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DETERMINATION OF MINIMUM NON-PROPAGATION DISTANCE OF ALUMINUM BUCKETS CONTAINING 15 POUNDS OF COMPOSITION A5

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A series of tests was conducted to establish the minimum non-propagation distance between adjacent aluminum buckets containing 6.8 kilograms (15.0 pounds) of Composition A5. The buckets were suspended from a pendant-type conveyor within a covered ramp. This effort was in direct support of the modernization of the Milan Army Ammunition Plant, Tennessee, but also applies to other similar facilities. The test results indicate that the minimum non-propagation distance is 6.1 metres (20.0 feet). The tests also demonstrated

20. ABSTRACT (Continued)

that buckets with covers will produce higher donor blast outputs than buckets without covers.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following individuals for their participation, guidance and co-operation during the performance of this Safe Separation Distance Program: Messrs. James I. Jensen and Kenneth O. Rhea of Tooele Army Depot, Utah, and Robert S. Kukuvka of ARRADCOM, Dover, New Jersey.

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SUMMARY

The safe separation distance testing of 6.80 kilograms (15.0 pounds) of Composition A5 in aluminum buckets 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 LAP conditions, it was determined that tests would be conducted with the aluminum buckets suspended from a pendant-type conveyor and contained within a covered ramp. A program to determine the minimum non-propagation safe separation distance was drafted by ARRADCOM and performed by Tooele Army Depot, Utah, from April 1976 to 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 aluminum buckets containing 6.80 kilograms (15.0 pounds) of explosive Composition A5 as 6.10 metres (20.0 feet) with an upper limit of 7.0 percent probability of propagation at a 95 percent confidence level.

Background

At the present time, an Army-wide modernization program is underway to upgrade existing and develop new explosive manufacturing, loading, assembly and packaging facilities. This effort will enable the U.S. Army to achieve increased production cost effectiveness with improved safety. As an integral part of this overall program, the Manufacturing Technology Division, Large Caliber Weapon Systems Laboratory, ARRADCOM, Dover, New Jersey, is engaged in the continuous development of safety criteria as an activity entitled "Safety Engineering in Support of Ammunition Plants" which includes safe separation distance studies of munition end-items as well as in-process explosive materials. These criteria will be utilized as part of the basis for the design of all explosive production installations due for modernization and expansion, including Government-owned contractor-operated (GOCO) plants. The tests reported herein were part of this Army-wide overall program.

The testing for the safe separation distance between two aluminum buckets containing 6.80 kilograms (15 pounds) of Composition A5 in support of the LAP facility at the Milan Army Ammunition Plant, Tennessee, was conducted at the request of the Project Manager for Munitions Production Base Modernization and Expansion.

The test plan was first to determine the safe separation distance between aluminum buckets of 6.80 kilograms (15 pounds) of Composition A5. If the distance were found to be unacceptable and incompatible with the production rate, then buckets containing 3.17 kilograms (7 pounds) of Composition A5 would be tested next.

Objective

The objective of this test program was to establish a safe separation distance, relative to the propagation of an explosion, between aluminum buckets containing Composition A5 explosive under simulated plant conditions.

The program may be considered as consisting of two phases. The first phase involved exploratory testing for the purpose of establishing the required clear spacing between buckets. The second phase consisted of confirmatory testing as required to establish statistical confidence in the results.

Criteria for Tests

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

TEST CONFIGURATION

General

The tests were performed from April 1976 to January 1977 at Tooele Army Depot, Utah. Two phases of testing, exploratory and confirmatory, were accomplished in order to firmly establish the minimum non-propagative distance between the buckets.

Test Specimen

The test specimen consisted of 6.80 kilograms (15.0 pounds) of explosive Composition A5, bulk, Type 1, Specification MIL-E-14970, contained in an open-top aluminum bucket.

Test Arrangements

Figures 1 and 2 illustrate the typical set-up for the tests. The set-up consisted of three aluminum buckets containing 6.80 kg (15 lbs) of Composition A5 placed within a simulated conveyor tunnel. The center bucket served as the donor, while the two outer buckets served as acceptors. The tunnels were 2.44 metres (8 feet) wide and 2.44 metres (8 feet) high and fabricated in 3.05-metre (10-foot) modular sections. The sections were welded together in the field prior to testing. The tunnels were fabricated from 1-1/2 inch by 1-1/2 inch by 1/8 inch structural steel angles welded together as frame and covered with 18- to 22-gauge aluminum sheets. I-beams were welded to angles on both sides and ceiling of the tunnel along the direction of the tunnel. Buckets were suspended from the I-beam at the ceiling so that the bottoms of the buckets were 1.83 metres (6 feet) from the ground.

