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

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A series of tests were conducted to establish the minimum nonpropagation distance between adjacent rubber buckets containing 4.5 kilograms (10 lb) of Composition A5 suspended from a simulated conveyor within an enclosed tunnel. This effort was in direct support of the modernization of the Milan Army Ammunition Plant, Tennessee, but it is also applicable to other similar facilities. The test results indicate that the minimum nonpropagation distance is 1.83 metres (6 ft).

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SUMMARY

The safe separation distance testing program for 4.5 kilogram (10 pound) quantities of explosive composition A5 contained in open rubber buckets was requested by the Project Manager for Munition Production Base Modernization and Expansion, specifically in support of the Milan AAP and Blue Grass AD. After a review of LAP (Load-Assemble-Pack) conditions, it was decided to reduce the quantities of explosive composition A5 in the open rubber buckets from 11.2 kilograms (25 pounds) to 4.5 kilograms (10 pounds) as the lower quantity was more compatible with the bucket delivery system and the loading press arrangement. A program to determine the minimum nonpropagation safe separation distance was drafted by ARRADCOM, reviewed by the appropriate Army safety organizations, and performed by the ARRADCOM Resident Operations Office located at NSTL Station, Mississippi during the fall of 1977. The tests performed under the auspicies of this program simulated the actual in-plant LAP operational conditions.

The safe separation distance test program was conducted in two distinct phases, an exploratory phase during which the probable minimum safe separation distance was determined by trial and error in spacing of the donor and acceptor buckets, and a confirmatory test phase where a sufficient quantity of repetitive testing was accomplished to statistically establish the probability of nonpropagation of an explosive incident.

The confirmatory test phase established the minimum safe spacing for open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 as 1.83 metres (6 feet) with an upper limit of 5.4 percent probability at a 95 percent confidence level of propagation occurrence.

INTRODUCTION

Background

The determination of the minimum nonpropagative distance for open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 is part of a continuing Army-wide program, presently in progress to upgrade existing installations and to develop design criteria for new explosive-manufacturing and LAP (Load, Assemble and Pack) facilities. This effort was undertaken in order that the U.S. Army could achieve increased production cost effectiveness through improved loading plant safety, as well as provide necessary design data for manufacturing facilities technology for new, improved and/or renovated weaponry. As an integral part of this overall facilities modernization 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 the safe separation distance studies of munition end items as well as in-process explosive materials. These developed criteria will be utilized in the modernization of explosive and munition production facilities and will be available for reference purposes to privately owned and operated (POPO) plants engaged in ordnance manufacturing operations.

The present LAP facility at the Milan Army Ammunition Plant, Milan, Tennessee, was examined in order to determine the necessity of providing safe separation distance information and nonpropagation test data, at the request of the Project Manager for Munition Production Base Modernization and Expansion. Accordingly, a test program was conducted utilizing open aluminum buckets containing 6.8 kilograms (15 pounds) of explosive composition A5; however, the confirmed safe separation distance of 6.1 metres (20 feet) was not compatible with normal conveyor belt system speeds, and not conducive to safe work conditions. Therefore, a second safe separation distance study program was initiated, using open rubber buckets in lieu of the aluminum ones, on the theory that the reduced fragmentation (rubber versus aluminum) would shorten the necessary nonpropagation distance. The quantity of explosive composition A5 was also reduced to 4.5 Kilograms (10 pounds) at the request of the manufacturing facility.

Purpose and Objective

The purpose of this safe separation distance testing program is to provide existing and future explosive ordnance loading and manufacturing plants with viable nonpropagation safe spacing criteria for the transportation of bulk quantities (4.5 kilogram/10 pound increments) of explosive composition A5 in open rubber buckets, located on conveyor belt systems, between LAP operations.

The objectives of this test program are twofold: First, to determine through a series of trial-and-error tests (exploratory test phase), the minimum nonpropagative safe separation distance for loose 4.5 kilogram (10 pound) quantities of explosive composition A5 contained in open rubber buckets. Second , to conduct an adequate number of repetitive tests (confirmatory test phase), at the previously established non-propagative safe separation distance to provide statistically valid test data.

Criteria for Tests

The testing was conducted in such a manner as to as accurately as possible simulate the actual loading plant facilities and conditions of operation, with the only acceptable criteria for determining the safe separation distance being the nonpropagation of the donor unit detonation to the acceptor units. Also it should be noted that all safe separation distances shown were measured centerline-to-centerline between the open rubber buckets.

