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TECHNICAL REPORT ARLCD-TR-78021

DETERMINATION OF MINIMUM NON-PROPAGATION  
DISTANCE OF 81-MM M374A1 PROJECTILES

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APRIL 1978



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
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indicated that the minimum non-propagation distance for single projectiles is 45.72 centimeters (18 inches) and 9.14 meters (30 feet) for 72-projectile pallets.

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## TABLE OF CONTENTS

	<u>Page</u>
SUMMARY . . . . .	1
Background . . . . .	2
Objectives of Test Program . . . . .	3
Criteria for Tests . . . . .	3
TEST CONFIGURATIONS . . . . .	4
General. . . . .	4
Test Specimens . . . . .	4
Test Arrangements. . . . .	5
TEST RESULTS. . . . .	7
General. . . . .	7
Single Projectile Exploratory Tests. . . . .	7
Single Projectile Confirmatory Tests at 60.96-cm Safe Separation Distance . . . . .	7
Single Projectile Confirmatory Tests at 45.72-cm Safe Separation Distance . . . . .	8
72-Projectile Pallet Exploratory Tests . . . . .	8
72-Projectile Pallet Confirmatory Tests. . . . .	9
Tests on Propagation Within the 72-Projectile Donor Pallet . . . . .	9
Summary of Test Results. . . . .	11
Analysis of Test Results . . . . .	11
CONCLUSIONS . . . . .	12
LIST OF TABLES	
<u>No.</u>	
1 Nomenclature used in Tables 2 through 6. . . . .	13
2 Single projectile exploratory tests. . . . .	14
3 Single projectile confirmatory tests - 60.96-cm (24-inch) safe separation distance. . . . .	16
4 Single projectile confirmatory tests - 45.72-cm (18-inch) safe separation distance. . . . .	18

TABLE OF CONTENTS  
(continued)

Page

LIST OF TABLES (cont'd)

No.

5	72-projectile pallet exploratory tests . . . . .	24
6	72-projectile pallet confirmatory tests - 9.14-m (30-foot) separation distance . . . . .	26
7	Summary of single 81-mm projectile test results. . .	30
8	Summary of 72-projectile pallet test results . . . .	31

LIST OF FIGURES

No.

1	81-mm M374A1 in the test configuration . . . . .	32
2	81-mm projectile support fixture (single projectile/fixture). . . . .	33
3	81-mm projectile test set-up (single projectile/fixture) . . . . .	34
4	Single projectile safe separation distance test set-up prior to ignition . . . . .	35
5	81-mm projectile support fixture (72-projectile/fixture) . . . . .	36
6	81-mm projectile test set-up (72-projectile/fixture) . . . . .	37
7	81-mm projectile in 72-round pallets in test configuration prior to ignition . . . . .	38
7A	81-mm projectile in 72-round pallets in test configuration prior to ignition . . . . .	39
8	Single projectile post-test results showing typical acceptors at 6-inch and 12-inch safe separation distances . . . . .	40

TABLE OF CONTENTS  
(continued)

	<u>Page</u>
LIST OF FIGURES (cont'd)	
<u>No.</u>	
9	Single projectile post-test results showing typical acceptors at the 24-inch safe separation distance . . . . . 41
10	Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E44) . . . . . 42
11	Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E45) . . . . . 43
12	Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E46) . . . . . 44
13	Single projectile post-test results showing typical fragment penetrations and a pneumatically ruptured case from Test E36 . . . . . 45
14	Single projectile post-test results showing typical fragment penetrations and an acceptor projectile (on right with 60% of Composition B burned). . . . . 46
15	72-projectile acceptor pallet after test at 6.1-meter (20-foot) separation distance - propagation to detonation did not occur . . . . . 47
16	72-projectile acceptor pallet after test at 3.05-meter (10-foot) separation distance - propagation did not occur . . . . . 48
17	Typical donor crater after simultaneous detonation of 72 rounds . . . . . 49
18	Typical 72-projectile acceptor pallet at the 9.14-meter (30-foot) safe separation distance after test . . . . . 50

TABLE OF CONTENTS  
(concluded)

	<u>Page</u>
LIST OF FIGURES (cont'd)	
<u>No.</u>	
19 Typical acceptor projectiles at the 9.14-meter (30-foot) safe separation distance. . . . .	51
20 Typical acceptor projectile penetration (with partial burning) at the 9.14-meter (30-foot) safe separation distance. . . . .	52
21 Typical fragment damage of test fixture and acceptor projectile at the 9.14-meter (30-foot) safe separation distance. . . . .	53
22 81-mm projectile support fixture (72-projectile/fixture) . . . . .	54
23 Variation of propagation probability versus number of observations as a function of confidence level. . . . .	55
APPENDIX . . . . .	56
DISTRIBUTION LIST. . . . .	60

## SUMMARY

The safe separation distance testing of 81-mm M374A1 projectiles containing 0.981 kilogram (2.163 pounds) of Composition B was requested by the Project Manager for Munitions Production Base Modernization and Expansion specifically to support Milan Army Ammunition Plant, Tennessee. After a review of Load-Assemble-Pack (LAP) conditions, it was determined that tests would be conducted with single projectiles as well as 72-projectile pallets supported above the ground surface with low density concrete blocks. A program to determine the minimum non-propagation safe separation distance was drafted by ARRADCOM and performed by Computer Sciences Corporation, technical support contractor at the National Space Technology Laboratories (NASA/NSTL), Bay St. Louis, Mississippi, during December 1976 and January 1977. The tests performed under the auspices of this Program simulated the actual LAP plant operational conditions.

The tests were conducted in two phases: an exploratory phase during which the probable minimum safe separation distance was determined by trial and error and a confirmatory phase where sufficient tests were performed to statistically establish the probability of propagation of an explosive incident.

The confirmatory test phase established the minimum safe spacing for single projectiles and 72-projectile pallets; each projectile containing 0.981 kilogram (2.163 pounds) of explosive Composition B as 45.72 centimeters (18 inches) with an upper limit of 5.1 percent probability of propagation at a 95 percent confidence limit and 9.14 meters (30 feet) with an upper limit of 6.8 percent probability of propagation at a 95 percent confidence limit, respectively.

It should be noted that the established safe separation distance for 72-projectile pallets of 9.14 meters (30 feet) is a 70% reduction in the explosive distance requirements as specified by AMCR 385-100. This reduction in the safe spacing required will also reduce ammunition manufacturing costs.

## INTRODUCTION

### Background

At the present time, an Army-wide modernization program is underway to upgrade existing installations and to develop new explosive manufacturing and LAP (Load, Assemble, Pack) facilities. This effort will enable the U.S. Army to achieve increased production cost effectiveness with improved safety. As a part of this overall program, the Manufacturing Technology Division, Large Caliber Weapon Systems Laboratory, ARRADCOM, Dover, New Jersey, is engaged in the development of safety criteria as an activity entitled "Safety Engineering in Support of Ammunition Plants". These criteria will be used as part of the basis for the design of all explosive production installations due for modernization including Government-owned, contractor-operated ammunition plants. The activities covered in this report provide safety data to specifically support modernization activities in the 81-mm (M374A1) projectile LAP areas at Milan AAP, Tennessee, but it is also applicable to other similar LAP facilities.

The planned melt/pour facilities at Milan will utilize a powered roller conveyor system to transport 72 projectiles loaded with Composition B explosive on a specially designed fixture (pallet). This pallet is to be loaded with projectiles and pouring adapters in an inert metal parts area and transported to the melt/pour area where the projectiles are filled. In the melt/pour area, the explosive will be automatically melted, conditioned and dispensed into the projectiles on the pallets. After the projectiles have been precisely filled with the exact quantity of explosive, 0.981 kilogram (2.163 pounds) per projectile, they are then transferred by conveyor to the cooling building. The pouring adapters, which do not contain composition risers due to improved filling techniques, are removed from the projectiles at a subsequent work station, after the cooling process. The pallets are transported to additional work stations where the projectiles are removed from the pallets, thenceforth being conveyed singly in and about the various operations. The pallets and single projectiles must be spaced at non-propagating distance on the conveyors.

Table 17-1 of the Safety Manual (Army Materiel Command Regulation AMCR 385-100) specifies the safe spacings for ammunition and explosives in containers. However, there is no data relative to the configurations for in-process 81-mm projectiles such as those found at the new Milan AAP facility. Items not listed in Table 17-1 must be separated by intraline distance based on net explosive weight. The spacing of items at intraline distances often

results in undesirable and impossible conveyor speeds in order to meet process and/or production requirements.

#### Objectives of Test Program

The tests described in this report were undertaken to experimentally establish the minimum non-propagative clear spacing between single projectiles, and between pallets containing 72 projectiles each, in configurations representative of an actual in-process condition.

#### Criteria Tests

The primary criterion for determination of safe separation (non-propagative) distance between the projectiles either single or in 72 items on a pallet was that detonation of the single donor projectile or pallet does not cause sympathetic detonation of the adjacent acceptor items. This go/no-go criterion is tempered by a second criterion which is the presence of extensive fire or severe fragment damage in the acceptor projectiles. Following the establishment of a minimum clear spacing, repetitive confirmatory testing was performed to establish a measure of confidence in the results.

## TEST CONFIGURATIONS

### General

The tests were performed during December 1976 and January 1977 at the National Aeronautics and Space Administration/ National Space Technology Laboratories (NASA/NSTL), Bay St. Louis, Mississippi. All tests were conducted under the direction of the ARRADCOM Resident Laboratory by Computer Sciences Corporation, technical support contractor at the NASA/NSTL. ARRADCOM personnel provided the basic test criteria, engineering sketches for test fixtures and the initial test guidance and direction for the single round and pallet exploratory test series.

The tests were designed to simulate two actual loading plant conditions relative to transporting loaded projectiles between manufacturing operations. The first condition is that of a single projectile being moved in a vertical position on a powered link-belt conveyor. The second is that of the powered roller conveyor system which is designed to transport 72 projectiles in a vertical position. The 72 projectiles are held by a pallet in a 6 by 12 matrix with a 2.11-centimeter (0.83-inch) spacing between adjacent projectile cases. In both transporting configurations, tests were performed using test fixtures which simulated actual plant hardware; i.e., pallets and single round holding fixtures. To simulate the projectile height above the plant floor and the reflective surface of the respective conveyor systems, the test fixtures were elevated above the level surface of the ground by low density concrete blocks. Tests were conducted for single projectiles and 72 projectiles using a donor item and two acceptor items - one acceptor on either side of the donor. To further simulate plant loading conditions, the metal cup liner, P/N 7549011, was removed from each round to expose the cast Composition B explosive.

### Test Specimen

The test specimen was the 81-mm M374A1 projectile, body loading assembly only, as shown in Figure 1. The projectile was loaded with approximately 0.981 kilogram (2.163 pounds) of Composition B explosive, and the liners (P/N 7549011) were removed prior to testing. Removal of the liner was necessitated by the requirement to duplicate actual plant operating conditions; i.e., the majority of the operations occur with the liner absent and the explosive charge exposed.

## Test Arrangements

### Single Projectiles

The single projectile tests were conducted utilizing the fixture shown in Figure 2. This fixture holds the projectile in a vertical, nose-up position as shown in Figure 3. Two low-density concrete blocks were used to achieve an approximate height of 81.28 centimeters (32 inches) above the ground level. For each test, one donor and two acceptor fixtures were positioned in a straight line as shown in Figure 4. The spacing or separation distance is defined as the distance measured from the outside surface of the donor projectile to the corresponding outside surface of the acceptor projectile. Initiation of the donor projectile was accompanied by placing approximately 85 grams (3 ounces) of Composition C4 and an Engineer's Special (J-2) blasting cap in the fuze well of the projectile. For all tests in the exploratory phase, the acceptor fixtures were located at varying distances from the donor fixture as measured from the outside surfaces of the projectile steel body assembly. The degree of propagation, fragment damage, and presence or absence of flame were observed by closed circuit TV during and immediately after each test. A careful examination of the debris was conducted after a 45-minute hold (cook-off) period. The acceptor projectiles were color coded to facilitate identification of the projectile cases and fragments. Color coding was required only for the exploratory phase wherein the acceptor distances were being varied from test to test.

