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INVESTIGATION OF EXPLOSIVES SENSITIVITY TO MULTIPLE-FRAGMENT IMPACT TRACK TESTS (E-7101)

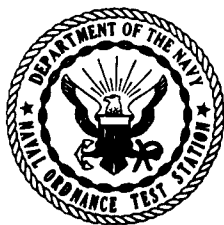
by

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ABSTRACT. As part of the ASESb program for determining the effectiveness of substantial dividing walls in preventing the propagation of explosions, multifragment impact tests were conducted on the NOTS K-2 track. These tests employed a rocket-powered sled to throw a collection of concrete fragments at an explosive 'acceptor' charge. In four of eight test rounds the acceptor detonated high order when struck by the fragment sample. The fragment velocities chosen for investigation corresponded to those which occurred during the destruction by explosion of full-scale walls. The results prove that wall fragment impact can cause propagation.

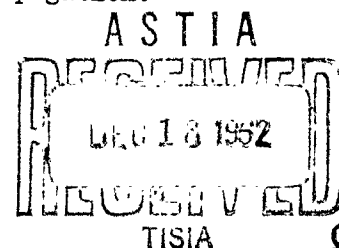
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U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

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INTRODUCTION

During the period from 1960 to date, approximately 20 full-scale cubicle tests have been conducted at NOTS under the cognizance of the Armed Services Explosives Safety Board (ASESB) to determine the effectiveness of standard dividing walls in preventing the propagation of explosions between adjacent bays. The concrete cubicles used in these tests were designed to simulate the standard construction used in existing explosives storage and processing facilities. In the cubicle tests in which propagation occurred, high-speed motion pictures showed that the acceptor explosives were engulfed by a cloud of wall fragments prior to their detonation. Since no other evidence from these tests conclusively contradicted the evidence of detonation by wall fragments, further investigation of this factor was indicated.

Therefore, an investigation to establish whether detonation of standard dividing wall acceptors could be initiated by wall-fragment impact alone was undertaken. In this study, an especially-designed, rocket-powered sled was used to throw a collection of concrete and aggregate fragments at an explosive acceptor charge at velocities within the range of those occurring in full-scale cubicle tests. (Only a few reliable fragment-cloud velocity data were available from the various cubicle tests; those obtained ranged from approximately 200 to 1,150 fps.)

TEST VEHICLE AND FRAGMENTATION CONTAINER DESIGN

A test setup that would isolate fragment impact from other possible causes of detonation was needed. The K-2 ballistics track facility, which consists of 1,500 feet of twin rail mounted on a concrete base, provided a means of obtaining high velocity and accurate delivery of a test item against a relatively small target. For use on this track, a rocket-powered sled that would propel a container of concrete rubble downtrack at selected velocities between 300 and 1,200 fps, was designed. It was then necessary to provide for the release of the fragment specimen without altering its velocity. Of several methods considered, a water-brake system, which would decelerate the sled and thus cause the fragments to be thrown from the sled against the acceptor charge target, was chosen as the most economical and reliable. A container to carry the concrete specimen was also needed. It was determined that a cylinder 12 inches in diameter and 12 inches long (this length corresponds to the thickness of a standard 12-inch dividing wall) would hold an acceptable load and that it would represent a reasonable size and weight for

use with the test vehicle as designed. It was anticipated that there would be a slight dispersion of the fragments between release and impact so that the fragments would cover a full impact area on the 18-inch diameter acceptor charge.

Figure 1 shows the rocket sled, sledborne water brake wedge, and fragment-containing cylinder; Fig. 2 is a rear view of the test sled showing additional structural members used to support the container; Fig. 3 shows the polyethylene water bag brake, the deflector plate used to deflect the test vehicle away from the target, and the acceptor charge target; Fig. 4 shows the general arrangement of test equipment at the track area.

TEST SETUP*

The test setup involved the following units:

Test Vehicle and Fragment Container. Two 5-inch HVAR rocket motors were used as the main sled structure. The fragment container, with a frangible plastic cover taped across the open front end, was attached (lying on its side) to the top of the motors. On the front of the sled was a water-brake wedge, shaped to force the water out to either side. Auxiliary structural members used to support the container are shown in Fig. 2.

Fragments. The fragment specimen (Fig. 5) used for each test round weighed an average 73 pounds** and contained the following material:

Concrete--50 lb (+0, -2)	{ Approx 6 pcs, 4 to 8 in diameter Approx 5 pcs, 3 in. diameter Various pcs, 1 to 2 in diameter
Aggregate--25 lb (+0, -2)	3/8- to 3/4-in. gravel

Fragment samples of this specification are designated Mk 1 Rubble.

Water-Brake Setup. Water-braking action was supplied by partially-filled polyethylene water bags fastened to the last 10 to 15 feet of track. Sled deceleration was accomplished when the wedge on the front of the sled hit the water-filled bags fastened to the track.

*The test setup described incorporates the changes and modifications indicated by checkout tests E-1 and E-6, described on page 9.

**The fragments used in E-Round 14 were 10 pounds light. They consisted of 43 lb concrete and 20 lb gravel.

Deflector Plate. A standard 2-inch steel deflector plate, placed 6 feet from the end of the track at a 5-deg angle from the track centerline, was used to deflect the test vehicle to keep it from striking the target.

Target. Standard dividing wall acceptor charges, identical to those used in most of the cubicle tests, were used as targets. These charges were spherical, special weapon warheads with simulated covers of aluminum and a full complement of detonators; each sphere contained 100 pounds of cyclotol explosive. An acceptor-charge target was placed on a wooden stand 30 feet from the end of the track for each test.

Instrumentation. Several 16mm Fastax cameras, operating at approximately 2,500 fr/sec, were positioned to record the entrance of the sled into the water brake, fragment travel, and the impact of fragments on the acceptor. Two 35mm Fastax streak cameras also covered fragment impact and part of sled travel; one Bowen covered the area from start of water-brake action to fragment impact on the target. Camera locations are shown in Fig. 4.

Other instrumentation included two counterchronometer switches placed 12 inches apart at the muzzle end of the track and magnetic pickup coils installed on the track at 24-ft intervals to determine sled velocity.

TEST METHOD

The launching of the test vehicle encompassed two major phases: (1) the acceleration phase which consisted of ignition of one or two rocket motors to accelerate the vehicle to a predicted velocity, and (2) the separation of the fragments from the vehicle by means of water-brake deceleration of the vehicle. The velocity of the vehicle and test item was controlled in several ways: by selecting the number of rocket motors used, by changing the distance of the ignition point from the water brake, and by varying the weight of the sled. The following variations were used:

Sled velocity* (fps)	Motor & sled configuration	Total wt (lb)	Ignition point (ft from muzzle)	Water brake (length, ft)
400	1 live HVAR 1 inert HVAR (gravel filled)	324**	-1,500	10
550	1 live HVAR 1 inert HVAR (empty)	283	-270	10
900	2 live HVARs	312	-1,200	15

*Nominal velocity computed from film records, see Appendix A.

