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MINIMUM NONPROPAGATION DISTANCE FOR 8-INCH M509 HE PROJECTILES.(U)
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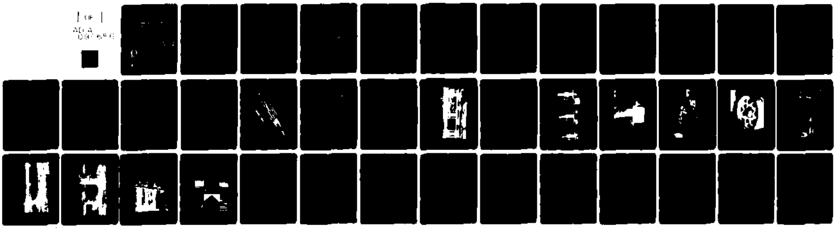

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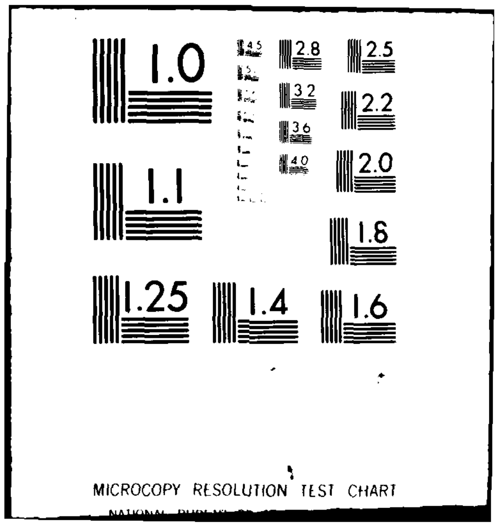
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TECHNICAL REPORT ARLCD-TR-81005

MINIMUM NONPROPAGATION DISTANCE FOR 8-INCH M509 HE PROJECTILES

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APRIL 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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18. SUPPLEMENTARY NOTES

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. (Continued)

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

8-inch 509 HE projectiles
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MMT-Ammunition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of the overall modernization and expansion of LAP (Load-Assembly-Pack) manufacturing explosive facilities, the Special Technology Branch, Energetic Systems Process Division, LCWSL of ARRADCOM, Dover, New Jersey, is presently engaged in the development of safety criteria in support of LAP facilities. One of these criteria is the safe separation distance between 8-inch M509 HE projectiles as they are transported along the production line. The actual test program consisted of a series of tests, each using three test specimens within their prototype transfer pallets, aligned in a straight line and elevated to simulate the (Continued)

20. ABSTRACT (Cont)

conveyor system. The test specimens were all mounted within prototype transfer pallets using V-shaped steel shielding. From these tests, it was concluded that the projectiles could be spaced 1.5 meters (5.0 feet) from each other.

18. SUPPLEMENTARY NOTES (Cont)

The exploratory test phase and basic reduction of the confirmatory test phase were accomplished by the National Space Technology Laboratories, Mississippi. The Hawthorne Army Ammunition Plant, Nevada was responsible for the execution of the confirmatory test data.

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INTRODUCTION

Background

At the present time an Army-wide expansion program is in process to modernize existing and develop new manufacturing and LAP (Load-Assemble-Pack) facilities for the handling of energetic materials and their related end items. This systematized effort will enable existing ammunition plants to achieve increased production cost effectiveness with improved contingency safety, as well as provide for the integrated capability of manufacturing new weaponry within existing facilities. As an integral component of the overall programming concept, the Special Technology Branch, Energetic Systems Process Division, LCWSL of ARRADCOM, Dover, N.J., under the direction of the Office of the Project Manager for Munitions Production Base Modernization and Expansion, is currently engaged in the development of safety criteria in direct responsive support of ammunition plant manufacturing and LAP operations.

An essential increment within this responsive effort, is the determination of the minimum safe separation (non-propagative) distance between 8-inch M509 HE projectiles (fig. 1) as they are transported from one loading station to the next, along a production-line conveyor.

Objective

The primary objective of this program is to establish and statistically confirm, through experimental evaluation, the safe non-propagative separation distance between 8-inch M509 HE projectiles as they progress along their production line and to develop statistically acceptable safety criteria for use in determining loading line spacing for existing and future ammunition plants that will be utilized in the manufacture of this projectile.

The overall program objective is to supplement and/or modify existing safety regulations and criteria pertaining to the safe spacing of ammunition and other energetic materials in order to assist explosive loading plants in their LAP facility layouts for the most effective and economic man-machine relationship.

Criteria

This test program was implemented in order to determine the safe spacing of 8-inch M509 HE projectiles under simulated loading plant conditions for the necessary shielding between projectiles, such that the effects of a major accidental detonation of a munition on the assembly line will be limited to the immediate area, or loading bay, and not be propagated to adjacent loading activities. Therefore, the only acceptable criteria in the establishment of safe separation distances is the nonpropagation of the donor detonation to the acceptor units. Since the 8-inch M509 HE projectile also contains a quantity of fuzed sub-projectiles (grenades), the safe spacing criteria contains an additional requirement of non-arming of acceptor projectile grenades.

Note that all safe separation distances specified within this report are measured between axial centerlines of the donor and acceptor units.

TEST CONFIGURATION

General

Testing of the 8-inch M509 HE projectile to establish and statistically confirm the minimum nonpropagative distance between donor and acceptor projectiles under simulated manufacturing line conditions was conducted at two locations. The exploratory testing phase of the program, utilizing live donors and inert acceptors, was performed at the National Space Technology Laboratories, Mississippi. The confirmatory test phase, with both live donors and acceptors, was carried out at the Hawthorne Army Ammunition Plant, Nevada, since there was a potential for acceptors to dispense live and armed grenades throughout the test area. Also, Hawthorne AAP had, on standby, a Navy Explosive Ordnance Disposal Team for test site decontamination.

After a facility review meeting on the 8-inch M509 HE projectile conducted by the munitions project manager, it was determined that the projectile's test conditions should be a vertical, base-up configuration. Also, in order to simulate closely the actual loading line conditions, the nose-located expelling charge was removed, along with the base plug and related padding, in order to fully expose the rearmost layer of sub-projectiles (M42 grenades). Finally, the projectile was to be tested within a prototype pallet that could be adapted to the various loading plants' production lines cross transfer-conveyor systems.

The actual test program consisted of the following two phases: an exploratory phase and a confirmatory phase. By varying the donor-to-acceptor centerline distances during the exploratory phase, the minimum non-propagation distance between adjacent projectiles could be established. Next, the confirmatory phase followed in which a sufficient number of tests were conducted, at the previously determined distance, to establish a statistical reliability of non-propagation at that distance.

Test Specimen

Each test specimen consisted of a single 8-inch M509 HE projectile contained in a vertical, base-up configuration within a prototype cross transfer-system pallet. The projectile (fig. 1) contains a total of 180 dual purpose M42 grenades arranged axially in 12 rows with 15 grenades to a row. The M42 grenades are groundburst sub-missiles which arm in the air and function upon impact, providing anti-materiel (shaped charge) and anti-personnel (fragmented body) capabilities. In normal operation, fuze functioning (in mid-air) initiates the ogive-located expulsion charge, shearing the base plate off and ejecting the entire grenade load from the rear of the projectile. A combination of the projectile's axial velocity and centrifugal force disperses the grenades along and away from the projectile's line of flight. The projectile's total weight is 93.0 kilograms (206.5 pounds) and contains 5.9 kilograms (13.1 pounds) of Composition A5 within the grenade load. As mentioned above, each test specimen had its expelling charge and base plug removed, and was inserted vertically, base end up, into a prototype transfer pallet.

