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TECHNICAL MEMORANDUM 2189

SAFE SEPARATION TESTS OF COMPOSITION A-7 EXPLOSIVE IN 165-POUND TOTE BINS

(INTERIM REPORT)

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

An interline distance of at least 100 feet between stainless steel tote bins conveying 165 pounds of Composition B is required by Army Materiel Command Regulation AMCR 385-100. Large scale safe separation tests performed at the Sierra Army Depot indicated that a high order detonation from primary and secondary fragments will occur at 130 feet. In the Composition B production line at the Holston Army Ammunition Plant spacings greater than 130 feet are unacceptable because of production requirements and equipment constraints.

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20. Abstract (Continued)

In order to resolve this problem small-scale tests were designed and executed at Picatinny Arsenal. Several approaches to reduce the energy of impact of primary and secondary fragments were taken. These approaches included the substitution of plastic materials for the stainless steel of which the tote bins are constructed, the insertion of fragment stopping (energy absorbing) screens or shields between tote bins, and the application of energy absorbing materials to the exterior of the bins themselves. The test results showed that all three approaches could successfully reduce the required nonpropagative spacing between tote bins. The application of an energy absorbing material, Kevlar, to the exterior surface of the bins appeared to be the most promising solution. Full-scale confirmatory tests of this laminate is recommended.

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The authors wish to express their sincere appreciation to the test personnel at the Sierra Army Depot, Herlong, California and at Picatinny Arsenal, Dover, New Jersey, and in particular to Charles Quelette, Charles Bohan and Charles Okum for their kind assistance during the performance of the tests.

SUMMARY

The tests described in this report were performed as part of an overall Safety Engineering Program entitled "Safety Engineering in Support of Ammunition Plants" conducted under the guidance of the Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey, for the U.S. Army Armament Command (ARMCOM).

Bulk Composition A-7, in the form of a granulated powder, must be conveyed between operating buildings through a tunnel or ramp structure as a result of the modernization of the Composition B production line at Holston Army Ammunition Plant (HAAP), Kingsport, Tennessee. Present designs and equipment are predicated on transporting the explosive in stainless steel tote bins covered by a plastic lid. Each tote bin is to contain 165 $\pm$ 3 pounds of A-7. Army Materiel Command Regulation AMCR 385-100 requires that the spacing between bins on this conveyor be at least 100 feet (intraline distance). An exploratory test sequence was initiated to determine a safe spacing between full tote bins less than this requirement.

Tests were performed during August and December 1974 and February 1975 at the Sierra Army Depot, Herlong, California. The results of these tests indicated that there is no safe spacing between tote bins out to a distance of 130 feet, the maximum spacing investigated. High order detonations were propagated at all distances tested. Primary and secondary fragments were implicated as the propagation agent. Spacings greater than 130 feet are unacceptable to HAAP because of production requirements and equipment constraints. Full scale testing was, therefore, temporarily suspended in favor of a small scale test program designed to reduce the propagation hazard and thus reduce the required safe spacing. Remedial actions derived from this scaled program shall be confirmed by full scale testing.

Several approaches to reducing the energy of impact of the primary and secondary fragments resulting from a tote bin detonation were explored in a carefully designed test program executed at Picatinny Arsenal, Dover, New Jersey. These approaches included the substitution of plastic materials for the stainless steel of which the tote bins are constructed, the insertion of fragment stopping (energy absorbing) screens or shields between tote bins, and the application of energy absorbing materials to the exterior of the bins themselves. The test results showed that all three approaches could successfully reduce the required non-propagative spacing between tote bins. The most promising approach within the constraints of cost, schedule and ease of implementation appears to be the application of non-metallic energy absorbing materials

to the exterior surfaces of the tote bins. Of the several materials investigated for this purpose, a Kevlar composite (an aramid fabric laminated with polyester resin) offers the best promise. Confirmatory testing of this laminate attached to the tote bins under full scale conditions is recommended.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

(1) Stainless steel tote bins containing 168 pounds of Composition A-7 may not be spaced closer than 130 feet without the risk of propagation of detonation from bin to bin. A safe spacing has not yet been determined.

(2) Primary and secondary fragments are the most likely agent of explosive propagation.

(3) Kevlar and NVF hard fiber sheets are effective in reducing the required clear spacing.

(4) Flexible stainless steel mesh suspended between tote bins reduces the hazard of detonation propagation.

(5) Substituting polyethylene, noryl or lexan for the tote bin material appears to reduce the required safe spacing.

Recommendations:

Full scale testing utilizing either Kevlar or NVF hard fiber shields attached to the tote bins or using plastic tote bins should be undertaken. The use of Kevlar shields attached to the existing tote bins at HAAP appears to be the most promising solution.

INTRODUCTION

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 Army to achieve increased production cost effectiveness with improved safety. As a part of this overall program, the Manufacturing Technology Directorate of Picatinny Arsenal, Dover, New Jersey, under the direction of the U.S. Army Armament Command (ARMCOM) is engaged in the development of safety criteria as an activity entitled "Safety Engineering in Support of Ammunition Plants". These criteria will be used a part of the basis for the design of all explosive production installations due for modernization. The activities covered in this report provide safety data to support modernization activities in the manufacture of Composition B at Holston Army Ammunition Plant (HAAP), Kingsport, Tennessee, Newport Army Ammunition Plant (NAAP), Newport, Indiana and such new facilities as may be constructed at as yet undetermined sites.

The Composition B production line at HAAP requires that Composition A-7 explosive be transported between operational buildings through a corrugated fiberglass sheet tunnel or ramp for a distance of slightly over 330 feet. The explosive, in the form of a granulated powder, is conveyed in stainless steel tote bins containing 165 ± 3 pounds of Composition A-7 per bin. The steel tote bins are covered by hinged plastic lids. In the absence of empirical data concerning safe separation (non-propagative) distances for this conveying configuration, guidance was obtained from Army Materiel Command Regulation AMCR 385-100. The intra-line separation, 100 feet, was adopted as a basis for design subject to experimental confirmation of non-propagation.

Objectives of Test Program

The Test Program, evolved to determine a non-propagative configuration for transporting 165 pounds of Composition A-7, may be divided into three parts. Only the first two parts of the Program are reported here. For Part I, a full scale exploratory test series was undertaken at Sierra Army Depot, Herlong, California, in an effort to determine a safe spacing. It was believed that such a spacing was found at 130 feet. A confirmatory test sequence was, therefore, initiated. This phase of the Program was terminated after a propagation from a donor tote bin to an acceptor bin 130 feet distant occurred.

Part II of the Test Program, conducted at Picatinny Arsenal, Dover, New Jersey, explored several approaches to reducing the energy of fragments originating at the donor detonation. Since such fragments were the primary agent responsible for propagation of an explosive event from one tote bin to another, it was felt that a significant reduction in fragment velocity at its point of penetration of a potential acceptor bin would reduce the required safe spacing. The use of energy absorbing materials applied to the exterior surfaces of the tote bins or between the tote bins was explored. Fragment velocity measurements were made in free flight and after impact to assess the stopping power of various materials. Scale model tests were then conducted to demonstrate that fragments slowed by the several shield materials would not detonate the explosive. Finally, several non-metallic scale model tote bins were fabricated and tested to demonstrate that the elimination of primary fragments (the tote bin structure itself) also reduces the required safe spacing. The ultimate objective of this complex series of tests was to develop recommendations for reducing the non-propagative spacing required with minimum impact on the operations at HAAP.

Part III, not yet conducted, will confirm the validity of the recommendations made in Part II through full scale testing.

PART I

FULL SCALE EXPLORATORY TESTS

FULL SCALE EXPLORATORY TESTS

General

This phase of the Test Program consisted of a total of 26 tests. All tests were conducted with three tote bins (one donor, two acceptor) filled with 168 pounds of Composition A-7 explosive. This quantity represents the upper loading limit for the tote bins under operational conditions at HAAP. The tests were conducted at Sierra Army Depot, Herlong, California. The first eight tests were performed during the period 20-23 August 1974; the second nine tests were performed during the period 10-11 December 1974 and the remaining nine tests during February 1975. Five tests did not utilize tunnel structures. Twenty tests involved wood-framed, fiberglass-sheathed structures to simulate the plant tunnel or ramp. One test used a steel framed structure as a simulated tunnel.

Test Specimens

The bulk Composition A-7 explosive used in these tests was manufactured at HAAP and identified as Batch No. 3-1, Lot No. 030-2 (November 1973). It was furnished in cardboard boxes, each containing 60 pounds of explosive.

The tote bins used were of the same geometry and size as the containers to be installed in the conveyance system at HAAP. Figure 1 illustrates the design of these tote bins. They were fabricated of .074-inch thick, welded type 304 stainless steel sheet. The hinged lids were made of textolite or plexiglass. The tote bins were fabricated at Sierra Army Depot.

Test Set-Up

Twenty-one of the 26 tests performed were conducted in simulated tunnels. These enclosures were sheathed with corrugated fiberglass sheets. For all but one of the tunnels, the framing to which the sheathing was attached was constructed of 2" x 4" lumber. The remaining tunnel was framed with steel. The tunnel sections measured 7 feet in width by 9 feet in height and were 8 feet long.

Three tote bins arranged in a straight line were used for each test. The center bin acted as donor and the bins at each side acted as acceptors. In order to simulate actual plant conditions as closely as possible, the tote bins were placed on 18-inch wide by 10-foot long steel roller conveyor sections. This assembly was supported at a height of 4 feet 10 inches from the ground by wooden supports. Figure 2 schematically shows the test set-up.

Initiation of the donors was accomplished by inserting a No. 8 blasting cap into 4 ounces of Composition C-4 explosive and placing it into the Composition A-7 explosive in the tote bins.

Test Results

The test results are summarized in Table 1. For those tests in which tunnels were used, approximately 100 feet of the 128-foot total length of tunnel used for each test were completely destroyed or rendered unusable for further tests. The sections of roller conveyor were displaced approximately 25 feet as a result of the detonations. The side channels of these conveyors were severely distorted with rollers torn apart and pieces scattered as debris up to 130 feet distant from the point of origin.

Detonation propagation was observed for separation distances up to 90 feet without the confinement of tunnels. Detonation of an acceptor bin was observed at a separation distance of 100 feet with a tunnel in place. At 110 feet, a penetration of an acceptor bin above the level of the explosives occurred without a detonation. Finally, a high order detonation of an acceptor bin occurred at a 130-foot spacing when the steel framed tunnel was used.

Discussion

High order detonation of the donor occurred in all tests. Propagation of the detonation occurred at all distances tested except at 110 and 120 feet. A small penetration in the tote bin above the level of the explosives was found at 110 feet; while a penetration through a conveyor roller was found at the 120-foot distance. These observations were considered evidence that fragments from the donor detonation possessed sufficient energy at impact with the acceptors at these distances to initiate detonation. Subsequent detonation of an acceptor at a 130-foot spacing justified this conclusion. The numerous penetrations in the acceptor bins encountered at the 130-foot spacing were generally extremely small, the largest being under 1/8 inch in diameter.

Primary (tote bin) and secondary (conveyor) fragments play the major role in the propagation of detonation for this configuration, particularly at the larger distances. Roller and conveyor structure debris were found at and beyond the acceptor locations. Further, the propagation at the 130-foot spacing occurred when the wood framing of the tunnel was replaced with steel. It is also believed that the confinement afforded by the tunnel contributes to the propagation problem. Test No. 7 conducted at a 100-foot spacing without a tunnel structure did not yield an acceptor detonation while Test No. 8 conducted with the same spacing but with a tunnel present did yield a propagative event. Since propagation by fragments is a stochastic process, definitive conclusions concerning the effect of tunnel confinement cannot be drawn. It is clear, based on the test results, that a safe spacing for the tote bins filled with Composition A-7 has not yet been found.

