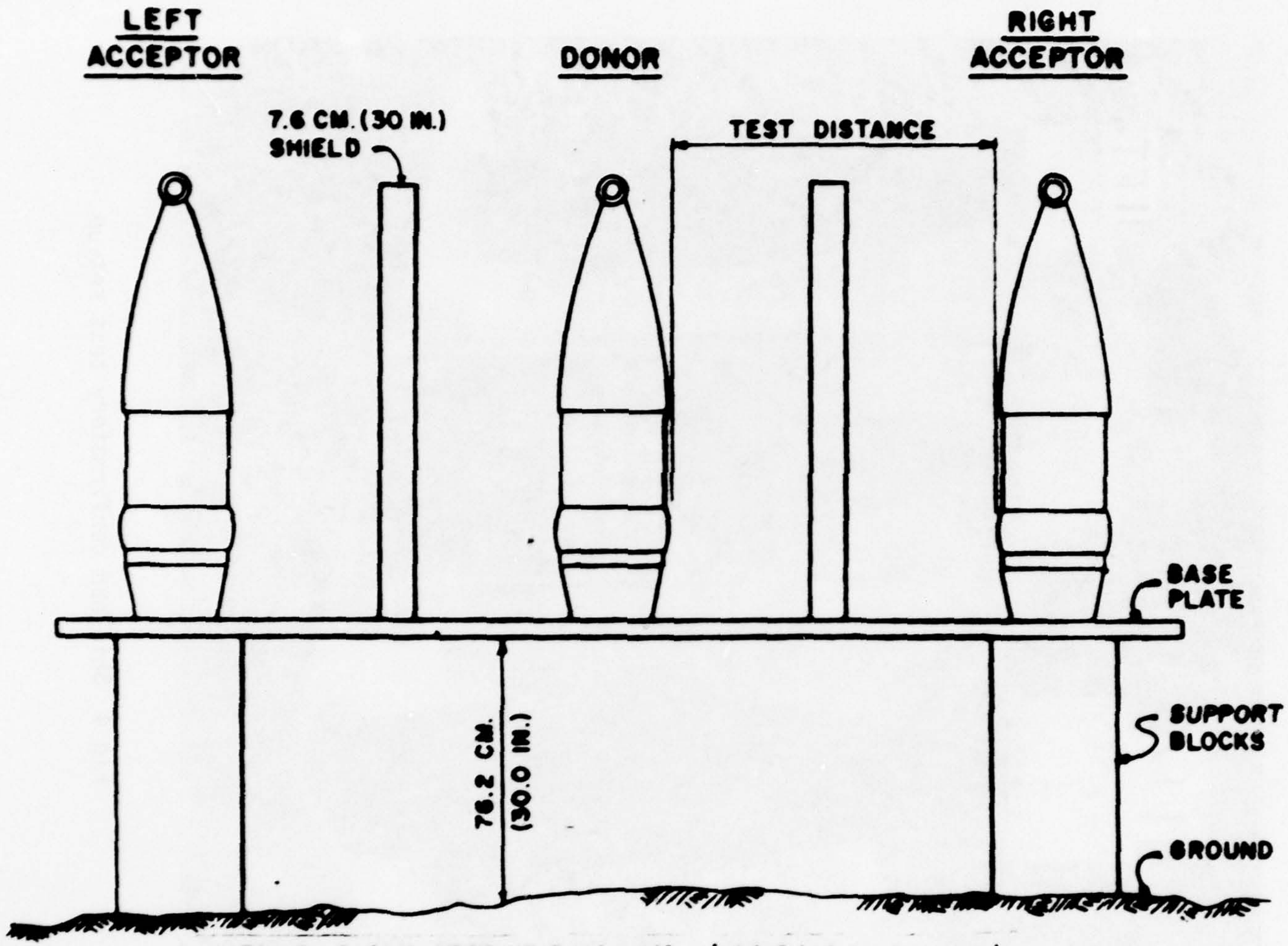

Fig 3 8-inch M106 HE Projectile (shielded test array)