TEST CONFIGURATION

General

The safe separation distance tests on the open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 were initiated during September 1977 and completed by November 1977. The tests were conducted by the ARRADCOM Resident Operations Office at the National Space Technology Laboratories, NSTL Station, Mississippi. The two phases of the test program, exploratory and confirmatory, were accomplished in order to firmly establish the minimum nonpropagative distance between the open rubber buckets.

Test Specimen

Each test specimen utilized consisted of 4.5 kilograms (10 pounds) of explosive composition A5, bulk, type I, contained in an open top rubber bucket.

The explosive composition A5, type I consisted of RDX type A or B, complying with the requirements of specification MIL-R-398, a minimum of 98.5 percent to a maximum of 99.0 percent by weight, and Stearic Acid, complying with the requirements of Specification MIL-S-271, a minimum of 1.0 percent to a maximum of 1.5 percent by weight. Its granulation was a minimum of 99.0 percent through a U.S. Standard Sieve No. 12 and a maximum of 2.0 percent through a U.S. Standard Sieve No. 200.

The open-top rubber bucket (figure 1) as supplied for this test program by the Iowa AAP, Burlington, Iowa was 34.0 centimeters (13.3 inches) in height, with an upper diameter of 24.0 centimeters (9.5 inches) and a lower diameter of 18.3 centimeters (7.2 inches). It was custom made from layers of canvas covered with conductive rubber, and has a 67.0 centimeter (26.4 inch) long rubberized canvas handle attached to the bucket by copper rivets which are rubber covered at final assembly. The bucket is supplied with a conductive rubber top 25.5 centimeters (10.0 inches) in diameter with a 5.8 centimeter (2.3 inch) lip.

Test Arrangements

The first test series, the exploratory testing phase, utilized the basic test set-up as shown in Figure 2; however, the distances between open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 was varied. The test series, using a donor unit positioned between two acceptor units, was conducted within a simulated conveyor ramp. It was originally planned to conduct fifteen of these exploratory tests; however, after the fourth test, the preliminary non-propagation distance had been satisfactorily established.

Following the exploratory test phase, a series of 25 confirmatory tests were conducted. Each confirmatory test was considered as a double test, since each donor initiated exposed two acceptors to the detonation environments, thus yielding two data points per test firing.

All of the tests, exploratory and confirmatory, were conducted within the confines of a simulated ramp or tunnel (figure 2). The tunnel was 3.65 metres (12 feet) wide by 3.65 metres (12 feet) high and long enough to position all three buckets (one donor and two acceptors) within its confines. The tunnel was made from wooden support beams (2 inches x 4 inches) with frangible corrugated fiberglass panels attached to the beams on the long sides and the roof (figure 3). The rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 were suspended from a simulated conveyor at a height of 3.25 metres (10.7 feet) above the ground and 0.31 metre (1 foot) from the front wall. The conveyor was simulated by using a 1 by 6 inch pine board (figures 4 and 5).

The donor bucket was initiated to a high order explosive detonation, in each case, by utilizing a J2 special detonator and a 0.045 Kilogram (0.1 pound) charge of explosive composition C4.

TEST RESULTS

General

The safe separation distance studies of 4.5 kilogram (10 pound) quantities of explosive composition A5 in rubber buckets is divided into two (2) phases, exploratory testing and confirmatory testing, the results of which are described in detail below. Figures 6 and 7 are area and close-up views, respectively, of the post test results.

Exploratory Test Phase

This phase of the safe separation distance study contained seven (7) exploratory test detonations utilizing the one donor/two acceptor technique, thus producing fourteen (14) data points. The test data is presented in table I, test numbers 1 to 7 inclusive. The separation distances, between donor and acceptors, ranged from a minimum of 0.61 metre (2 feet) to a maximum of 3.66 metres (12 feet), with high order detonations being experienced at distances of 1.52 metres (5 feet) and below. At distances of 1.83 metres (6 feet) and above, no propagations of the donor detonation occurred, and only burning of the composition was observed. Therefore a distance of 1.83 metres (6 feet) was selected as the minimum nonpropagative safe separation distance for the exploratory test phase.

Confirmatory Test Phase

This phase of the safe separation distance study contained twenty five (25) confimatory test detonations, again utilizing the one donor/two acceptor technique, thus producing fifty (50) data points for analysis. The basic test data is presented in table I, test numbers 8 to 32 inclusive, with all tests being conducted at a safe separation distance of 1.83 metres (6 feet) between the donor and acceptor buckets of explosive composition A5. While no propagation of the high order detonation of the donor unit to the acceptor units occurred during the confirmatory test phase, more than half of the acceptor buckets experienced complete or partial burning of the explosive composition A5. And where percent recovered is noted in table I, it represents that amount of composition A5 still in the buckets; no attempt was made to salvage any spilled explosive compositions.