**E-Round 14 was 10 pounds light.

TEST RESULTS

Tests E-1 and E-6 were fired on 27 and 29 June 1962 to check out equipment and test setup. These rounds are reported in Appendix B.

Between the two checkout rounds, four single-fragment, mortar rounds (E-2, 3, 4, and 5) were fired. These rounds are reported in Appendix C.

Eight test runs, E-Rounds 7 through 14, were fired on 5 and 6 July under E-7101, with the following results:

Acceptor Detonation

Acceptor reaction was as follows:

<u>E-Round</u>	<u>Nominal Fragment velocity (fps)</u>	<u>Detonation</u>
7	550	None
8	850	High order
9	400	High order
10	400	None
11	550	Partial
12	550	High order
13	850	High order
14	400	None

Film records on all high-order detonations confirm the results observed by test witnesses, and no acceptor fragments were found. The film shows the acceptors detonating in place, on their stands.

Film records also confirm witness observation on the rounds that did not detonate. The partial detonation of E-Round 11, as determined by film record, was not noted by observers. Acceptors from all rounds that did not detonate high order were badly damaged. Aluminum covers, particularly the front halves, were torn and dented (see Figs. 6 and 7), explosive was broken; detonators and pieces of explosive were scattered in a generally fan-shaped area back of the original acceptor location.

Film records of the test rounds show approximately 1/2 of the acceptor engulfed by the fragment cloud prior to detonation. This is illustrated for E-Rounds 8, 11, 12, and 13 in the sequence shots of Figs. 8 through 11. Detonation times are tabulated in Fig. 12. (The timing for the cameras in E-Round 9 was faulty and the film was badly washed out by the time detonation occurred. Detonation is discernable in the motion shots but it was impossible to obtain still prints.)

On Round 13 a flash, which appears to be plate flash, can be detected during early contact between fragments and acceptor prior to detonation. The same type of flash occurred in the second checkout round (E-Round 6), which did not detonate.

Equipment Performance

Sled, water brake, and deflector plate performed satisfactorily and separation between fragment mass and sled was good in all rounds. Film records show sled parts to be from 2 to 8 feet behind the fragments. Also, the sled was clearly shown to be well deflected to one side.

The fragments remained in a well-defined mass during travel to the acceptor, spreading only slightly. In all cases the fragment cloud appeared to be between 18 and 24 inches diameter by approximately the same depth. The front face of the cloud appeared to be flat in the majority of rounds.

Due to instrumentation difficulties, no usable sled velocity data were obtained from counterchronometers, and few were obtained from track coils. Film coverage from Bowen and high-speed Fastax cameras yielded the following nominal velocities:

<u>E-Round</u>	<u>Sled velocity (fps)</u>
9,10,14	400
7,11,12	550
8,13	900

CONCLUSIONS

High-order detonations in E-Rounds 8, 9, 12, and 13, and a partial detonation in E-Round 11, were caused by the impact of concrete fragments on the acceptor. Therefore, it can be concluded that the propagation of explosions to adjacent bays can be caused by the impact of fragments from concrete dividing walls when similar acceptors are involved.

Comparison With Cubicle Tests

Not enough data are available to draw conclusions regarding velocity effect, but the results of this test series are in general agreement with the velocity data from full-scale cubicle tests. Because of the difficulties of photographic coverage inherent in full-scale cubicle testing, reliable velocity data from those tests were very limited. Prior to the multifragment track tests described in this report, the NOTS cubicle tests had yielded the following velocity data:

<u>Test</u>	<u>Average Wall cloud velocity (to nearest 50 fps)</u>	<u>Detonation</u>
C-6	500	no
	200	no
C-10	700*	yes
	800**	yes
C-11	600**	yes
	450*	yes
B-2	1150	yes

*24-in. wall

**18-in. wall (all others 12-in. walls)

After the track tests were completed, the high-speed film from the cubicle tests was re-read in an effort to obtain additional data points for comparison with the track tests. However, the film was difficult to read and the velocities between successive frames fluctuated widely. Since these data have not yet been satisfactorily interpreted they have not been included in the velocity and detonation table nor in Fig. 13. The seven average velocities given above are regarded as somewhat more reliable since they were obtained from only the best of the film record; however, their accuracy is probably no greater than ± 100 fps. The velocity and detonation table and Fig. 13 combine these data with the velocity data from the track tests. Accuracy of the track test data is estimated to be within the ± 100 fps. See Appendix A.

Figure 13 shows percentages of detonations at each (nominal) velocity for which data is available. It is a table of test results, not a prediction of probabilities. Further testing will be required to establish the effect of velocity and the relationship between scaled distance ($R/W^{1/3}$), wall thickness, and velocity.

Velocity and Detonation Table
(Combined data from cubicle and track tests)

Cubicle Tests			Detonation	Track Tests (E-7101)
Test No.	Fragment velocity (fps)	Wall (in.)		Fragment velocity (fps)
B-2	1,150	12	X	
			X	850
			X	850
			X	
C-10	800	18	X	
C-10	700	24	X	
C-11	600	18	X	
			X	550
			P	550
			O	550
C-6	500	12	O	
C-11	450	24	X	
			X	400
			O	400
			O	400
C-6	200	12	O	

NOTES: X = high order detonation

O = no detonation

P = partial detonation

Cubicle test velocities given to nearest 50 fps

Appendix A

VELOCITY DATA

ROUND NO.	Sled velocities (fps)			Fragment velocities (fps)		
	Bowen	Average	Nominal* (average to nearest 50)	16mm Fastax (best reading)	Average	Nominal* (average to nearest 50)
9	412			416		
10	402	407	400	376	391	400
14	no data			382		
7	570			463**		
11	580	572	550	556	518	550**
12	567			536		
8	957			837		
13	855***	906	900	847	842	850

* Difficulties encountered in assessing the velocity data from the 16mm Fastax cameras have led to the use of a 'nominal' average throughout this report in order to avoid misrepresentation of the accuracy of the data.

** Round 7 fragment velocity data appear questionable in view of the sled velocity for this round and the relation between sled and fragment velocities for other rounds in this velocity range. Nominal average is weighted accordingly.

*** Data obtained from 16mm Fastax.

Appendix B

CHECKOUT TESTS (E-ROUNDS 1 AND 6)

Purpose

To check out sled and water brake performance, fragment separation, dispersion and velocity, and sled deflection.