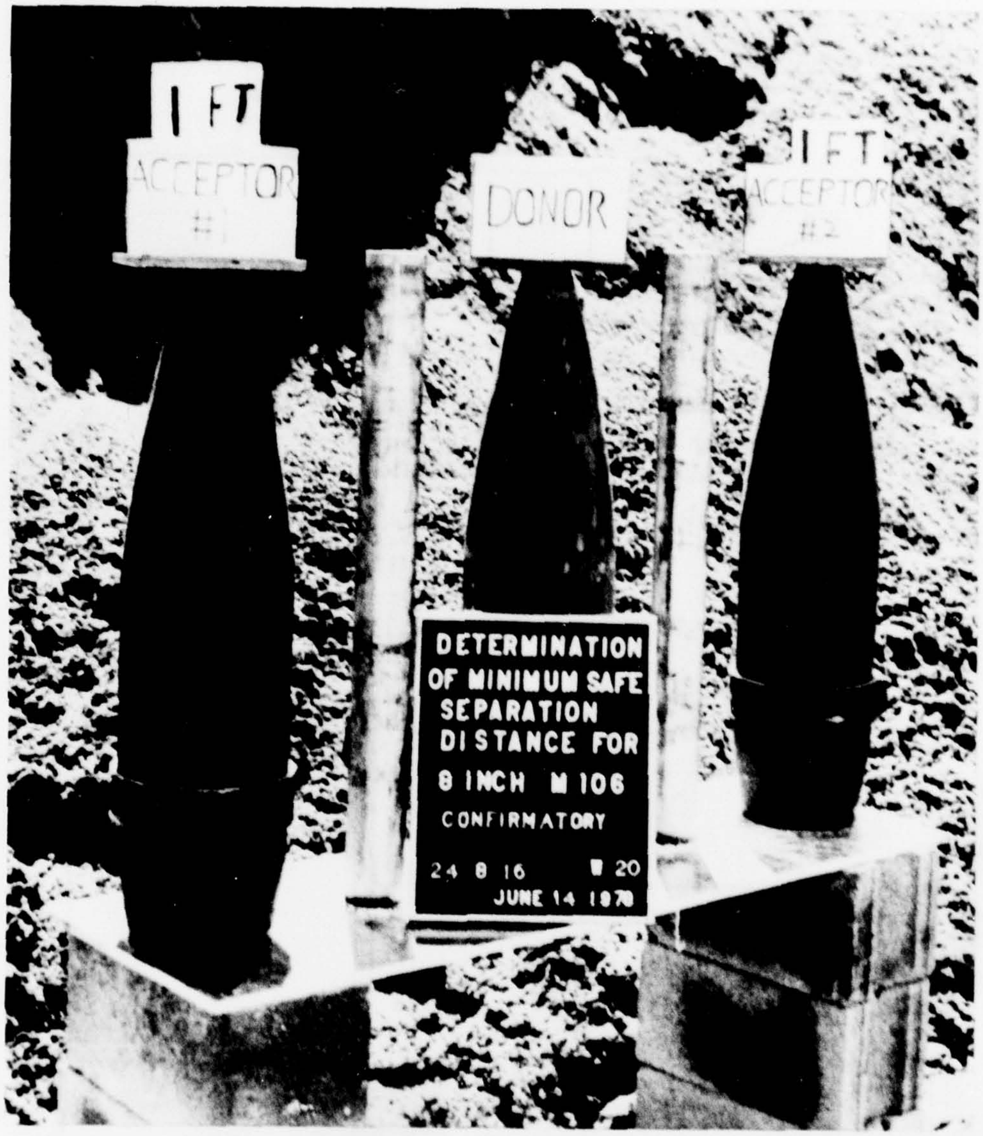

Fig 4 Shielded confirmatory test set-up

Fig 5 Acceptor projectile (body cracking)