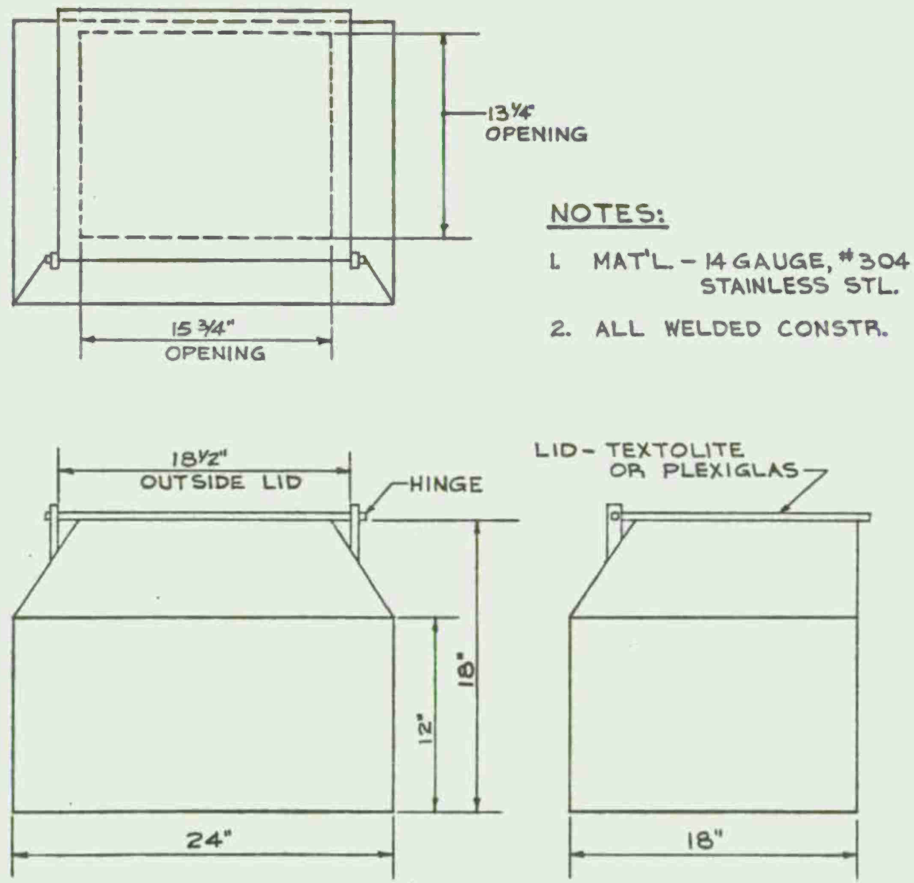


Figure 1. Tote bin geometry

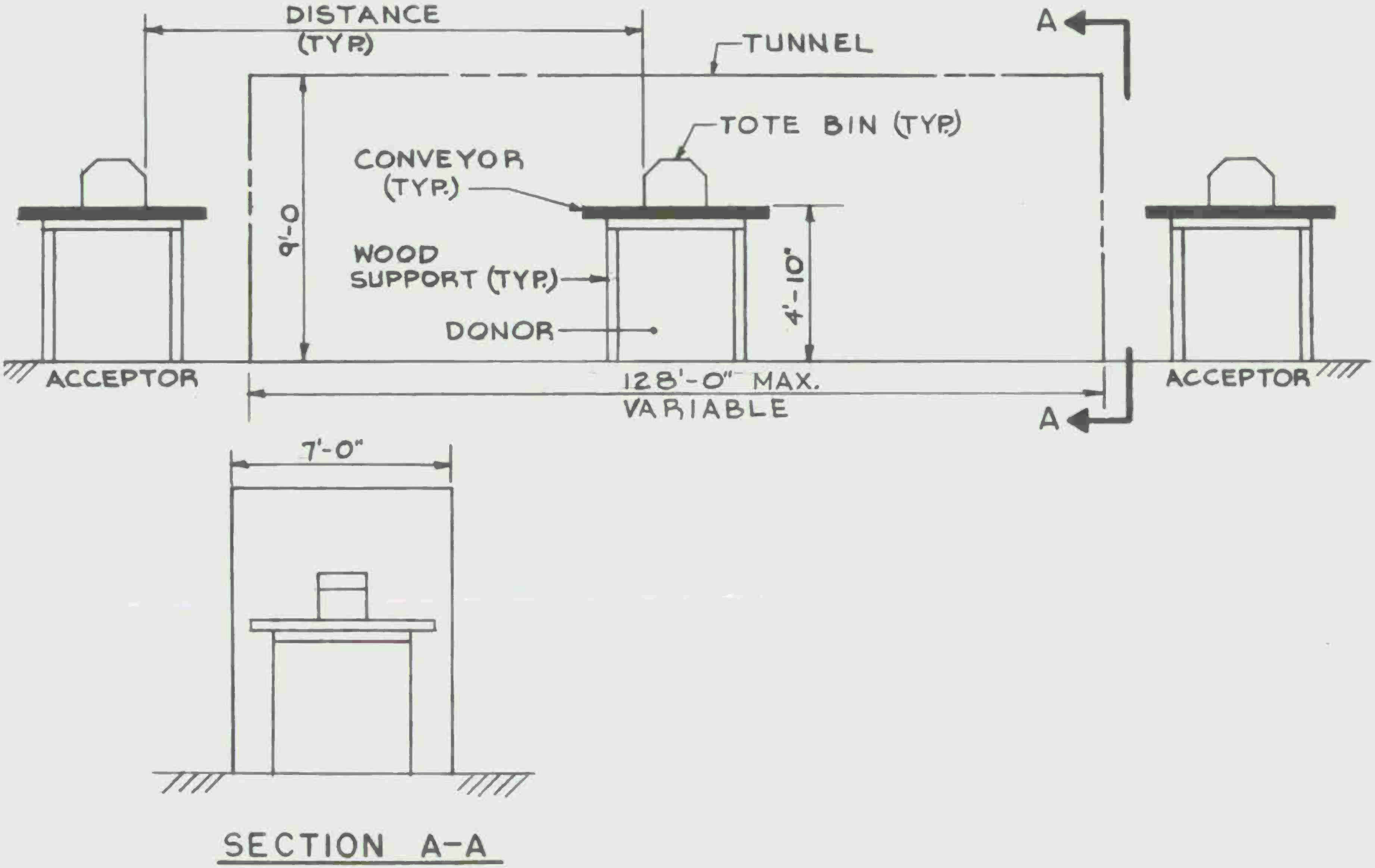


Figure 2. Full scale test arrangement.

TABLE 1

FULL SCALE TOTE BIN SEPARATION TEST DATA

Test	Distance (Ft.)(1)	Tunnel	Results
1	20		
	30	Yes	Both high order detonation
2	50		
	70	Yes	Both high order detonation
3	100		
	120	No	No communication
4	80		
	90	No	No communication
5	80		1 high order detonation
	80	No	1 no communication
6	90		1 high order detonation
	90	No	1 no communication
7	100		
	100	No	No communication
8	100		1 high order detonation
	100	Yes	1 no communication
9	110		Penetration in bin above explosive level
	120	Yes	Penetration thru conveyor roller
10	120		Dent on bin, penetration thru conveyor roller
	130	Yes	Dent on bin
11	130		
	130	Yes	No communication
12	130		No communication
	130	Yes	Penetration thru conveyor roller

TABLE 1
(continued)

FULL SCALE TOTE BIN SEPARATION TEST DATA

Test	Distance (Ft.)(1)	Tunnel	Results
13	130		No communication
	130	Yes	Dent on bin
14	130		Dent on bin, 2 dents on conveyor roller
	130	Yes	Dent on bin, 1 dent on conveyor roller
15	130		No communication
	130	Yes	No communication
16	130		2 dents on bin, small penetrations thru roller
	130	Yes	Dent on bin
17	130		Small penetration in bin above explosive, 2 dents on bin
	130	Yes	Small penetration in bin
18	130		Small penetration in bin
	130	Yes	No communication
19	130		Small penetration in bin
	130	Yes	No communication
20	130		Small penetration in bin
	130	Yes	No communication
21	130		2 pieces shrapnel lodged in bin
	130	Yes	No communication
22	130		Small penetration thru roller
	130	Yes	No communication
23	130		No communication
	130	Yes	No communication

TABLE 1
(concluded)

FULL SCALE TOTE BIN SEPARATION TEST DATA

Test	Distance (Ft.)[1]	Tunnel	Results
24	130		No communication
	130	Yes	No communication
25	130		High order detonation. Shrapnel projected 1/2 mile.
	130	Yes[2]	No communication
26	130		No communication
	130	Yes	No communication

NOTES: (1) Distance measured edge-to-edge of bins
(2) Steel framed tunnel

PART II

SMALL SCALE EXPLORATORY TESTS

SMALL SCALE EXPLORATORY TESTS

General

The results of the full scale exploratory tests reported in Part I indicate the significance of primary and secondary fragments to the propagation of explosive detonations over relatively large distances. Since the requirements of HAAP necessitate spacing tote bins on conveyors at intervals less than would constitute non-propagative distances for the given geometry, protective measures must be explored. These protective measures include the insertion of shields between bins to either stop or decelerate fragments, and the removal of potential fragment material through the substitution of non-metallic substances for the stainless steel of the tote bins themselves.

Two different approaches to the provision of shields were considered. The first involves suspending steel mesh mats between bins. These screens would be moved aside as the full tote bins passed below them. Fragments from a detonation would either be stopped or slowed down by the screens. The second approach involves non-metallic materials attached to the exterior bin surfaces. These materials are intended to absorb fragment energy so that they are unable to penetrate the bin with sufficient energy to initiate a detonation. The materials tested were woven steel mesh; Kevlar, a nylon-like aramid fabric laminated with a polyester resin; ABS, a terpolymer of acrylonitrile, butadiene and styrene; NVF hard fiber, a cellulosic; and lexan, a polycarbonate. Polyethylene, lexan and noryl, a phenylene-oxide-based thermoplastic, were tested as substitutes for the steel used in the bins themselves. Selection of these materials was based on a review of their physical properties and consideration of the compatibility requirements of the explosives.

Test Procedures

The stopping power of each of the selected materials was investigated as a function of fragment velocity. The residual velocity of the fragment after impact with the test sample was also measured. The ability of fragments with these residual velocities to initiate a detonation in Composition A-7 explosive was then determined. Finally, scale model tote bins were constructed with shields in-place and tested for safe separation distance.

The substitute tote bin materials were evaluated by fabricating scale models and performing non-propagative safe separation tests.

Shield Material Stopping Power Tests

General

Since primary and secondary fragments have been identified as the primary agent for propagation of tote bin detonations, an investigation of the ability of several materials to stop or significantly retard such fragments was undertaken. The selection of materials to be examined was based on chemical compatibility with Composition A-7 explosive, physical toughness as a measure of stopping power and ease of availability and use. These materials were stainless steel sheet (1/16 inch thick); stainless steel wire mesh in two different weaves; lexan (polycarbonate) sheet 1 inch thick; ABS (acrylonitrile-butediene-styrene) sheet 1 inch thick; NVF hard fiber (cellulosic) sheet 1/2 and 1 inch thick and Kevlar (polyester resin-impregnated aramid cloth laminate) sheet 3/10 and 1 inch thick.

Fragments were simulated by 0.1- and 0.5-ounce projectiles fired by a rifle from a test bench. These correspond to 30- and 50-caliber projectiles, respectively. The velocity of the simulated fragments was measured prior to impact with the candidate shield material. A second velocity measuring station was provided behind the test sample to measure the residual velocity of fragments penetrating the shield materials. This allowed determination of the minimum penetration velocity for each shield and fragment combination. When coupled with the minimum residual velocity required to detonate the explosive, this data also permits the determination of the maximum safe impact velocity for each shield-fragment combination.

Test Set-Up

Simulated fragments were fired at the test samples from a rifle mounted on a test bench as shown in Figure 3. Provision was made for firing 30- or 50-caliber (0.1- and 0.5-ounce, respectively) projectiles from this set-up. The powder charge propelling these projectiles may be varied in order to vary the impact velocity from relatively low levels until penetration of the shield was achieved.

Fragment velocity was measured by a time-of-flight apparatus as shown in Figure 3. This apparatus consisted of two conductive mylar sheets separated by a fixed distance and connected to an electronic timing circuit. Penetration of the first sheet initiated the timing circuit. The circuit was stopped by the penetration of the second sheet. The time interval thus measured was converted to velocity.

The Kevlar shields were tested in 1- and 3/10-inch thicknesses. For the 50-caliber projectiles, the Kevlar sheets were attached to a stainless steel plate (1/16 inch) of the same thickness as the tote bins. For the 30-caliber projectiles, only the 3/10-inch thick Kevlar sheets were backed. This thickness was also tested without backing.

The NVF hard fiber shields were tested in 1- and 1/2-inch thicknesses. Both thicknesses were mounted on the steel backing plate for 50-caliber projectiles and without backing for the 30-caliber projectiles. The ABS and Lexan samples were both 1 inch thick and tested with backing plates. Only 50-caliber projectiles were used against these shields.

The two wire mesh screens were tested against 30-caliber projectiles. Steel backing plates were tested without protection against the 50-caliber (0.5-ounce projectiles).

Test Results

A summary of the fragment impact tests is given in Table 2. The maximum impact velocity achieved by each shield before penetration is summarized in Table 3. It may be seen that the Kevlar and NVF hard fiber are clearly superior in their stopping power.

The effects of the fragments on the various shield materials are represented in Figures 4 through 8. Figure 4 shows a Kevlar shield with a 50-caliber (0.5-ounce) projectile embedded in it. Figures 5 and 6 show the Hard Fiber shields that have been penetrated. Steel backing plates are also shown. Figures 7 and 8 show the steel mesh screens. These were arranged so that one screen was placed behind the other. An embedded fragment of a projectile is visible in the right-hand screen in Figure 7, while a completely stopped projectile is visible on the left in Figure 8.

Discussion of Results

All of the materials tested were effective in either stopping or reducing the residual velocity of projectiles. The ABS and lexan afforded the least protection for a constant thickness, while the Kevlar and NVF hard fiber afforded the most and were nearly equivalent.

The steel mesh screens also afforded an attractive measure of protection. In actual use, it was assumed that flexible screens of this type could be suspended at a fixed position on the conveyor and thus act as a shield between tote bins. They are sufficiently flexible so that the tote bins could displace them as they passed their position. This approach would represent a minimum addition of material to the system and impose the least horsepower penalty on the conveyance system. It would, however, require the introduction of a substantial additional quantity of steel to the system. In the event of a tote bin detonation in the vicinity of these screens, they could add to the quantity of shrapnel enitted.

