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SENSITIVITY OF MOLTEN AND SOLID AMATEX CHARGES TO IMPACT BY PRIMARY STEEL FRAGMENTS

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An experimental program was conducted to establish the sensitivity of molten and solid Amatex to impact by non-spinning, primary steel fragments weighing 14 to 42 grams (0.5 to 1.5 oz) and traveling at velocities of 533 to 2,105 m/sec (1,748 to 6,907 fps). Parameters that were varied included the absence or presence of steel acceptor plates of different thicknesses, fragment mass per unit impact area and the molten vs solid physical state of the Amatex.

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20. Abstract (Continued)

Results of this program indicate that molten Amatex charges are significantly more sensitive to fragment impact than solid Amatex charges. Molten Amatex is also more sensitive than molten Composition B while solid Composition B is more sensitive to fragment impact than solid Amatex. In addition, it appears that a relationship exists between the kinetic energy of the fragment, its impact area and the threshold detonation velocity.

PREFACE

The fragment impact experiments reported on in this program are a continuation of the work presented in Picatinny Arsenal Technical Report No. 4975 entitled, "Sensitivity of Cased Charges of Molten and Solid Composition B to Impact by Primary Steel Fragments," dated June 1976 by Petino and DeMella. The experiments reported on in PATR 4975 and the current program are modeled after the work presented in Arthur D. Little, Inc., Report No. 64514 entitled, "An Experimental Program to Determine the Sensitivity of Explosive Materials to Impact by Regular Fragments," dated December 29, 1965 by McLean and Allan. This previous work studied the sensitivity of both cased and uncased solid charges of Pentolite and Cyclotol to impact by steel fragments.

Other personnel who contributed to the program were Messrs. Howard Gibson and Harry McClary of Hazards Research Corporation.

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SUMMARY

An experimental program has been performed to establish the sensitivity of molten and solid Amatex to impact by non-spinning, primary steel fragments weighing 14 to 42 grams (0.5 to 1.0 oz) and traveling at velocities up to 2,105 m/sec (6,907 fps). Parameters that were varied included the absence or presence of steel acceptor plates of different thicknesses, fragment mass per unit impact area and the molten vs solid physical state of the Amatex. The following table summarizes the results of this program:

Summary of fragment impact test results

Frag. wt. gm (oz)	Acceptor plate thk. cm (in)	Min. vel. for det.		Max. vel. without det.	
		solid m/sec. (fps)	molten m/sec. (fps)	solid m/sec. (fps)	molten m/sec. (fps)
14 (0.5)	none	1,517 (4,978)	965 (3,167)	1,343 (4,405)	814 (2,669)
28 (1.0)	none	1,464 (4,803)	959 (3,146)	1,444 (4,739)	857 (2,813)
42 (1.5)	none	1,248 (4,094)	735 (2,412)	1,166 (3,825)	673 (2,209)
14 (0.5)	0.318 (0.125)	1,956 (6,418)	937 (3,075)	1,913 (6,277)	821 (2,692)
28 (1.0)	0.318 (0.125)	1,711 (5,614)	1,122 (3,682)	1,648 (5,407)	959 (3,146)
42 (1.5)	0.318 (0.125)	1,278 (4,194)	855 (2,806)	1,256 (4,121)	777 (2,550)
14 (0.5)	0.635 (0.250)	2,103 (6,900)	1,158 (3,800)	2,096 (6,876)	1,037 (3,401)
28 (1.0)	0.635 (0.250)	-	934 (3,065)	≥1,816* (5,957)	853 (2,800)
42 (1.5)	0.635 (0.250)	-	852 (2,794)	≥1,383* (4,539)	814 (2,669)

*Maximum velocity attainable with the 7.6 cm dia. x 7.6 cm long booster.

The explosive launching technique used on this program propelled 14, 28 and 42 gm (0.5, 1.0 and 1.5 oz) steel fragments at maximum velocities of 2,105, 1,816 and 1,383 m/sec (6,907, 5,957 and 4,539 fps) respectively. Molten Amatex was found to be significantly more

sensitive to fragment impact than solid Amatex. Test results indicate that the minimum fragment velocity required for detonation increases as the thickness of the cover plate increases and that threshold initiation velocities are inversely proportional to fragment mass per unit impact area. Molten Amatex was found to be more sensitive to fragment impact than molten Composition B while solid Composition B was more sensitive than solid Amatex. Finally, it is concluded that an empirical relationship has been established between fragment mass per unit impact area and threshold detonation velocity for most of the cases investigated. Work conducted by previous investigators (ref 1 and 3) has been extended to allow for the effects of impact area on threshold velocity.