Summary of Test Results

While more than 50 percent of the acceptor units experienced complete or partial burning of the explosive composition A5 during the confirmatory test phase, the confirmatory test results showed that the established safe clear separation distance for rubber buckets is 1.83 metres (6 feet).

Analysis of Test Results

Variations in manufacturing tolerances, materials, wear, etc., require that statistical reasoning be employed in the comparative interpretation of the test data. The actual probability of the propagation of an explosive incident is a function of the number of propagative occurrences in the individual test series and the number of tests conducted. The confirmatory test results for open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 produce a probability of detonation of an acceptor bucket by a donor detonation of 6.8 percent at a confidence level of 95 percent.

These values are equivalent to stating that in a large number of tests, 95 out of 100 times, the probability of the propagation of an explosive incident will be less than or equal to the stated value of 6.8 percent. This value indicates the quality of the tests and the reliance that can be placed upon the conclusions drawn from the testing.

CONCLUSIONS

A sufficiently large sample of open rubber buckets containing 4.5 kilograms (10 pounds) of explosive composition A5 was utilized to conclusively determine the minimum nonpropagation safe separation distance between adjacent buckets on transfer lines within and between LAP facility operations. The minimum safe spacing for the buckets positioned on an overhead conveyor system was established at 1.83 metres (6 feet) as a result of an upper limit of 6.8 percent probability of propagation at the 95 percent confidence level as based upon 52 test observations.

TABLE 1

SAFE SEPARATION DISTANCE TESTS
10 POUNDS OF COMP. A5 IN RUBBER BUCKETS

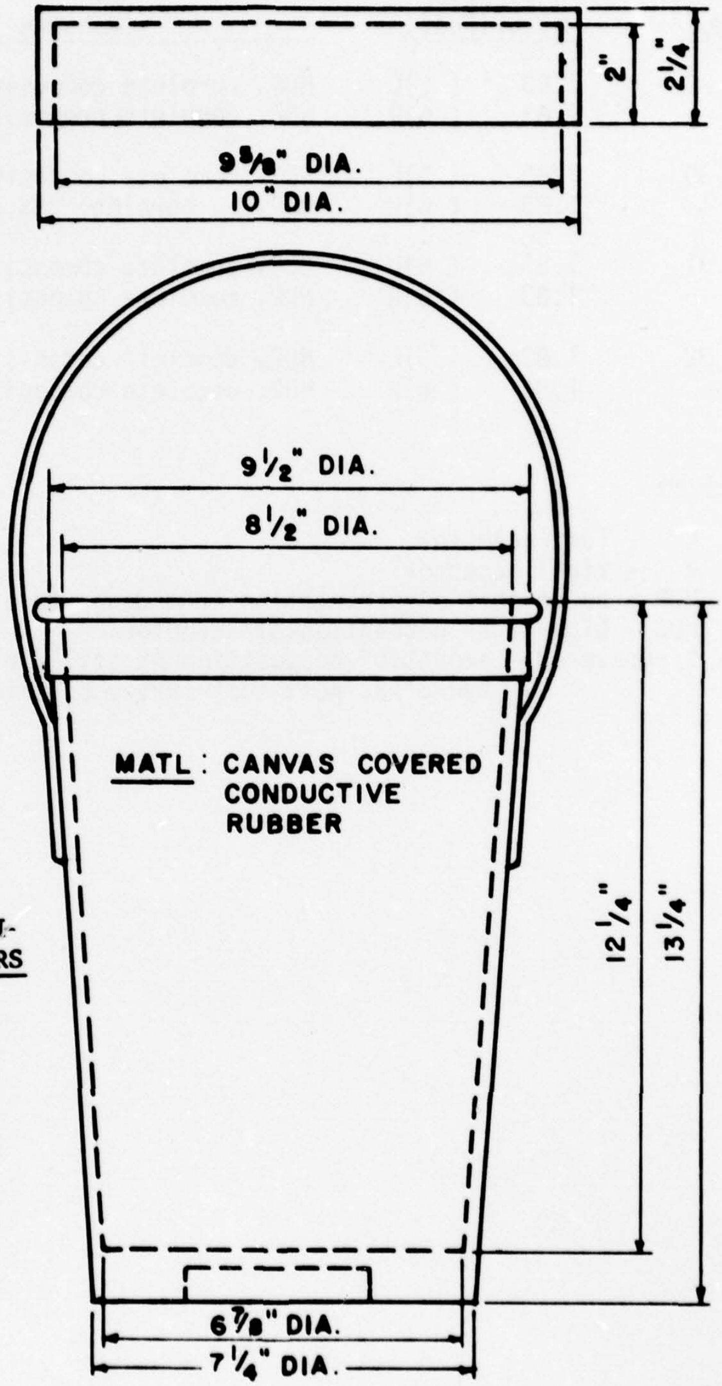
Test No.	Separation Metre	(Feet)	Remarks
1	2.44	(8)L	NDP, composition completely burned
	3.66	(12)R	NDP, no burning
2	1.22	(4)L	NDP, no burning
	1.83	(6)R	NDP, no burning
3	0.61	(2)L	HOD
	1.22	(4)R	NDP, bucket broken up, no burning
4	0.61	(2)L	HOD
	1.22	(4)R	NDP, bucket broken up, no burning
5	0.91	(3)L	HOD
	0.91	(3)R	HOD
6	1.22	(4)L	HOD
	1.22	(4)R	HOD
7	1.52	(5)L	HOD
	1.83	(6)R	NDP, no burning
8	1.83	(6)L	NDP, no burning, 20% recovered
	1.83	(6)R	NDP, no burning, 35% recovered
9	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, no burning, 25% recovered
10	1.83	(6)L	NDP, no burning
	1.83	(6)R	NDP, 10% burned up
11	1.83	(6)L	NDP, no burning, 55% recovered
	1.83	(6)R	NDP, 50% burned up
12	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, complete composition burning
13	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, complete composition burning