TABLE 2

SIMULATED FRAGMENT IMPACT TESTS

Test No.	Material Tested	Material Thickness (inch)	Test Gun Caliber	Steel Plate Backing	Impact Velocity (ft/sec)	Residual Velocity (ft/sec)	Penetration
4	Kevlar	1	50	Yes	2408	1157	Yes
5	Kevlar	1	50	Yes	1259	-	No
6	Kevlar	1	50	Yes	1748	-	No
7	Kevlar	1	50	Yes	1818	-	No
8	Kevlar	1	50	Yes	1976	-	Yes
9	Kevlar	3/10	50	Yes	980	101	Yes
10	Kevlar	3/10	50	Yes	862	-	No
28	Kevlar	3/10	30	Yes	1684	592	Yes
29	Kevlar	3/10	30	Yes	1408	-	No
30	Kevlar	3/10	30	Yes	1416	-	No
31	Kevlar	3/10	30	Yes	1534	-	No
32	Kevlar	3/10	30	No	1337	624	Yes
33	Kevlar	3/10	30	No	474	-	No
34	Kevlar	3/10	30	No	1241	140	Yes
35	Kevlar	3/10	30	No	936	-	No
36	Kevlar	1	30	No	2762	-	No
37	Kevlar	1	30	No	3878	1488	Yes
38	Kevlar	1	30	No	3268	1141	Yes
39	Kevlar	1	30	No	2996	(lost)	Yes

TABLE 2
(continued)

SIMULATED FRAGMENT IMPACT TESTS

Test No.	Material Tested	Material Thickness (inch)	Test Gun Caliber	Steel Plate Backing	Impact Velocity (ft/sec)	Residual Velocity (ft/sec)	Penetration
40	Kevlar	1	30	No	3030	-	No
18	NVF	1	50	Yes	1300	-	No
19	NVF	1	50	Yes	1500	-	No
20	NVF	1	50	Yes	1525	-	No
21	NVF	1	50	Yes	1783	-	Plate Fractured
22	NVF	1	50	Yes	1953		Yes
24	NVF	1/2	50	Yes	1309	(lost)	Yes
25	NVF	1/2	50	Yes	1124	-	No
26	NVF	1/2	50	Yes	1276	291	Yes
43	NVF	1/2	30	No	1077	100	Yes
44	NVF	1/2	30	No	753	-	No
45	NVF	1/2	30	No	462	-	No
46	NVF	1/2	30	No	689	-	No
47	NVF	1/2	30	No	1316	694	Yes
48	NVF	1	30	No	2415	1027	Yes
49	NVF	1	30	No	(lost)	397	Yes
50	NVF	1	30	No	1712	-	No

TABLE 2
(concluded)

SIMULATED FRAGMENT IMPACT TESTS

Test No.	Material Tested	Material Thickness (inch)	Test Gun Caliber	Steel Plate Backing	Impact Velocity (ft/sec)	Residual Velocity (ft/sec)	Penetration
51	NVF	1	30	No	1908	245	Yes
52	NVF	1	30	No	1887	124	Yes
1	ABS	1	50	Yes	2358	(lost)	Yes
16	ABS	1	50	Yes	1480	380	Yes
17	ABS	1	50	Yes	1253	-	No
2	Lexan	1	50	Yes	2183	1506	Yes
13	Lexan	1	50	Yes	970	-	No
14	Lexan	1	50	Yes	1450	-	No
15	Lexan	1	50	Yes	1750	546	Yes
11	SS	1/16	50	-	901	628	Yes
12	SS	1/16	50	-	627	-	No
**	GRATEX 695		30	-	2604	2370	Yes
**	Mesh 209		30	-	1340	992	Yes

TABLE 3

SUMMARY OF SHIELDING MATERIALS RESISTANT TO PENETRATION BY SIMULATED FRAGMENTS

Material Tested	Material Thickness (inch)	Fragment Weight (ounce)	Steel Plate Backing	Maximum Impact Resistant Velocity (ft/sec)
Kevlar	1	0.5	Yes	1900
Kevlar	3/10	0.5	Yes	900
Kevlar	1	0.1	No	3000
Kevlar	3/10	0.1	No	1100
NVF	1	0.5	Yes	1800
NVF	1/2	0.5	Yes	1100
NVF	1	0.1	No	1800
NVF	1/2	0.1	No	1000
ABS	1	0.5	Yes	1200
Lexan	1	0.5	Yes	1400
Gratex 695*	3/8	0.1	No	1800
Mesh 209*	1/4	0.1	No	1600

* Two shields held 6 inches apart.

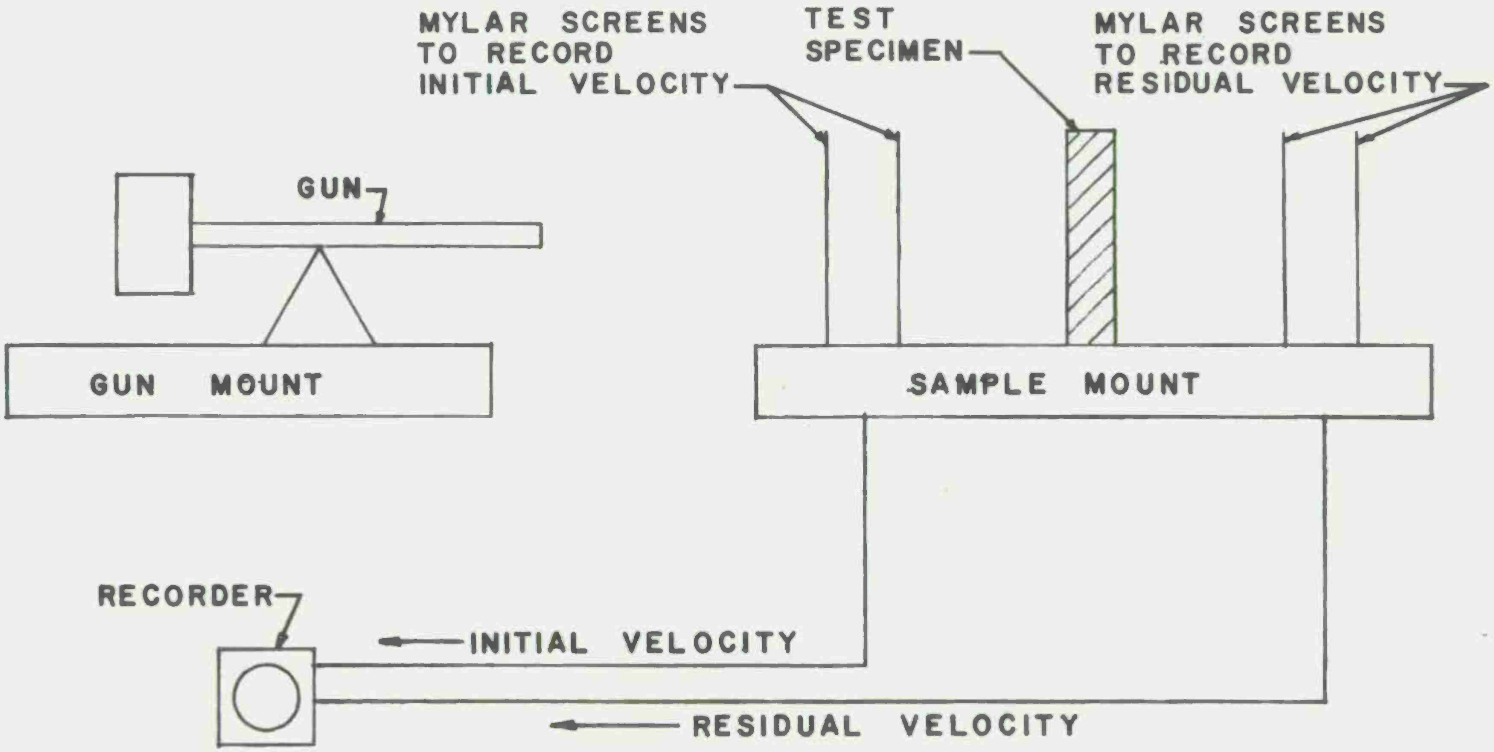


Figure 3. Stopping power test arrangement.

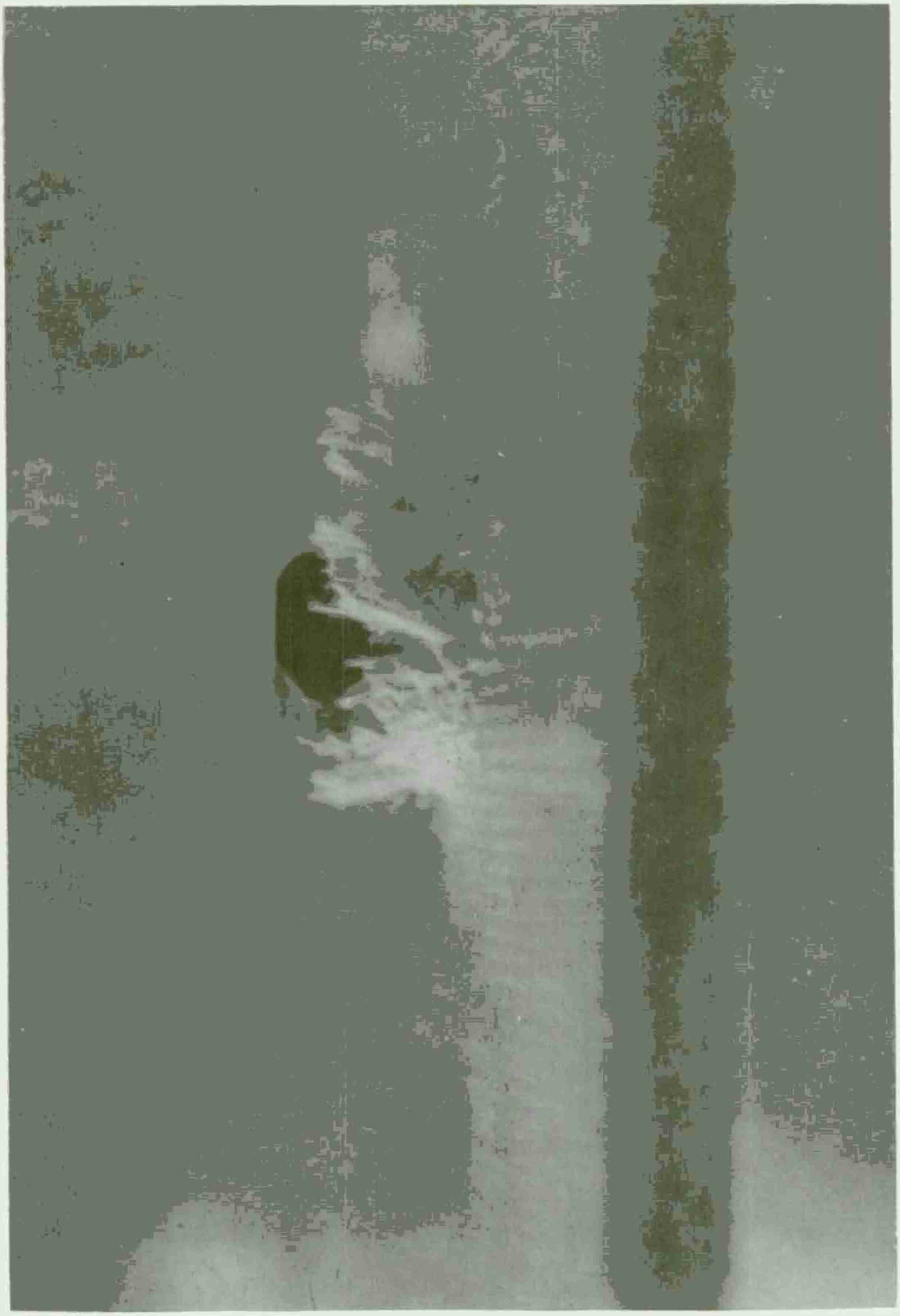
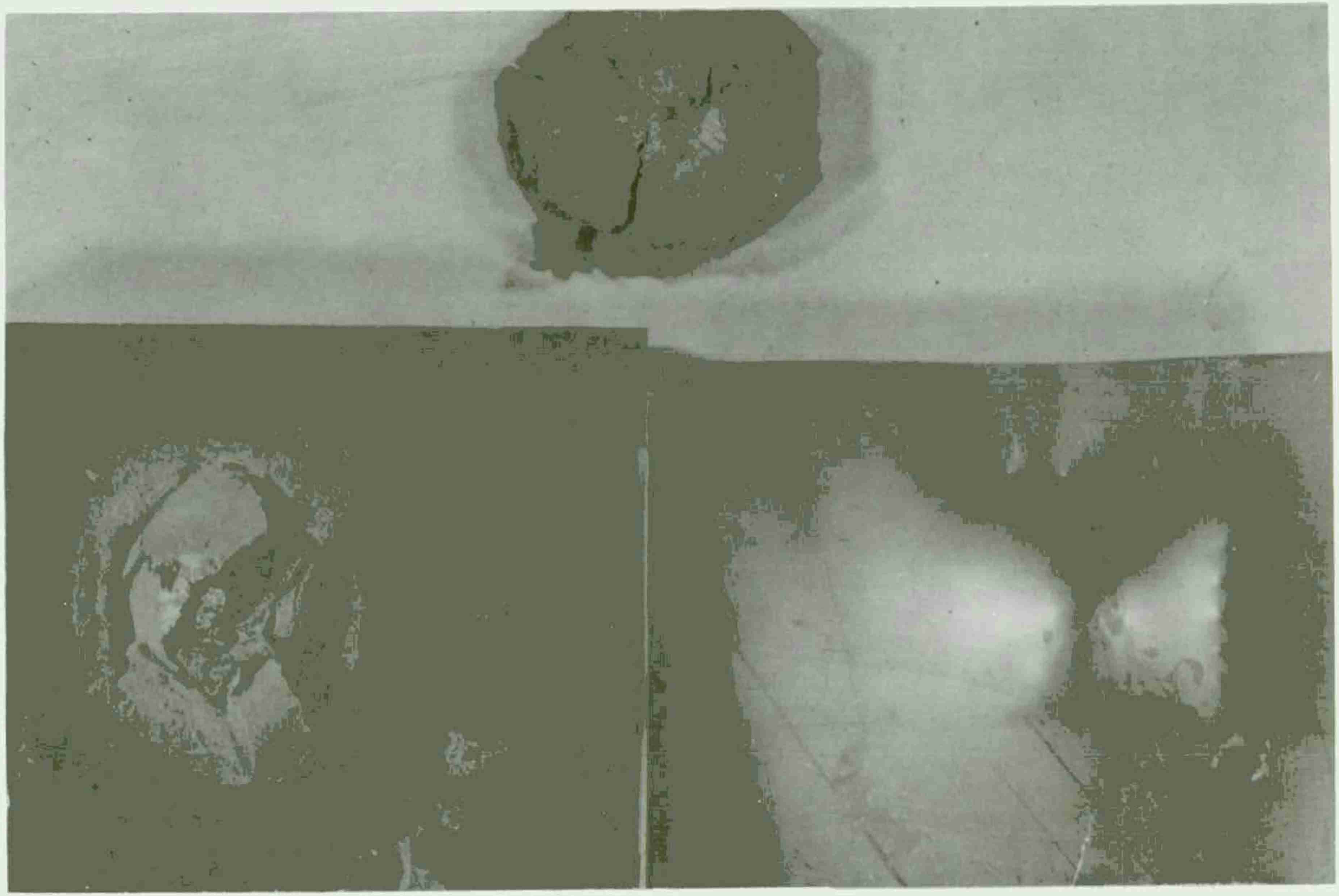


Figure 4. Projectile imbedded in Kevlar shield.