### 72-Projectile Pallets

The 72-projectile pallet tests were conducted utilizing the fixture shown in Figure 5. This fixture holds the projectiles in a vertical, nose-up position in a 6 by 12 matrix as shown in Figure 6. The spacing between rounds resulting from this arrangement was 2.11 centimeters (0.83 inch). The loaded pallet was placed on 36 low density concrete blocks, which were arranged to provide the required 81.28-centimeter (32-inch) distance from ground level. Initiation of one projectile in the 72-projectile pallet was accomplished in the same manner as in the single projectile tests; i.e., with 85 grams (3 ounces) of Composition C4 and a J-2 blasting cap placed in the fuze cavity. The projectile thus primed for initiation was as near the center of the pallet as possible (see Figure 5). For each test, a donor pallet and two acceptors were positioned in a straight line as shown in Figures 7 and 7A. In all tests, the short sides (6-projectile sides) of each pallet faced the adjacent pallets.

The distances between the donor and acceptors were varied in the pallet exploratory tests. Projectiles on the acceptor pallets were painted different colors to facilitate identification of the remaining projectiles, fragments and fixtures. The degree of propagation, presence of fire and fragment damage were observed immediately after each test. A closer examination of the debris was also performed after a 45-minute hold period.

## TEST RESULTS

### General

As previously mentioned, the exploratory tests on projectiles filled with 0.981 kilogram (2.163 pounds) of explosive Composition B were grouped into two categories: single projectiles and 72-projectile pallets. The results of these exploratory tests are detailed below. Also described are the results of the confirmatory tests.

### Single Projectile Exploratory Tests

Ten single projectile exploratory tests (E01 - E10) were conducted with the results as shown in Table 2. Table 1 presents a more definitive description of terms used in the "remarks" section of Tables 2 through 6. Separation distances ranged from 15.24 centimeters (6 inches) to 60.96 centimeters (24 inches). In only one case, the 15.24-centimeter (6-inch) distance, was there an indication of a detonation propagation to reaction. This was not wholly confirmed, but was surmised due to the absence of the aft section of the projectile; i.e., no major fragments from this section were found. The remainder of the case was ruptured as shown in Figure 8.

As shown in Table 2, three acceptors at 30.48 centimeters (12 inches) had severe penetrations or pneumatic case rupture. For these cases, there was a 90 percent burn of the Composition B in one case, less than 5 percent in the second, and none in the third. Of the 15 acceptors at 45.72 centimeters (18 inches), Composition B burned in five projectiles, three of these burned 100 percent. Severe perforations were experienced in all but one acceptor at this distance. The one acceptor at 60.96 centimeters (24 inches) was penetrated, but less than 5 percent of the Composition B melted or burned. From this analysis, a decision was made to use a 60.96-centimeter (24-inch) separation distance in the confirmatory phase. This decision was based on the occurrence of burning: 5 of 15 at 45.72 centimeters (18 inches); 2 of 3 at 30.48 centimeters (12 inches), and 1 at 15.24 centimeters (6 inches).

### Single Projectile Confirmatory Tests at the 60.96-centimeter (24-inch) Safe Separation Distance

Seventeen tests (34 acceptors), E11 - E26 and E54, were conducted at the 60.96-centimeter (24-inch) separation distance. The results of these tests are summarized in Table 3. Of primary

interest is the fact that there were no detonation propagation reactions in any of the 34 acceptors. These results, added to the 19 acceptors from the exploratory phase, give a statistical population of 53 single acceptor projectiles which did not propagate to detonation at safe separation distances less than or equal to 60.96 centimeters (24 inches). All but one of the 34 acceptors at 60.96 centimeters (24 inches) were penetrated by fragments. In three cases, the Composition B was entirely burned; in four cases, only slight (less than 5 percent) burning resulted. Figure 9 shows typical fragment penetration results at this distance.

#### Single Projectile Confirmatory Tests at the 45.72-centimeter (18-inch) Safe Separation Distance

At the completion of the confirmatory tests at the 60.96-centimeter (24-inch) safe separation distance, a decision was made in conjunction with PTA technical personnel to conduct additional single projectile tests at the 45.72-centimeter (18-inch) distance. This action was based on the desire, by cognizant production personnel at Milan AAP and the Production Base Modernization and Expansion Program Office, to minimize the safe separation distance. Without the reduction from 60.96 centimeters (24 inches) to 45.72 centimeters (18 inches), production rates would be significantly reduced, causing serious production and facility cost problems.

An additional 26 tests (52 acceptors), E28 - E53, were conducted at the 45.72-centimeter (18-inch) separation distance. The results of these tests are summarized in Table 4. Of significance regarding this data is that there were no propagation to detonation reactions in any of the 52 acceptors analyzed, although 50 of the acceptors were penetrated by fragments as described in the "remarks" columns of the table. Figures 10 and 11 show typical acceptor projectiles from this test series. The Composition B in slightly less than 10 percent of the rounds (5 of 52) was totally burned; in one case, approximately 60 percent of the explosive burned and in nine cases, only slight (less than 5 percent) burning resulted. Seven rounds suffered severe damage to the extent that they were cracked open, or pneumatically ruptured. In all of these cases there was sufficient physical evidence in the form of large case segments and unburned Composition B remaining to support the conclusion that no detonations had occurred. Figures 12, 13, 14 and 15 show additional typical acceptor projectiles from this test series.

#### 72-Projectile Pallet Exploratory Tests

Five 72-projectile pallet exploratory tests (P01 - P05) were conducted with the results shown in Table 5. Separation distances

between donor and acceptors ranged from 1.52 meters (5 feet) to 12.19 meters (40 feet), and only the 1.52-meter (5-foot) distance (Test P04) resulted in a propagation to detonation reaction. In this case, immediate detonation of all 72 projectiles in the acceptor pallet was observed. The acceptor at 3.04 meters (10 feet) (Test P02) resulted in a fire in one of the rounds; this round pneumatically ruptured. The pneumatic rupture conclusion was based on the muffled, low-order sound of the reaction, the large fragments recovered, the appearance of the fracture, the presence of unconsumed Composition B and the relatively undisturbed area where the round reacted. The seven acceptor pallets at 6.1 meters (20 feet) exhibited relatively little damage in terms of projectiles penetrated by fragments. One projectile burned 100 percent on the acceptor pallet in Test P05. The acceptor at 12.19 meters (40 feet) (Test P01) had only one projectile penetrated. Figures 16, 17 and 18 show typical results of this series.

After an analysis and evaluation of test results from the 10 acceptors, a decision was made in conjunction with the PTA technical representative to conduct confirmatory tests at a 9.14-meter (30-foot) distance between donor and acceptors.

#### 72-Projectile Pallet Confirmatory Tests

Twenty-two (P06 - P27) tests with 44 acceptors were conducted at a separation of 9.14 meters (30 feet). The results from these tests are summarized in Table 6. There were no propagation to detonation reactions evidenced in any projectile in any of the 72-projectile pallets. Only three projectiles were entirely burned and six projectiles showed approximately 5 to 10 percent burning of the Composition B. Of the 3,168 projectiles exposed (44 acceptors x 72 projectiles), only 13 were penetrated by fragments. All of these were located in the first row of the acceptor pallet; i.e., the two nearest the donor. Figures 19, 20, 21 and 22 show typical test results at the separation distance of 9.14 meters (30 feet).

#### Tests on Propagation Within the 72-Projectile Donor Pallet

Two additional tests were conducted on the 72-projectile pallet to determine if the entire pallet will detonate simultaneously irrespective of the point of initiation within the 6 x 12 matrix.

In all 54 of the 72-projectile pallet exploratory and confirmatory tests (P01 - P27), the projectile nearest the center of the pallet was initiated in all cases. The point of initiation

is shown on the sketch in Figure 5. Simultaneous detonation of all 72 projectiles occurred in all cases.

In one of the special tests (P28), a projectile in the center of the outer row of the long side (12-projectile side) was initiated by placing Composition C4 and a blasting cap in the fuze well of the projectile. Complete detonation of all 72 projectiles resulted. In the second test, a projectile at one corner was initiated; again, all 72 projectiles detonated simultaneously. Figure 21 depicts the projectile initiated for these tests.

It may be concluded from these tests that propagation of detonation to all 72 projectiles will result if any one projectile in any location is initiated.

### Summary of Test Results

The confirmatory test results clearly demonstrated that no propagation of detonations occurred at the established safe clear separation distances. The established safe clear distances are 45.78 centimeters (18 inches) for single projectiles and 9.14 meters (30 feet) for 72-projectile pallets.

### Analysis of Test Results

The actual probability of an explosive event is a function of the number of propagative occurrences in the individual test series and the number of tests conducted.

The confirmatory test results, as shown in Table 7, for single projectiles containing explosive Composition B produce a probability of detonation of an acceptor projectile by a donor projectile of 5.1 percent at a confidence level of 95 percent (see Fig 23).

The confirmatory test results, as shown in Table 8, for 72-projectile pallets with each projectile containing Composition B, produce a probability of detonation of an acceptor pallet by a donor pallet of 6.8 percent at a confidence level of 95 percent (see Fig 23).

These values are equivalent to stating that in a large number of tests, 95 out of a 100 times, the probability of the propagation in an explosive event will be less 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.

## CONCLUSIONS

### Single Projectile Tests

It may be concluded from the test results that if a separation distance of 45.72 centimeters (18 inches) is maintained between single 81-mm M374A1 projectiles, the probability of a detonation of the adjacent acceptor projectile by a donor initiation is 5.1 percent at 95 percent confidence level. This conclusion is based on a statistical population of 67 acceptor projectiles at 45.72 centimeters (18 inches) and 3 acceptors at 30.48 centimeters (12 inches) (see Table 7). Ten of the 70 projectiles burned from 60-100 percent of the Composition B at these distances and 10 ruptured pneumatically. However, the pneumatic ruptures did not result in propagation to a detonation reaction in adjacent projectiles.

### 72-Projectile Pallet Tests

It may be concluded from the test results (Table 8) that if a separation distance of 9.14 meters (30 feet) is maintained between full 72-projectile pallets of M374A1 81-mm projectiles, the probability of a detonation of the adjacent pallet by the donor pallet is 6.8 percent at 95 percent confidence level. This conclusion is based on a statistical population of 44 acceptor pallets at 9.14 meters (30 feet), 7 at 6.1 meters (20 feet), and 1 at 3.05 meters (10 feet). Five of the projectiles on the acceptor pallets burned 100 percent of the Composition B at these distances and one round ruptured pneumatically at 3.05 meters (10 feet). However, the pneumatic rupture did not result in the propagation to a detonation reaction in adjacent pallets.

TABLE 1

Nomenclature used in Tables 2 through 6

Major dent	= Non-penetration of case; cavity greater than or equal to 1.59 millimeters (1/16 inch) deep.
Minor dent	= Non-penetration of case; cavity less than 1.59 millimeters (1/16 inch) deep.
Perforation	= Complete penetration of case. Hole dimension usually given.
SLT	= Slight burn, between trace and 5 percent.
UNK	= Unknown quantity burned.

Table 2 Single projectile exploratory tests

OBSERVED RESULTS												
Test No.	LEFT ACCEPTOR						RIGHT ACCEPTOR					
	Acceptor Distance		Distance Thrown		Percent Burn	Remarks	Acceptor Distance		Distance Thrown		Percent Burn	Remarks
	cm	(in)	m	(ft)			cm	(in)	m	(ft)		
E01	30.48	(12)	36.58	(120)	90	Perforation, 6.35 mm (1/4") x 19.05 mm (3/4")	15.24	(6)	24.38	(80)	UNK*	Apparent partial detonation in aft section
E02	45.72	(18)	13.72	(45)	10	Perforation, 12.7-mm (1/2") diameter, 10% (15 minutes burn time)	30.48	(12)	19.29	(60)	SLT**	Perforation, 9.53-mm (3/8") diameter
E03	45.72	(18)	13.72	(45)	0	Perforation, 9.53-mm (3/8") diameter	60.96	(24)	9.14	(30)	SLT	Perforation, 6.35 mm (1/4") x 19.05 mm (3/4")
E04	45.72	(18)	7.62	(25)	0	Rupture case	30.48	(12)	22.86	(75)	0	Rupture case
E05	45.72	(18)	13.72	(45)	100	Perforation, 9.53-mm (3/8") diameter	45.72	(18)	18.28	(60)	0	Perforation, 9.53-mm (3/8") diameter

\* UNK = Unknown quantity burned.