To obtain data on acceptor sensitivity to multifragment impact if test equipment performs satisfactorily during checkout rounds.

Dates

27 and 29 June 1962

Location

K-2 Terminal Ballistics Track, U. S. Naval Ordnance Test Station

Test Setup, E-Round 1

Equipment and setup were as described for the test rounds on pages 2 and 3 of this report with the following exceptions:

The water brake installed at the end of the track was 50 ft long.

The sled did not have a water baffle plate on the bottom of the water brake wedge. Figure 1 shows the sled with the water baffle plate installed.

The deflector plate was placed at right angles to end of track.

The two live HVAR motors which propelled the sled were ignited at -540 feet from the muzzle end of the track to give an estimated velocity of 1,000 fps.

The fragment container was filled with 58 lb of 3/8- to 3/4-inch gravel and 14 lb of ungraded sand. The sand was in the rear quarter section of the container. Total weight of sand and gravel was 72 lb.

Results, E-Round 1

Deceleration of the sled at the water brake was excessive. Two sections of track rail were damaged. The fragment container was tilted before fragment separation was complete, resulting in excessive fragment dispersion. High-speed motion picture film shows the acceptor hit by the bottom of the fragment cloud only. The acceptor was knocked from its stand and the front half of its aluminum cover sustained multiple small dents and penetrations; however, the acceptor remained in one piece and did not detonate (Figs. 14 and 15). Fragment velocity was approximately 1,000 fps.

Test Setup, E-Round 6

As the result of E-Round 1 the following modifications were made to the test setup and equipment:

- a. Damaged track rails were replaced and aligned.
- b. Water brake installation on the track was shortened to 10 feet and the cross-section area of water was reduced.
- c. A plate was added to the bottom of the water brake wedge on the sled.
- d. The deflector plate was raised and the angle it made with the line of the track was changed from 90° to 5°.

One HVAR motor was ignited at -270 feet from the muzzle end of the track to give an estimated velocity of 500 fps. The fragments used were Mk 1 Rubble as described on page 2.

Results, E-Round 6

Equipment functioned satisfactorily except that impact of fragments on acceptor was high. The top of the front half of the aluminum acceptor cover was badly damaged and all of the explosive was broken into small pieces and scattered about the area, but no detonation occurred (Fig. 16). Velocity of the fragments was approximately 500 fps. As the result of this round, the acceptor stand was raised for all test rounds (E-Rounds 7-14).

Appendix C

DIVIDING WALL SINGLE FRAGMENT IMPACT TEST (E-7101)

Between multifragment checkout Rounds 1 and 6 under E-7101, four single fragment mortar rounds were fired. These were designated E-Rounds 2, 3, 4, and 5.

Purpose

The purpose of this portion of the experiment was to test the sensitivity of the standard dividing wall acceptor (explosive charge) to the impact of a single fragment of known mass and velocity, and to check out the operation of the sled and mortar. The single fragment rounds were fired while modifications to the multifragment sleds were being made.

Dates

28 and 29 June 1962

Location

K-2 Terminal Ballistics Track, U. S. Naval Ordnance Test Station

Test Setup, Single Fragment Rounds

Layout of test equipment was the same as for the multifragment rounds, except that no water brake was used.

Sled. A sled with a 5-inch HVAR motor propulsion system was used to accelerate a spigot mortar. At 15 feet from the muzzle end of the track, two knife blades on the carriage intersected two screen boxes, generating a firing pulse that set off an explosive cartridge in the mortar body. The finned projectile was propelled forward, shearing the four brass screws which attached it to the sled.

One HVAR motor propelled the carriage (Fig. 17) and velocity was controlled by the addition of weights (gravel) in an inert second motor (Fig. 18).

In all rounds the HVAR motor was ignited at the breech end of the track.

Fragment. The 'fragment' was the spigot mortar, consisting of a 2-inch diameter aluminum tube threaded at the forward end and with fins

aft. Threaded to the forward end was a 90° aluminum cone with a blunted point, as shown in Figs. 17 and 18. Total weight of the conical head was approximately 2½ lb and of the finned body, approximately 2 lb. Aluminum was selected for the head because its density is reasonably close to that of concrete.

Deflector Plate. The steel deflector plate was placed 6 feet off the end of the track at an angle of 5° from the centerline of the track. (For the first single fragment round, E-Round 2, the plate was placed at 90°.) This plate slowed and deflected the carriage while the spigot continued in line to the acceptor charge.

Results

<u>E-Round</u>	<u>Velocity</u>	<u>Detonation</u>
2	1,550	Partial
3	1,550	Yes
4	750	No
5	900	No

E-Round 2. The conical head separated from the finned body of the mortar. In the film, the head appeared to pass behind the acceptor, missing it completely. The finned body of the spigot struck the acceptor, causing plate flash but apparently no further reaction. The carriage was not deflected by the deflector plate and struck the acceptor, causing partial detonation or burning. The acceptor was badly broken, but no high-order detonation occurred. Figure 19 shows the acceptor cover after the test.

E-Round 3. The conical head remained attached to the finned body, striking the acceptor about 2 inches above center. The acceptor detonated high order. No traces of the acceptor remained.

E-Round 4. The conical head separated from the finned body and only the head struck the acceptor. Impact was about 3 inches above center. The head penetrated to the center of the acceptor charge, but no detonation occurred (Fig. 20).

E-Round 5. The conical head remained attached to the finned body. The impact was high, with the mortar going through the aluminum flange, the edge of the aluminum cover, and the compression pad, but the explosive was not damaged.

Conclusions. The standard dividing wall acceptor can be detonated by a single 4-lb fragment impacting at 1,550 fps. Neither the effect of fragment shape nor the possibility of detonation by a 4-lb fragment at lower velocities can be assessed from these tests, due to mortar malfunction and deflection in the lower velocity rounds.