Fig 6 Acceptor projectile

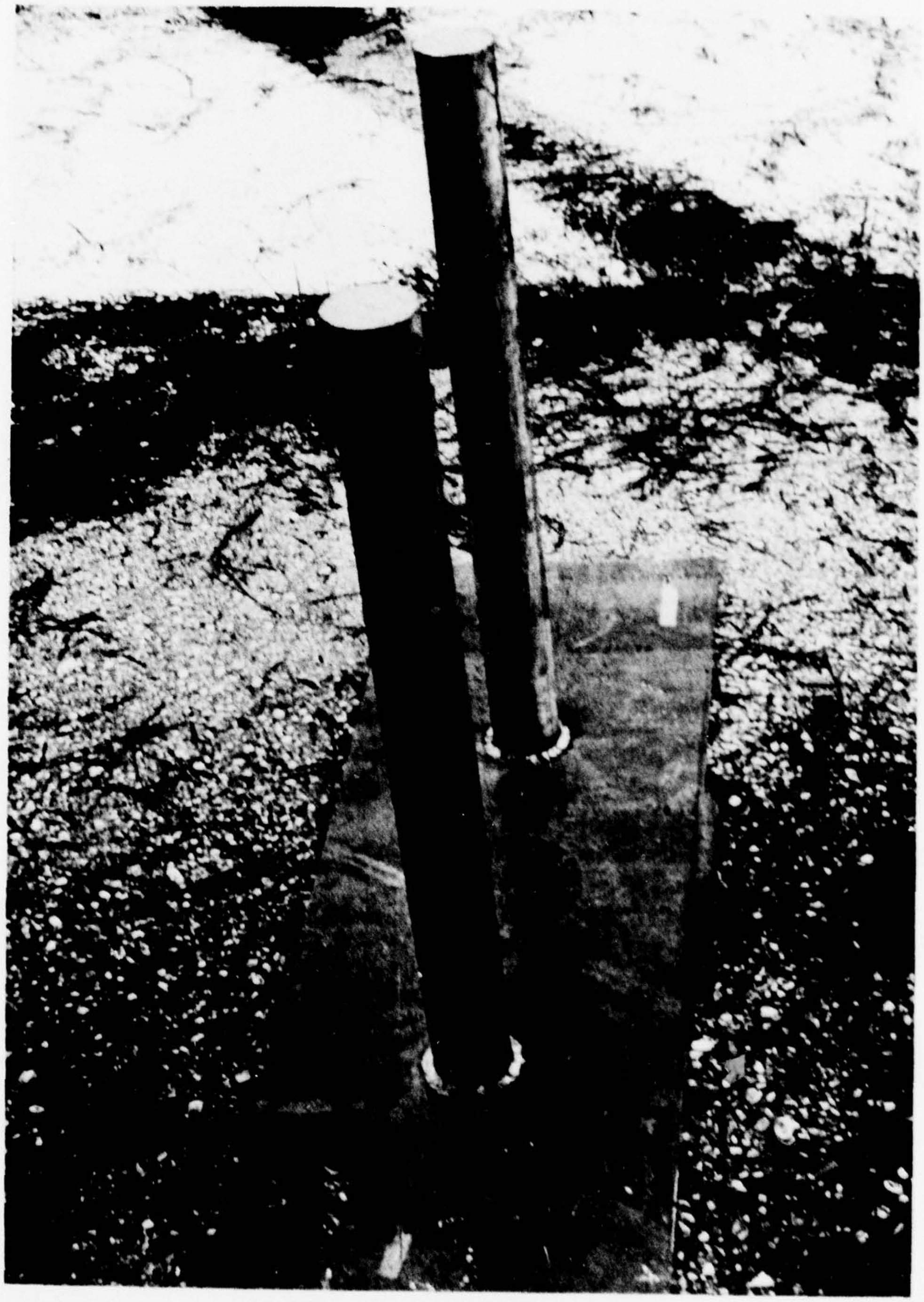

Fig 7 Aluminum shielding rods

Fig 8 Acceptor projectiles with aluminum bruise marks

Fig 9 Aluminum shielding rods (post-test condition)