Prior to the exploration tests, two tests were conducted in open space (without tunnel) in order to determine the proper donor initiator and the effects of close proximity of the buckets. It was originally planned to conduct seven tests during the exploration phase; however, the distance was established at the end of the third test. For informational purposes, three tests were conducted utilizing aluminum buckets with tight-fitted covers. Following the exploratory tests, a series of 25 confirmatory tests were conducted.

TEST RESULTS

General

As previously mentioned, the exploratory tests on the 6.80 kilograms (15 pounds) of explosive Composition A5 were grouped into three categories: open buckets without tunnels, open buckets with tunnels, and closed buckets with tunnels. The results of these exploratory tests are detailed below. Also described are the results of the 25 confirmatory tests.

Open Bucket Without Tunnel Tests

Two tests were conducted in order to insure the high order detonations of the donor, with acceptor units emplaced for information purposes only. The separation distances between donor and acceptors utilized during these tests varied from 1.52 metres (5.0 feet) to 4.57 metres (15.0 feet), measured edge-to-edge on the aluminum buckets. In both tests, the donor functioned with a high order detonation and the resultant damages to the acceptors at the various distances are outlined in Table 1.

Open Bucket With Tunnel Tests

It was originally planned to conduct seven tests during this series. However, after three tests, the probable safe separation distance was established (Table 2). The clear separation distances between donor and acceptors utilized during these tests were varied from 3.05 metres (10.0 feet) to 6.10 metres (20.0 feet) in 1.52-metre (5.0-foot) increments. As can be seen from Table 2, 6.10 metres (20.0 feet) was the minimum non-propagation clear distance, which was subsequently utilized in the confirmatory tests. Figure 3 shows the post test results of one of these tests.

Closed Buckets With Tunnel Tests

This series consisted of three tests to determine the effects of placing a weather-protective cover on each of the aluminum buckets. The covers were lightly force-fitted. The tests utilized a 6.00-metre (20-foot) safe separation distance. As can be seen from Table 3, the adding of the covers to the buckets resulted in only a larger donor output blast. No detonation propagations were observed.

Confirmatory Tests

A total of 25 confirmatory tests were performed to confirm the previously established distance of 6.10 metres (20 feet) as the minimum safe clear separation distance. Each test consisted of one donor bucket and two acceptor buckets. The results of tests are listed in Table 4. There were no detonation propagations observed for all tests. It should be noted that included in the 25 test results are four preliminary test data; namely, Test No. 3 from Table 2 and Test Nos. 1, 2 and 3 from Table 3. Since these preliminary tests and donor outputs were either equal to or greater than those of the rest of the tests, it was felt that these preliminary test data were valid.

Summary of Test Results

While a few propagations of donor detonations to acceptors were observed during the exploratory test phases, the confirmatory test results clearly demonstrated that no propagations of detonations occurred if the 6.10-metre (20-foot) safe separation distance were maintained.

The results also demonstrated that the placing of a tightly fitted lid over buckets would increase the donor detonation output and thus create a safety hazard although no detonations propagating to any of the acceptors were observed.

Analysis of Test Results

Variations in manufacturing tolerances, materials, wear, etc., required 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, as shown in Table 4, for aluminum buckets containing 6.80 kilograms (15 pounds) of explosive Composition A5, produce a probability of detonation of an acceptor bucket by a donor detonation of 7.0 percent at a confidence level of 95 percent (see Figure 4).

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. This value indicates the quality of the tests and the reliance that can be placed upon the conclusions drawn from the testing.

CONCLUSIONS

The minimum clear separation distance between aluminum buckets containing 6.8 kilograms (15.0 pounds) of Composition A5 suspended from a pendant conveyor within a weather protective tunnel was established at 6.10 metres (20.0 feet) as a result of an upper limit of 7.0 percent probability of propagation at the 95 percent confidence level for 50 test observations.

It was also established that covered buckets yielded a higher donor blast output and resulted in increased tunnel damage. Although no detonation propagations were observed for covered bucket tests, it is recommended that further tests are necessary should the covered buckets be considered for use in any explosive facility.

Table 1

Test data of open buckets without tunnel

Test No.	Separation Distance Metres	(Feet)	Results
1	3.05	(10) left	Six holes approximately 1/8-inch diameter.
	4.57	(15) right	No action or damage.
2	2.44	(8) left	Many penetrations and bucket deformed by blast; composition scattered and some burned.
	1.52	(5) right	Bucket torn apart; composition scattered and some burned.