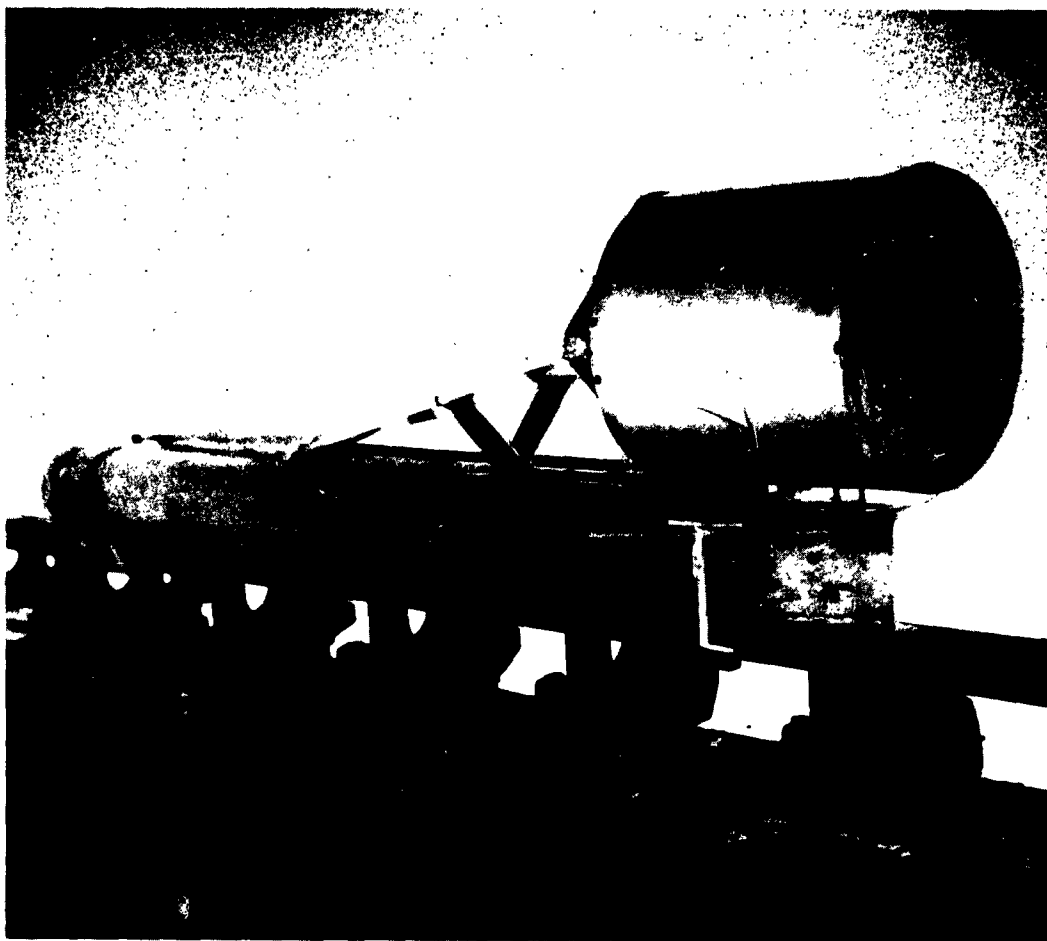


FIG. 1. Front View of Fragment Sled on Track Showing Water Brake Wedge Configuration and Fragment Container in Firing Position.



FIG. 2. Rear View of Fragment Sled Showing Auxiliary Structural Members for Test Item Support.

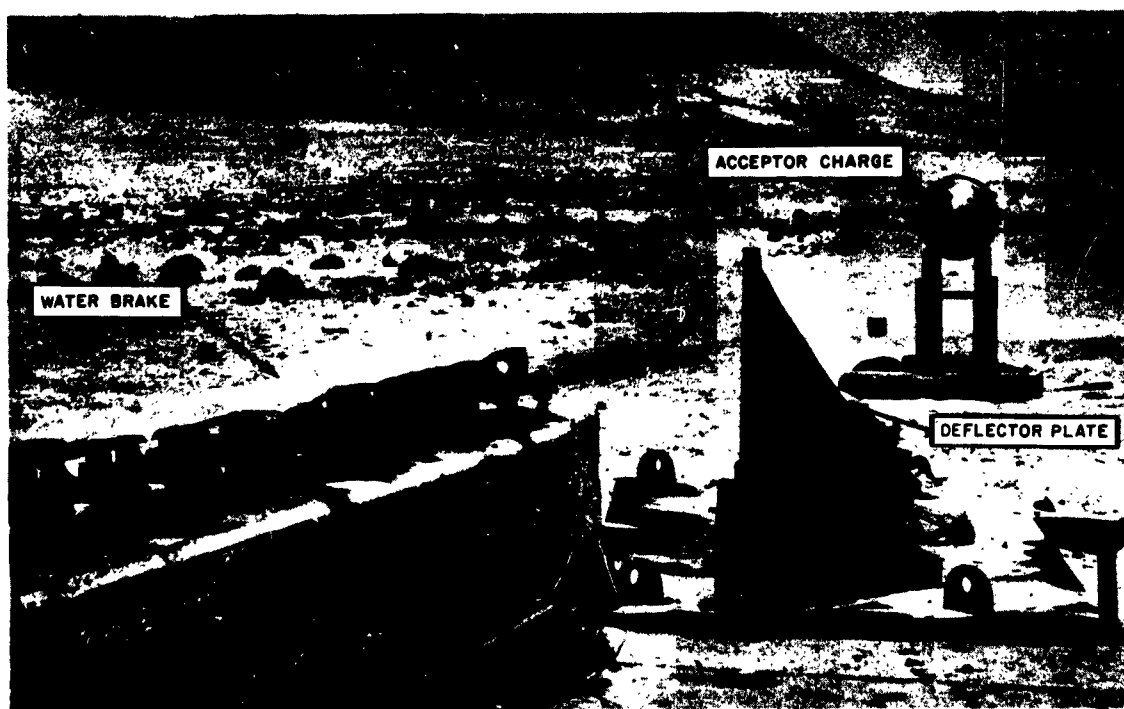


FIG. 3. Detail of Test Setup Showing Water Brake, Deflector Plate, and Acceptor Charge Target.

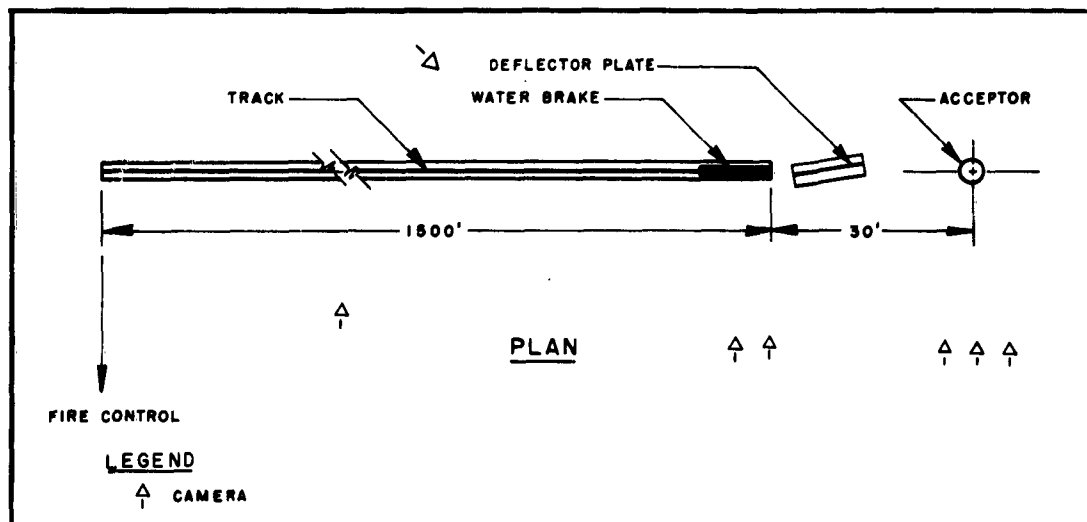


FIG. 4. Test Setup Showing Camera Locations.