\*\* SLT = Slight burn, between trace and 5 percent.

Table 2 Single projectile exploratory tests  
(concluded)

OBSERVED RESULTS												
Test No.	LEFT ACCEPTOR					RIGHT ACCEPTOR						
	Acceptor Distance		Distance Thrown	Percent Burn	Remarks	Acceptor Distance	Distance Thrown	Percent Burn	Remarks			
	cm	(in)								m	(ft)	cm
E06	45.72	(18)	13.72	(45)	0	Rupture case	45.72	(18)	0	(0)	0	Perforation, 12.70-mm (1/2") diameter
E07	45.72	(18)	10.67	(35)	0	Three major dents	45.72	(18)	13.72	(45)	SLT**	Perforation, 6.35 mm (1/4") x 19.05 mm (3/4")
E08	45.72	(18)	7.62	(25)	0	One perforation, 6.35-mm (1/4") diameter, two major dents	45.72	(18)	13.72	(45)	100	Perforation, 9.53-mm (3/8") diameter (10 minutes), 1 major dent
E09	45.72	(18)	10.61	(35)	0	Perforation, 9.53-mm (3/8") diameter and 1/2" diameter	45.72	(18)	12.19	(40)	0	Perforation, 6.35-mm (1/4") diameter, two major dents
E10	45.72	(18)	9.14	(30)	100	Perforation, 9.53-mm (3/8") diameter - (17 minutes burn time)	45.72	(18)	4.57	(15)	0	Perforation 6.35 mm (1/4") x 19.05 mm (3/4")

\* UNK = Unknown quantity burned.  
 \*\* SLT = Slight burn, between trace and 5 percent.

Table 3 Single projectile confirmatory tests -  
60.96-cm (24-inch) safe separation distance

OBSERVED RESULTS									
Test No.	LEFT ACCEPTOR					RIGHT ACCEPTOR			
	Distance Thrown		Percent Burn	Remarks	Distance Thrown		Percent Burn	Remarks	
	m	(ft)			m	(ft)			
E11	4.57	(15)	0	Two perforations	6.1	(20)	SLT*	Two perforations - slight burn	
E12	3.05	(10)	0	Three perforations	4.51	(15)	SLT	Two perforations - slight burn	
E13	10.67	(35)	100	Four perforations	10.67	(35)	100	Two perforations - burr complete	
E14	9.14	(30)	0	Two perforations	6.1	(20)	0	Four perforations	
E15	10.67	(35)	0	Two perforations	4.57	(15)	0	Two perforations	
E16	6.1	(20)	100	Three perforations (7 minutes burn time)	6.1	(20)	0	Two perforations	
E17	9.14	(30)	0	Four perforations	4.57	(15)	0	One perforation	
E18	7.62	(25)	0	Two perforations	7.62	(25)	SLT	Two perforations - slight burn	
E19	7.62	(25)	0	Two perforations - case split	10.67	(35)	0	Two perforations - case split	

\*SLT = Slight burn, between trace and 5 percent.

Table 3 Single projectile confirmatory tests -  
60.96-cm (24-inch) safe separation distance  
(concluded)

OBSERVED RESULTS								
Test No.	LEFT ACCEPTOR			RIGHT ACCEPTOR				
	Distance Thrown		Remarks	Distance Thrown	Percent Burn	Remarks		
	m	(ft)					m	(ft)
E20	4.57	(15)	0	One perforation - two major dents	4.57	(15)	0	Two perforations
E21	4.57	(15)	0	Three perforations	6.1	(20)	0	Three perforations
E22	1.52	(5)	0	One perforation - 9.53-mm (3/8") diameter	6.1	(20)	0	Four perforations
E23	1.52	(5)	0	Two perforations - 9.53-mm (3/8") diameter - two major dents	7.62	(25)	100	One perforation, 9.53 mm (3/8") x 50.8 mm (2")
E24	6.1	(20)	0	One perforation - two major dents	10.67	(35)	0	One perforation, 9.53 mm (3/8") x 50.8 mm (2")
E25	3.05	(10)	0	Two minor dents	6.1	(20)	0	One perforation - one major dent
E26	7.62	(25)	0	Three perforations	4.57	(15)	0	Two perforations - one major dent
E27	6.1	(20)	0	Two perforations	7.62	(25)	0	One perforation - one major dent
E54 (shot for photo)	1.52	(5)	0	Three perforations, 12.7 mm (1/2") x 50.8 mm (2"), 6.35 mm (1/4") x 19.05 mm (3/4"), 6.35-mm (1/4") diameter	4.57	(15)	10	Two perforations, 6.35 mm (1/4") x 25.4 mm (1"), 12.7-mm (1/2") diameter

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation distance

Test No.	OBSERVED RESULTS					
	LEFT ACCEPTOR			RIGHT ACCEPTOR		
	Distance Thrown m (ft)	Percent Burn	Remarks	Distance Thrown m (ft)	Percent Burn	Remarks
E28	7.62 (25)	0	Body broken - did not burn	7.62 (25)	100	Burned completely in 5-6 minutes, 12.7-mm (1/2") x 50.8 mm (2") perforations, cracked body
E29	4.57 (15)	0	One perforation 12.7-mm (1/2") x 50.8-mm (2"), 3 minor dents, one almost through	13.72 (45)	100	Burned completely in 5-6 min. Two perforations 12.7-mm (1/2") diameter x 50.8 mm (2") long; cracked body
E30	7.62 (25)	0	Four major dents	10.67 (35)	0	Three major dents
E31	4.57 (15)	0	Three perforations - two 6.55 mm (1/4") and one 12.7 mm (1/2"). Case cracked but did not burn	4.57 (15)	0	6.35-mm (1/4") x 63.5-mm (2-1/2") perforation but not burned
E32	7.62, (25)	SLT*	One perforation, 6.35-mm (1/4") chevron, one major dent	6.1 (20)	0	Two perforations, 9.53-mm (3/8") diameter; two perforations 6.35-mm (1/4") diameter; did not burn. Case cracked opposite to perforations.

\*SLT = Slight burn, between trace and 5 percent.

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation distance  
(continued)

OBSERVED RESULTS						
Test No.	LEFT ACCEPTOR			RIGHT ACCEPTOR		
	Distance Thrown	Percent Burn	Remarks	Distance Thrown	Percent Burn	Remarks
	m (ft)			m (ft)		
E33	15.24 (50)	SLT*	Several perforations - one 12.7-mm (1/2" diameter, two 9.53-mm (3/8") diameter, one 6.35-mm (1/4") diameter, 1 major dent	10.67 (35)	0	One large 25.4-mm (1" diameter perforation thru aft section, one perforation 9.53-mm (3/8") diameter, three major dents
E34	13.72 (45)	0	Three perforations, 12.7-mm (1/2") diameter	12.19 (40)	SLT	Three perforations - 57.15-mm (2-1/4") diameter, 50.8-mm (2" diameter and 12.7-mm (1/2") diameter
E35	7.62 (25)	SLT	Two perforations 6.35-mm (1/4") diameter, one perforation 6.35 mm (1/4") x 50.8 mm (2")	10.67 (35)	100	Three perforations, 9.53-mm (3/8") diameter
E36	6.1 (20)	0	Three 6.35-mm (1/4") diameter perforations	24.38 (80) 45.72 (150)	UNK**	Large piece found 24.38 m (80') from ground zero; small piece found approximately 45.70 m (150') away. Pneumatic rupture of case, no evidence of detonation or burning. Remainder of case never found. Large piece of Comp B found in ditch to south (200 feet away).

\* SLT = Slight burn, between trace and 5 percent.

\*\* UNK = Unknown quantity burned.

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation distance  
(continued)

Test No.	OBSERVED RESULTS			
	LEFT ACCEPTOR		RIGHT ACCEPTOR	
	Distance Thrown m (ft)	Percent Burn	Distance Thrown m (ft)	Percent Burn
E37	9.14 (30)	SLT*	10.67 (35)	SLT
		Remarks Three perforations, 12.70-mm (1/2") diameter		Remarks Three perforations, 9.53-mm (3/8") diameter; slight burn, two perforations < 6.35-mm (< 1/4") diameter
E38	10.67 (35)	0	3.05 (10)	100
		Remarks Two perforations of unknown size < 12.70 mm (< 1/2"); case ruptured Comp B spilled out		Remarks Two perforations, 9.53-mm (3/8") diameter, one perforation 6.35-mm (1/4") diameter
E39	10.67 (35)	0	15.24 (50)	0
		Remarks One perforation, 6.35 mm (1/4") x 19.05 mm (3/4"), one perforation 9.53 mm (1/4") x 76.2 mm (3")		Remarks Three perforations, 12.70-mm (1/2") diameter, overlapping
E40	12.19 (40)	0	13.72 (45)	0
		Remarks Two perforations, 9.53-mm (3/8") diameter - one perforation 6.35 mm (1/4") x 76.2 mm (3")		Remarks Two perforations, 9.53-mm (3/8") diameter, cracked after section almost separated

\* SLT = Slight burn, between trace and 5 percent.

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation distance  
(continued)

OBSERVED RESULTS								
Test No.	LEFT ACCEPTOR			RIGHT ACCEPTOR				
	Distance Thrown		Remarks	Distance Thrown		Percent Burn	Remarks	
	m	(ft)		m	(ft)			
E41	15.24	(50)	0	Three perforations, 9.53-mm (3/8") diameter	15.24	(50)	0	Two perforations, 9.53 mm (3/8") x 25.4 mm (1") and 6.35 mm (1/4") x 19.05 mm (3/4")
E42	7.62	(25)	SLT*	Three perforations, 6.35-mm (1/4") diameter, 12.70-mm (1/2") diameter and 15.88-mm (5/8") diameter	21.34	(70)	0	Five perforations, 25.4-mm (1") diameter, 6.35-mm (1/4") diameter, 6.35-mm (1/4") diameter, 3.18-mm (1/8") diameter and 6.35 mm (1/4") x 19.05 mm (3/4")
E43	7.62	(25)	0	Two perforations, 6.35-mm (1/4") diameter and 6.35 mm (1/4") x 19.05 mm (3/4")	12.19	(40)	0	Three perforations, 6.35-mm (1/4") x 25.4 mm (1"), 6.35 mm (1/4") x 25.4 mm (1") and 15.88-mm (5/8") diameter
E44	10.67	(35)	60	One perforation, 12.7 mm (1/2") x 50.8 mm (2"); two perforations 6.35-mm (1/4") diameter	21.34	(70)		Three perforations, 6.35-mm (1/4") diameter

\* SLT = Slight burn, between trace and 5 percent.

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation distance  
(continued)

OBSERVED RESULTS								
Test No.	LEFT ACCEPTOR			RIGHT ACCEPTOR				
	Distance Thrown		Percent Burn	Remarks	Distance Thrown		Percent Burn	
	m	(ft)			m	(ft)		
E45	6.1	(20)	SLT*	Two perforations, 3.18-mm (1/8") diameter and 12.7-mm (1/2") diameter; 3 perforations, 3.18-mm (1/8") diameter (in obturator groove)	15.24	(50)	SLT	One perforation, 6.35-mm (1/4") diameter, 2 or more perforations in tail section which was burst (but not exploded)
E46	7.62	(25)	0	One perforation, 12.7-mm (1/2") diameter	6.1	(20)	100	One perforation, 6.35-mm (1/4") diameter
E47	10.67	(35)	0	Four perforations, 6.35-mm (1/4") diameter	10.67	(35)	0	Two perforations, 6.35-mm (1/4") diameter
E48	9.14	(30)	0	Three perforations, 12.7-mm (1/2") diameter, 12.7-mm (1/2") diameter and 6.55-mm (1/4") diameter (case cracked) - no evidence of burn. Comp B scattered.	30.48	(100)	UNK**	Pneumatic rupture of case, no evidence of detonation or burning. Remainder of case never found.

\* SLT = Slight burn, between trace and 5 percent.

\*\* UNK = Unknown quantity burned.