Test Arrangements

1. Exploratory Phase

The exploratory phase of the 8-inch M509 HE projectile nonpropagation criteria program consisted of a series of tests, each utilizing three test specimens within their prototype transfer pallets, aligned in a straight line and elevated to simulate the conveyor system's standoff distance from the building floor (fig. 2). The center specimen serves as the donor or the projectile which is initiated to a compete high order detonation, while the two end specimens are the acceptor projectiles. This arrangement will produce two acceptor data points for each test firing performed.

During the exploratory test phase (in order to save time and program funds), inert projectiles were utilized as acceptor specimens. Potential propagation determinations were made based upon fragment impacts and/or penetrations of the acceptor projectile bodies. Also, the inert projectiles were ballasted to the weight of live-loaded projectiles in order to fully simulate the true loading-plant conditions. In addition, all three prototype pallets containing the test specimens for each test array were attached to a 2.5-centimeter (1.0-inch) thick steel rail assembly to simulate the conveyor confinement of the transfer pallets within the loading facility.

The prototype pallets, utilized within this non-propagation test program, had two types of shielding. Initially, the shielding was based upon that used on the prototype pallet for the 155mm M483 HE projectile and was just scaled up to fit the 8-inch M509 HE projectile's silhouette (fig. 3). Shielding was provided by a flat steel plate 112.0 centimeters (44.5 inches) high by 23.0 centimeters (9.0 inches) wide and 2.5 centimeters (1.0 inch) thick located at both ends of the prototype pallet. Figure 4 is a pre-test view of the test array, showing the prototype pallet with the flat, steel shields. A revised shield was designed after the flat, steel shielding proved to be totally inadequate in protecting the acceptor projectiles for the donor's high order detonation. The guideline distance of 1.5 meters (5.0 feet) is compatible with the equipment spacing at the existing loading facilities. The revised design utilized a V-shaped shield facing outward from the prototype pallet's center with the same axial silhouette dimensions as the previous shield and an angle of 130° between the legs of the "V" (fig. 5). Figure 6 is a pre-test view of the test array showing the prototype pallets with the V-shaped steel shield. Figures 7 and 8 are pre-test close-ups of the prototype pallet showing its construction details.

2. Confirmatory Phase

The confirmatory phase of the 8-inch M509 HE projectile's non-propagation criteria program consisted of a series of 25 tests yielding 50 data points. The test specimens were all mounted within prototype transfer pallets utilizing the V-shaped steel shielding.

3. Method of Initiation

The donor projectiles in every test were initiated to a high order detonation by using an M6 electric blasting cap. After all three test specimens were emplaced within their respective prototype transfer pallets, and their base plugs and related padding had been removed, the donor was primed. Priming the donor specimen consisted of replacing one of the grenades within the inner ring of the top(rear) row with an unfuzed grenade. The M6 blasting cap, utilizing a wooden guide dowel (fig. 9), was positioned over the lead cap assembly on the unfuzed grenade. In all cases, this initiation method produced a complete high order detonation of all the grenades within the donor projectile.

TEST RESULTS

General

The actual tests to determine the safe non-propagation separation distance between single 8-inch M509 HE projectiles were grouped into two test phases: exploratory and confirmatory. The exploratory test phase determined the type of shielding to be utilized on the prototype transfer pallet, as well as establishing a tentative separation distance, while the confirmatory test phase ran sufficiently similar tests to statistically determine the probability of the propagation of an explosive incident under the established conditions.

Exploratory Tests

The initial exploratory test configuration consisted of a single donor projectile and two acceptor projectiles arranged in a straight line, with each projectile contained within a prototype transfer pallet by 2.5-centimeter (1.0-inch) thick flat steel shields at either end (fig. 4). The separation distances used during the flat shielded prototype pallet exploratory tests ranged from 0.7 to 2.3 meters (2.3 to 7.3 feet) center-to-center distances. In Table 1, Tests Nos. E1 through E6 (inclusive) are an annotated tabulation of all 8-inch M509 HE projectile non-propagation tests that utilized the flat shields on the prototype transfer pallets. While there was no actual propagation of an explosive incident within these tests, there was sufficient acceptor (projectile and prototype pallet) damage observed to warrant discontinuance of the flat shield approach. Also, to continue to increase the spacing between the prototype pallets would lead to distances far in excess of the guideline distance of 1.5 meters (5.0 feet) for compatiblity with the equipment spacing within existing loading plants. Figure 10 is a post test view of a flat shielded pallet test wherein both acceptor pallets were severely damaged and one projectle was thrown 0.9 meter (3 feet) from its pallet. Figure 11 is another post test view in which one pallet was completely sheared off its base and destroyed.

The secondary exploratory test configuration also consisted of a single donor projectile and two acceptor projectiles arranged in a straight line with each projectile contained within a prototype transfer pallet (fig. 6); however, the shielding in this test series was a 2.5-centimeter (1.0-inch) thick V-shaped shield with the same axial silhouette dimensions as the flat shield and an angle of 130° between the legs of the "V". Tests of the V-shaped shielding on the prototype pallets were only conducted at the 1.5-meter (5.0-foot) separation distance since that is the equipment spacing distance within the loading plants. In Table 1, Tests Nos. E7, E8 and E9 are an annotated tabulation of all the exploratory non-propagation testing of 8-inch M509 HE projectiles, utilizing the V-shaped shielding. In all three tests, not only was there no propagation of the initiated explosive incident, but there were no indications of major damage to either the prototype pallet or its contained projectile, as seen in the following figures. Figure 12 is a general post test view of a typical functioning in which the donor pallet is fully destroyed without any damage to the acceptor pallets and Figure 13 is a close-up post test view of a V-shaped shielded pallet, again not showing any major damage. Figure 14 is a post test close-up of a V-shaped shield. Note the fragment hits; there were no penetrations, nor any other form of damage.

To reiterate, it should be noted that all the exploratory phase testing was conducted with inert projectiles, which not only allowed for their reuse, but also allowed the performance of tests at sites they would normally be banned from, due to area contamination. Therefore, determination of non-propagation was based upon acceptor projectile fragment impacts and/or penetrations.

Confirmatory Tests

The confirmatory test phase of this safe separation distance study program contained 25 test detonations, again utilizing the one-donor, two-acceptor technique, this time with live projectiles in all three locations, thus producing a total of 50 data points for analysis. The basic data is presented in Table 1, Tests Nos. C10 through C34 inclusive, with all tests utilizing V-shielded prototype pallet and being conducted at a center-to-center distance of 0.9 meter (5.0 feet) between donor and acceptor projectile. Not only was there no damage (penetrations or impacts) to the acceptor projectiles, but there was not a single spillage of projectile submunitions.

Analysis of Test Results

During the exploratory test phase, the following two types of prototype pallet shields were examined: a flat plate and a V-shaped design. As the data in Table 1 clearly indicates, the flat plate shield was totally inadequate at separation distances far in excess of those compatible with equipment spacing at existing loading plants; therefore, testing and consideration of the flat plate shield were discontinued. Testing of the second shield design (the V-shaped) proved to be successful, in that during all of the tests conducted there were neither propagation nor grenade spillage.