Table 2

Test data of open buckets with tunnel

Test No.	Separation Distance Metres	(Feet)	Results
1	3.05	(10) left	High order detonation.
	3.05	(10) right	Low order detonation, bucket partially melted.
2	4.57	(15) left	No detonation propagation.
	4.57	(15) right	Low order detonation.
3	6.10	(20) left	No detonation propagation.
	6.10	(20) right	No detonation propagation, minor dents.

Table 3

Test data of closed buckets with tunnel

Test No.	Separation Distance Metres	(Feet)	Results
1	6.10	(20) left	NDP*
	6.10	(20) right	NDP
2	6.10	(20) left	NDP
	6.10	(20) right	NDP
3	6.10	(20) left	NDP
	6.10	(20) right	NDP

* NDP - No Detonation Propagation

Note: In all three tests, there was a larger than normal donor output blast and a corresponding increase in tunnel damages.

Table 4

Test data of confirmatory tests

Test No.	Separation Distance Metres	(Feet)	Results
1*	6.10	(20) left	NDP**
	6.10	(20) right	NDP, minor dents.
2*	6.10	(20) left	NDP, high donor output.
	6.10	(20) right	NDP
3*	6.10	(20) left	NDP, high donor output.
	6.10	(20) right	NDP
4*	6.10	(20) left	NDP, high donor output.
	6.10	(20) right	NDP
5	6.10	(20) left	NDP
	6.10	(20) right	NDP, minor dents.
6	6.10	(20) left	NDP, minor penetration.
	6.10	(20) right	NDP, minor dents.
7	6.10	(20) left	NDP
	6.10	(20) right	NDP
8	6.10	(20) left	NDP
	6.10	(20) right	NDP
9	6.10	(20) left	NDP
	6.10	(20) right	NDP
10	6.10	(20) left	NDP, minor penetration.
	6.10	(20) right	NDP
11	6.10	(20) left	NDP
	6.10	(20) right	NDP
12	6.10	(20) left	NDP
	6.10	(20) right	NDP

* Test No. 1 is Test No. 3 from Table 2; Tests Nos. 2, 3 and 4 are Tests Nos. 1, 2 and 3, respectively, from Table 3.

** NDP - No Detonation Propagation.

Table 4 (continued)

Test No.	Separation Distance Metres	(Feet)	Results
13	6.10	(20) left	NDP*
	6.10	(20) right	NDP
14	6.10	(20) left	NDP, minor dents.
	6.10	(20) right	NDP
15	6.10	(20) left	NDP
	6.10	(20) right	NDP
16	6.10	(20) left	NDP
	6.10	(20) right	NDP
17	6.10	(20) left	NDP
	6.10	(20) right	NDP
18	6.10	(20) left	NDP
	6.10	(20) right	NDP
19	6.10	(20) left	NDP
	6.10	(20) right	NDP
20	6.10	(20) left	NDP
	6.10	(20) right	NDP
21	6.10	(20) left	NDP
	6.10	(20) right	NDP
22	6.10	(20) left	NDP
	6.10	(20) right	NDP
23	6.10	(20) left	NDP, minor penetration.
	6.10	(20) right	NDP
24	6.10	(20) left	NDP
	6.10	(20) right	NDP
25	6.10	(20) left	NDP
	6.10	(20) right	NDP

* NDP - No Detonation Propagation.