Table 4 Single projectile confirmatory tests -  
45.72-cm (18-inch) safe separation  
(concluded)

OBSERVED RESULTS								
Test No.	LEFT ACCEPTOR			RIGHT ACCEPTOR				
	Distance Thrown		Remarks	Distance Thrown		Percent Burn	Remarks	
	m	(ft)		m	(ft)			
E49	12.19	(40)	0	Case split in two - no evidence of burn. Comp B scattered.	12.19	(40)	0	Two perforations, 6.35-mm (1/4") diameter
E50	25.91	(85)	0	Four perforations, 6.35-mm (1/4") diameter, split case - no evidence of burning	27.43	(90)	0	Four perforations, 6.35-mm (1/4") diameter
E51	18.29	(60)	0	One perforation, 12.7 mm (1/2") x 19.05 mm (3/4") - tail separated	13.72	(45)	0	Two perforations, 12.7-mm (1/2") diameter and 19.05-mm (3/4") diameter; 4 perforations, 6.35 mm (1/4") diameter - tail almost separated
E52	12.19	(40)	0	Four perforations, 6.35-mm (1/2") diameter	10.67	(35)	0	Two perforations, 6.35-mm (1/4") diameter - split case
E53	6.1	(20)	0	Four perforations, 6.35-mm (1/4") diameter	6.1	(20)	0	No perforations

Table 5 72-projectile pallet exploratory tests

OBSERVED RESULTS				
Test No.	LEFT ACCEPTOR		RIGHT ACCEPTOR	
	Distance Thrown m (ft)	Remarks	Distance Thrown m (ft)	Remarks
P01	6.1 (20)	Non-propagation block pile knocked down, four minor dents among three rounds	12.19 (40)	Non-propagation, one round 6.55-mm (1/4") diameter x 1.99-mm (1/16") deep dent
P02	3.05 (10)	Non-propagation, pile knocked down, one round perforated in aft section with subsequent burning of explosive after round was thrown into fifth row of pallets. No flame or smoke was observed. After about 15 minutes, the round exploded. Most of the case was re-covered and exhibited evidence of pneumatic rupture, and it appeared that there had been no burning of explosive in section forward of obturator; three rounds with minor dent each.	6.1 (20)	Non-propagation, five minor dents among four rounds.

Table 5 72-projectile pallet exploratory tests  
(concluded)

OBSERVED RESULTS					
Test No.	LEFT ACCEPTOR		RIGHT ACCEPTOR		
	Distance Thrown m (ft)	Remarks	Distance Thrown m (ft)	Remarks	
P03	6.1 (20)	Non-propagation, six minor dents among four rounds; pile knocked down.	6.1 (20)	Non-propagation, six minor dents among three rounds; pile knocked down.	
P04	1.52 (5)	Detonation propagated to acceptor which detonated completely.	6.1 (20)	Non-propagation, one round perforated 12.7 mm (1/2"), 6.35-mm (1/4") diameter overlapping - no burn, one dent 6.35 mm (1/4") x 1.59 mm (1/16") deep, 10 minor dents among five rounds.	
P05	6.1	Non-propagation, one round burned 100% (13 minutes), perforated 6.35-mm (1/4") diameter, one major dent 12.7 mm (1/2") x 3.18 mm (1/8") deep, six minor dents among three rounds; pile partially knocked down.	6.1 (20)	Non-propagation, five minor dents between two rounds; pile knocked down.	

Table 6 72-projectile pallet confirmatory tests -  
9.14-m (30-foot) separation distance

Test No.	OBSERVED RESULTS	
	LEFT ACCEPTOR Remarks	RIGHT ACCEPTOR Remarks
P06	3 rounds with minor dents	1 round perforated and thrown back between the second and third row; 12.7-mm (1/2") diameter hole. One deep dent and three minor dents.
P07	1 round burned 100%. 12.7 mm (1/2") x 25.4 mm (1") oval perforation.	1 round with 9.53 mm (3/8") diameter x 1.59-mm (1/16") deep dent.
P08	1 round with minor dent	2 rounds with minor dents; 1 round with 6.35-mm (1/4") diameter x 1.59-mm (1/16") deep dent.
P09	1 round burned 100%. 12.7-mm (1/2") x 25.4-mm (1") oval perforated. Fell to ground in front of pallet. 2 rounds with 2 minor dents each. 1 round with 3 minor dents in 8th row.	1 round with 3 minor dents.
P10	1 round with small dent and one 6.35-mm (1/4") diameter nearly through.	1 round burned 100%; 2 rounds 6.35-mm (1/4") diameter perforations.
P11	10 minor dents among 4 rounds.	8 minor dents among 3 rounds; one 6.35-mm (1/4") diameter nearly through.

Table 6 72-projectile pallet confirmatory tests -  
 9.14-m (30-foot) separation distance  
 (continued)

OBSERVED RESULTS		
Test No.	LEFT ACCEPTOR	RIGHT ACCEPTOR
	Remarks	Remarks
P12	5 minor dents among 3 rounds	4 minor dents among 3 rounds, one 6.35 mm (1/4") x 12.7 mm (1/2") almost through; one 3.18 mm (1/8") diameter almost through
P13	3 minor dents between 2 rounds; 1 major dent 6.35 mm (1/4") x 12.7 mm (1/2") x 1.59 mm (1/16") deep	1 major dent 6.35 mm (1/4") diameter x 1.59 mm (1/16") dent
P14	2 rounds with one minor dent; one major dent 4.76-mm (3/16") diameter x 1.59 mm (1/16") deep	9 minor dents among 4 rounds; 1 major dent 6.35-mm (1/4") diameter x 1.59 mm (1/16"); one major 6.35 mm (1/4") x 3.18 mm (1/8") x 3.18 mm (1/8") deep
P15	4 minor dents among 3 rounds; one 6.35-mm (1/4") diameter x 3.18 mm (1/8") deep	5 minor dents among 4 rounds.
P16	1 round with 1 dent 6.35-mm (1/4") diameter almost through. 13 minor dents among 6 rounds.	No damaged rounds.

Table 6 72-projectile pallet confirmatory tests -  
 9.14-m (30-foot) separation distance  
 (continued)

OBSERVED RESULTS		
Test No.	LEFT ACCEPTOR	RIGHT ACCEPTOR
	Remarks	Remarks
P17	One 6.35-mm (1/4") diameter penetration - 10% burn; 6.35-mm (1/4") diameter almost through; 6.35 mm (1/4") x 12.7 mm (1/2") x 1.59 mm (1/16") deep; 2 rounds with 1 minor dent each; One 6.35-mm (1/4") diameter almost through.	6 minor dents among 4 rounds
P18	2 rounds with 1 minor dent each	5 minor dents among 4 rounds
P19	2 rounds with 1 minor dent each; one 6.35-mm (1/4") diameter x 1.59 mm (1/16") deep	5 minor dents among 4 rounds
P20	4 minor dents among 3 rounds	7 minor dents among 5 rounds
P21	3 rounds with 1 minor dent; 1 major dent; three 6.35-mm (1/4") diameter overlapping. Almost through.	2 rounds with 1 minor dent; 1 major dent, 12.7 mm (1/2") x 6.35 mm (1/4") x 3.18 mm (1/8") deep

Table 6 72-projectile pallet confirmatory tests -  
 9.14-m (30-foot) separation distance  
 (concluded)

OBSERVED RESULTS		
Test No.	LEFT ACCEPTOR Remarks	RIGHT ACCEPTOR Remarks
P22	3 rounds with 1 minor dent; 1 perforated 6.35-mm (1/4") diameter, slight (5% burn); major dent 6.35-mm (1/4") diameter x 3.18 mm (1/8") deep.	
P23	5 minor dents among 4 rounds; 1 major dent 6.35 mm (1/4") diameter. Almost through.	6 minor dents among 3 rounds; 1 perforated 9.53 mm (3/8") diameter, slight burn; 1 perforated 9.53 mm (3/8") diameter; no burn; 1 major dent, 9.53 mm (3/8") x 6.35 mm (1/4") x 3.18 mm (1/8")
P24	5 minor dents among 4 rounds	1 round with 4 minor dents
P25	4 rounds with 1 minor dent each; 1 perforated 6.35 mm (1/4") x 25.4 mm (1"), slight burn	5 minor dents among 3 rounds
P26	2 rounds with 1 minor dent each	5 minor dents among 3 rounds; 1 perforation 1.35 mm (1/4") x 19.05 mm (3/4"), slight burn.
P27	3 rounds with 1 minor dent each; 1 perforated 9.53-mm (3/8") diameter. No burn. Plus 2 minor dents.	5 minor dents among 3 rounds, 1 almost through 6.35-mm (1/4") diameter.

Table 7 Summary of single 81-mm projectile test results

Number of Acceptors	Safe Separation Distance		No. Acceptors Detonation Propagation	No. Acceptors w/Fragment Penetrations	No. Acceptors Burned 60-100%	No. Acceptors Burned Slight	No. Acceptors Pneumatic Case Rupture
	cm	(in)					
1	15.24	(6)	Partial	1	-	-	-
3	30.48	(12)	None	3	1	1	1
67	45.72	(18)	None	56	9	11	9
37	60.96	(24)	None	34	3	4	0
108			1 Partial	94*	13	16	10*

\*Those projectile acceptors which were not penetrated by fragments and/or ruptured, were dented or scored by fragments.

Table 8 Summary of 72-projectile pallet test results

No. of Acceptor Pallets	No. of Acceptor Projectiles	Safe Separation Distance m	Safe Separation Distance (ft)	No. of Acceptor Pallets/Projectiles Detonation Propagations	No. of Acceptor Projectiles w/Fragment Penetrations	No. Acceptor Projectiles Burned 100%	No. Acceptor Projectiles Burned SLT*	No. Acceptor Pneumatic Rupture
1	72	1.52	(5)	1/72	N/A	N/A	N/A	N/A
1	72	3.05	(10)	None	1	1	None	1
7	504	6.1	(20)	None	2	1	None	None
44	3,168	9.14	(30)	None	13	3	6	None
1	72	12.19	(40)	None	None	None	None	None
54	3,888			1/72	16	5	6	1

\*SLT = Slight burn, between trace and 5 percent.