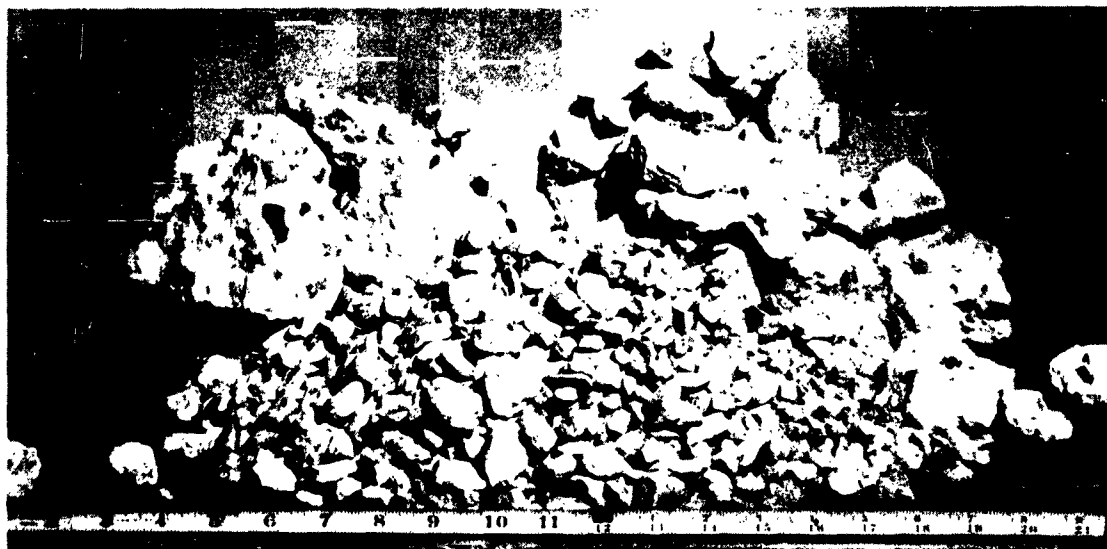


FIG. 5. Typical Fragment Collection Designated Mk 1 Rubble.



FIG. 6. Front Half of Outer Acceptor Cover After Round 10.

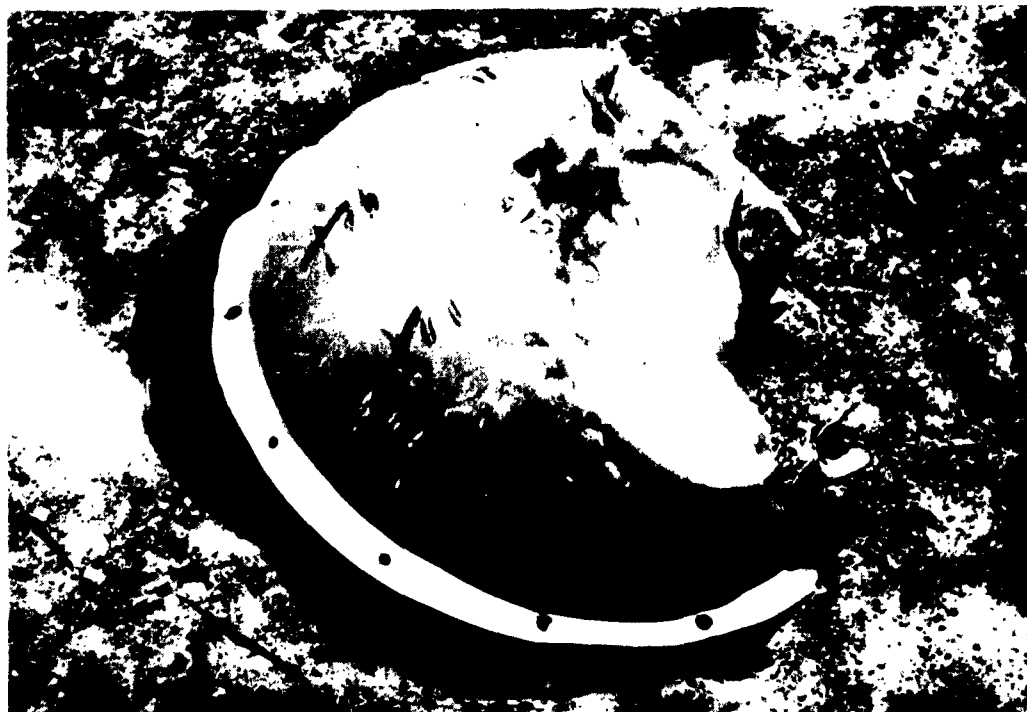


FIG. 7. Front Half of Outer Acceptor Cover After Round 14.