Variations in manufacturing tolerances, materials, wear, etc., require that statistical reasoning be enlisted in the interpretation of the established non-propagation distance test data. The actual probability of the propagation of an explosive incident is dependent upon the confidence level desired, and has lower and upper limits. The lower limit for all confidence levels is zero, whereas the upper or practical limit is a function of the number of observations or test data points available for analysis (see Appendix for statistical theory). In the confirmatory testing of the 8-inch M509 HE projectile contained within the prototype pallet having V-shaped shields, the upper limit of the probability of propagation of an explosive incident is 6.2% at the 95% confidence level. This is equivalent to stating that in a large number of tests, 95 out of 100 times, the probability of propagation of an explosive incident will be less than, or equal to, the 6.2% value. This is an indication of the quality of the tests and the reliability that can be placed upon the conclusion drawn from the testing (fig. 15).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It may be concluded from the confirmatory results shown in Table 1 that 8-inch M509 HE projectiles contained within prototype pallets with V-shielding (fig. 5) can be positioned with a 1.5-meter (5.0-foot) center-to-center distance between projectiles without a significant chance of propagation of an explosive incident. Also, the rigidity of the prototype pallet is sufficient to prevent major grenade spills and the resultant hazard of secondary sub-projectile detonations.

Recommendations

Based upon the results of the 8-inch M509 HE projectile's safe non-propagation separation distance tests, it is recommended that the V-shield pallet design be considered as a prototype and those loading facilities, either in operation or being planned, consider adaptation of the prototype pallet design to their line layouts.

Table 1. 8-inch M509 HE projectile non-propagation test data

Test No.	Separation distance m	(ft)	Shield design	Results
E1 L[a]	0.7	(2.3)	Flat	Projectile thrown 106 ft, pallet destroyed
E1 R	0.7	(2.3)	Flat	Projectile thrown 117 ft, pallet severely damaged
E2 L	0.7	(2.3)	Flat	Projectile thrown 129 ft, pallet severely damaged
E2 R	0.7	(2.3)	Flat	Projectile thrown 63 ft, pallet severely damaged
E3 L	2.3	(7.3)	Flat	Projectile and pallet severely damaged
E3 R	2.3	(7.3)	Flat	Projectile and pallet severely damaged
E4 L	1.6	(5.3)	Flat	Projectile thrown 3 ft, pallet severely damaged
E4 R	1.6	(5.3)	Flat	Projectile and pallet severely damaged
E5 L	1.5	(5.0)	Flat	Projectile thrown 3 ft, pallet destroyed
E5 R	1.5	(5.0)	Flat	Projectile thrown 51 ft, pallet destroyed
E6 L	1.5	(5.0)	Flat	Projectile and pallet destroyed
E6 R	1.5	(5.0)	Flat	Projectile and pallet destroyed
E7 L	1.5	(5.0)	Vee	Projectile and pallet undamaged
E7 R	1.5	(5.0)	Vee	Projectile and pallet undamaged
E8 L	1.5	(5.0)	Vee	No damage
E8 R	1.5	(5.0)	Vee	No damage
E9 L	1.5	(5.0)	Vee	No damage
E9 R	1.5	(5.0)	Vee	No damage

[a]"E" refers to Exploratory Testing with inert acceptor; "L" and "R" refer to left and right acceptors, respectively.

Table 1. (Cont)

Test No.	Separation distance m	(ft)	Shield design	Results
C10 L[b]	1.5	(5.0)	Vee	NDP[c]
C10 R	1.5	(5.0)	Vee	NDP
C11 L	1.5	(5.0)	Vee	NDP
C11 R	1.5	(5.0)	Vee	NDP
C12 L	1.5	(5.0)	Vee	NDP
C12 R	1.5	(5.0)	Vee	NDP
C13 L	1.5	(5.0)	Vee	NDP
C13 R	1.5	(5.0)	Vee	NDP
C14 L	1.5	(5.0)	Vee	NDP
C14 R	1.5	(5.0)	Vee	NDP
C15 L	1.5	(5.0)	Vee	NDP
C15 R	1.5	(5.0)	Vee	NDP
C16 L	1.5	(5.0)	Vee	NDP
C16 R	1.5	(5.0)	Vee	NDP
C17 L	1.5	(5.0)	Vee	NDP
C17 R	1.5	(5.0)	Vee	NDP
C18 L	1.5	(5.0)	Vee	NDP
C18 R	1.5	(5.0)	Vee	NDP
C19 L	1.5	(5.0)	Vee	NDP
C19 R	1.5	(5.0)	Vee	NDP
C20 L	1.5	(5.0)	Vee	NDP
C20 R	1.5	(5.0)	Vee	NDP

[b]"C" refers to Confirmatory Testing with live load acceptor; "L" and "R" refer to left and right acceptors, respectively.

[c]NDP - No Detonation Propagation.

Table 1. (Cont)

Test No.	Separation distance m	(ft)	Shield design	Results
C21 L	1.5	(5.0)	Vee	NDP
C21 R	1.5	(5.0)	Vee	NDP
C22 L	1.5	(5.0)	Vee	NDP
C22 R	1.5	(5.0)	Vee	NDP
C23 L	1.5	(5.0)	Vee	NDP
C23 R	1.5	(5.0)	Vee	NDP
C24 L	1.5	(5.0)	Vee	NDP
C24 R	1.5	(5.0)	Vee	NDP
C25 L	1.5	(5.0)	Vee	NDP
C25 R	1.5	(5.0)	Vee	NDP
C26 L	1.5	(5.0)	Vee	NDP
C26 R	1.5	(5.0)	Vee	NDP
C27 L	1.5	(5.0)	Vee	NDP
C27 R	1.5	(5.0)	Vee	NDP
C28 L	1.5	(5.0)	Vee	NDP
C28 R	1.5	(5.0)	Vee	NDP
C29 L	1.5	(5.0)	Vee	NDP
C29 R	1.5	(5.0)	Vee	NDP
C30 L	1.5	(5.0)	Vee	NDP
C30 R	1.5	(5.0)	Vee	NDP
C31 L	1.5	(5.0)	Vee	NDP
C31 R	1.5	(5.0)	Vee	NDP
C32 L	1.5	(5.0)	Vee	NDP
C32 R	1.5	(5.0)	Vee	NDP
C33 L	1.5	(5.0)	Vee	NDP
C33 R	1.5	(5.0)	Vee	NDP
C34 L	1.5	(5.0)	Vee	NDP
C34 R	1.5	(5.0)	Vee	NDP