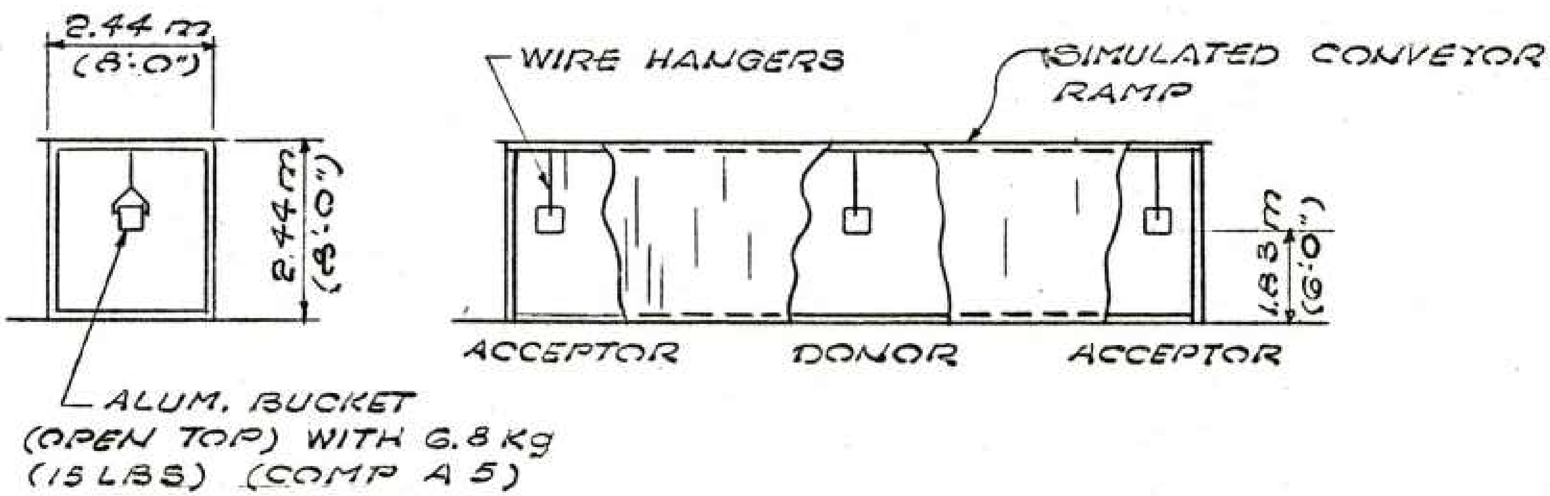

Fig 1 - Simulated conveyor tunnel

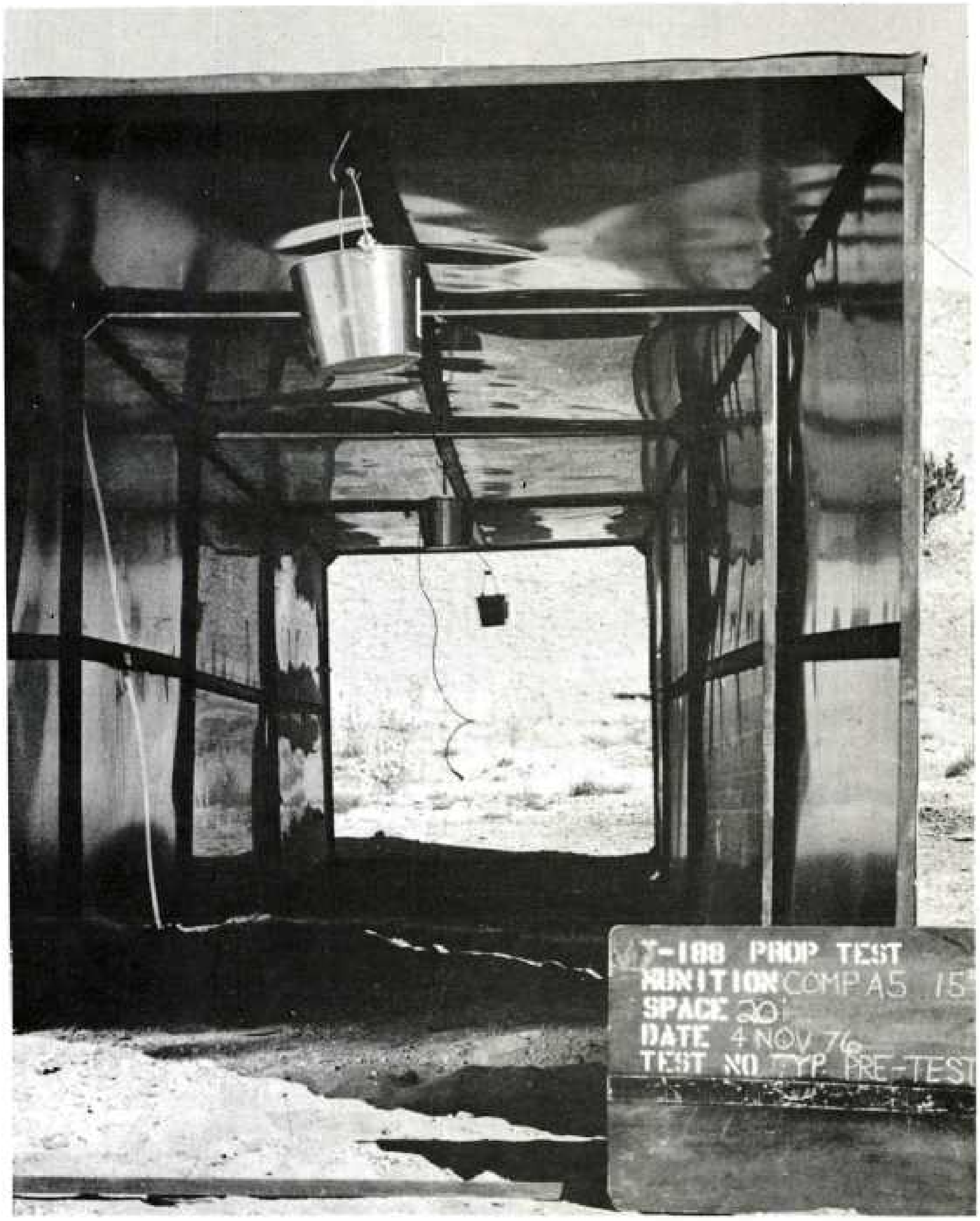

Fig 2   Test set-up