It is recommended that the data generated on this program be used to modify the mathematical equation for boundary velocity presented in References 1 and 3, by applying the effect of fragment mass per unit impact area on threshold velocity. Consideration should be given to the application of this explosive launch technique as a means of classifying the relative sensitivities of explosives, propellants and pyrotechnic materials to high velocity fragment impact. TNT should be tested next to allow it to be used as the baseline of comparison for all other hazardous materials.

INTRODUCTION

This report summarizes the results of a series of experiments performed by Hazards Research Corporation, Denville, New Jersey under the technical direction of the Large Caliber Weapon Systems Laboratory, Manufacturing Technology Division, Special Technology Branch of ARRADCOM, Dover, New Jersey. The work was funded under Contract No. DAAA21-76-C-0135.

The objective of this program was to investigate the sensitivity of molten and solid Amatex to impact by non-spinning, primary steel fragments weighing 14 to 42 gms (0.5 to 1.5 oz) and traveling at velocities up to 1,829 m/sec (6,000 fps). Primary fragments are defined as those fragments that result from break-up of an explosive casing in the event of a detonation. Usually, these fragments are characterized by having high velocity and are comparatively small in size. Variables studied included acceptor plate thickness, fragment mass per unit area, and the molten vs. solid physical state of the Amatex. Results were analyzed by comparing minimum velocities for detonation to maximum velocities without detonation. The data for Amatex was then compared to that previously obtained for Composition B in order to determine which explosive was the most sensitive.

An attempt was made to establish a relationship between fragment mass per unit frontal area and threshold detonation velocity. Information derived from this program will be used to develop a mathematical model which can be used to predict the boundary velocity of high velocity fragments, with variable mass per unit frontal areas, impacting explosive charges that have either no acceptor plates or acceptor plates of varying thicknesses. The mathematical model will then be applied in the design of new explosive facilities, modernization of existing facilities and in any operations where it is desired to limit the effects of accidental detonations. The net result of this effort will be increased safety at explosive facilities and cost reductions through efficient, knowledgeable design.

EXPERIMENTAL PROGRAM

Materials

The following materials were supplied by ARRADCOM for use in this test program:

(1) Composition B, cast, cylindrical booster, 7.6 cm (3.0 in) diameter x 7.6 cm (3.0 in) long, Lot PAE-09941

(2) Amatex[1], cast in 12.7 cm (5.0 in) x 12.7 cm (5.0 in) x 7.6 cm (3.0 in) high, 304 stainless steel pans with 0.159 cm (0.063 in) thick side walls, Lot PAE-09921

(3) Amatex, flake, Lot PAE-09922, batch no. 4

(4) Steel pans, 304 stainless, 12.7 cm (5.0 in) x 12.7 cm (5.0 in) x 7.6 cm (3.0 in) high, with 0.159 cm (0.063 in) thick side walls

Hazards Research Corporation furnished the following materials:

(1) High Speed, B & W Reversal Film Type 2962, 16 mm x 122 m (400 ft) rolls, mfg. by GAF Corporation

(2) E-83 blasting caps

(3) A-5 booster pellet, 75 grams, 5.1 cm (2.0 in) diameter x 2.5 cm (1.0 in) long

(4) Wooden test stands

(5) Lucite buffer plates

(6) Steel fragments, type 1020 H.R.

(7) Steel surrounds, type 1020 H.R.

(8) Steel acceptor plates, type 1020 H.R., 0.318 cm (0.125 in) and 0.635 cm (0.250 in) thick x 20.3 cm (8 in) square

(9) Steel witness plates, type 1020 H.R., 0.953 cm (0.375 in) thk. x 20.3 cm (8.0 in) square

[1]The Amatex used on this program is sometimes designated Amatex 20. Its nominal composition is TNT, Ammonium Nitrate and RDX in 40%, 40% and 20% weight concentrations respectively.

Equipment

Hazards Research Corporation supplied the following high speed camera system:

(1) Model 16-51 NOVA high speed camera with 400 to 20,000 picture per sec prism

(2) Model 16-301, 122 m (400 ft) film magazine

(3) Model 16-321 A balanced film spools, 122 m (400 ft) capacity

(4) Model 1002 rectifier power supply, 120 volt AC, 60 cycle input with 140 to 150 volts DC to camera