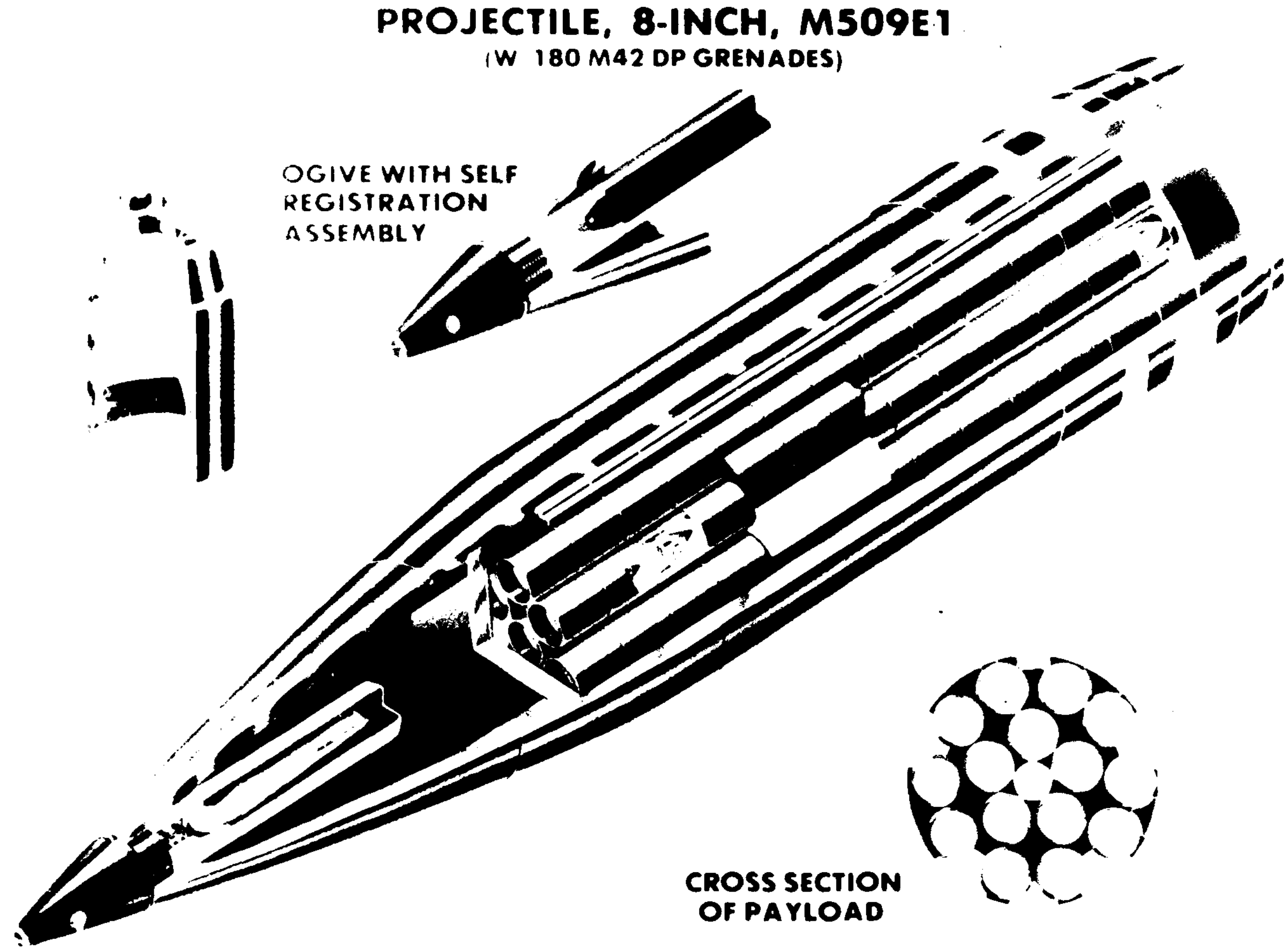

Figure 1. 8-inch M509 HE projectile, cross-sectional view.

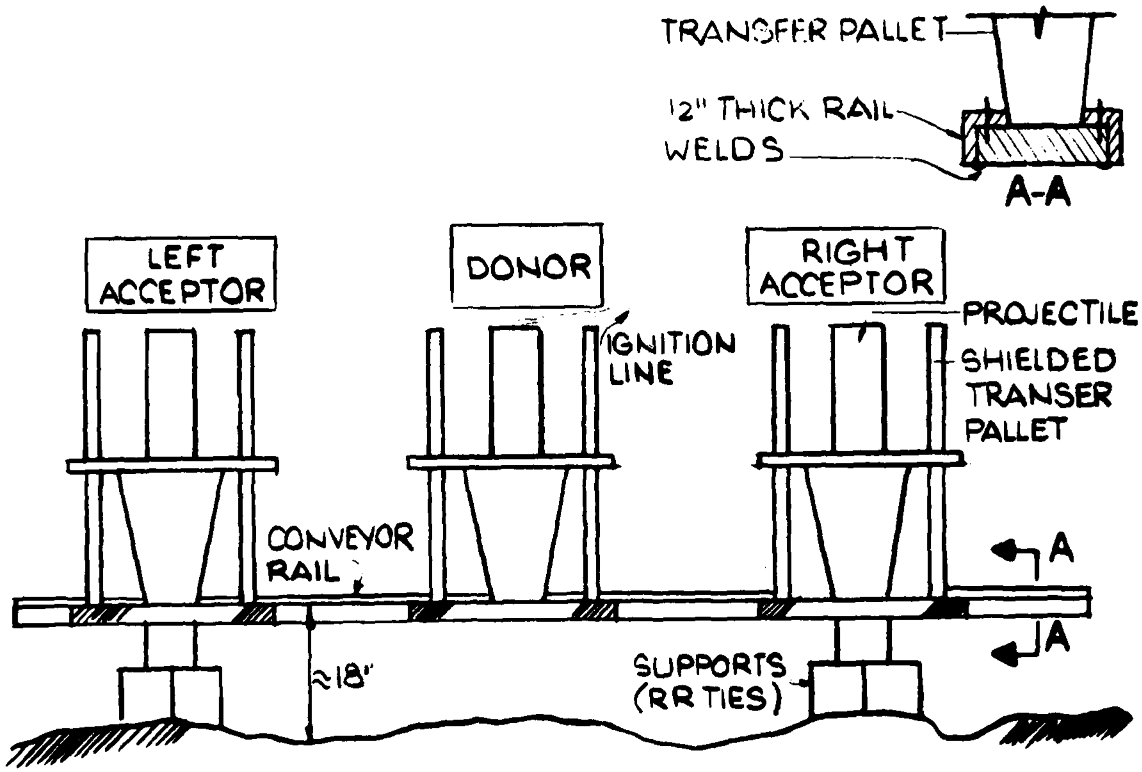

Figure 2. Non-propagation, general test array.