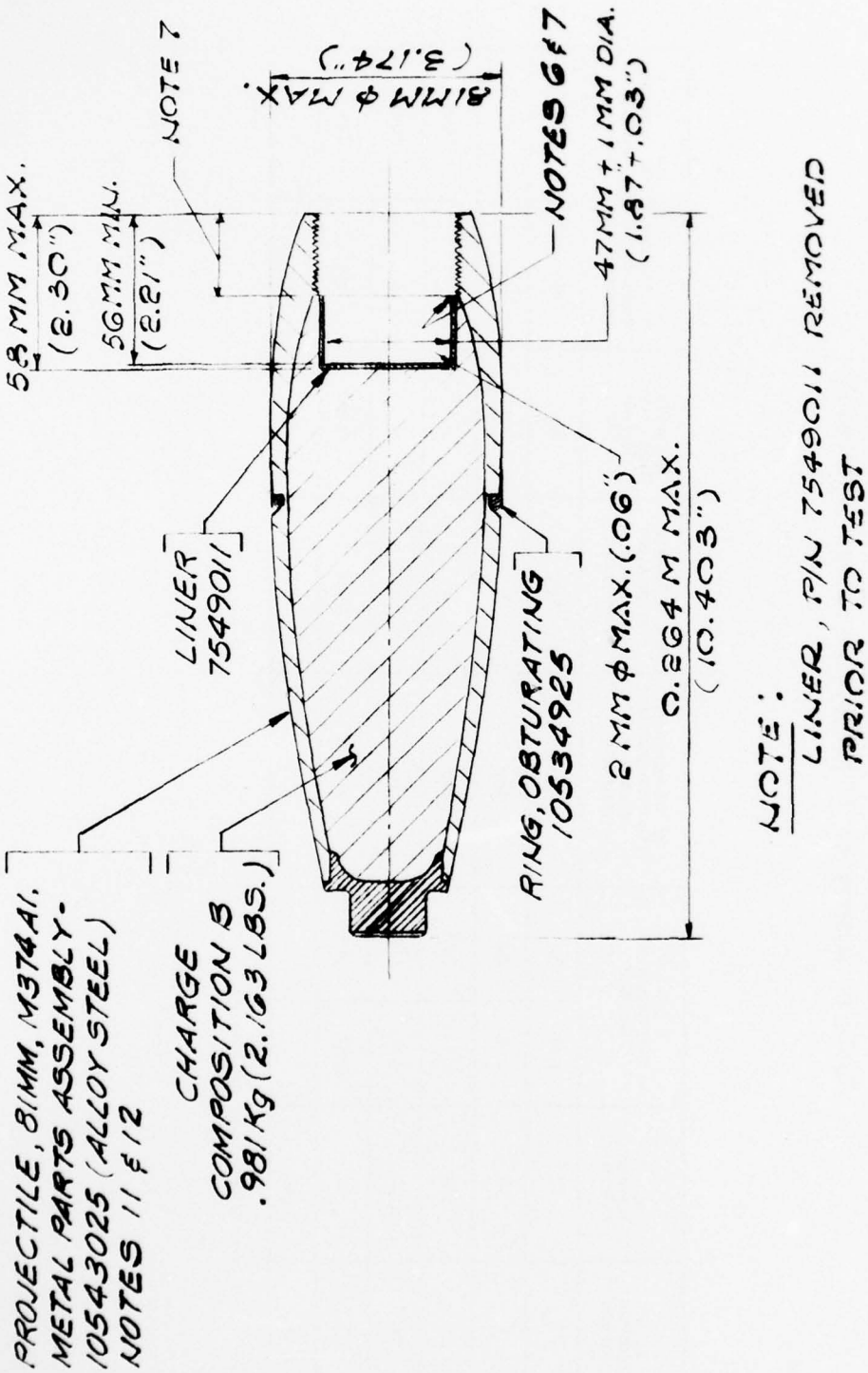


Fig 1 81-mm M374A1 in the test configuration

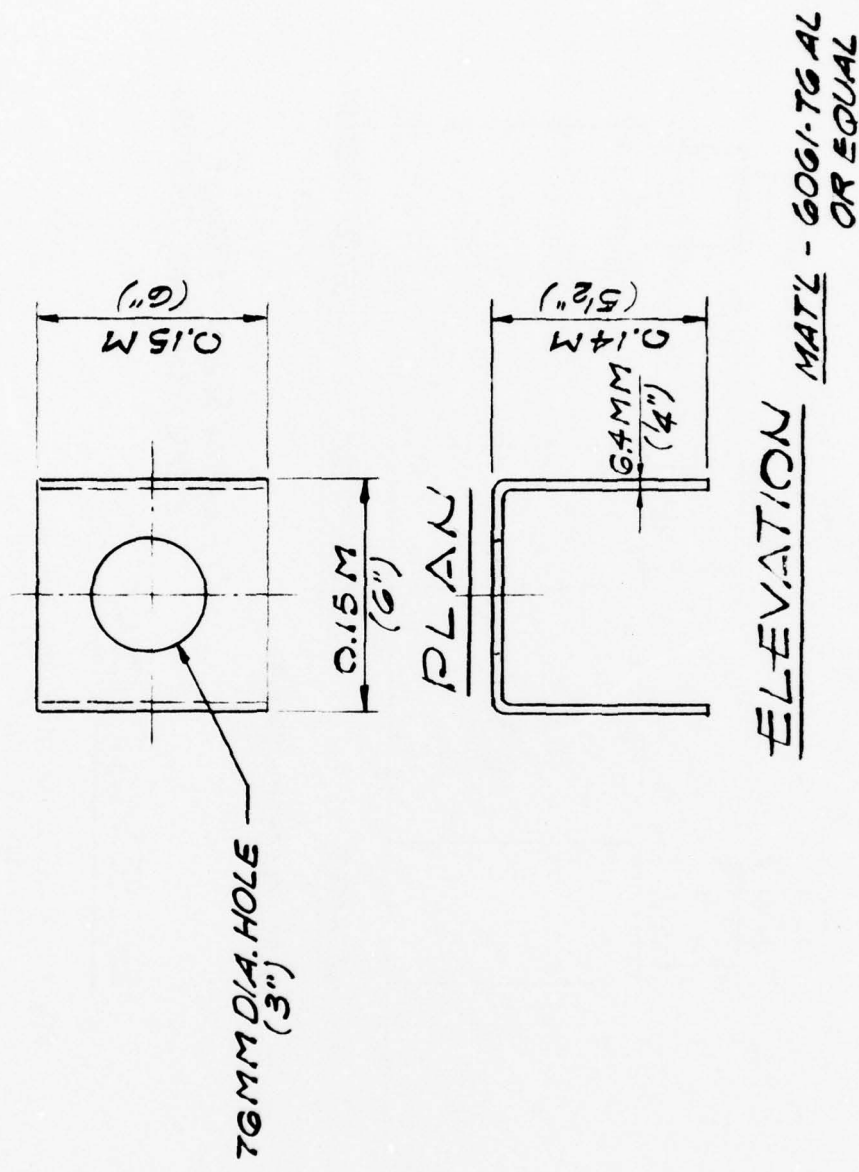
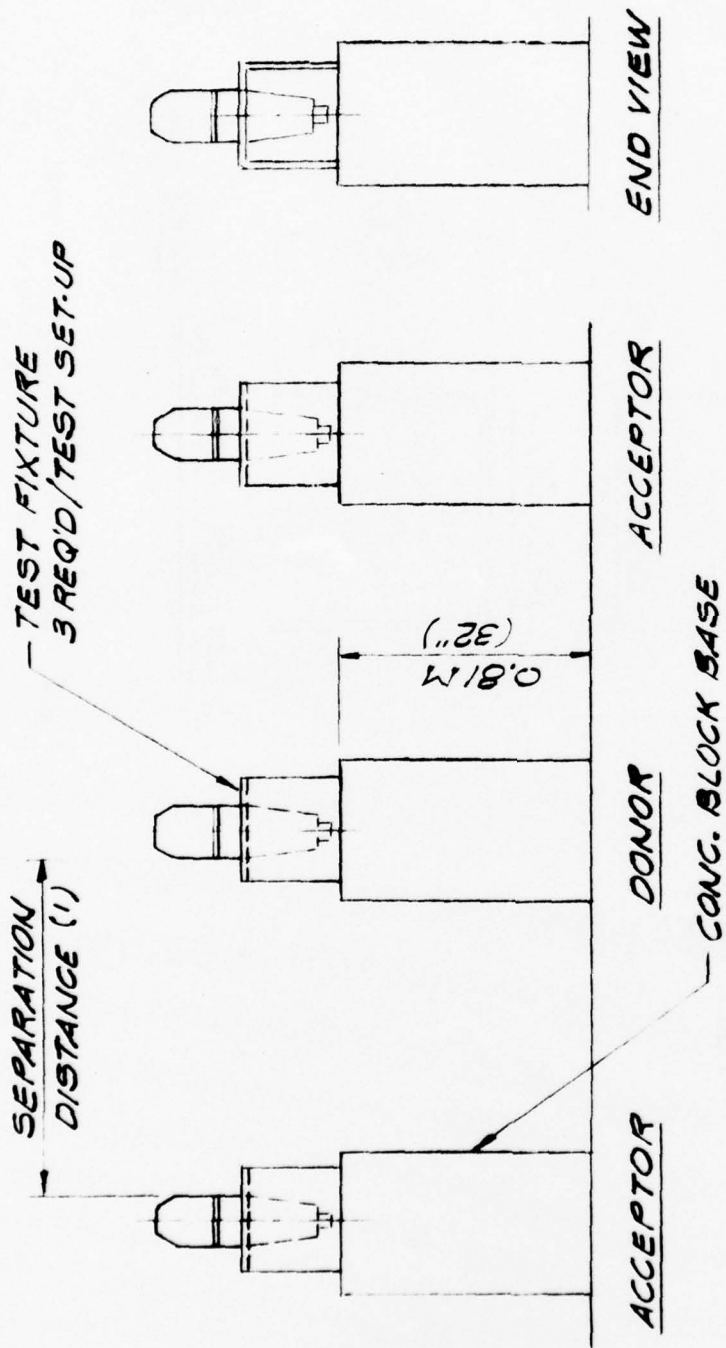


Fig 2 81-mm projectile support fixture (single projectile/fixture)



(1) VARIABLE IN PHASE I  
(EXPLORATORY TESTS)

ELEVATION

Fig 3 81-mm projectile test set-up  
(single projectile/fixture)