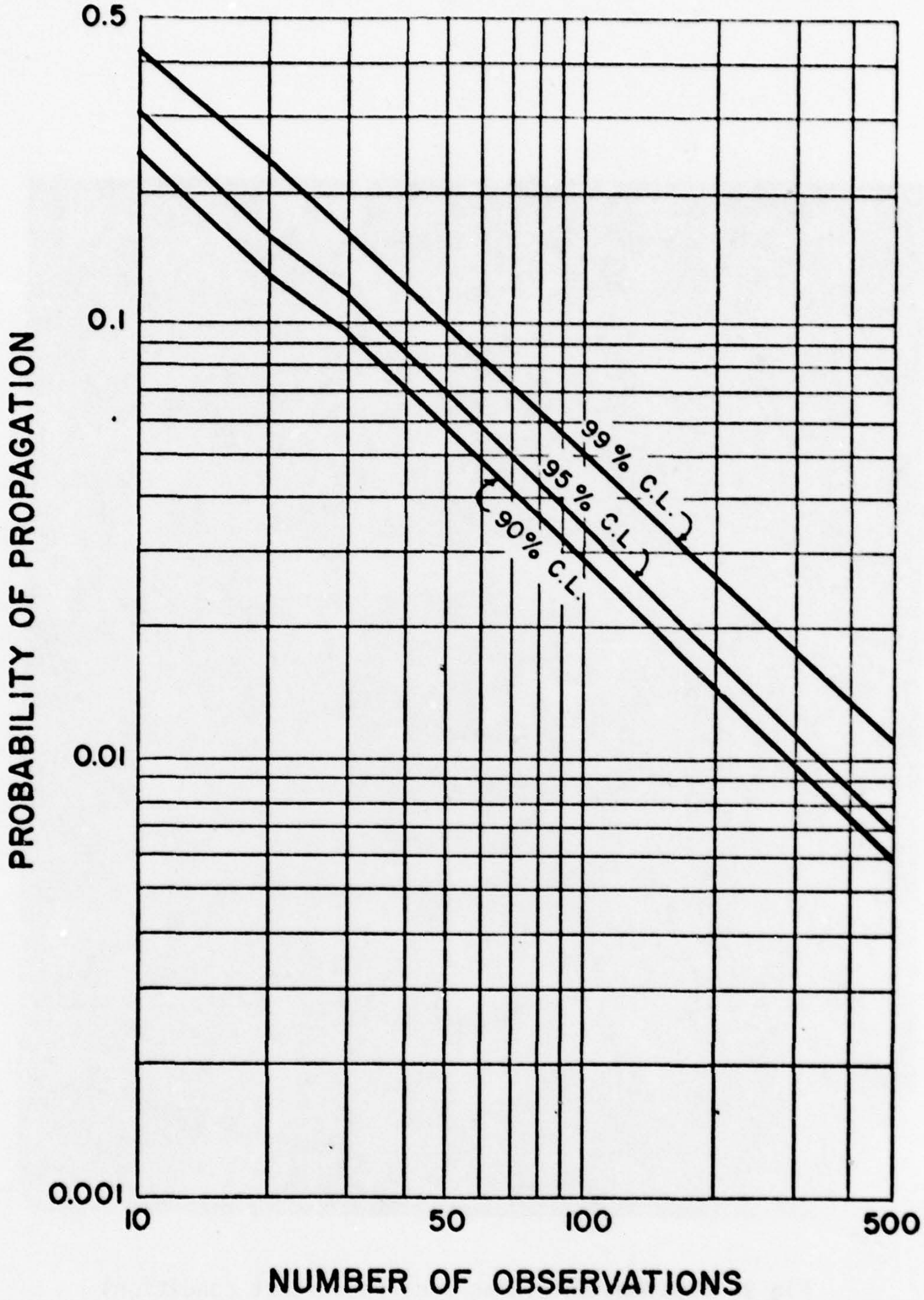

Fig 10 Variation of propagation probability versus number of observations as a function of confidence level

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

Attempt has been made in the main body of this report to evaluate the possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results. This section of the report is devoted to mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by:

$$p = x/n \qquad \text{Eq. 1}$$

and, therefore, the expected value of (x) is given by:

$$E(x) = np \qquad \text{Eq. 2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as:

$$(1 - p_2)^n = \epsilon \qquad \text{Eq. 3}$$

where $\epsilon = (1 - \alpha)/2$ and $\alpha < 1.0$ Eq. 4

Use of Equation 3 is illustrated in the following example:

Example

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95 percent based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence Level (α) = 95 percent

Solution

1. Substitute the given value of (α) into Equation 4 and solve for ϵ:

$$\epsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$$

2. Substitute the given value of (n) and value of (ϵ) into Equation 3 and solve for p_2:

$$\epsilon = 0.025 = (1 - p_2)^{30}$$

or

$$p_2 = 0.116(11.6 \text{ percent})$$

Conclusions

For a 95 percent confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of 3.48(0.116 x 30) observations could result in a reaction for a 95 percent confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99 percent, are used to derive the probabilities.

TABLE A-1

Probabilities of Propagation for Various Confidence Limits

Number of Observations	90 percent	C.L.	95 percent	C.L.	99 percent	C.L.
n	p_2	E(x)	p_2	E(x)	p_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

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