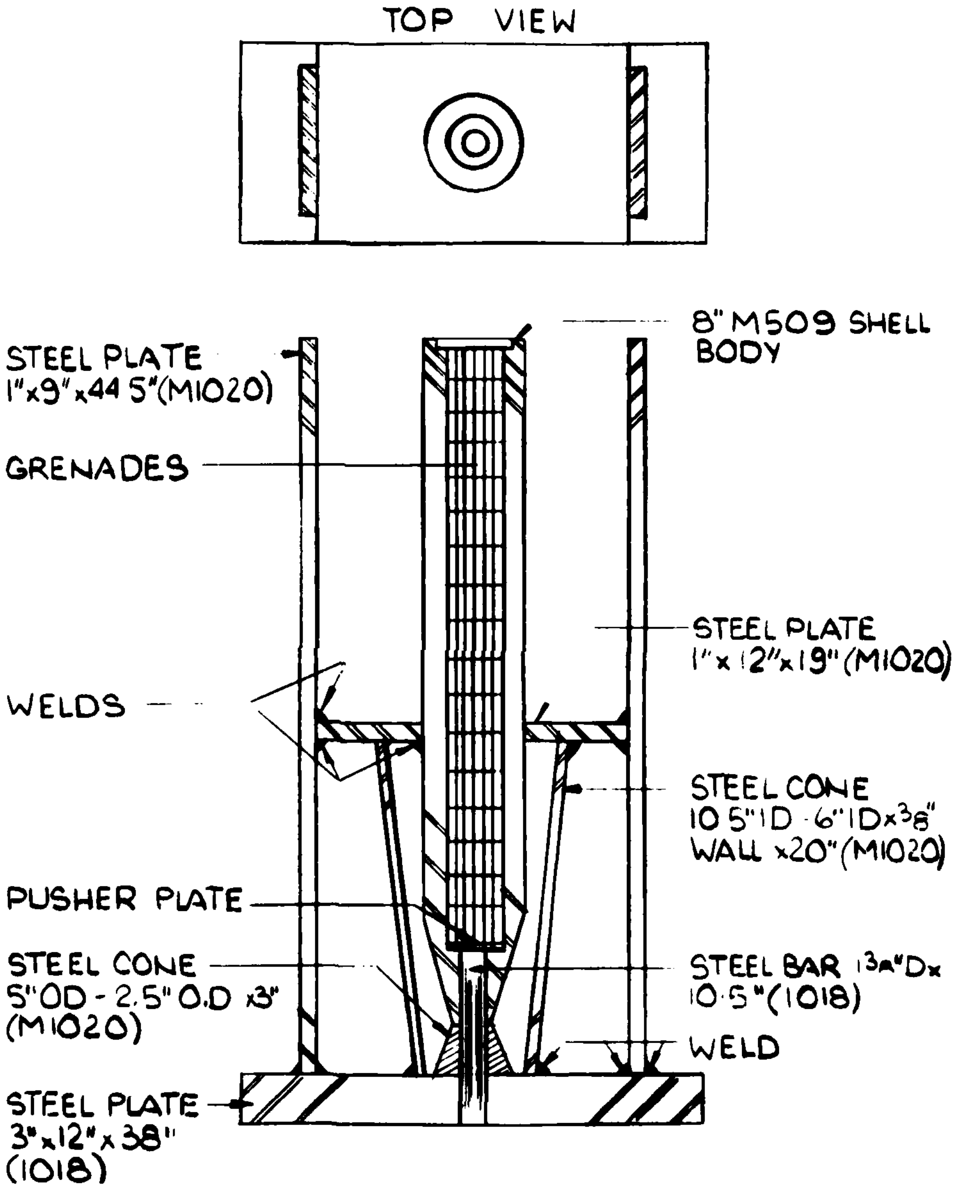

Figure 3. Prototype transfer pallet with flat shields.

Figure 4. Flat shielded test array.

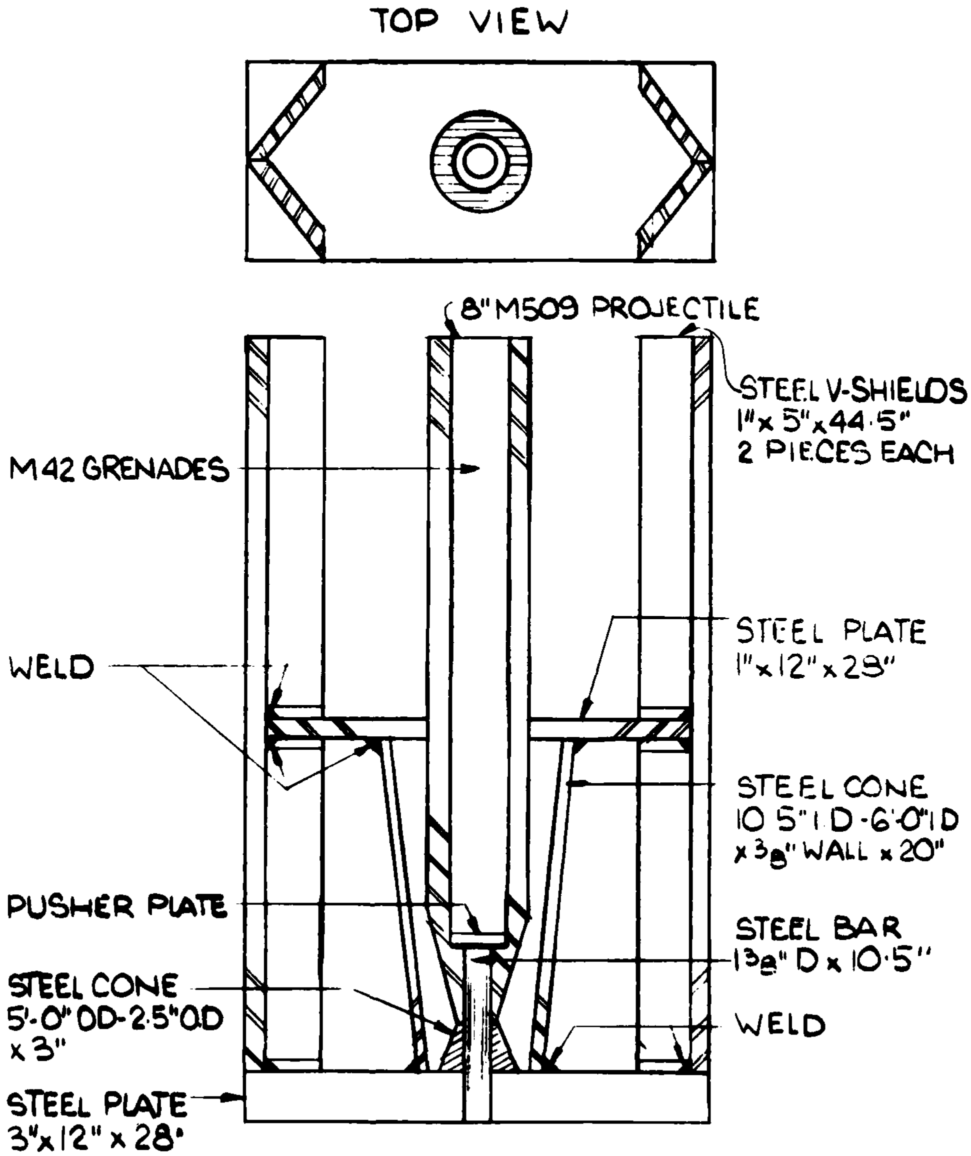

Figure 5. Prototype transfer pallet with V-shields.