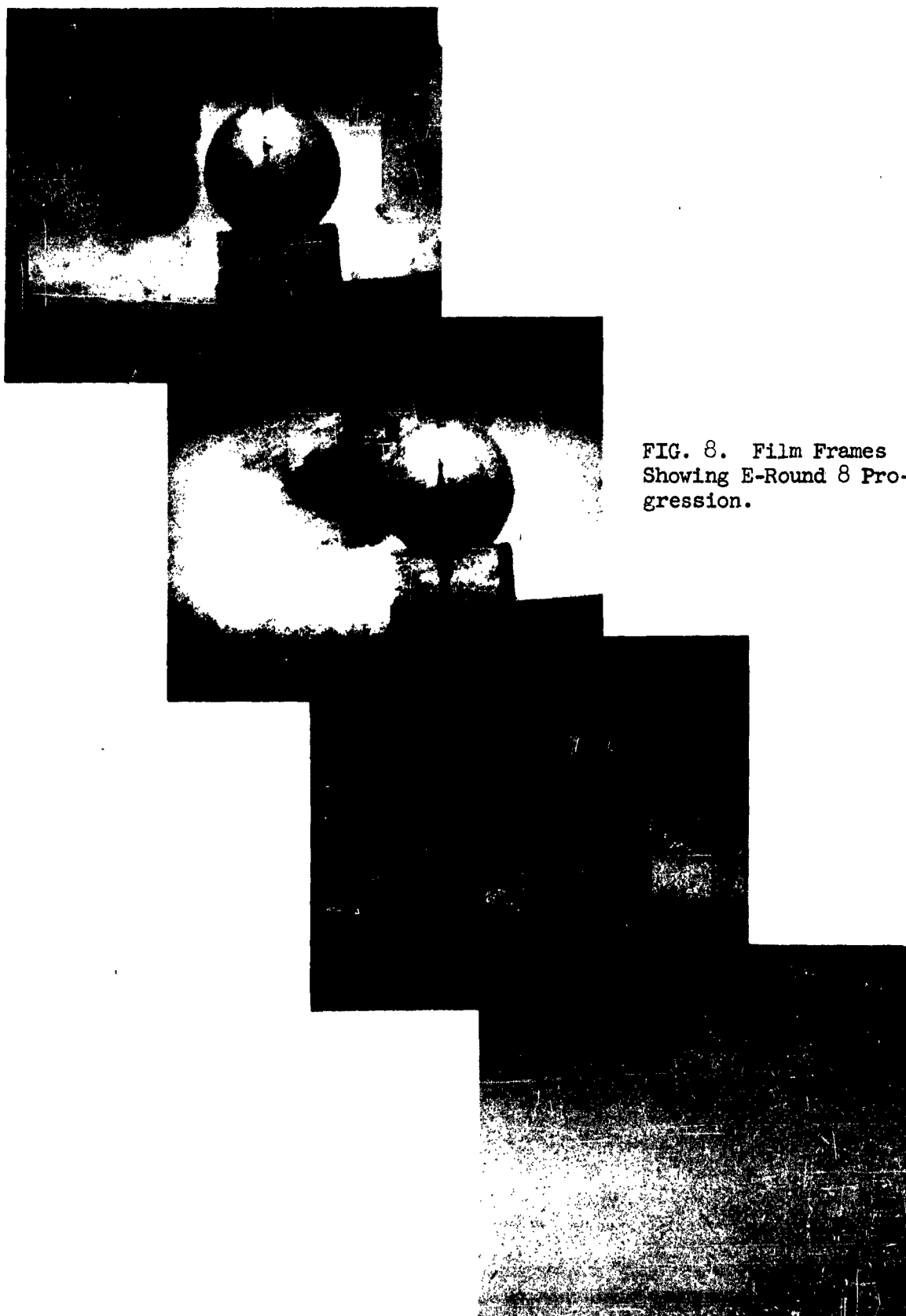


FIG. 8. Film Frames
Showing E-Round 8 Pro-
gression.

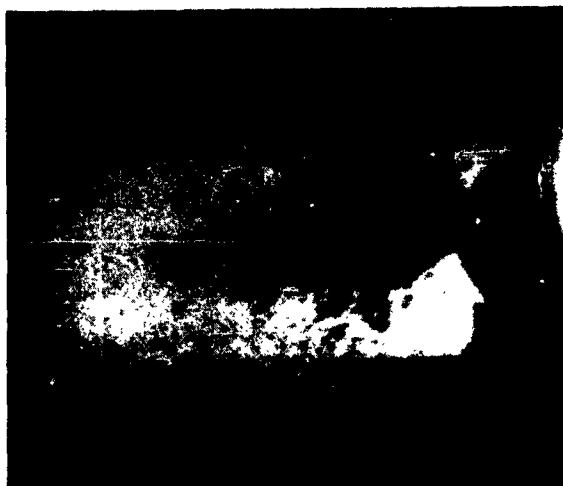
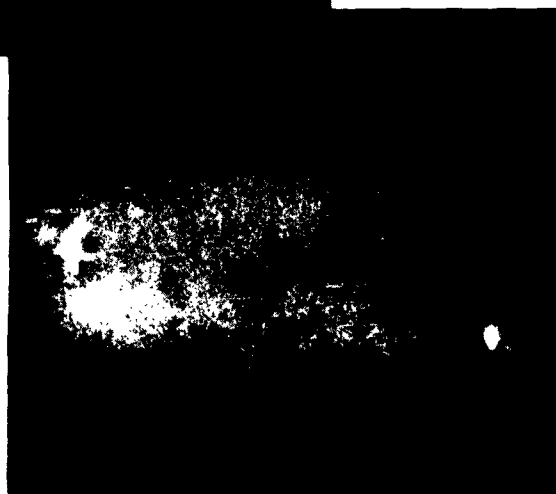
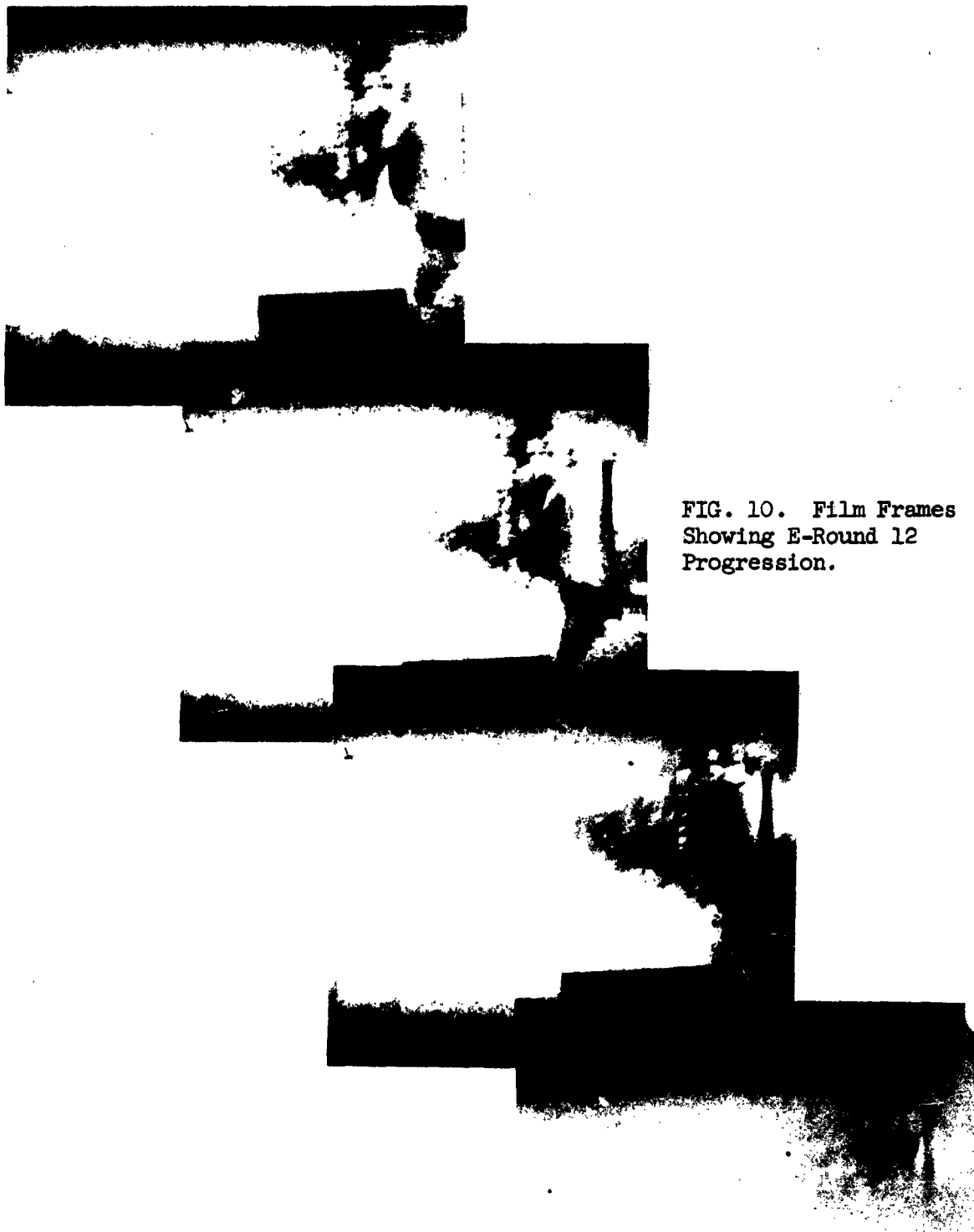