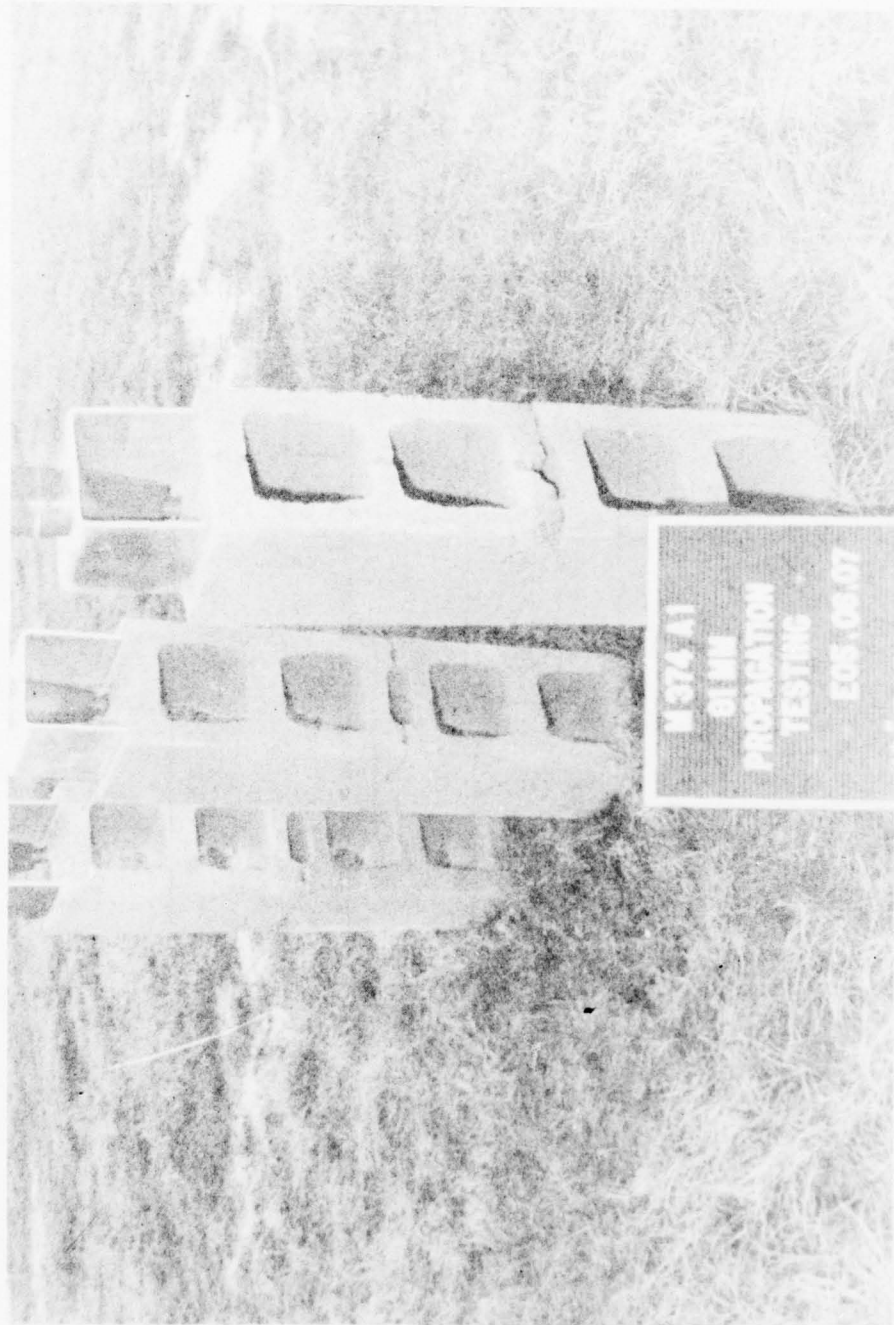


Fig 4 Single projectile safe separation distance test set-up prior to ignition

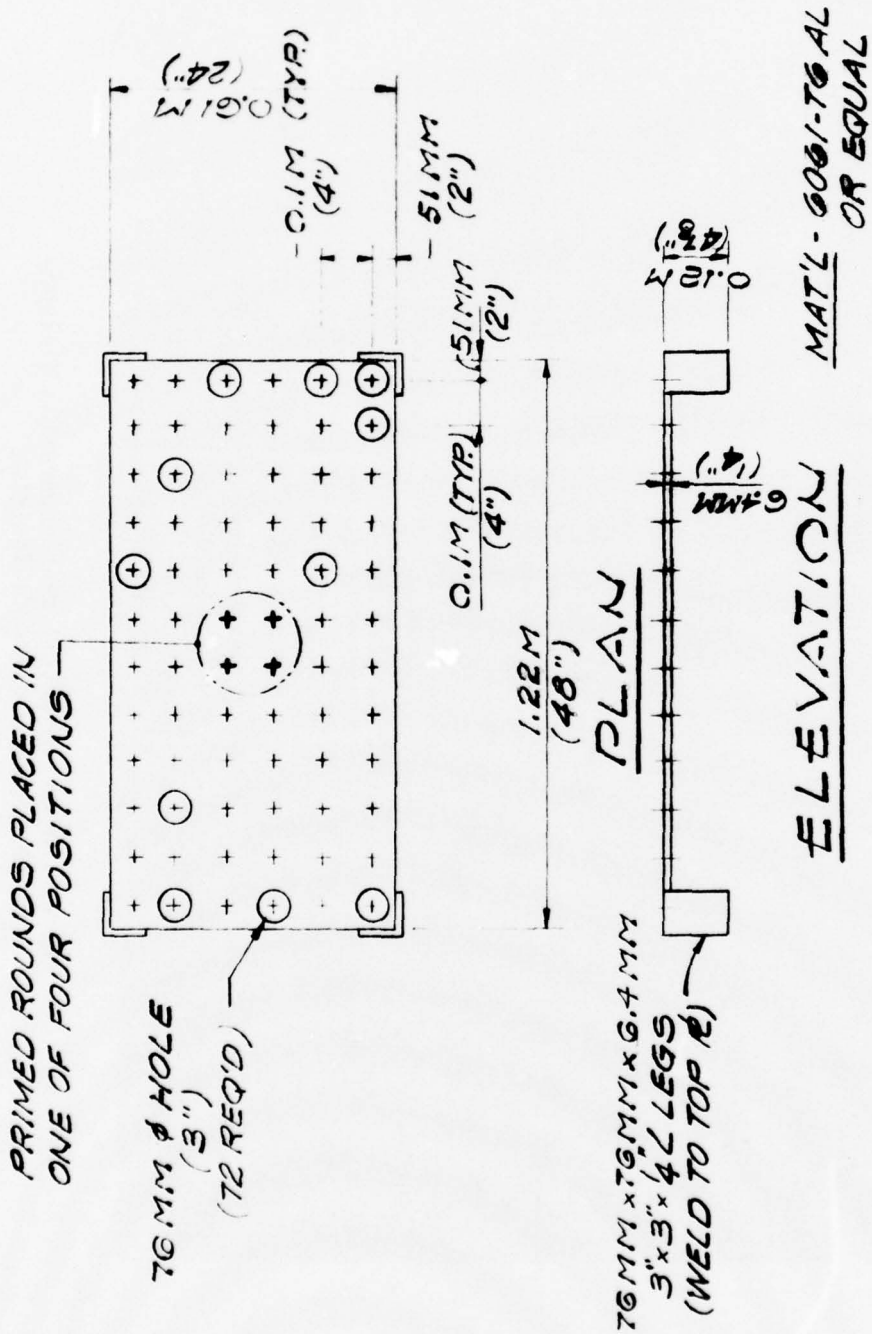


Fig 5 81-mm projectile support fixture (72 projectiles/fixture)

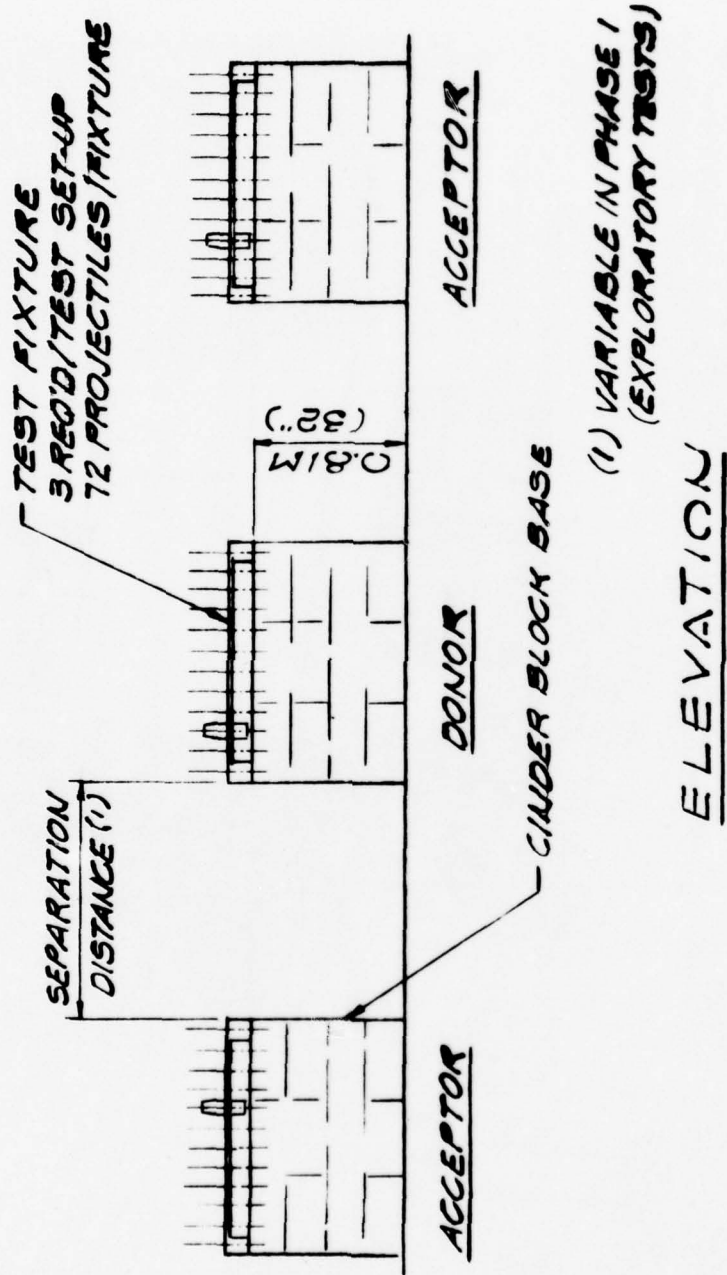


Fig 6 81-mm projectile test set-up  
(72 projectiles/fixture)

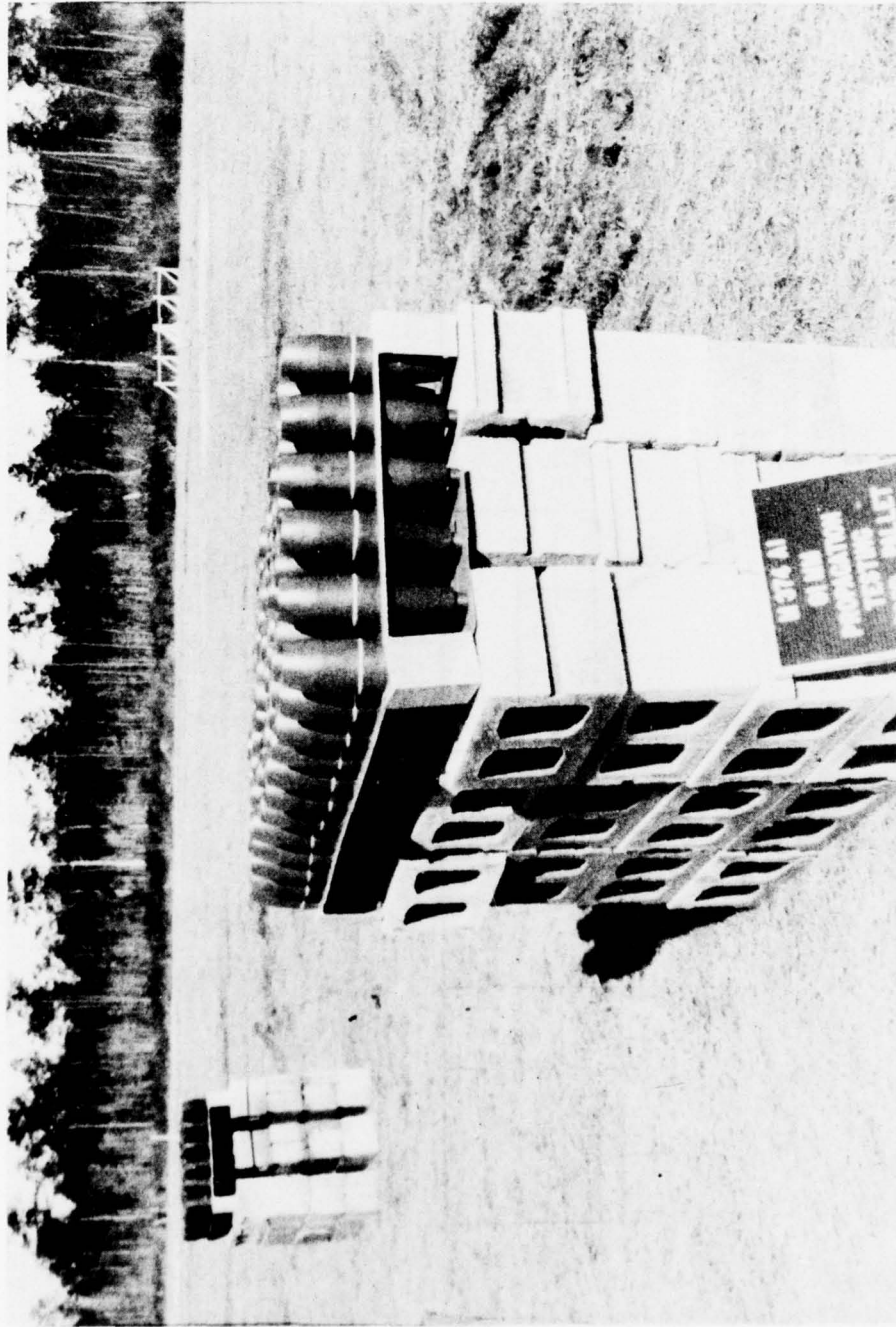


Fig 7 81-mm projectile in 72-round pallets in test configuration prior to ignition