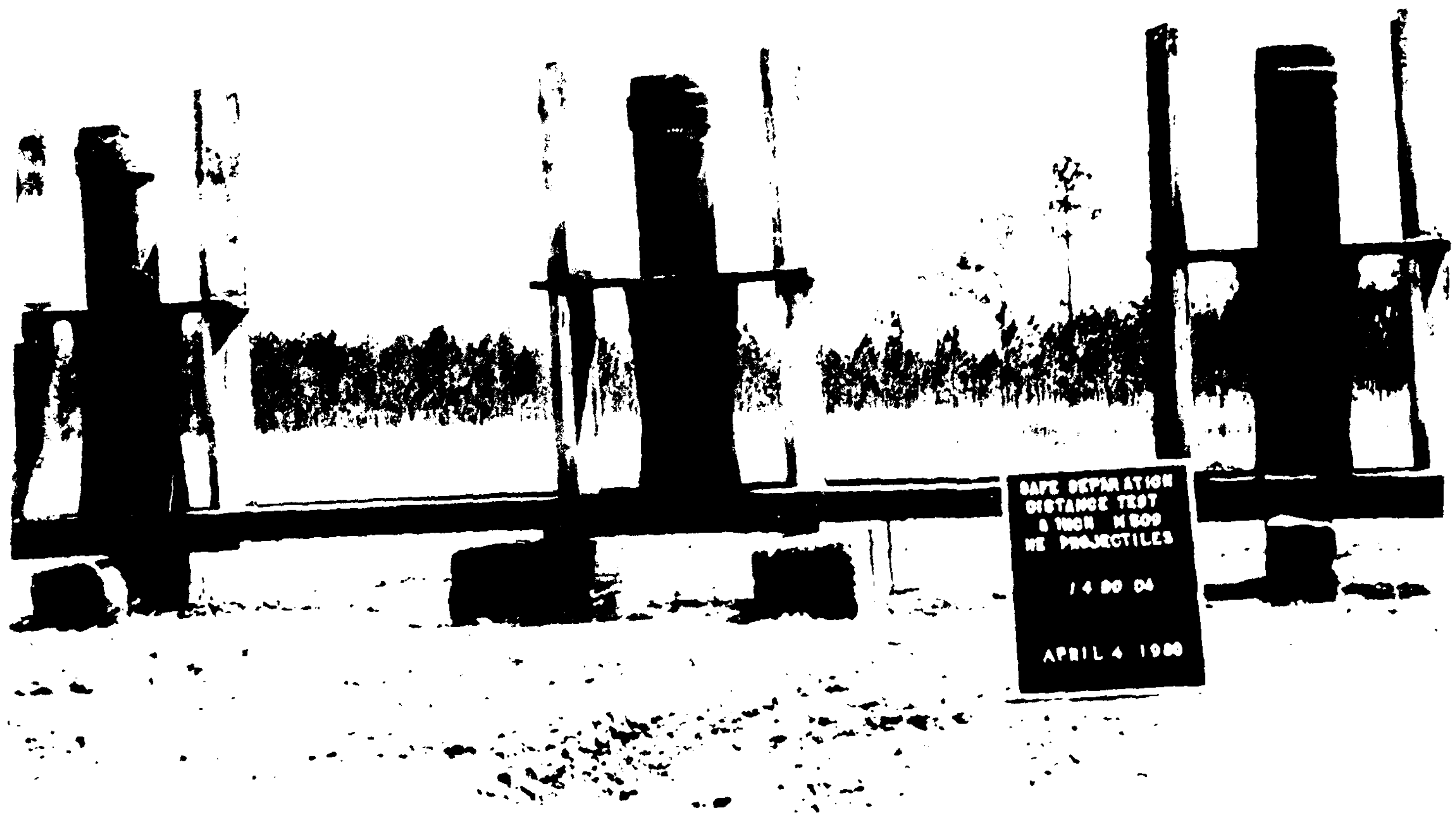

Figure 6. V-shielded test array.

Figure 7. V-shielded pallet, close-up view.

Figure 8. V-shield, close-up view.

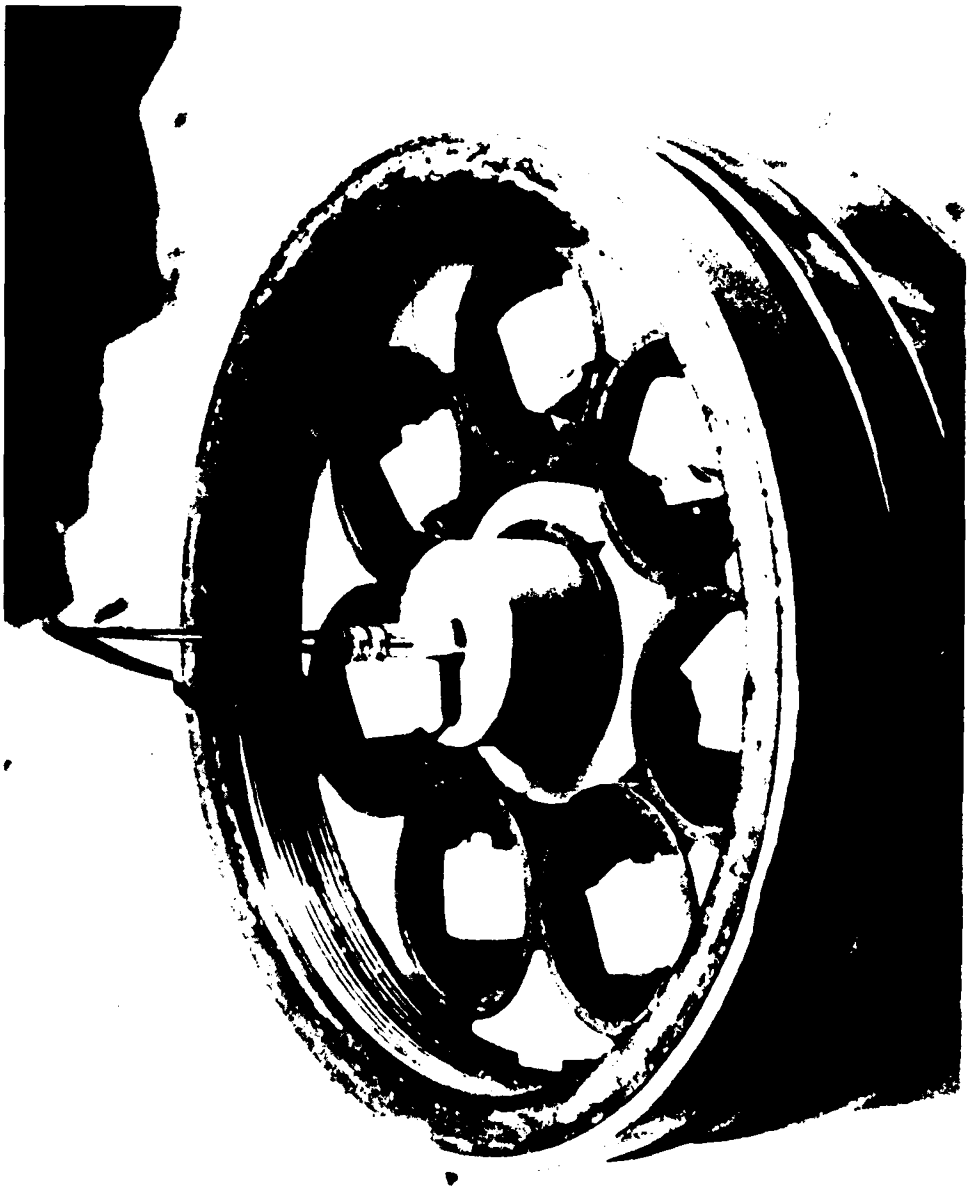

Figure 9. Donor ignition system.

Figure 10. Flat-shielded pallet, post-test view, with damaged pallets.