Figure 5. NVF Hard Fiber shield and steel backing plate



Fiqure 6. NVF Hard Fiber shields and steel backing plate.

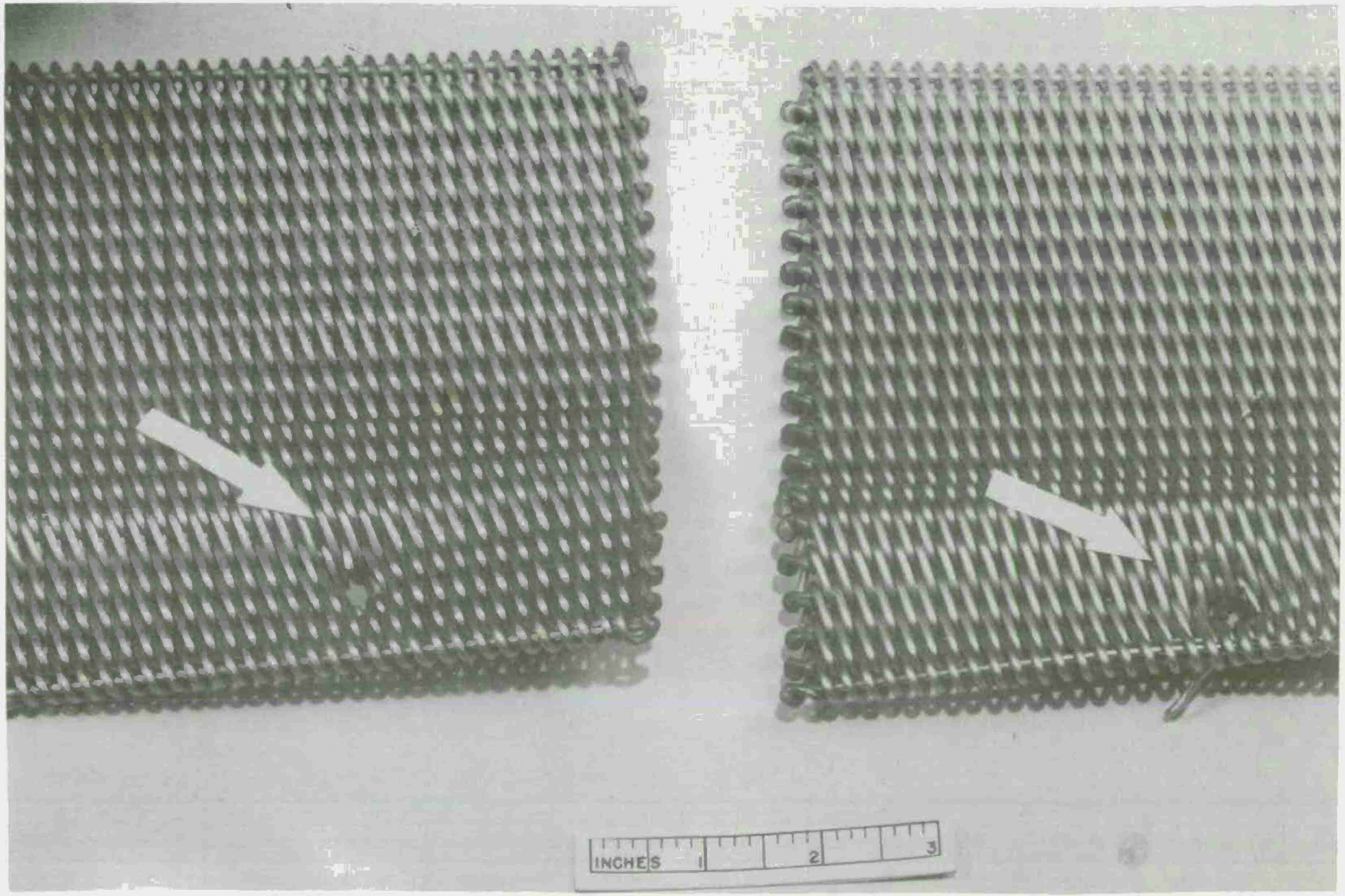


Figure 7. Steel mesh screens. Note projectile fragment in right-hand screen.

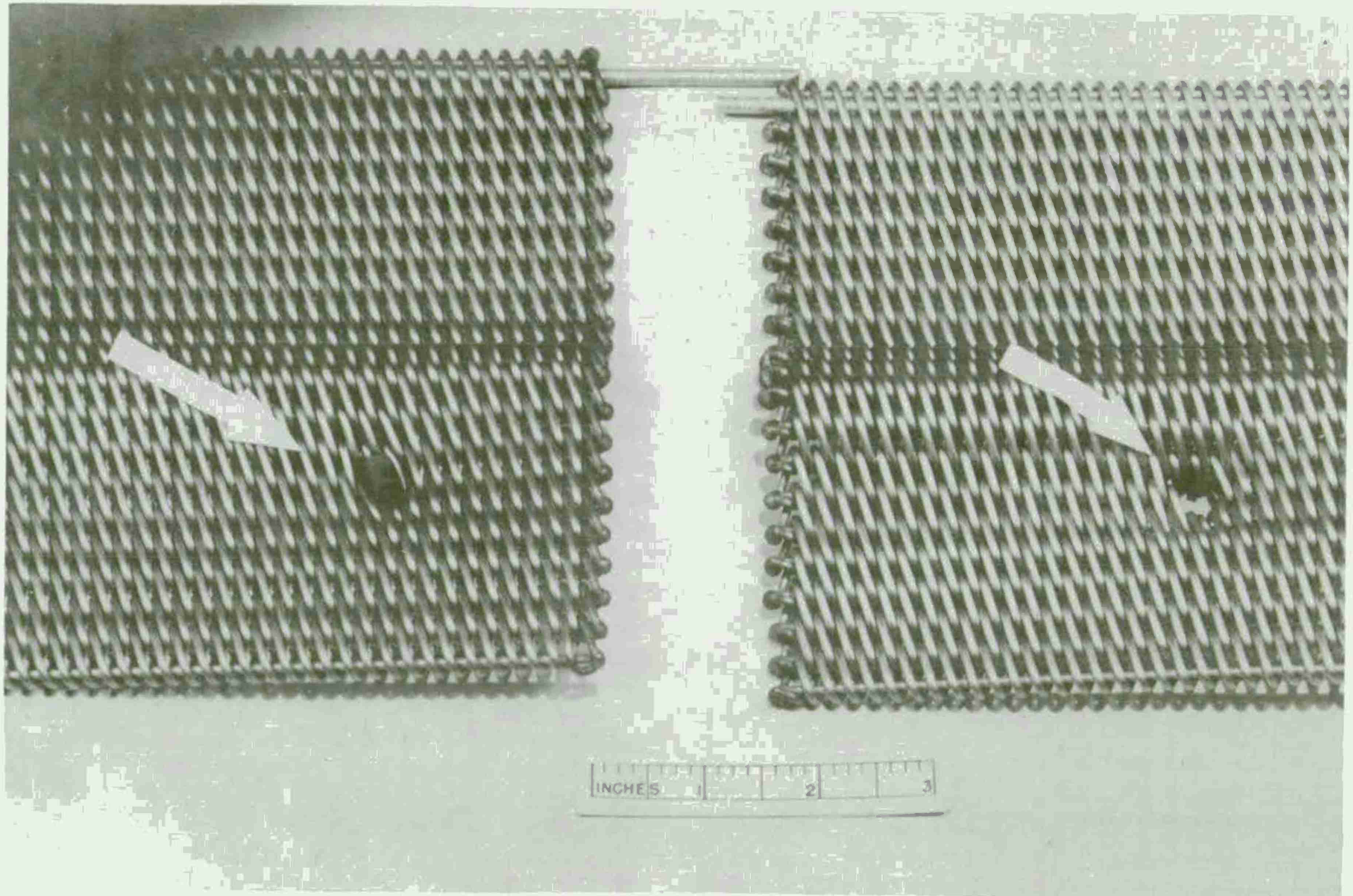


Figure 8. Steel mesh screens. Note projectile embedded in left-hand screen.

Fragment Impact Tests on Shielded Tote Bins

General

In order to evaluate the effectiveness of the selected shielding materials in terms of the reduction in explosive detonation hazard, it is necessary to conduct tests in which simulated fragments are fired against a shielded bin containing explosive. To facilitate the acquisition of such test data at reasonable cost, 1/3-scale models of the tote bins were constructed. These were protected with either Kevlar (3/8-inch thick) or NVF hard fiber (1/2-inch thick) shields. The model bins were filled with approximately 6 pounds of Composition A-7. Simulated fragments weighing 0.1 ounce (30 caliber) were fired at the models with their velocity measured in the same manner as for the previous tests as shown in Figure 9. As in the previous tests, the fragment propellant charge (2400 smokeless powder) was varied to provide a range of fragment velocities.

The model tote bins were constructed of 1/16-inch thick stainless steel. The shields were bonded to models. The models were located 130 feet from the rifle.

Test Results

The results of this series of tests are given in Table 4. They are summarized in Table 5. Two simulated tote bins were tested without shields as control samples. Both controls were detonated by projectiles of approximately 3,700 ft/sec impact velocity. No detonations occurred in either the Kevlar or NVF hard fiber shielded bins at similar levels of impact velocity.

TABLE 4

FRAGMENT IMPACT ON SHIELDED TOTE BINS TEST DATA

Impact Velocity (ft/sec)	Detonation	Visual Observations After Impact by Fragment
		KEVLAR
1230	No	Direct hit-fragment did not penetrate shield or bin SS frontal surface - 1/4 inch dent in SS.
1695	No	Fragment hit at top of bin - did not hit powder.
1635	No	Direct hit - no penetration of shield or bin SS frontal surface - 1/8-inch dent in SS.
1655	No	Fragment hit side of tote bin.
2300	No	Direct hit - fragment did not penetrate shield or bin SS frontal surface - 1/4-inch dent.
2620	No	Same as above.
3700	No	Direct hit - fragment penetrated shield and SS tote bin frontal surface - fragments lodged in Composition A-7.
3250	No	Direct hit - fragment did not penetrate shield or SS tote bin - 3/8-inch dent in frontal surface of tote bin.
3750	No	Direct hit - fragment penetrated shield and SS tote bin frontal surface - fragment lodged in Composition A-7.
		NVF HARD FIBER
3500	No	Direct hit - penetration through shield and SS frontal surface of bin - fragment lodged in Composition A-7.

TABLE 4
(concluded)

FRAGMENT IMPACT ON SHIELDED TOTE BINS TEST DATA

Impact Velocity (ft/sec)	Detonation	Visual Observations After Impact by Fragment
		NVF HARD FIBER (concluded)
3880	No	Same as above.
3760	No	Same as above.
		UNSHIELDED TOTE BINS
3700	Yes	High order detonation
3650	Yes	High order detonation

TABLE 5

SUMMARY OF SIMULATED FRAGMENT 30-CALIBER (BULLET) IMPACT TESTS
ON SHIELDED SCALED TOTE BINS FILLED WITH COMPOSITION A-7

Shield Material Tested	Material Thickness (inch)	Penetration of Shield	Penetration of Tote Bin	Detonation	Impact Velocity (ft/sec)
Kevlar	3/8	Yes	Yes	No	3750
NVF	1/2	Yes	Yes	No	3800
Control*		-	-	Yes	3700

* Unshielded tote bin

Safe Separation Distance Tests of Shielded Tote Bins

General

The results of the previous tests demonstrate the reduction in non-propagative spacing possible with the use of Kevlar or NVF hard fiber shields. In order to quantify the safe separation distances required at HAAP, a series of scale model propagation tests were undertaken. These tests were undertaken in two groups: a) with Kevlar shields and b) with NVF hard fiber shields. They were conducted using stainless steel boxes (1/16 inch thick) measuring 9-3/4" x 5-3/8" x 5-13/16" filled with 6 pounds of Composition A-7. Since fragments were considered as the main agent of propagation in the full scale configuration, provision was made to simulate conveyors and similar debris-forming sources of secondary fragments in the scaled tests. Each tote bin model acting as a donor was placed on top of an assemblage of spent Law Rocket Motors and test vehicles for M550 fuzes (40-mm M118). This is shown in Figure 10. An acceptor model was placed on blocks at a scaled separation distance as shown in Figure 11. Initiation of the donor detonation was achieved through the use of a J-2 blasting cap. Shields, used on both donors and acceptors, were oriented to face each other.