FIG. 9. Film Frames
Showing E-Round 11
Progression.





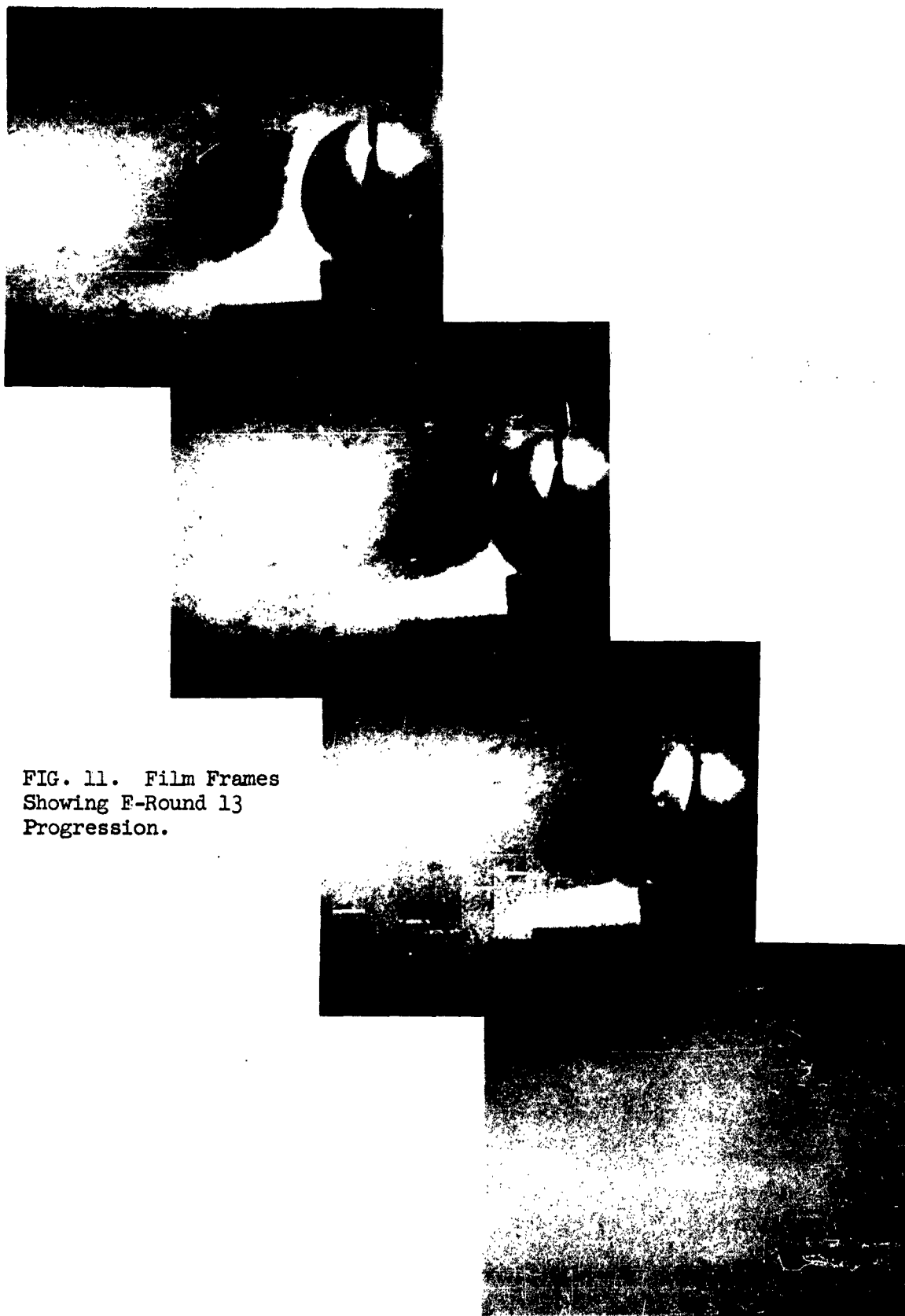


FIG. 11. Film Frames
Showing F-Round 13
Progression.

ROUND NO.	Frame #1	Frame #2	Frame #3	Frame #4	Frame #5	Frame #6
	Time (ms) Event	Time (ms) Event	Time (ms) Event	Time (ms) Event	Time (ms) Event	Time (ms) Event
8 (Camera 308) 0.33 ms/fr	0 First contact	0.33	0.66 Acceptor 1/3 engulf- ed by frag. cloud	0.99 Film washed out by detona- tion		
9 (Camera 309) 0.4 ms/fr	0 First contact	0.4 FILM	0.8 ALMOST	1.2 WASHED	1.6 OUT	2.0 Detonation discern- ible
11 (Camera 308) 0.35 ms/fr	0 First contact	0.35	0.7	1.0	1.4 $\frac{1}{2}$ en- gulfed	1.75 First flash of partial detonation
12 (Camera 308) 0.33 ms/fr	0 First contact	0.33	0.66	0.99 Film par- tially washed out by detona.	1.32 Film com- pletely washed out by detona.	
13 (Camera 308) 0.32 ms/fr	0 First contact	0.32 Plate flash	0.64 1/3 en- gulfed	0.96 Film washed out by detona- tion		

*Camera frame rates are in milliseconds (ms).