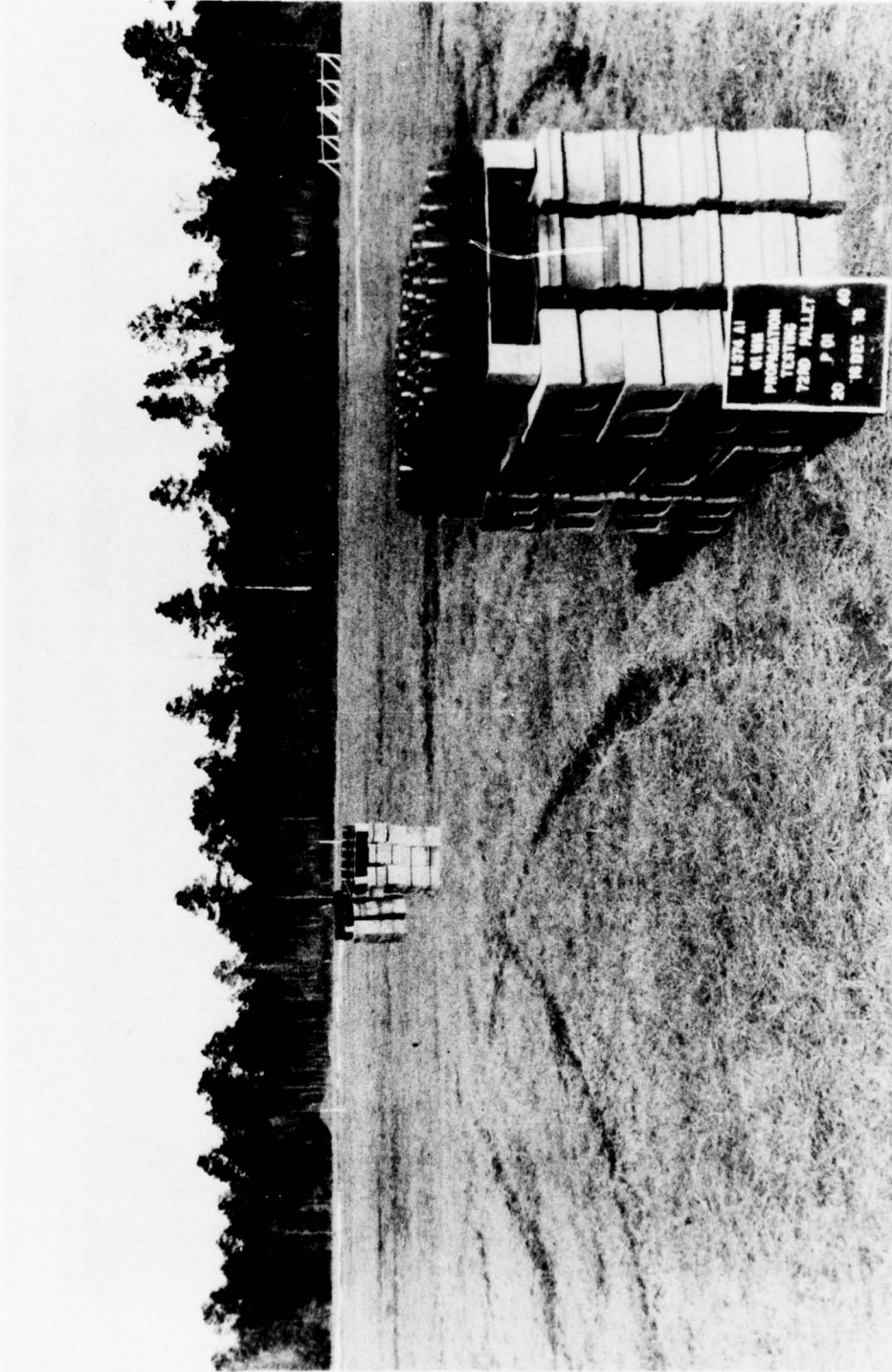


Fig 7A 81-mm projectile in 72-round pallets in test configuration prior to ignition



Fig 8 Single projectile post test results showing typical acceptors at 6-inch and 12-inch safe separation distances



Fig 9 Single projectile post-test results showing typical acceptors at the 24-inch safe separation distance



Fig 10 Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E44)



Fig 11 Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E45)



Fig 12 Single projectile post-test results showing typical fragment penetrations and case damage (Test No. E46)



Fig 13 Single projectile post-test results showing typical fragment penetrations and a pneumatically ruptured case from Test E36



Fig 14 Single projectile post-test results showing typical fragment penetrations and an acceptor projectile (on right with 60% of Composition B burned)

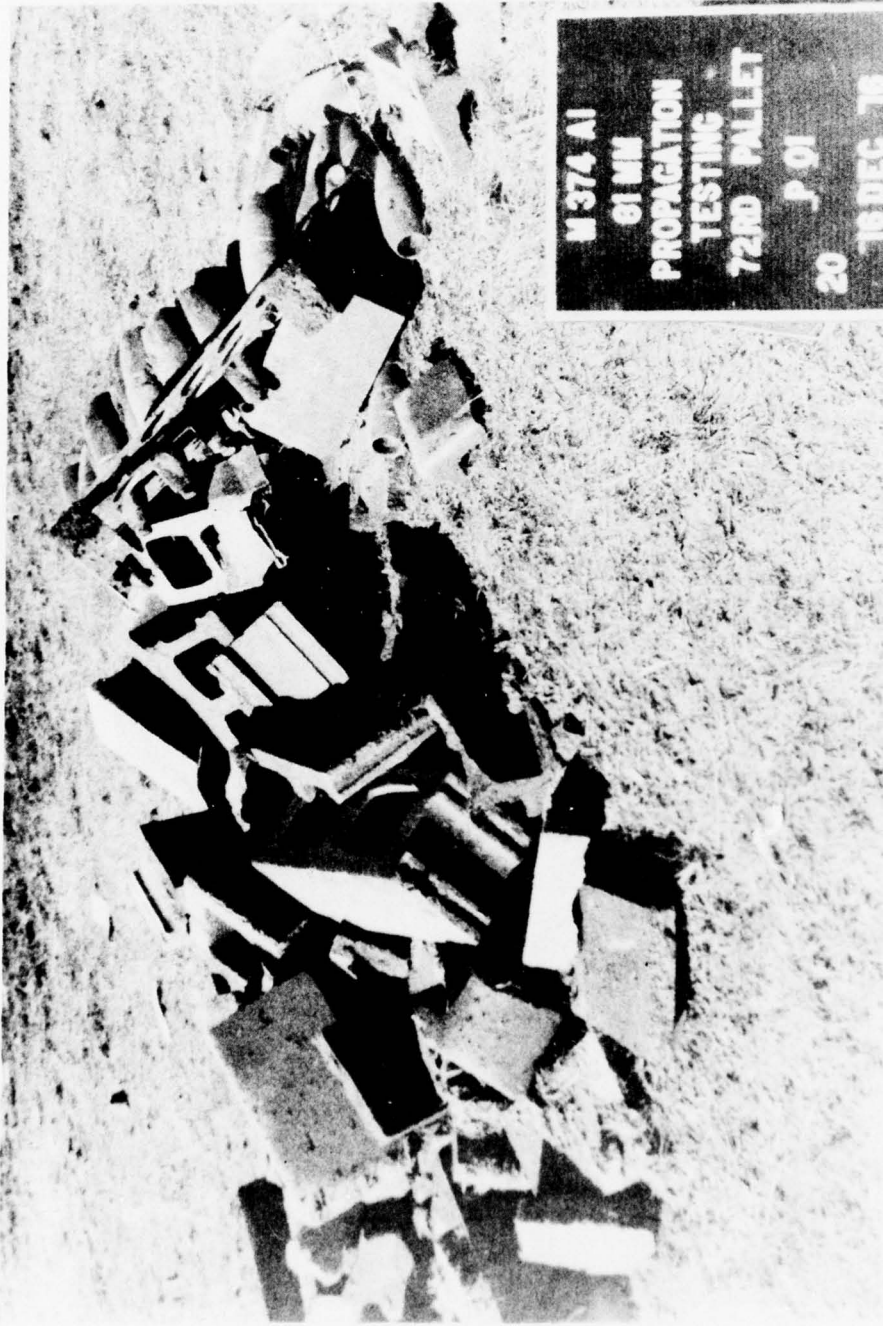


Fig 15 72-projectile acceptor pallet after test at 6.1-meter (20-foot) separation distance - propagation to detonation did not occur



Fig 16 72-projectile acceptor pallet after test at 3.05-meter  
(10-foot) separation distance - propagation did not occur



Fig 17 Typical donor crater after simultaneous detonation of 72 rounds



Fig 18 Typical 72-projectile acceptor pallet at the 9.14-meter (30-foot) safe separation distance after test

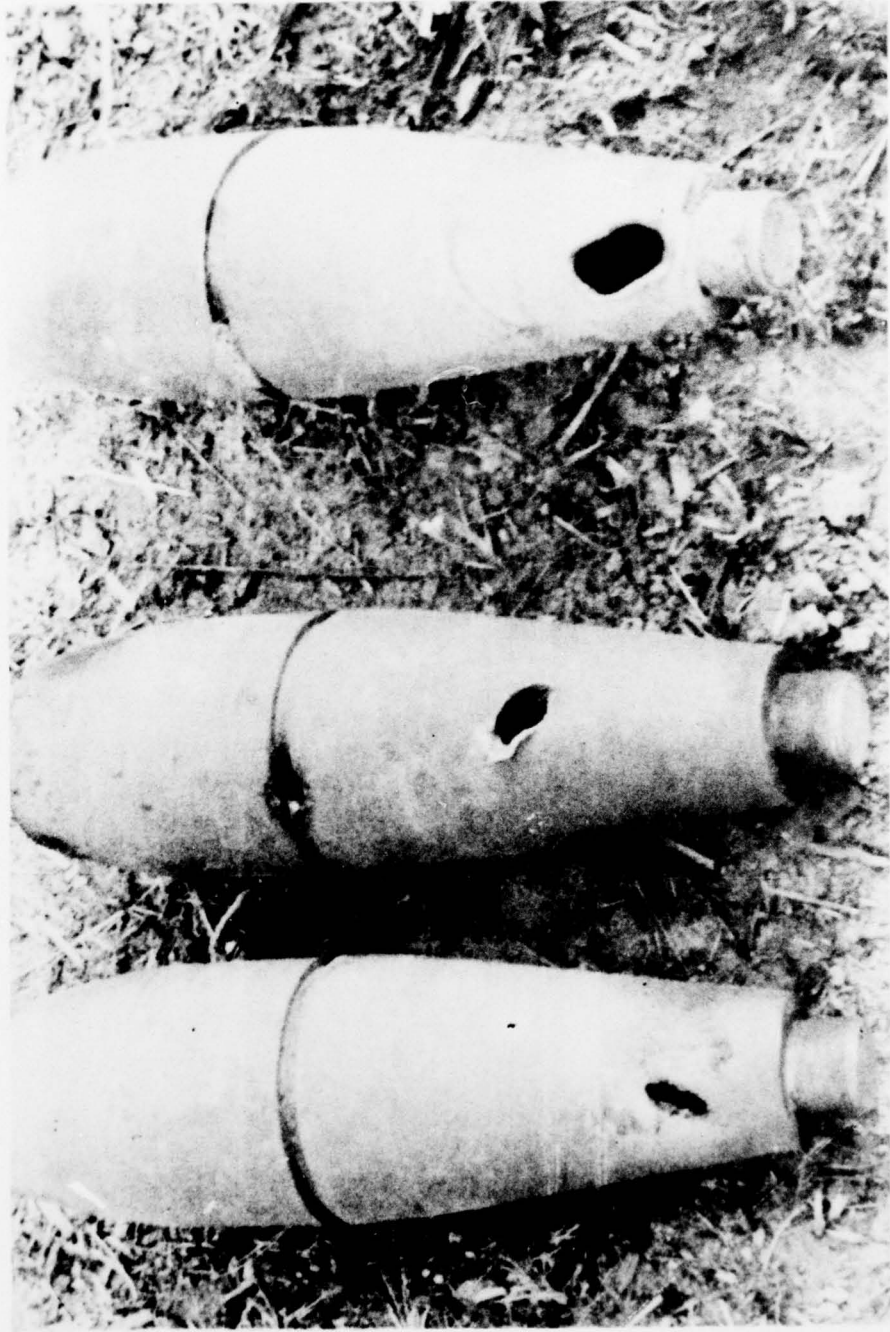


Fig 19 Typical acceptor projectiles at the 9.14-meter (30-foot) safe separation distance