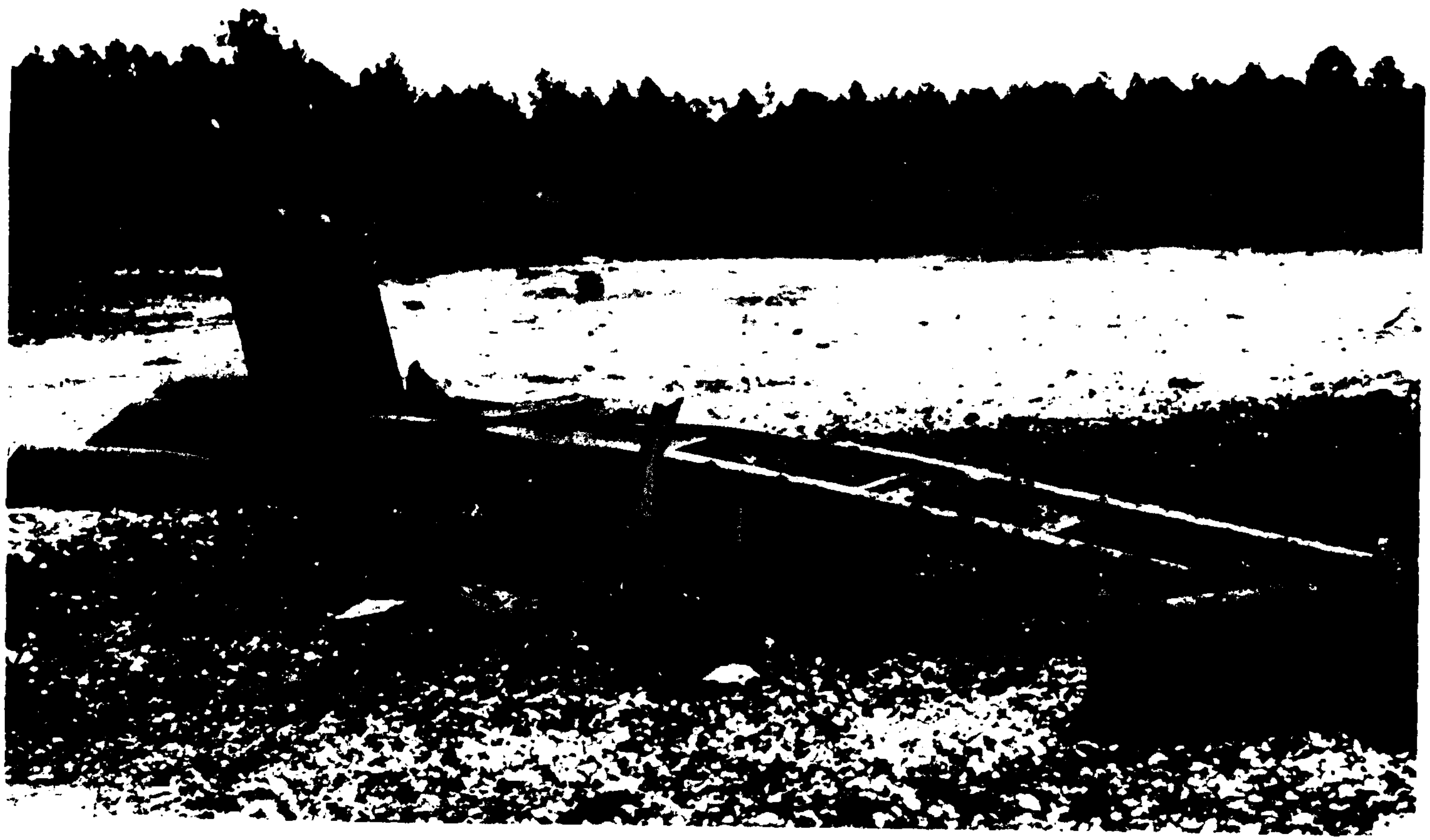

Figure 11. Flat-shielded pallet, post-test view, with destroyed pallets.

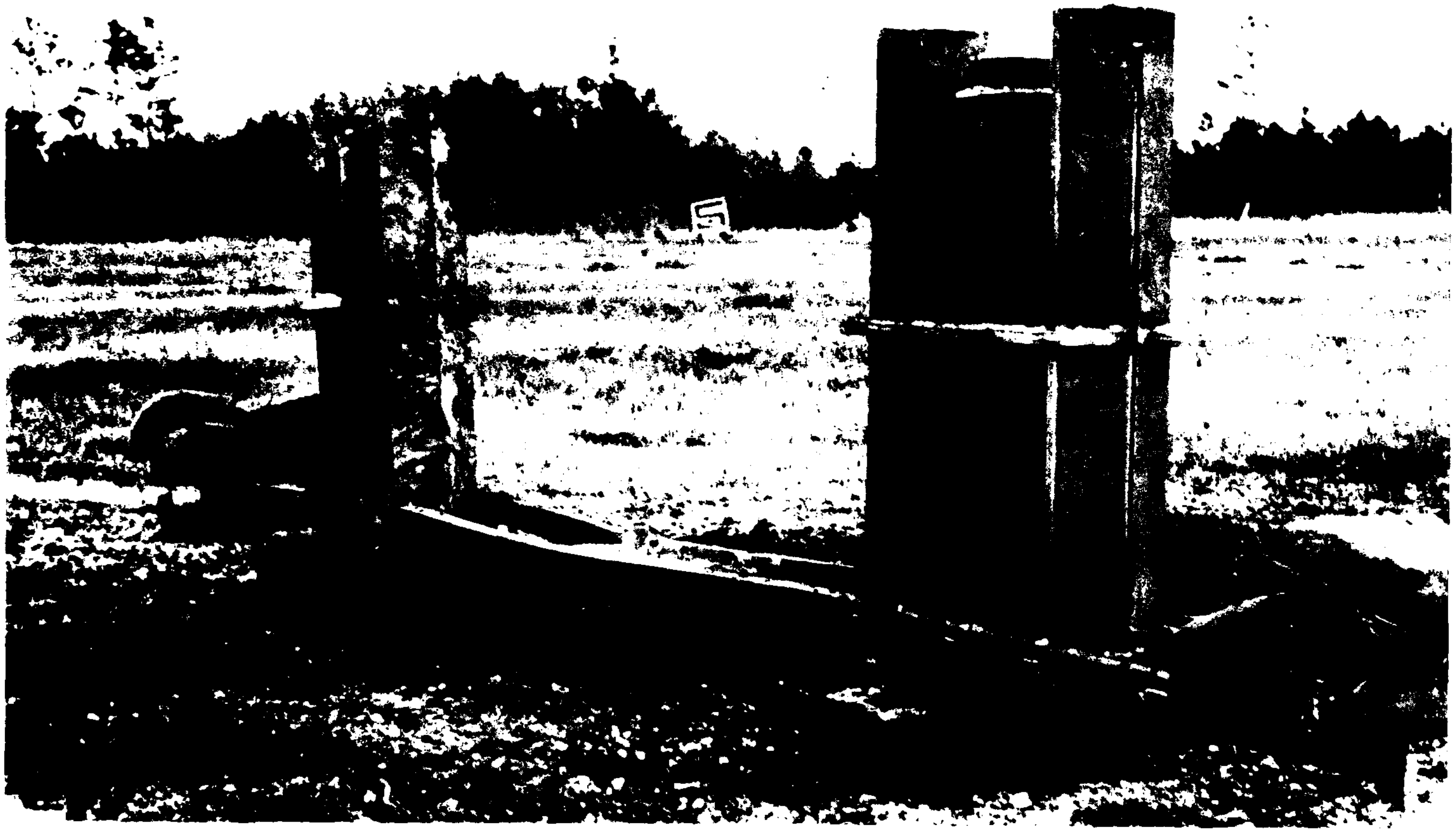

Figure 12. V-shielded pallet, post-test view.

Figure 13. V-shielded pallet, post-test view, pallet close-up.