Test No.	Separation Metre (Feet)	Remarks
14	1.83 (6)L	NDP, no burning, 10% recovered
	1.83 (6)R	NDP, complete composition burning
15	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, complete composition burning
16	1.83 (6)L	NDP, no burning, 30% recovered
	1.83 (6)R	NDP, no burning, 20% recovered
17	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, complete composition burning
18	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, complete composition burning
19	1.83 (6)L	NDP, no burning, 45% recovered
	1.83 (6)R	NDP, complete composition burning
20	1.83 (6)L	NDP, no burning, 30% recovered
	1.83 (6)R	NDP, no burning, 50% recovered
21	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, no burning, 25% recovered
22	1.83 (6)L	NDP, no burning, 17% recovered
	1.83 (6)R	NDP, no burning, 25% recovered
23	1.83 (6)L	NDP, no burning, 20% recovered
	1.83 (6)R	NDP, no burning, 11% recovered
24	1.83 (6)L	NDP, no burning, 40% recovered
	1.83 (6)R	NDP, no burning, 75% recovered
25	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, complete composition burning
26	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, complete composition burning
27	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, no burning, 50% recovered
28	1.83 (6)L	NDP, complete composition burning
	1.83 (6)R	NDP, no burning, 15% recovered

Test No.	Separation Metre (Feet)		Remarks
29	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, complete composition burning
30	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, no burning, 28% recovered
31	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, complete composition burning
32	1.83	(6)L	NDP, complete composition burning
	1.83	(6)R	NDP, complete composition burning

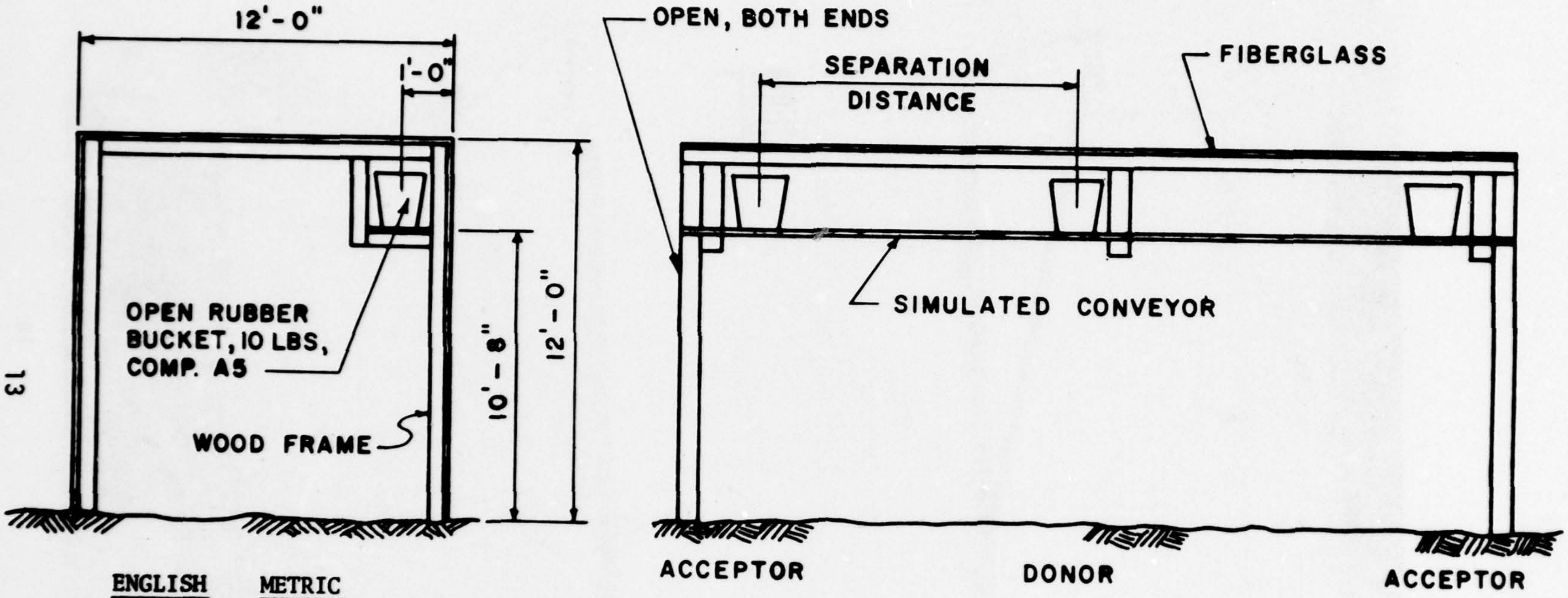
Terms:

L - left acceptor
R - right acceptor
NDP - no detonation propagation from donor to acceptor
HOD - high order detonation of acceptor
% recovered - amount of composition A5 still in rubber bucket at post test survey of site.



INCHES	CENTI-METERS
2	5.08
2 1/4	5.72
6 5/8	16.83
7 1/4	18.42
8 1/2	21.59
9 1/2	24.13
9 5/8	24.45
10	25.40
12 1/4	31.12
13 1/4	34.29

Fig. 1 - Rubber transfer bucket



ENGLISH	METRIC
1'0"	0.31 M
10' 8"	3.27 M
12' 0"	3.68 M
10 Lbs	4.55 Kgm

Fig. 2 - Simulated tunnel layout

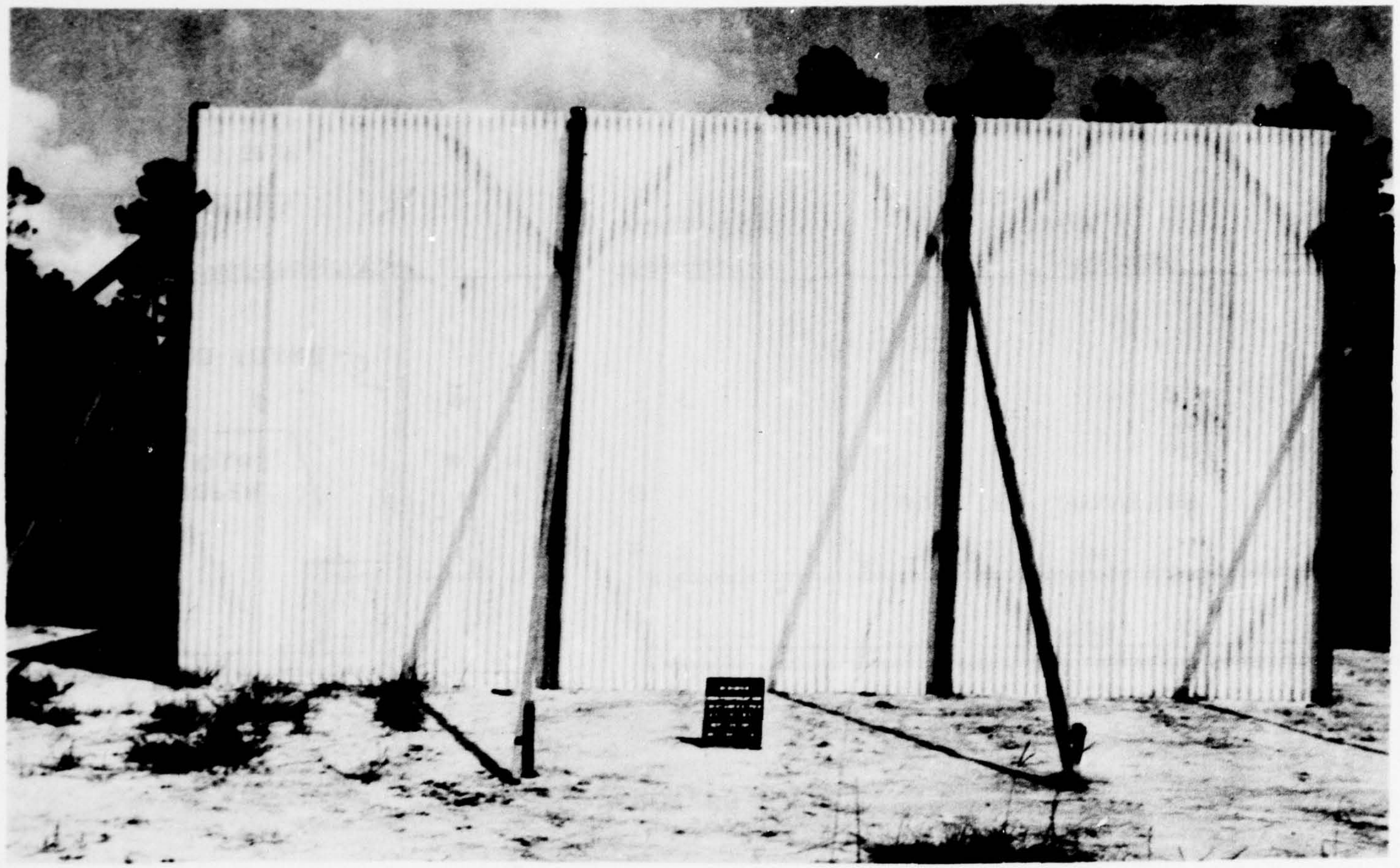


Fig. 3 - Simulated tunnel side view

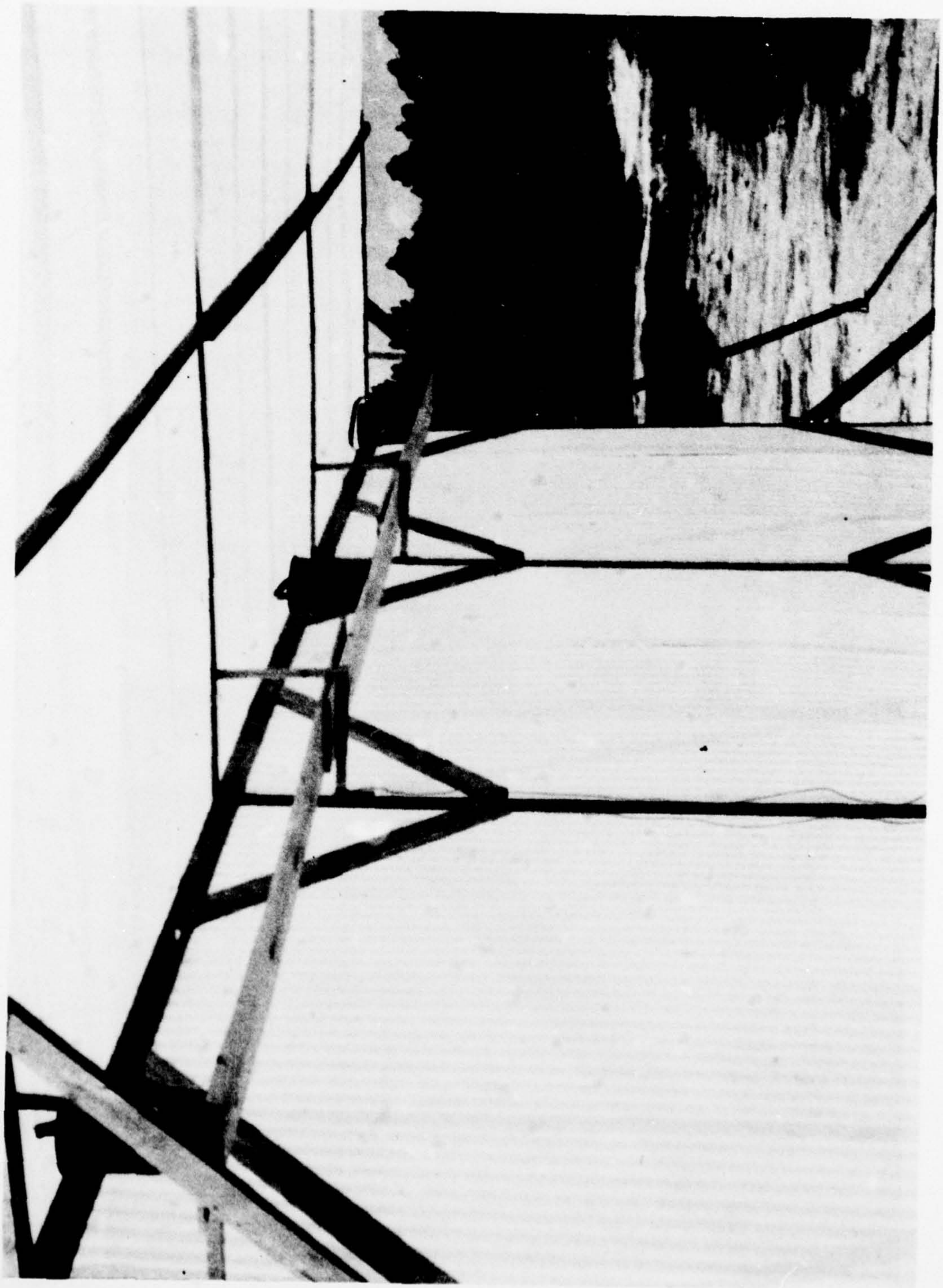


Fig. 4 - Simulated tunmel interior view

Fig. 5 - Rubber bucket pre-test

Fig. 6 - Simulated tunnel post-test view

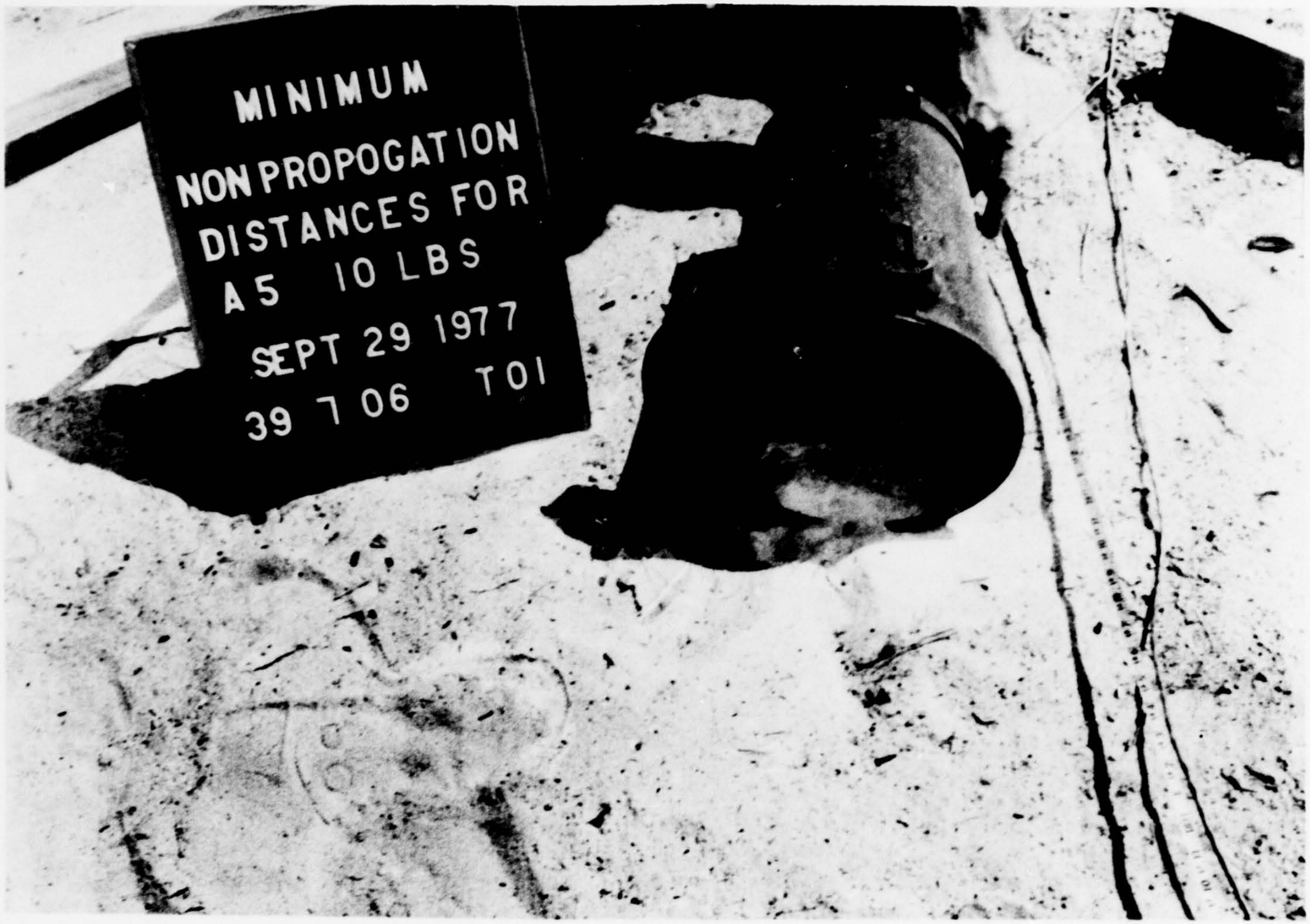