(5) Elgeet 15.2 cm (6 in), f: 3.8 lens

(6) Model 2001 event timer

(7) Model X-L exposure meter, 100 to 39,000 frames per sec, ASA 50 to 1600

(8) Model 1005 timing light generator, 10, 100, 1000 pulses per sec. output

Description of Experiments

All experiments performed during this program were conducted using the experimental set-up shown pictorially in Figure 1 and schematically in Figure 2. The booster charge was composed of an E-83 cap, a 75 gm A-5 pellet, and a 7.6 cm (3.0 in) diameter by 7.6 cm (3.0 in) long, Composition B charge. This entire explosive train was placed on top of a 12.7 cm (5.0 in) by 12.7 cm (5.0 in) square of Lucite of varying thickness. Glued to the opposite side of the Lucite was a square steel fragment of desired thickness and frontal area as shown in Figure 3. The fragment was surrounded by four pieces of equal thickness steel which prevent deformation at the edges of the fragment during the initial stages of launch. Figure 4 is a sketch which depicts the relative positions of the booster, Lucite, fragment and the surround. Figure 5 is a photo of the booster.

The entire fragment propulsion system was supported by a wooden stand that maintained a 145 cm (57 in) distance between the booster and the acceptor (target). There were two types of targets used on this program: solid and molten Amatex. Each type had a 0.953 cm (0.375 in) thick by 20.3 cm (8.0 in) square witness plate on the underside of the charge. The experiments were conducted with or without acceptor plates. Acceptor plates were either 0.318 cm (0.125 in) thick or 0.635 cm (0.250 in) thick as required by the experiment. Acceptor charges consisted of Amatex cast in 12.7 cm (5.0 in) by 12.7 cm (5.0 in) by 7.6 cm

(3.0 in) high, 304 stainless steel pans with 0.159 cm (0.063 in) thick side walls. Figure 6 is a photo of a molten Amatex acceptor charge with witness and acceptor plates in place.

A typical test sequence started with the selection of ; (a) the fragment velocity desired, (b) Lucite thickness required to attain that velocity, (c) cover plate thickness and (d) physical state of the acceptor charge (molten or solid). The booster charge was then placed on top of the stand, the fragment aimed at the center of the acceptor charge below, the cap armed and the event fired remotely by the high speed camera system. The camera was set-up 27 meters (90 feet) away from the detonation site. Nominal camera speed was 20,000 pictures per second. The high speed camera was the only instrumentation used to record fragment velocity. Tests were valid only when film coverage was acceptable and the fragment impacted on the target area.

Description of Experimental Methods

Fragment Aiming Procedure

Figure 7 depicts the technique used to aim the fragment at the center of the receiver charge. The receiver is placed into position at the bottom of the test stand where it is leveled in two horizontal planes. A 20 cm (8 in) square steel plate is then placed on top of the plywood platform. The plate has three equi-length plumb bobs suspended from three points 60 degrees apart. The plywood platform is adjusted in two horizontal planes until the tip of each plumb bob is exactly the same distance away from the acceptor cover plate. When this is accomplished, the plate is removed and the booster charge is placed into position on the plywood platform. The blasting cap is then connected to the firing circuit and the test set-up is ready to be fired by the camera.

Fragment Calibration Firings

The results of the previous program were used as a basis for selecting the Lucite thicknesses required to achieve the specific fragment velocities desired on this program. Figure 9, from reference 1, provided sufficient data to commence testing without performing any calibration firings. Figure 8 presents the results of the 90 tests performed during this experimental effort and provides a ready reference to the various fragment velocities attainable with a 7.6 cm diameter by 7.6 cm long Composition B booster.

Fragment Velocity Measurement

The Nova high speed camera was used to record fragment velocity. It photographed the last 61 cm (24 in) of fragment travel, including fragment impact. The last 36 cm (14 in) of flight were marked off in 5 cm (2 in) increments on the vertical test stand support. Fragment velocity was computed in two ways. The first technique was to determine the elapsed time of fragment travel between the graduated 5 cm (2 in) markings.

Velocity was then computed by dividing the distance traversed by the time it took to traverse that distance. The second technique involved taking the starting time as that frame which was overexposed due to initiation of the booster. Impact at the steel acceptor plate marked the end of the event. Therefore, with the distance from the face of the fragment to the top of the acceptor plate known, the average velocity was calculated by dividing this distance by the elapsed time. Initial comparisons of the two techniques revealed that at the 1219 m/sec (4000 fps) velocity level there was no significant difference in calculated velocities.

The advantage of the second technique is that lighting of the target area is not critical since initiation of the donor always overexposes the film and impact always results in a columnated beam of light emanating from the steel plate at impact. If impact results in a high order detonation, the detonation occurs within one frame. Since each frame is equal to 50 microseconds (at 20,000 frames per second), the detonation overexposes the film and obliterates the light given off by the columnation effect. Therefore, the high speed camera acts as a timer which is started and stopped by the light given off at initiation and impact.