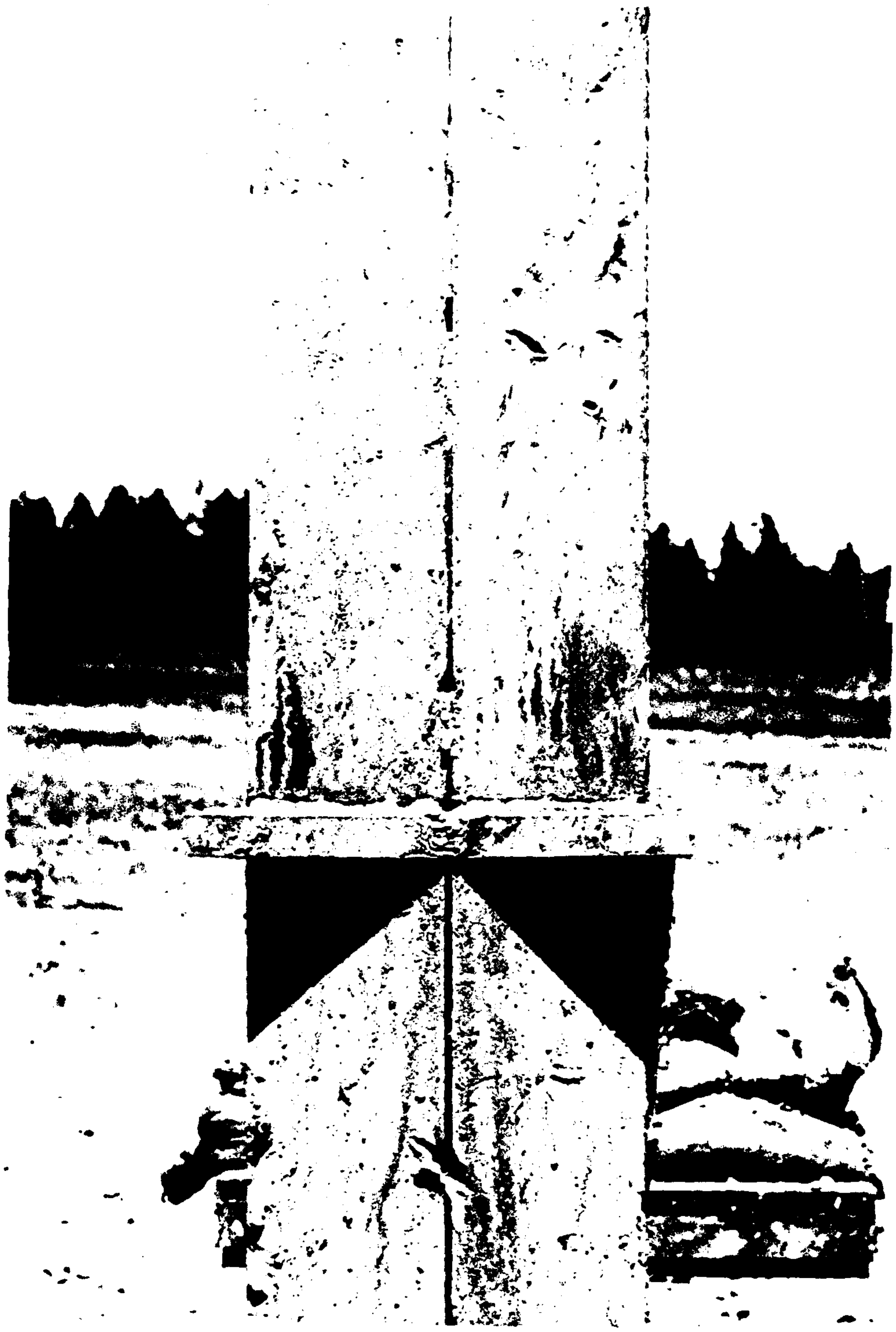

Figure 14. V-shield, post-test view, close-up.

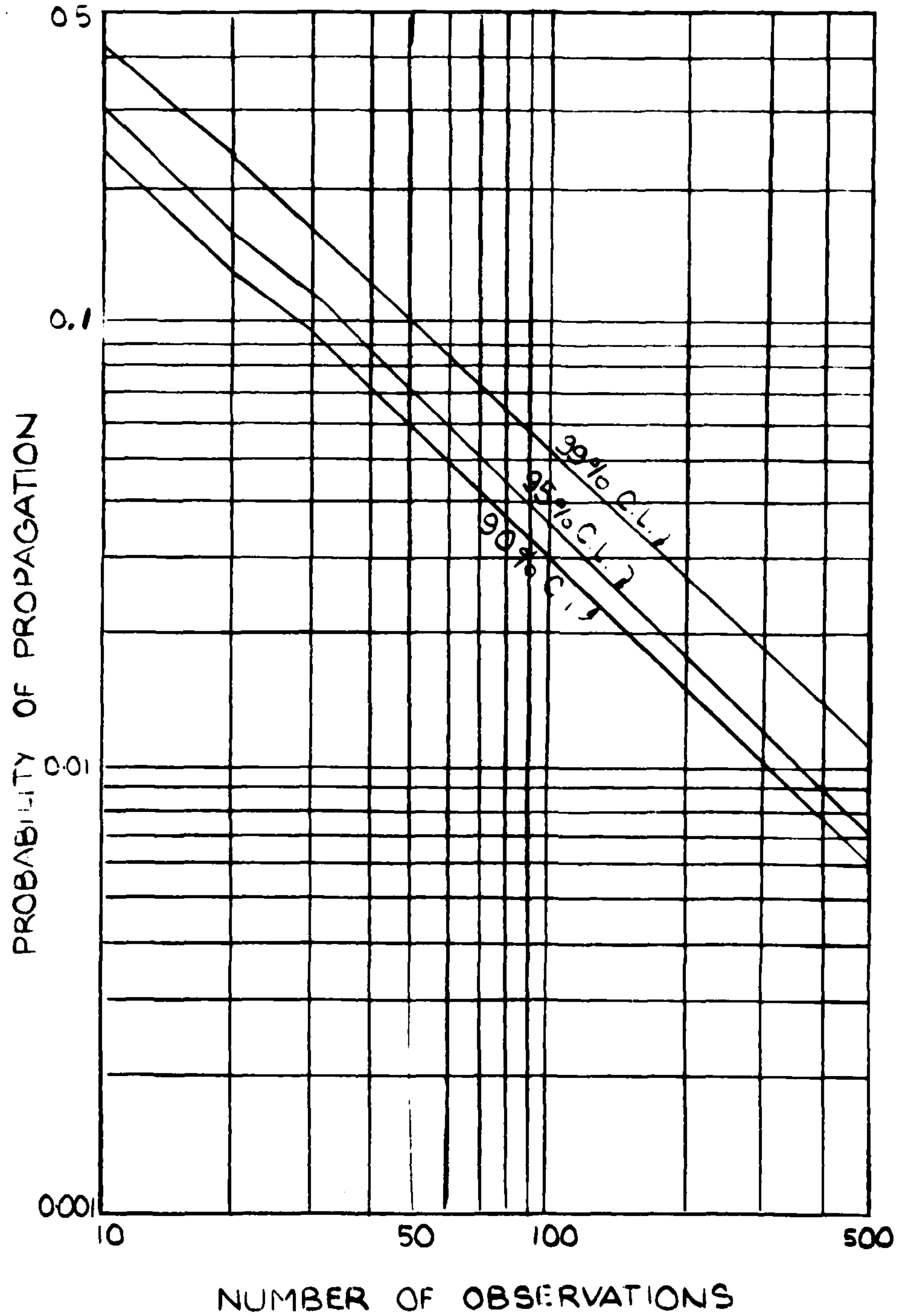

Figure 15. Variations of propagation probability vs. number of observations as a function of confidence level.

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the 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 the observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \qquad (1)$$

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

$$E(x) - np \qquad (2)$$

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

$$(1 - p_2)^n = \varepsilon \qquad (3)$$

where $$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \qquad (4)$$

Use of equation 3 is illustrated in the following example:

<u>Example</u>

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

Given

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

Solution

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

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

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

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

   or

   $p_2 = 0.116(11.6\%)$

Conclusions

For a 95% 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 (0.116 x 30) = 3.48 observations could result in a reaction for a 95% 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%, are used to derive the probabilities. The same values are plotted in Figure 15.

Table A-1. Probabilities of propagation for various confidence limits

Number of observations	90%	C.L.	95%	C.L.	99%	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	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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