Test Results

The results of these tests are given in Table 6 and summarized in Table 7. No detonations occurred in the entire test series though there were numerous penetrations of both the acceptor shields and the bins themselves. Figures 12 through 16 show typical acceptors. From these results, it may be concluded, subject to full-scale confirmatory tests, that the safe separation distance between tote bins filled with Composition A-7 explosive may be reduced below 100 feet with the use of either Kevlar or NVF hard fiber shields.

Figure 9. Projectile impact test arrangement.

Figure 10. Scaled tote bin test set-up (Kevlar shield).

Figure 11. Over-view of test area.

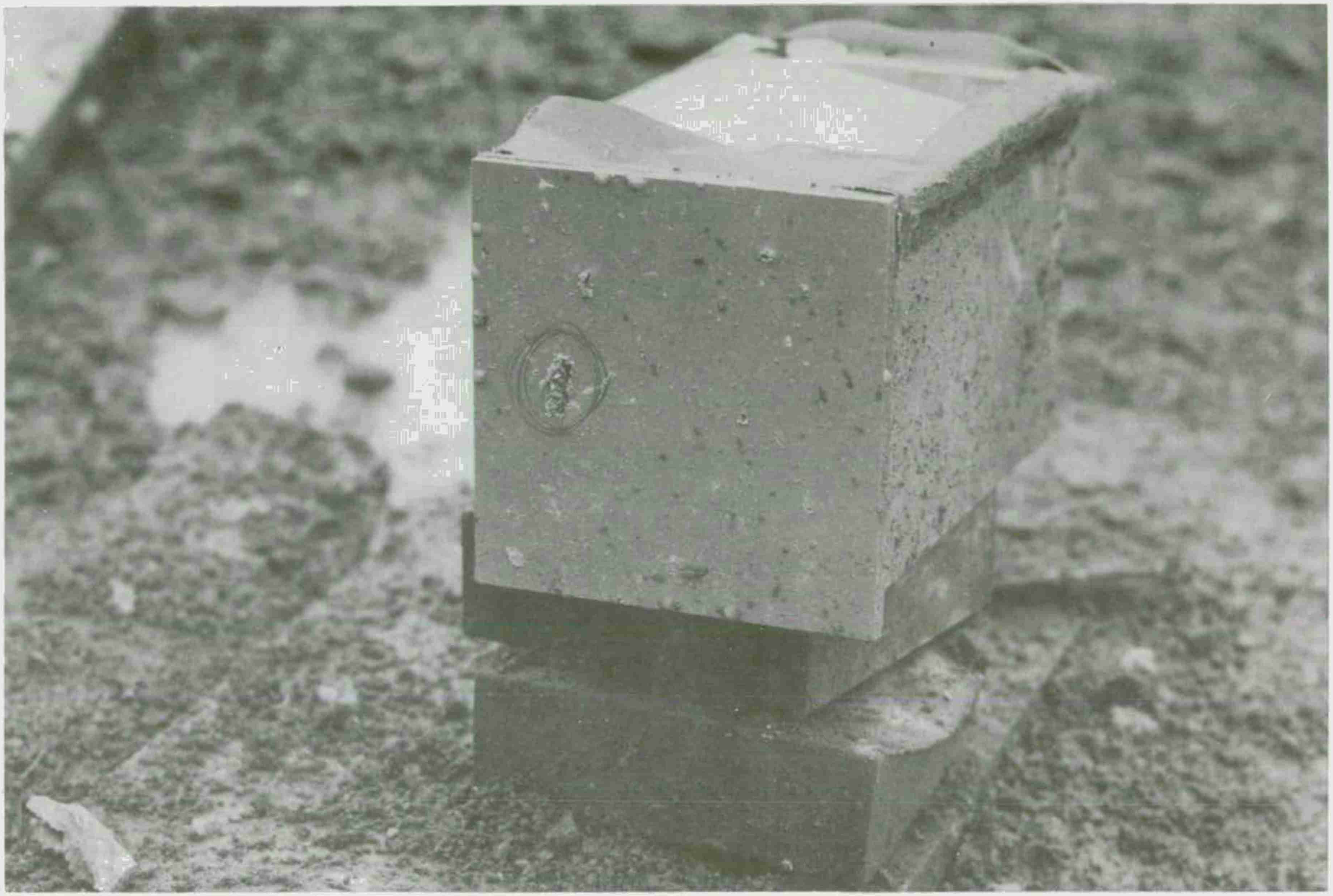


Figure 12. NVF Hard Fiber shielded scale model tote bin.

TABLE 6

SCALED TOTE BIN SAFE SEPARATION TESTS

Acceptor Distance from Donor (ft)	Scaled Separation (ft)	Acceptor Detonation	Acceptor Condition After Donor Detonation
			With Kevlar Shields
25	75	No	Tote bin dislodged from site - direct hit by fragments - no penetration of shield or SS bin fragment embedded in shield - no dents.
15	45	No	Direct hit - fragment penetrated shield - no penetration of SS bin - dent on SS frontal surface approximately 1/8 inch.
15	45	No	Same as above.
15	45	No	Direct hit - penetration by 2 fragments into shield - no penetration through tote bin frontal surface - dent on SS bin frontal surface approximately 1/8 inch.
15	45	No	Same as above.

TABLE 6
(continued)

SCALED TOTE BIN SAFE SEPARATION TESTS

Acceptor Distance from Donor (ft)	Scaled Separation (ft)	Acceptor Detonation	Acceptor Condition After Donor Detonation
		With Kevlar Shields (concluded)	
15	45	No	Direct hit - large fragment hole in shield. No penetration of shield or SS tote bin. Dent on SS frontal surface approximately 1/8 inch.
10	30	No	Same as above.
10	30	No	Direct hit - small fragment hits on front of shield - no penetration of shield or SS tote bin - dent in SS tote bin frontal surface approximately 1/8 inch.
		With NVF Hard Fiber Shields	
10	30	No	2 fragment holes - no penetration of shield or SS bin 1/8-inch dent in SS.

TABLE 6
(concluded)

SCALED TOTE BIN SAFE SEPARATION TESTS

Acceptor Distance from Donor (ft)	Scaled Separation (ft)	Acceptor Detonation	Acceptor Condition After Donor Detonation
		With NVF Hard Fiber Shields (concluded)	
10	30	No	3 fragment holes - no penetration of shield or SS bin - no dent on SS frontal surface.
10	30	No	Large fragment cut on shield - no penetration of shield or SS bin frontal surface. Dent in SS approximately 1/2 inch deep.
10	30	No	2 large fragment holes - no penetration of shield or SS bin frontal surface - dent in SS approximately 1/4 inch.

TABLE 7

SUMMARY OF ONE-THIRD SCALE COMPOSITION A-7
SHIELDED TOTE BIN SAFE SEPARATION TESTS

Shielding Materials	Shielding Material Thickness (inch)	Detonation	Tote Bin Penetration	Safe Separation Distance (feet)	Scaled Distance (feet)
Kevlar	3/8	No	No	25	75
Kevlar	3/8	No	No	15	45
Kevlar	3/8	No	No	10	30
NVF Hard Fiber	1/2	No	No	10	30

NOTE: Direct hits obtained with simulated secondary fragments.

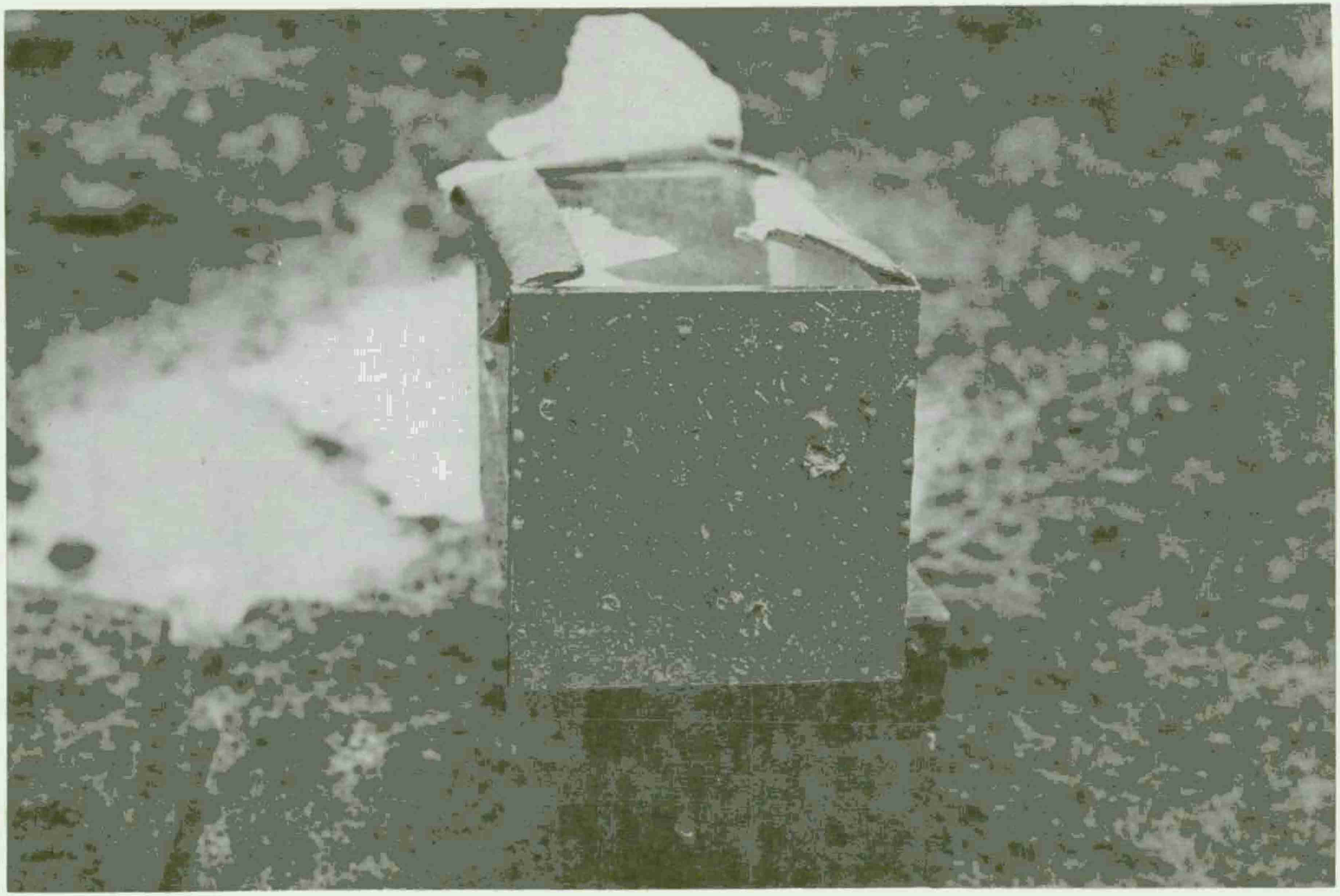


Figure 13. Scale model tote bin shielded with NVF Hard Fiber.

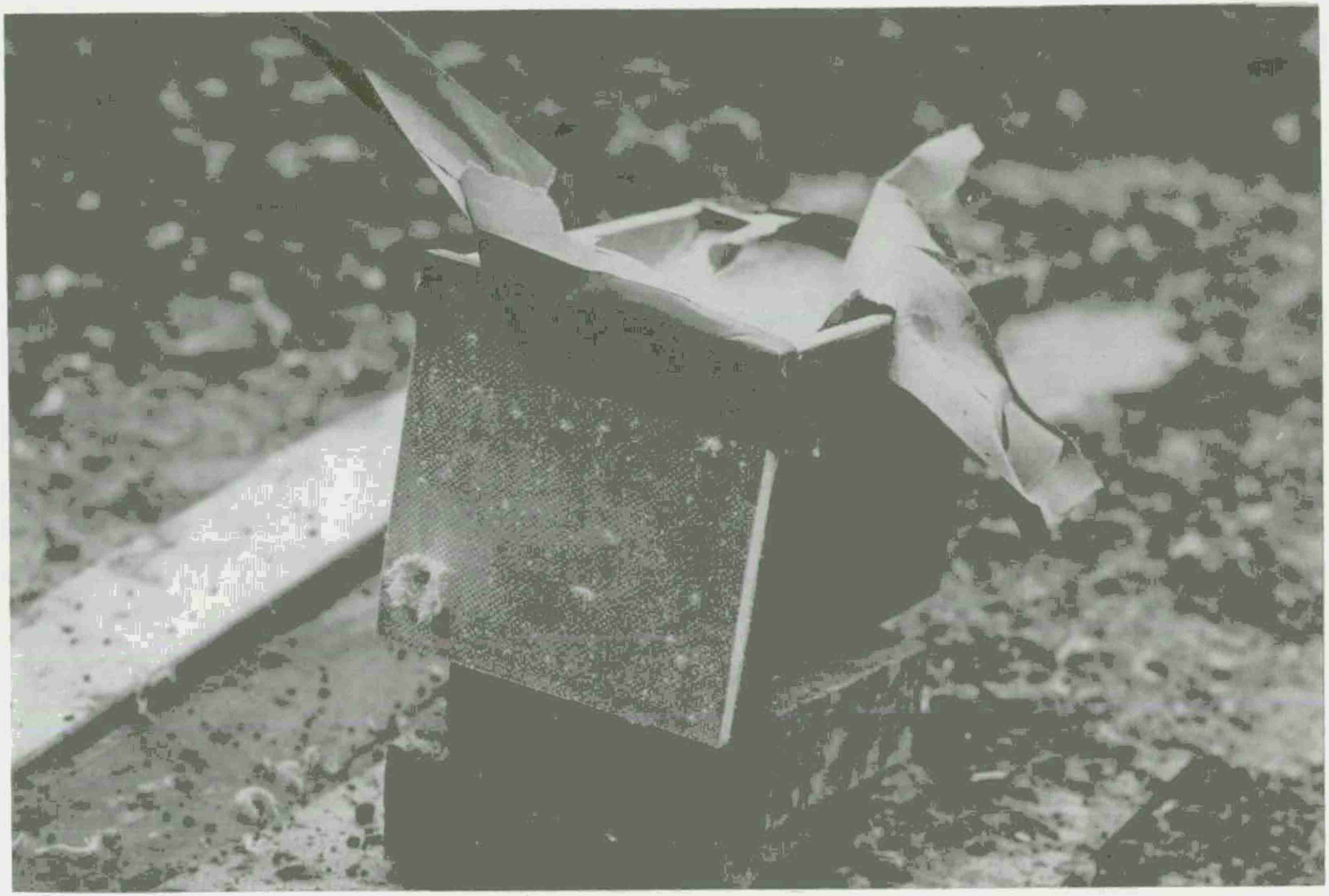


Figure 14. Scale model tote bin shielded with Kevlar.