Fig. 7 - Rubber bucket post-test

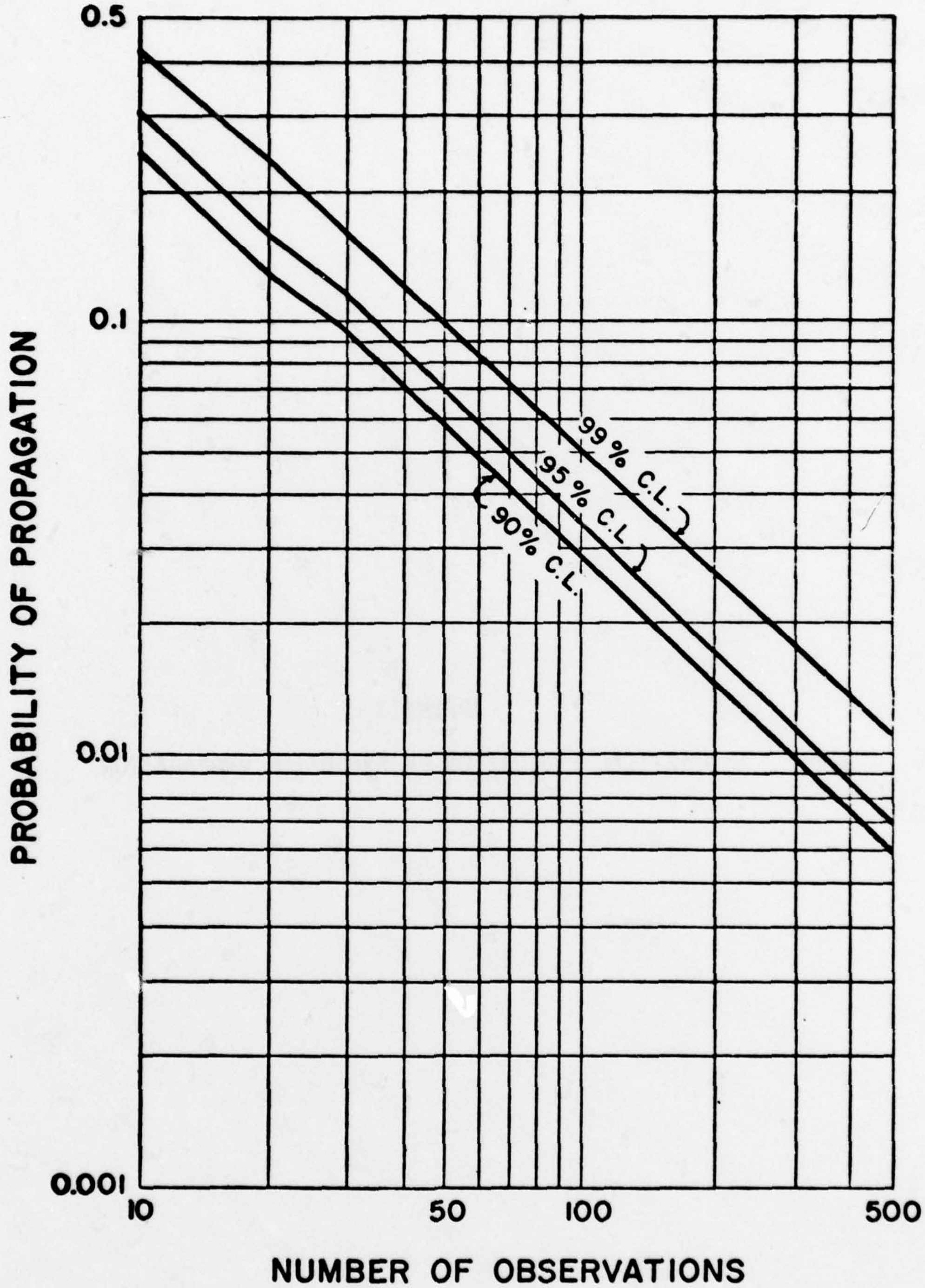


Fig. 8 - Variation of propagation probability versus number of observations as a function of confidence level

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:

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

where $\varepsilon = (1 - \alpha)/2$ 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:

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

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

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

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	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	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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