FIG. 12. Table of Detonation Times--From 16mm Fastax Camera Film.

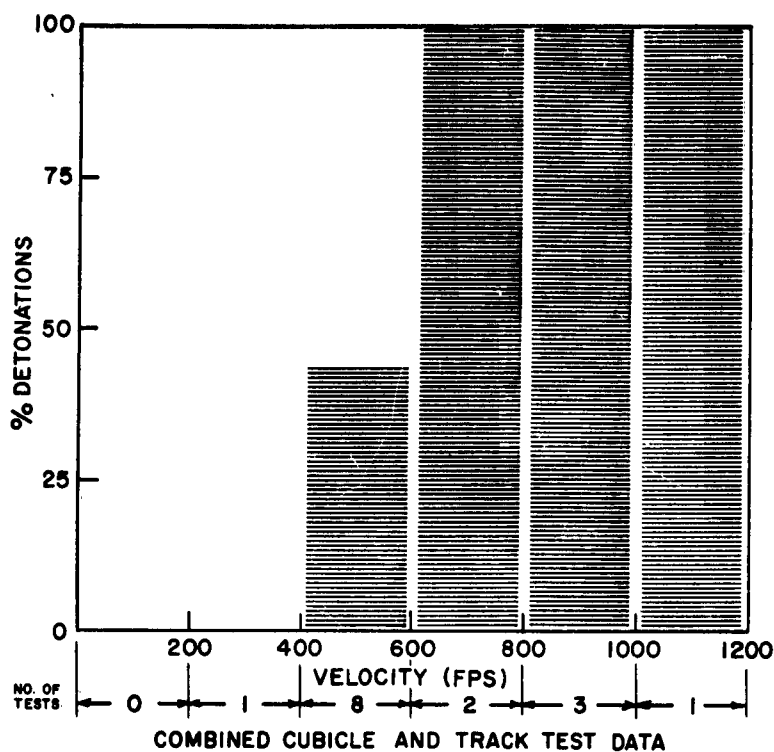


FIG. 13. Chart Showing Sensitivity of Mk 1 Acceptors to Concrete Fragments.



FIG. 14. Track and Water Brake After Checkout Test E-Round 1.



FIG. 15. Acceptor Cover After Checkout Test E-Round 1.



FIG. 16. Acceptor Cover After Checkout Test E-Round 6.

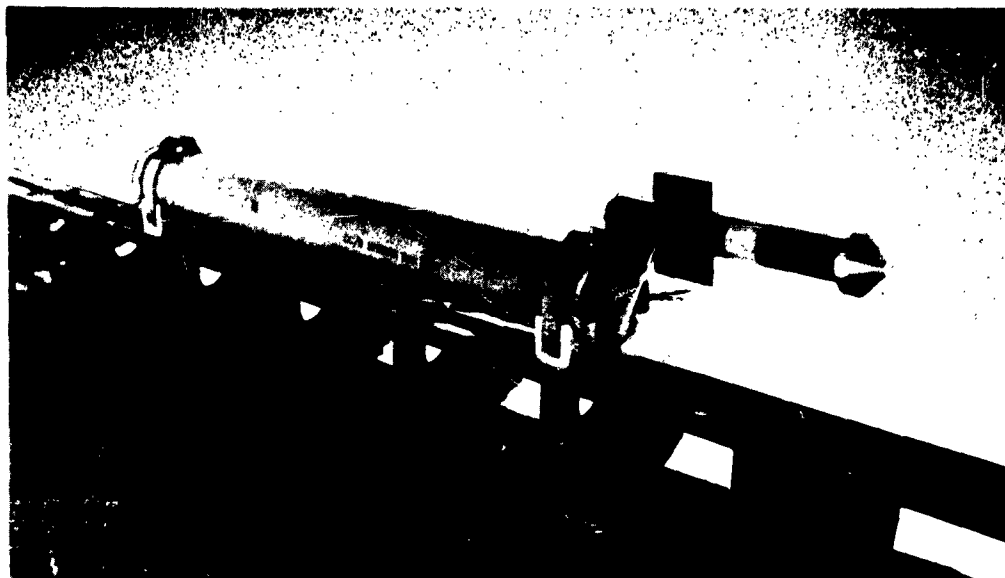


FIG. 17. HVAR Motor With Single Fragment Mortar Round.

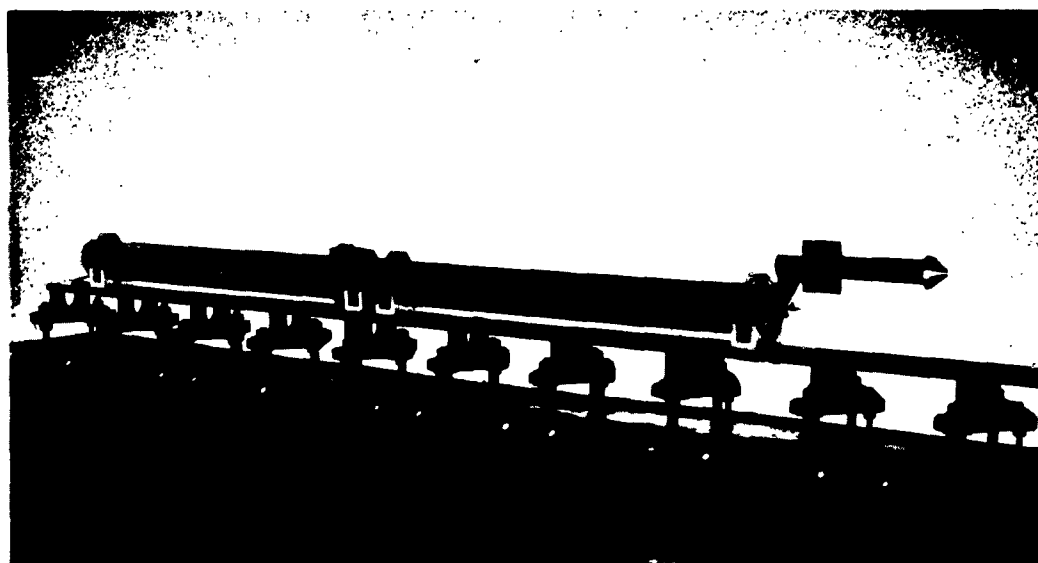


FIG. 18. Two-HVAR-Motor Sled Configuration With Single Fragment Mortar Round.



FIG. 19. Acceptor After Single Fragment Mortar
Test E-Round 2.



FIG. 20. Acceptor After Single Fragment Mortar
Test E-Round 4.

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ABSTRACT. As part of the ASESB program for determining the effectiveness of substantial dividing walls in preventing the propagation of explosions, multi-fragment impact tests were conducted on the NOTS K-2



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