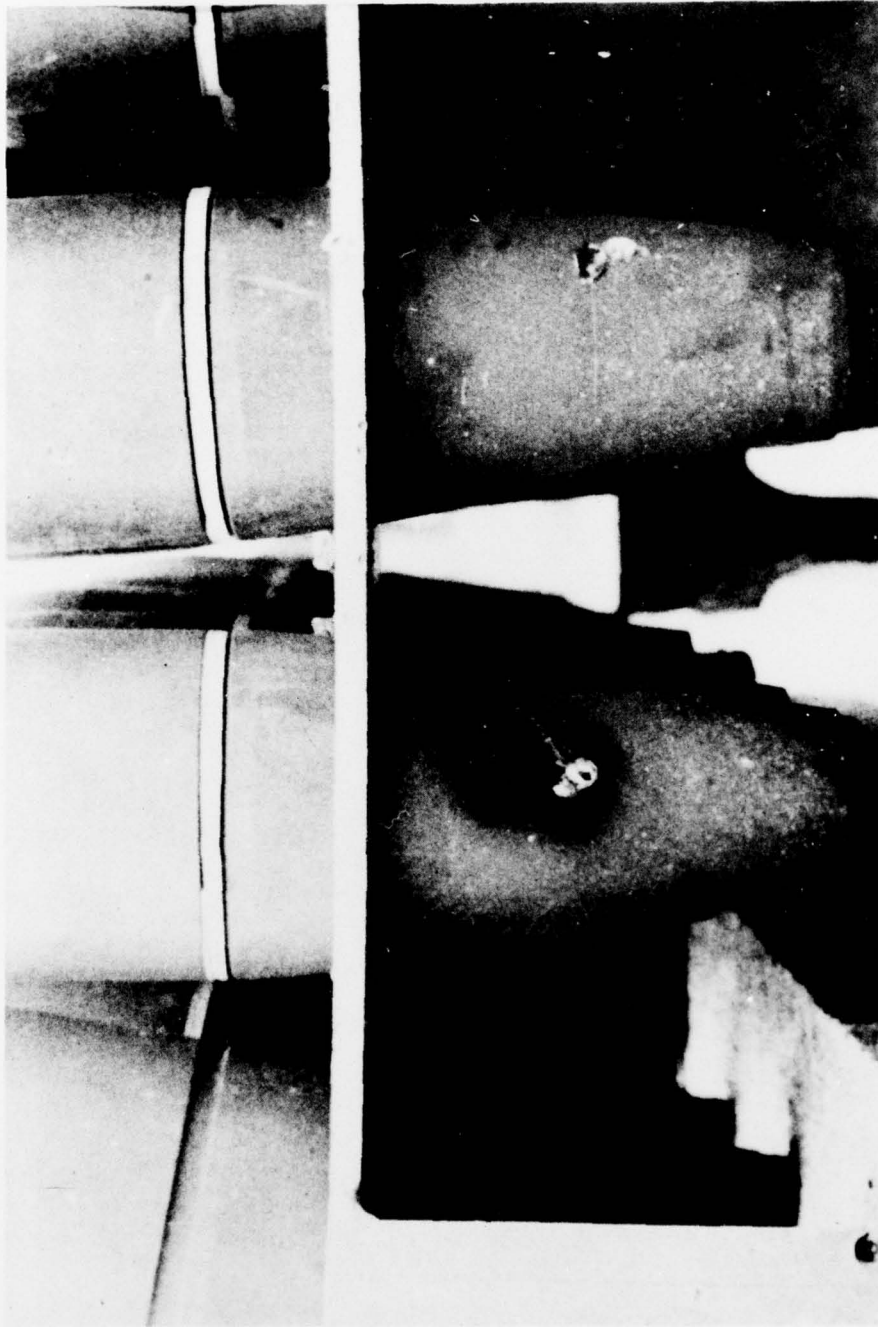


Fig 20 Typical acceptor projectile penetration (with partial burning) at the 9.14-meter (30-foot) safe separation distance

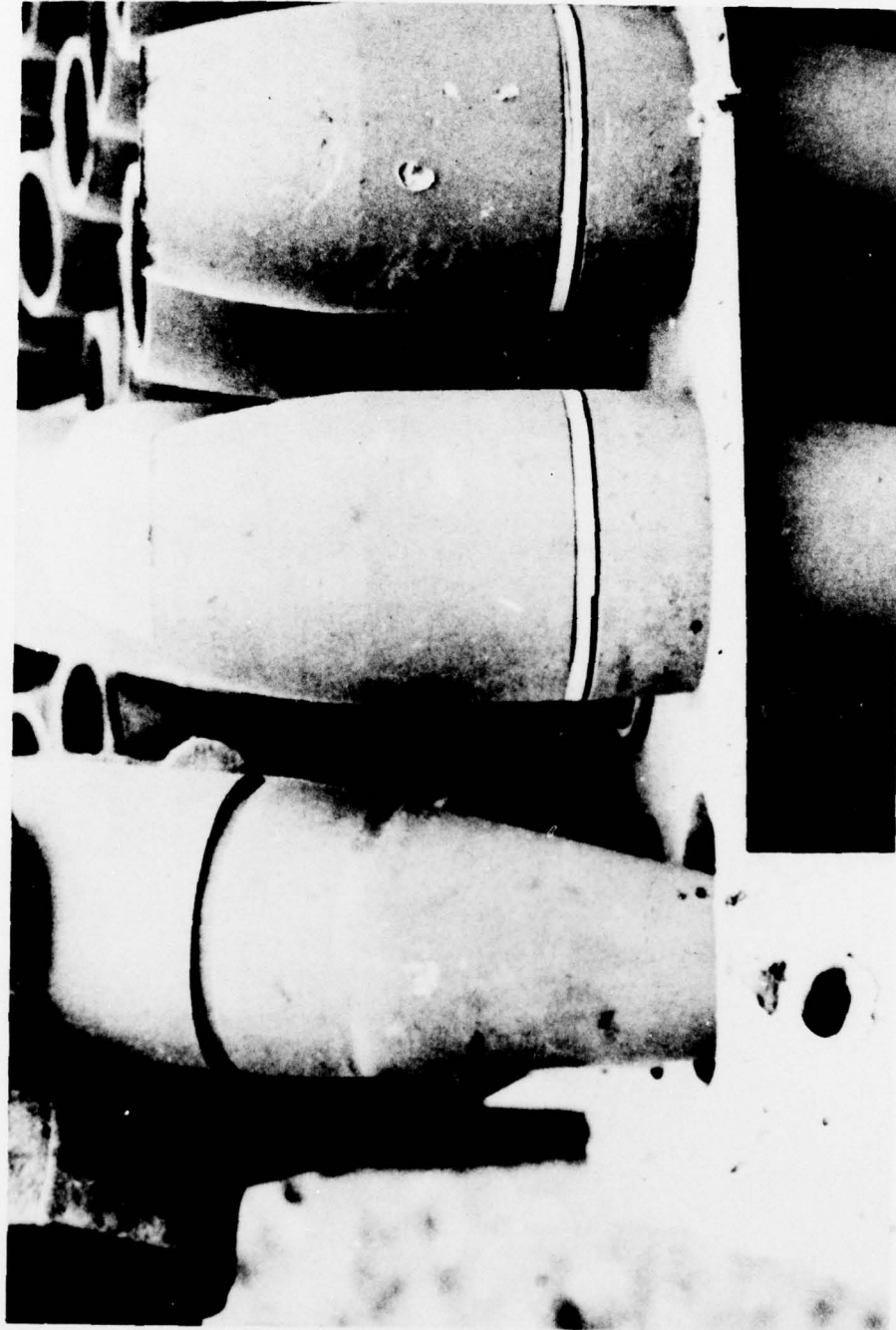
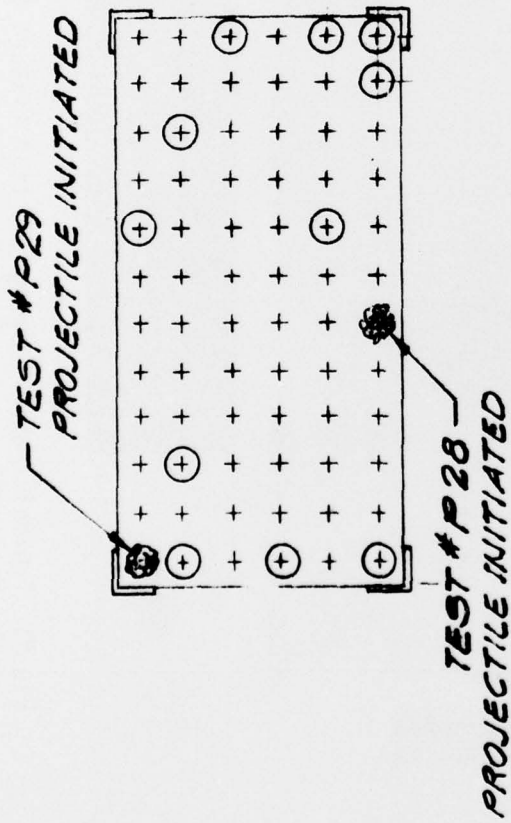


Fig 21 Typical fragment damage of test fixture and acceptor projectile at the 9.14-meter (30-foot) safe separation distance



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Fig 22 81-mm projectile support fixture  
(72 projectiles/fixture) -  
(Edge projectile initiated)

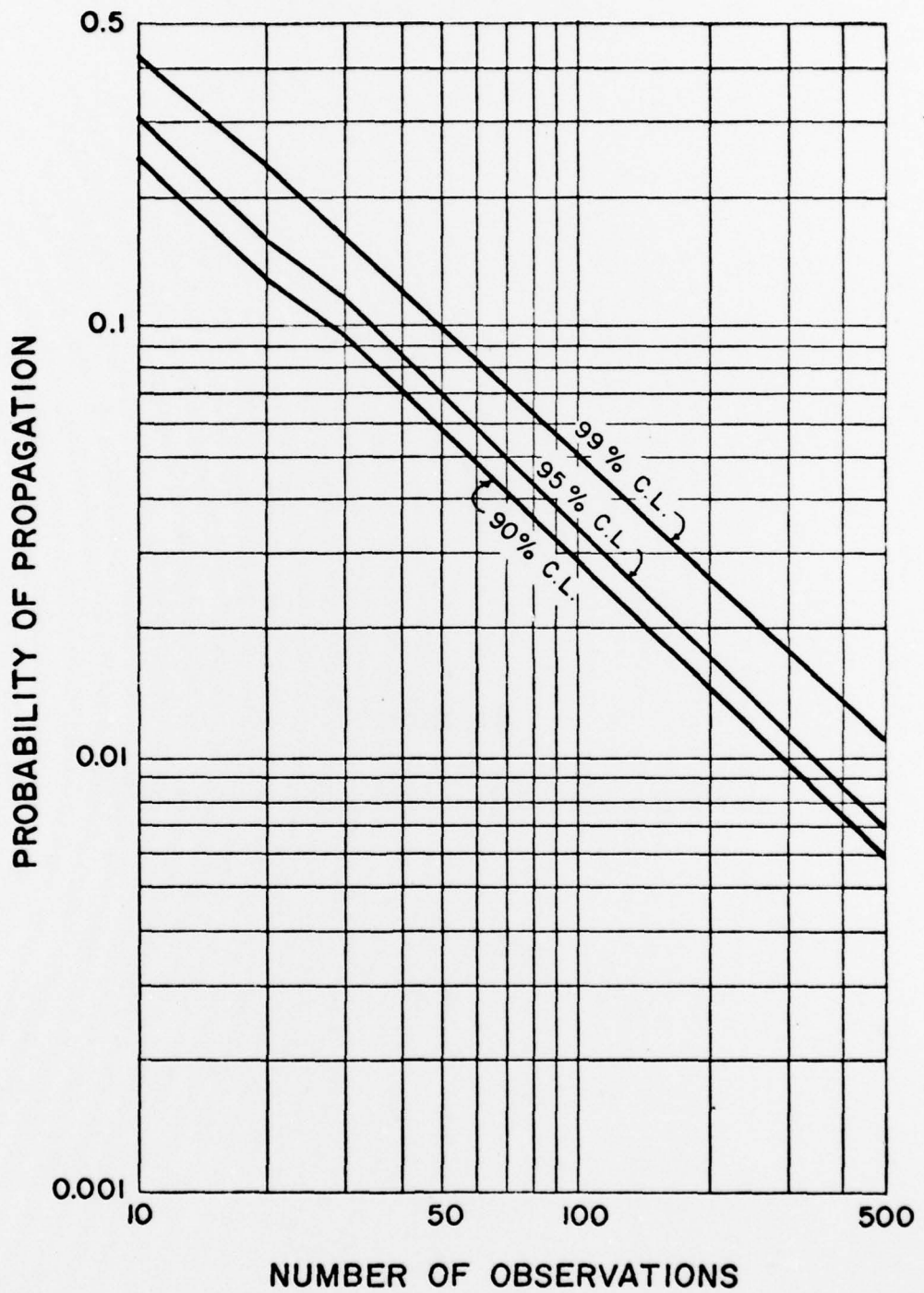


Fig 23 Variation of propagation probability versus number of observations as a function of confidence level

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:

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

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

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

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  $\alpha$ , when a reaction is not observed, is expressed as:

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

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 ( $\alpha$ ) = 95 percent

### Solution

1. Substitute the given value of ( $\alpha$ ) into Equation 4 and solve for  $\epsilon$ :

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

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

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

or

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

### 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 n	90 percent		95 percent		99 percent	
	P <sub>2</sub>	C.L. E(x)	P <sub>2</sub>	C.L. E(x)	P <sub>2</sub>	C.L. 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	0.010	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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