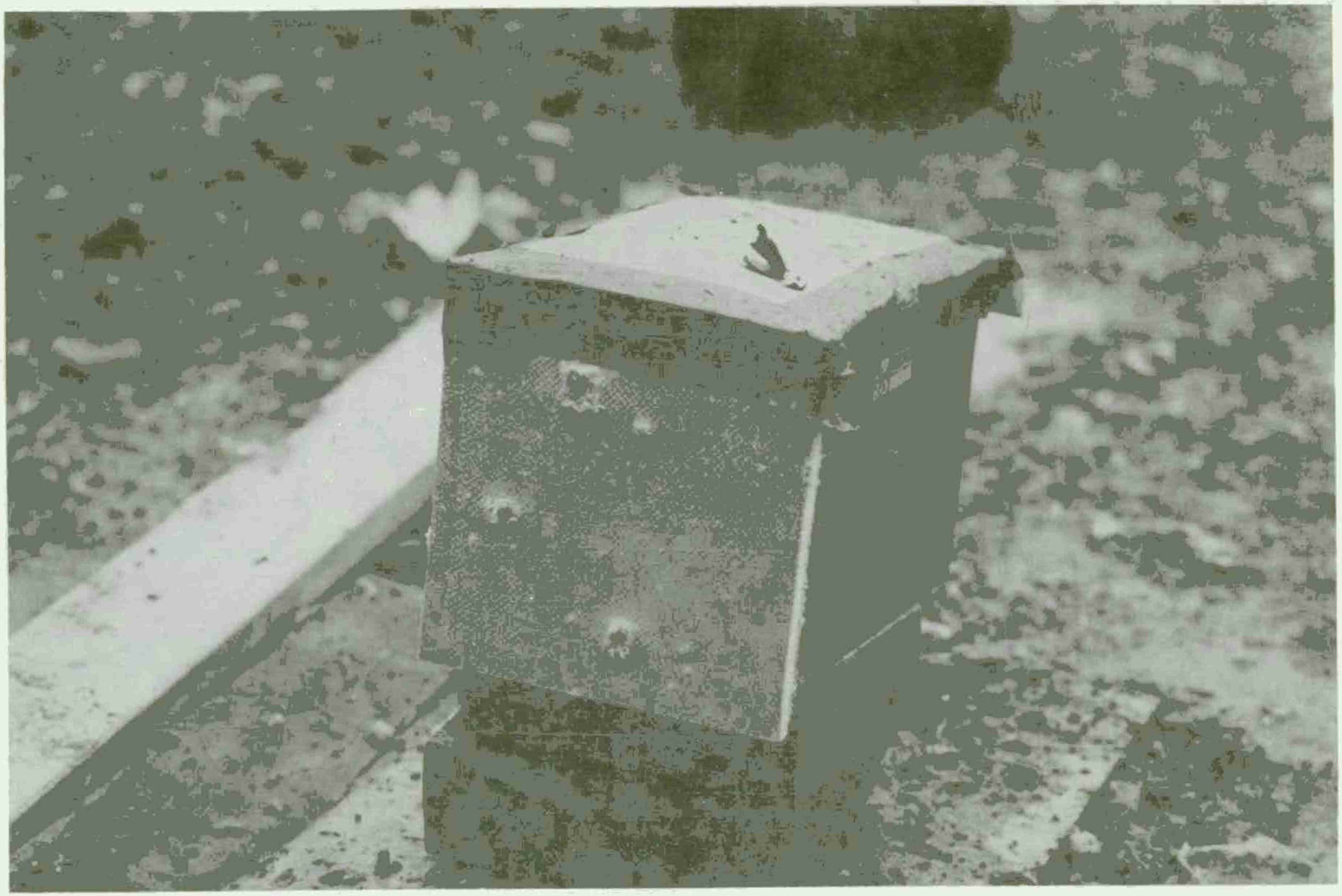


Figure 15. Scale model tote bin shielded with Kevlar.

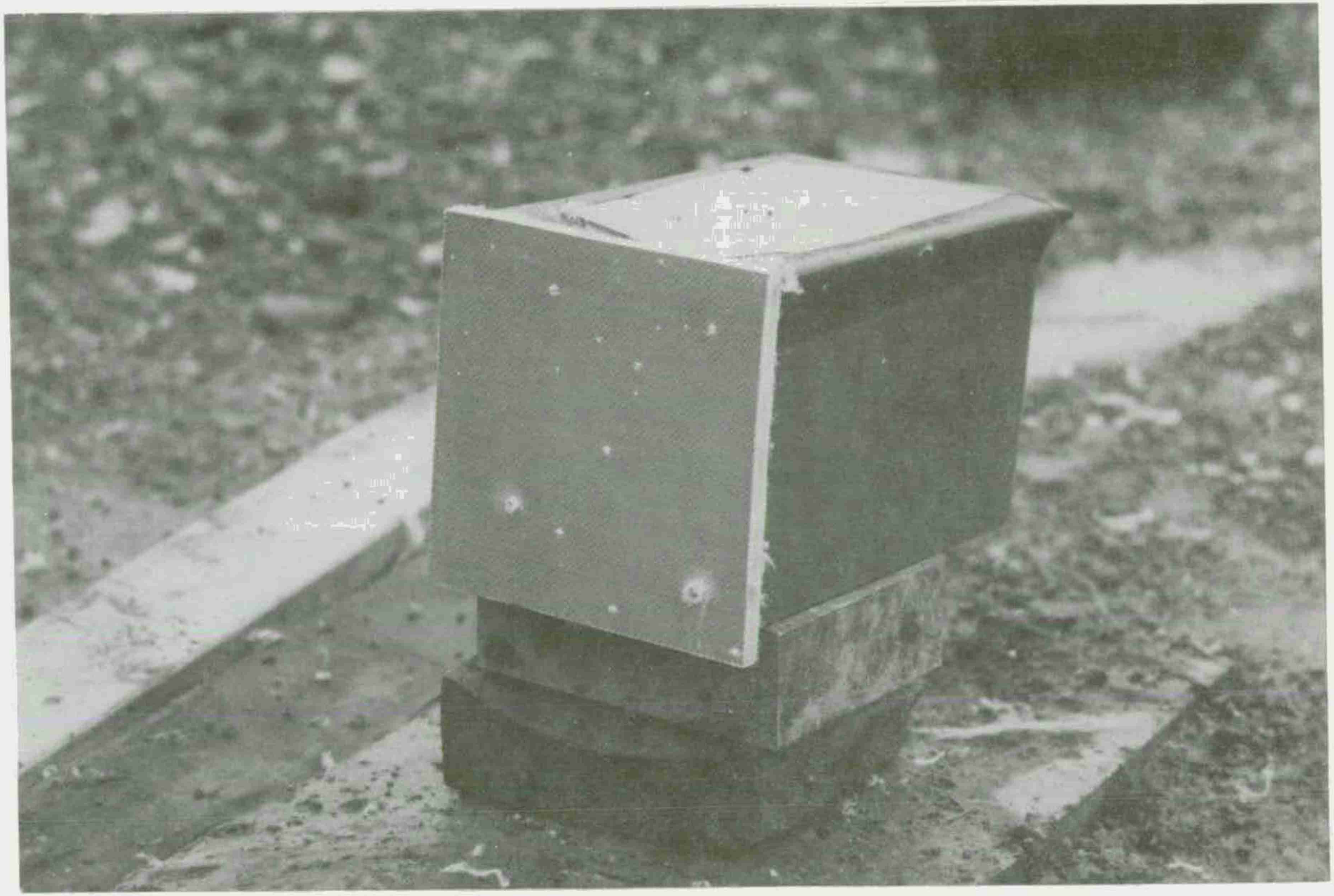


Figure 16. Scale model tote bin shielded with Kevlar.

Safe Separation Distance Tests of Plastic Tote Bins

General

The removal of potential fragment material from the conveyance system is a viable alternative to shielding against fragments. One means of accomplishing this is to fabricate the tote bins of a plastic material. Three materials were selected for small scale evaluation of this approach. These were polyethylene, noryl and lexan. All three were molded into approximately 1/3-scale models. The polyethylene was 1/16 inch thick while the noryl and lexan were 1/8 inch thick. The polyethylene models were 5" x 5" x 6-3/4", while the noryl and lexan bins were made 8" x 8" x 6". The dimensional differences were due to tooling constraints at the vendor selected for fabrication.

The models were tested with one acceptor model placed on either side of a donor model at the specified spacings. All models were supported 4 inches from the ground. The donor was placed on top of an assemblage of spent Law Rocket Motors to simulate secondary fragments. Each model tote bin was filled with 6 pounds of Composition A-7 explosive and covered with paper taped in place. Initiation of the donor was accomplished with a J-2 blasting cap.

Test Results

The test results are given in Table 8 and summarized in Table 9. Representative views of the plastic tote bins after the tests are shown in Figures 17 through 24. For the polyethylene tote bins, one high order detonation occurred at a distance of 15 feet (45 feet - scaled distance) and one low order detonation at 20 feet (60 feet - scaled distance). No detonations were observed with either the noryl or lexan models.

Discussion of Results

The test results show that it is possible to reduce the required safe spacing between tote bins filled with Composition A-7 below 100 feet by a number of alternative means. Each of these alternative means has its own strengths and weaknesses. The following discussion attempts to summarize these and to accord relative weights to each.

The use of plastic materials in the fabrication of the tote bins is an attractive solution to the problem. This approach essentially eliminates all primary fragments. Secondary fragments of lower energy, however, are able to penetrate the bins. Though the test data show a possible safe spacing (scaled) of 75 feet, with the lexan superior to the noryl which is, in turn, superior to the polyethylene, it is not certain that this would be borne out by full scale testing. Further, fabricating the tote bins of plastic materials is a significant change from current HAAP operations. No evaluation was made of the impact such a change would make on the conveying system nor of the time required to construct the new bins and get them operational. In addition, a means would have to be found to meet the grounding requirements of AMCR 385-100. This would probably involve some form of metalizing process applied to the plastic materials.

Suspension of steel mesh screens between the tote bins would reduce the available energy of impact of fragments. Several drawbacks to the application of this scheme to the situation of interest are apparent, however. First, a substantial quantity of steel would be added to the system. The additional steel represents additional potential fragment material under certain conditions. Such conditions would obtain, in the event of a detonation of a donor close to the location of the screens. Secondly, a suspension system of the screens would have to be designed and fabricated. This suspension would have to provide smooth articulation of the shields to allow passage of the bins without binding or potential sparking contacts between metals. It would also be necessary to insure that the screens can be arranged so that two tote bins cannot be simultaneously on the same side of the screens.

The most attractive scheme tested is the addition of energy absorbing shields to the existing tote bins. These shields can be attached to the bins with nylon nuts and bolts with minimum delay and consequent interruption of service. The shields would then be serviceable in the event of long term abuse. Of the materials selected, Kevlar and NVF hard fiber are clearly superior. The Kevlar afforded the same level of protection as the hard fiber with less material (3/8-inch thickness as compared to 1/2 inch). Kevlar is, therefore, recommended for full scale testing.

TABLE 8

SAFE SEPARATION DISTANCE FOR SCALED TOTE BINS

Charge Weight: 6 Pounds
Height off Ground: 4 inches

Fragments: Spent Law Rocket Motors
Dimensions: 5" x 5" x 6-3/4" x 1/16" thick

Acceptor Distance From Donor (feet)	Scaled Distance	Acceptor Detonation	Visual Observation of Acceptor Condition After Donor Detonation
			Polyethylene
20	60	No	Small dents from dirt. No penetration.
15	45	No	Several small holes.
15	45	Yes	High order detonation.
20	60	No	Small holes on frontal side. Small fragments embedded.
20	60	No	Small holes from dirt.
25	75	No	Small fragments embedded (see photo).
20	60	No	Small fragments embedded.
25	75	No	No fragments or dents.
20	60	No	Small fragments embedded.
25	75	No	Small dent on front.
20	60	No	Hole 1/8" x 1/16" - 2 fragments embedded.