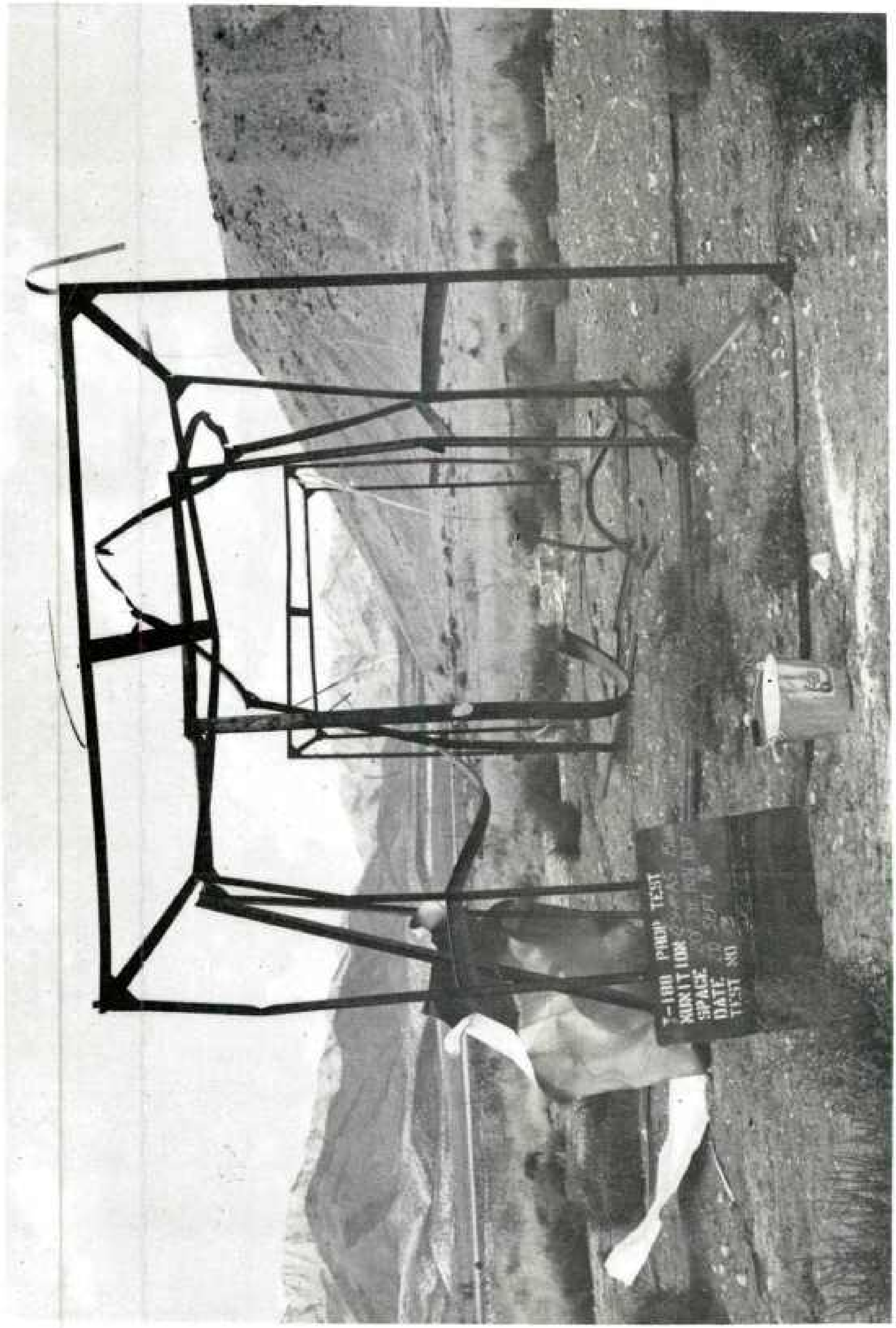

Fig 3 Post-test results

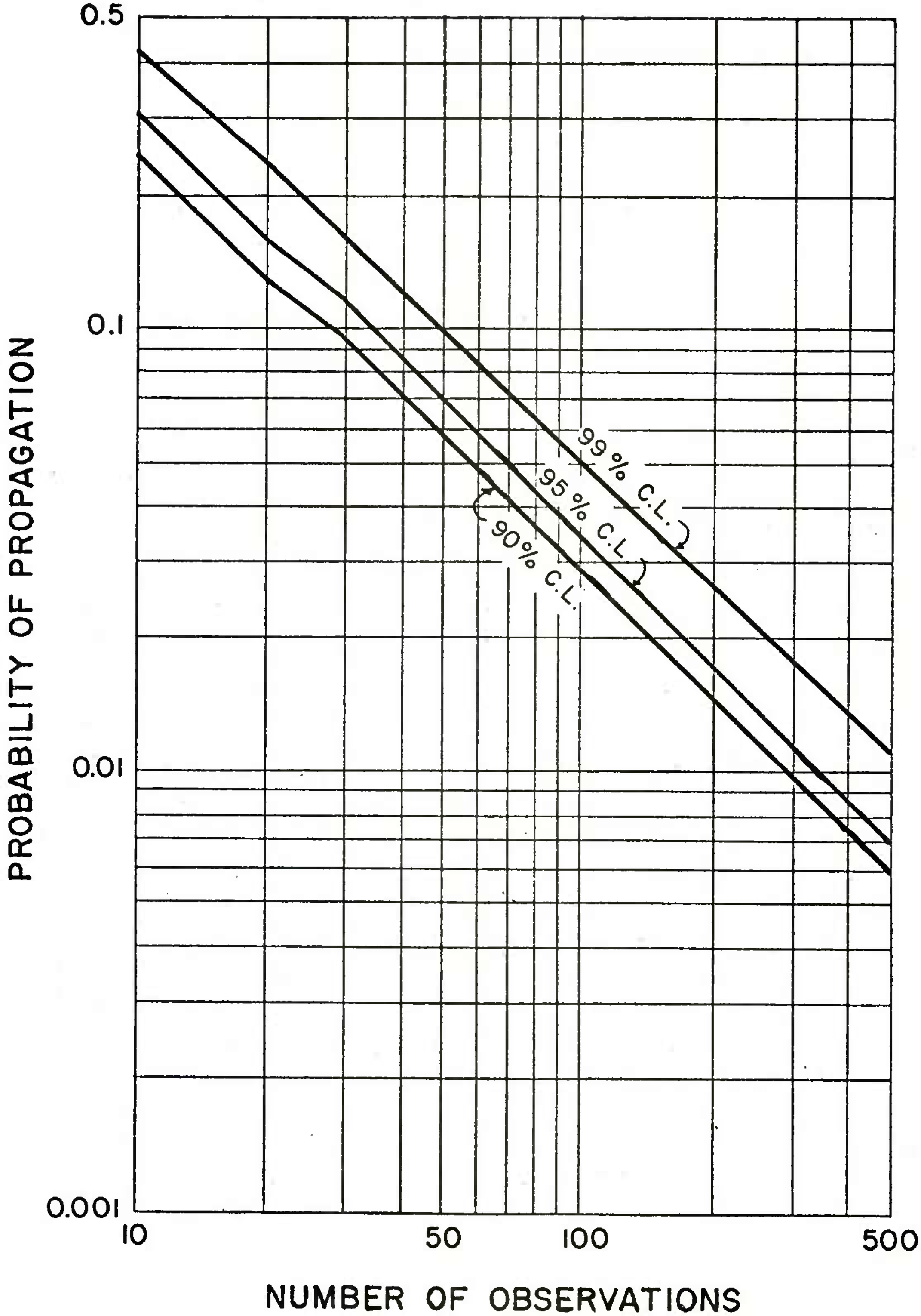

Fig 4 - Variation of propagation probability versus number of observations as a function of confidence level

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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