TABLE 8
(continued)

SAFE SEPARATION DISTANCE FOR SCALED TOTE BINS

Charge Weight: 6 Pounds
Height off Ground: 4 inches

Fragments: Spent Law Rocket Motors
Dimensions: 5" x 5" x 6-3/4" x 1/16" thick

Acceptor Distance From Donor (feet)	Scaled Distance	Acceptor Detonation	Visual Observation of Acceptor Condition After Donor Detonation
		Polyethylene (continued)	
25	75	No	4 fragments embedded.
20	60	Yes	First order detonation
25	75	No	2 fragments penetrated.
25	75	No	Cut on side from fragment.
30	90	No	2 holes - 2 fragments.
25	75	No	1/2-inch cut from fragment.
30	90	No	Small fragment embedded.
30	90	No	1/2" x 1/16" cut.
25	75	No	2 dents - 1 fragment penetration.
30	90	No	1/2" x 1/16" cut.
25	75	No	Clean.
30	90	No	2 fragments embedded.
25	75	No	2 penetrations - 2 fragments embedded.

TABLE 8
(continued)

SAFE SEPARATION DISTANCE FOR SCALED TOTE BINS

Charge Weight: 6 Pounds
Height off Ground: 4 inches

Fragments: Spent Law Rocket Motors
Dimensions: 5" x 5" x 6-3/4" x 1/16" thick

Acceptor Distance From Donor (feet)	Scaled Distance	Acceptor Detonation	Visual Observation of Acceptor Condition After Donor Detonation
		Polyethylene (concluded)	
30	90	No	Large hole in pin above powder.
25	75	No	3 fragments embedded.
		Noryl	
30	90	No	1/2" x 1/16" cut on frontal side.
25	75	No	2 dents - 2 fragment penetrations.
30	90	No	1/2" x 1/16" cut.
25	75	No	Clean.
30	90	No	Small cut on frontal side.
25	75	No	6 small cuts on frontal side.
30	90	No	Clean.
25	75	No	Small cut - 1 fragment penetration.

TABLE 8
(continued)

SAFE SEPARATION DISTANCE FOR SCALED TOTE BINS

Charge Weight: 6 Pounds
Height off Ground: 4 inches

Fragments: Spent Law Rocket Motors
Dimensions: 5" x 5" x 6-3/4" x 1/16" thick

Acceptor Distance From Donor (feet)	Scaled Distance	Acceptor Detonation	Visual Observation of Acceptor Condition After Donor Detonation
			Noryl (concluded)
30	90	No	2 small dents.
25	75	No	1 fragment embedded.
30	90	No	1 fragment embedded.
25	75	No	2 small cuts.
30	90	No	1 small cut.
25	75	No	Clean.
25	75	No	1/4" x 1/2" hole.
			Lexan
30	90	No	Clean.
25	75	No	Clean.
30	90	No	Clean.
25	75	No	1 fragment embedded.

TABLE 8
(concluded)

SAFE SEPARATION DISTANCE FOR SCALED TOTE BINS

Charge Weight: 6 Pounds
Height off Ground: 4 inches

Fragments: Spent Law Rocket Motors
Dimensions: 5" x 5" x 6-3/4" x 1/16" thick

Acceptor Distance From Donor (feet)	Scaled Distance	Acceptor Detonation	Visual Observation of Acceptor Condition After Donor Detonation
		Lexan (concluded)	
30	90	No	Clean.
25	75	No	1 indentation.
30	90	No	Clean.
25	75	No	Clean.
30	90	No	Clean.
25	75	No	Clean.

TABLE 9

SUMMARY OF SAFE SEPARATION DISTANCE FOR VARIOUS 1/3-SCALED PLASTIC TOTE BINS FILLED WITH COMPOSITION A-7 EXPLOSIVE UNDER IMPACT FROM SIMULATED SECONDARY FRAGMENTS

Material Tested	Material Dimensions (inch)	Safe Separation Distances (feet)	Tote Bin Penetration
Polyethylene	5x5x6-3/4x1/16	25*	Yes
Noryl	8x8x6x1/8	25**	Yes
Lexan	8x8x6x1/8	25**	No

* Detonated at 20 feet.
** Not tested at lower distances.

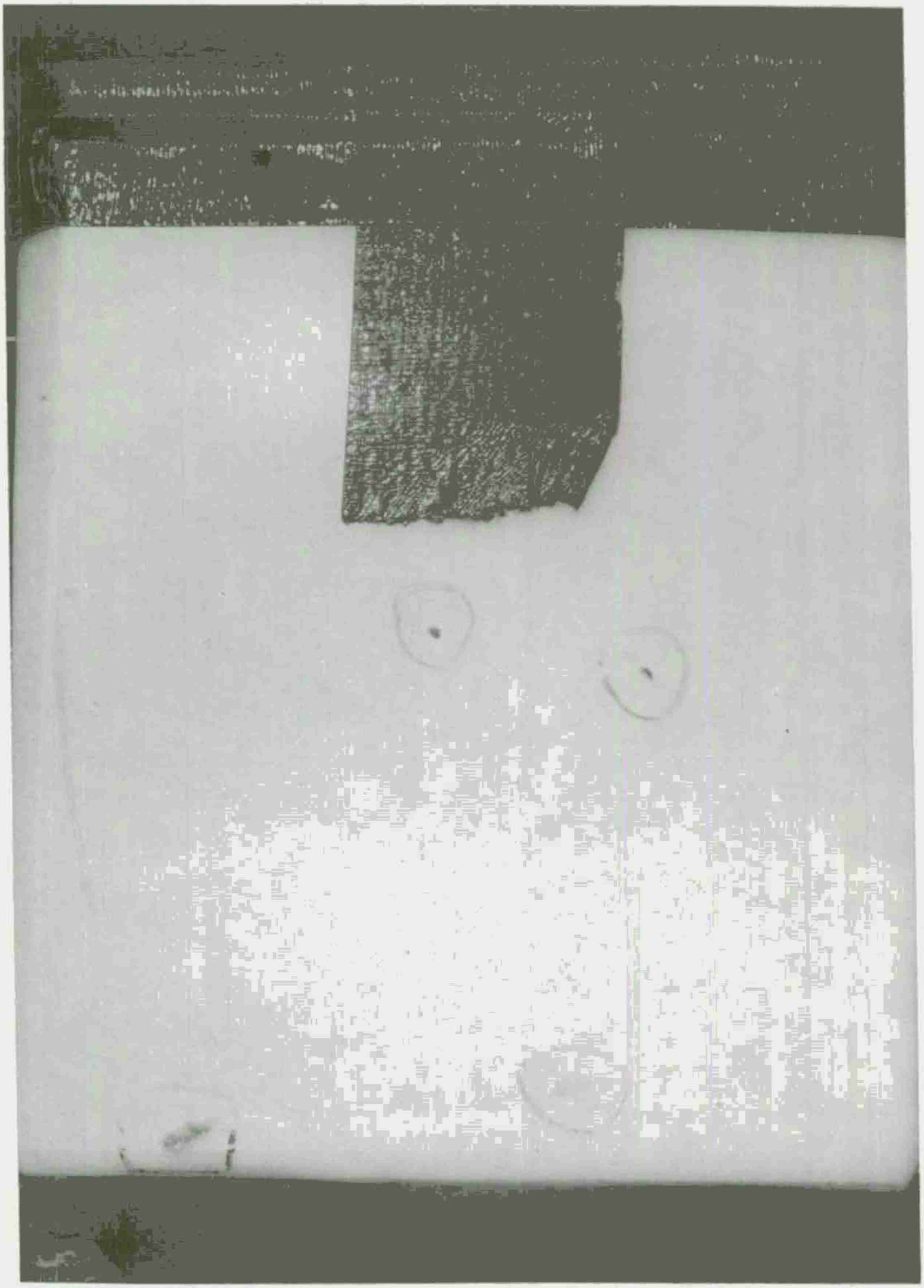


Figure 17. Polyethylene model tote bin.

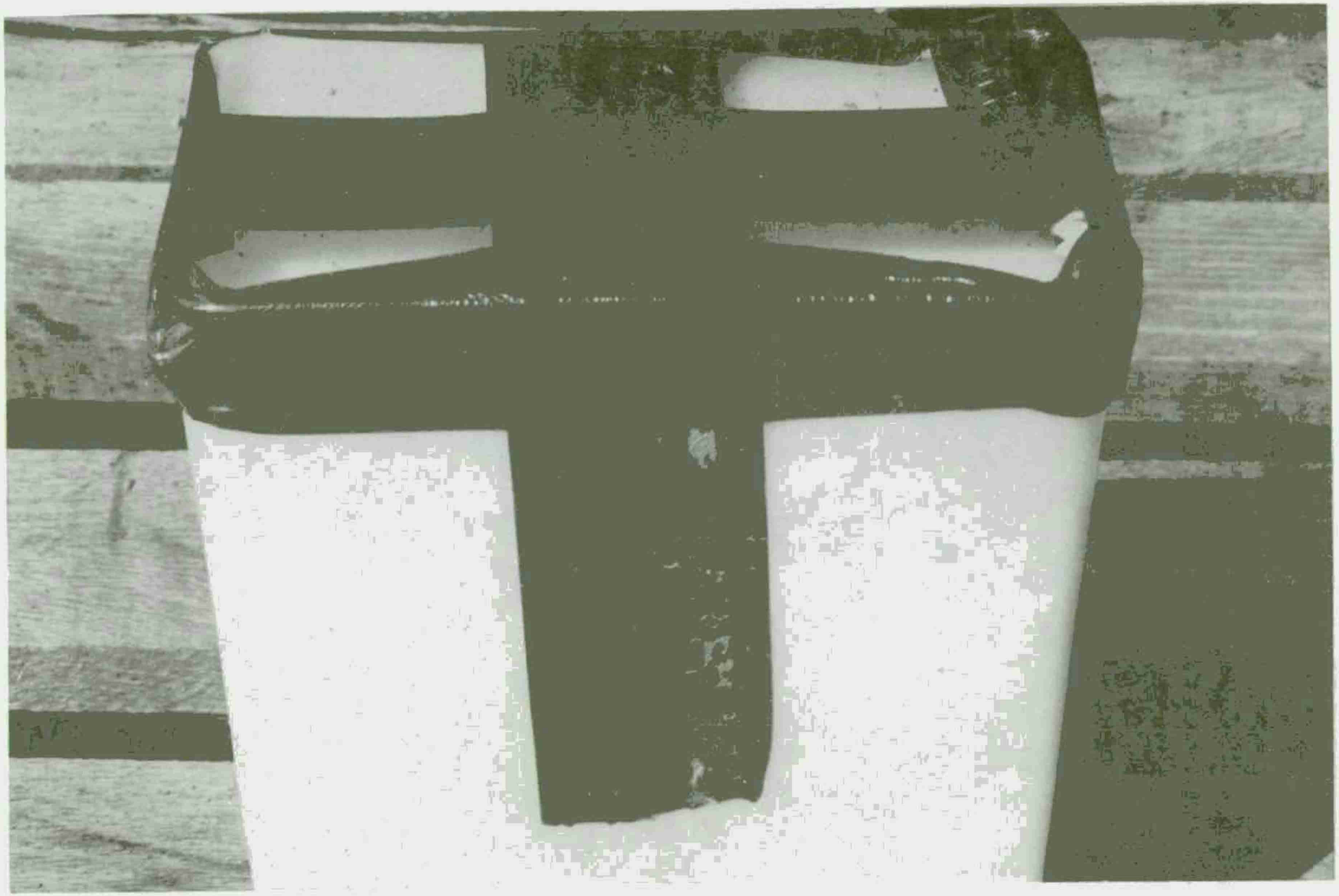


Figure 18. Polyethylene model tote bin.

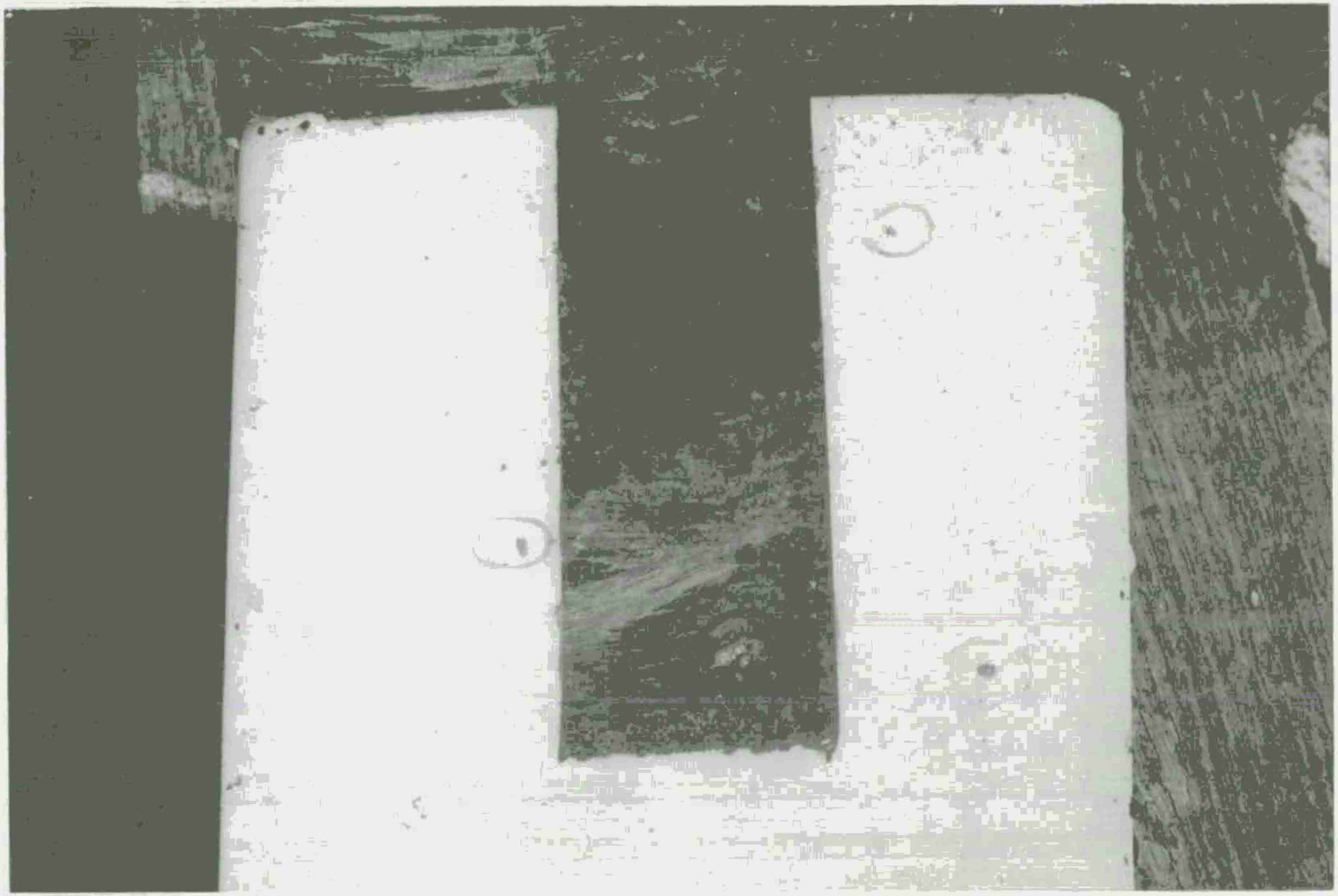


Figure 19. Polyethylene model tote bin after test.

Figure 20. Polyethylene model tote bin after test.

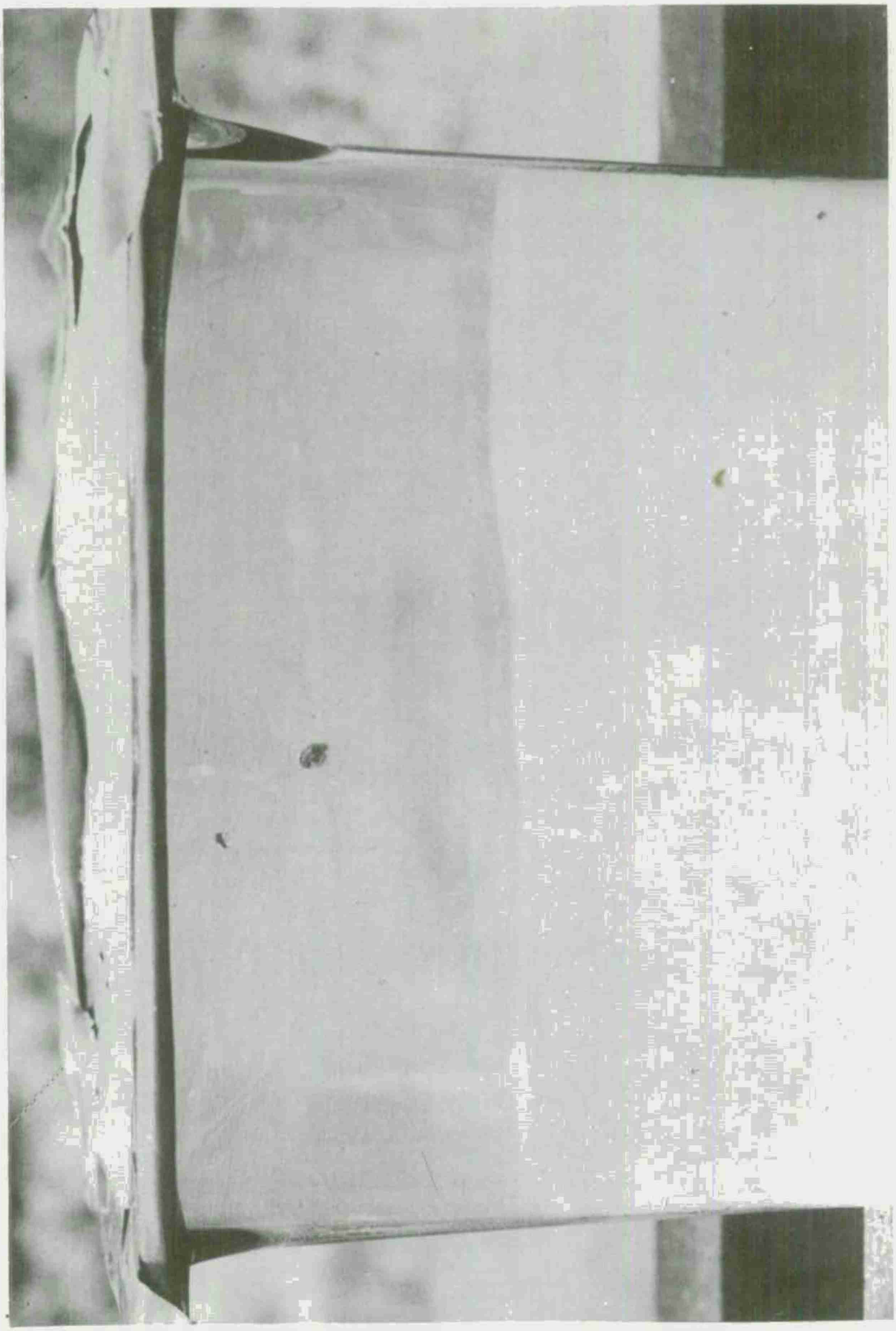


Figure 21. Lexan model tote bin.

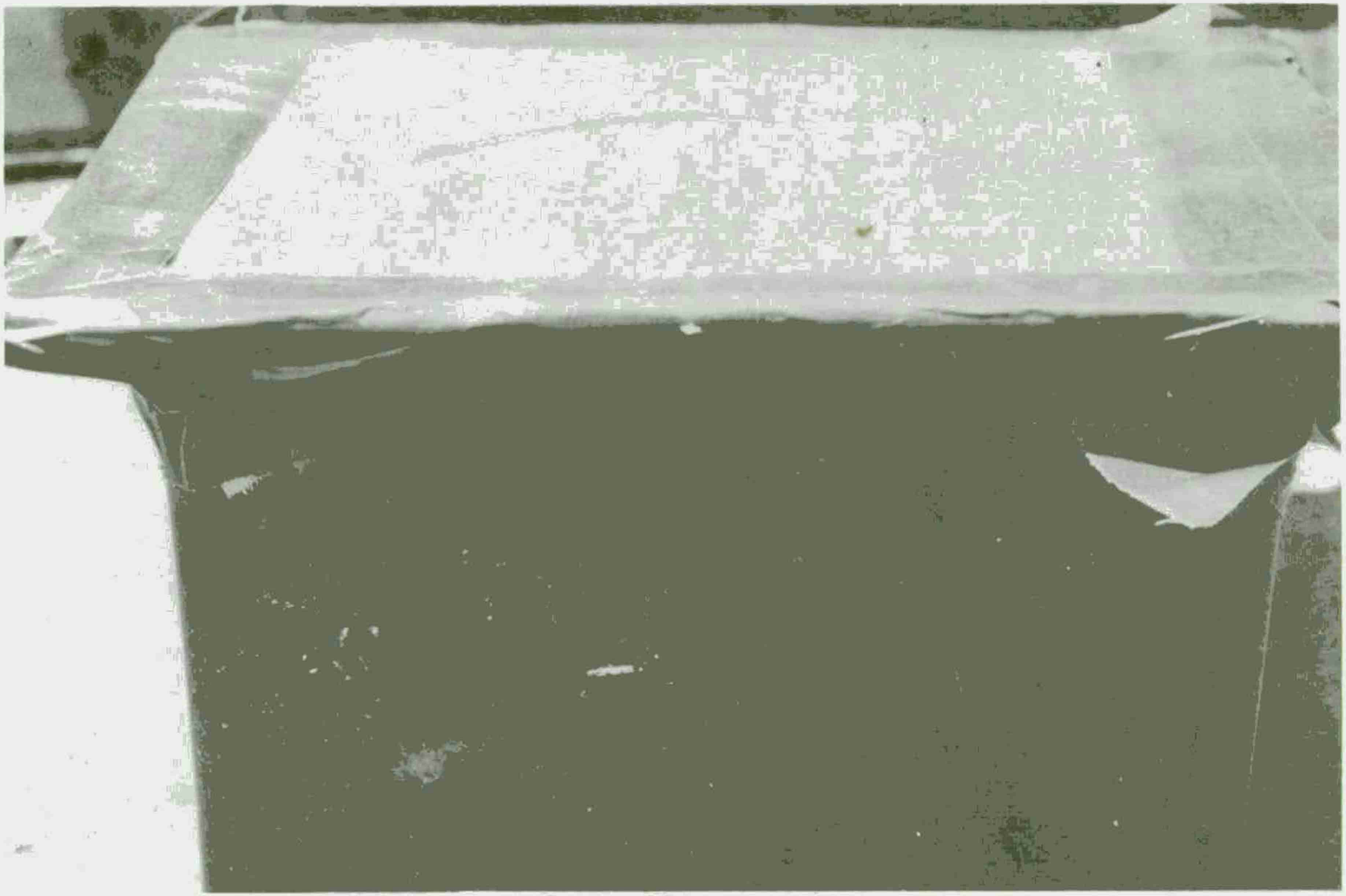


Figure 22. Noryl model tote bin.

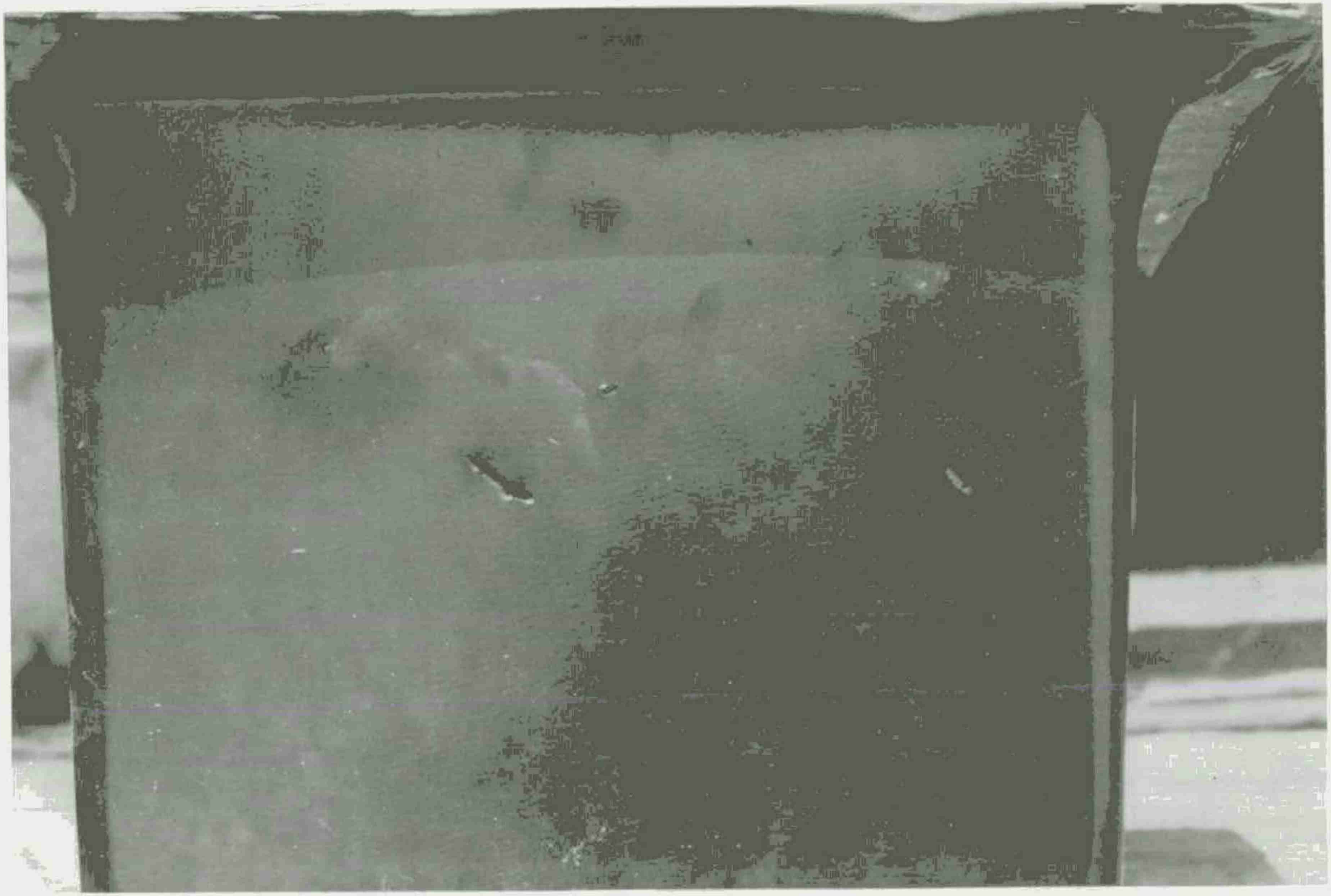


Figure 23. Noryl model tote bin after test.

Figure 24. Noryl model tote bin.

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