As fragment velocities exceeded 1219 m/sec (4000 fps), errors were introduced using the first technique due to blurring of the pictures of the fragment in flight. It was found that the second technique provided more accurate velocity data and it was decided that all velocity data reported would be that data generated using the second technique.

It should be noted that since the camera photographs in 50 microsecond increments, there is a slight error introduced in the time function. Initiation and impact each occur somewhere within a 50 microsecond time frame. Therefore, the time recorded could be up to 100 microseconds too long. At 1219 m/sec (4000 fps), over the 145 cm (57 in) flight path, an error of up to 112 m/sec (368 fps) could result. It was decided that for the purposes of this program, this was not a large experimental error and it was deemed acceptable.

Preparation of Molten Amatex Targets

Molten Amatex acceptors were prepared by placing the steel acceptor and witness plates, empty 12.7 cm (5.0 in) square stainless steel pans and a pitcher containing solid chunks of Amatex into an oven which was maintained at 120°C. Average soak time in the oven was 18 hours.

Prior to performing the first experiment, a series of dry runs were performed to determine the cooling rate of the acceptor with its hot steel plates in position. It was determined that no solidification occurred within a 3 minute period. All experiments were performed within this time frame.

The last operation performed during this portion of the program was the placing of the hot witness plate and empty steel pan into position on the test stand and the pouring of the molten Amatex into the pan. Prior to pouring, the molten material was stirred in the steel pitcher.

This stirring action was necessary to allow the RDX and ammonium nitrate to be suspended uniformly throughout the mixture. Settling time for these two materials was greater than the three minutes allowed for solidification. Therefore, settling was not considered to be a problem. The Amatex was poured into the pan until it overflowed slightly. This eliminated the entrainment of air between the top plate and the molten surface. After placement of the hot, steel cover plate in position, the cap was armed and fired.

Characterization of Results of Fragment Impact

Impact of high velocity steel fragments on solid and molten Amatex acceptors resulted in one of the following: no reaction, deflagration or detonation.

No Reaction

This result was characterized by shattered Amatex strewn all over the floor of the test cell (solid acceptor), droplets of solidified explosive on the floor (molten acceptor), an intact steel pan, and a flat witness plate with a slight dent in it. In those tests that were performed with steel acceptor plates, the plates were bowed slightly at the point where the fragment passed through the plate. In most cases, the opening in the plate was square and generally conformed to the cross-section of the fragment. Figure 11 is a post-run photo of typical witness plate, pan, and fragment after a no reaction test result (test no. 22).

Deflagration

Deflagrations were accompanied by clouds of smoke billowing out of the test cell and the recovery of all steel items in the condition described in the previous section. No physical evidence of the Amatex remained after a deflagration. Figures 9, 10 and 12 show typical deflagration results for covered and uncovered solid acceptors and for a covered molten acceptor (test nos. 38, 17 and 84 respectively).

Detonation

Detonations of both a low and high order class were considered to be positive results on this program. Low order detonations were characterised by the fracturing of the acceptor plate into 2 or more distorted pieces and the severe bowing of the witness plate. Bowing of 2 or more inches at the center of the witness plate was common. Some plates were bowed into crudely shaped hemispheres. Figure 13 is a photo which depicts the post-run condition of the steel plates after a low order detonation of a molten acceptor (test no. 80).

A high order detonation resulted in the complete shrapnellisation of the cover plate. In addition, the witness plate was always driven downward into its wooden support. Its physical appearance was the mirror image of the explosive charge which rested on it. Specifically, a bowed, 12.7 cm (5.0 in) square witness plate was always found with 3.8 cm (1.5 in) wide strips clearly sheared off around its outside edge. Figure 14 is a photograph which shows this typical post-run result (test no. 41).

Experimental Results

A total of 90 primary steel fragment impact experiments were performed on this program. Table 1 presents the combinations of parameters tested and the number of experiments performed on each combination. It is seen that 41 tests were performed on solid Amatex acceptors while 49 tests were performed on molten Amatex acceptors. Tests were conducted with and without steel acceptor (cover) plates. When cover plates were used, the thicknesses were either 0.318 cm (0.125 in) or 0.635 cm (0.250 in). Tables 2 through 7 contain the detailed results of each test. A comparison of minimum velocity for detonation and maximum velocity without detonation for all combinations of parameters tested is presented in Table 8. Table 9 provides a summary of test program results. It allows a ready comparison of impact sensitivity for molten and solid Amatex for both covered and uncovered acceptor charges. Figures 15 through 20 graphically present the data contained in Tables 2 through 7.

Solid Amatex Acceptor: 14 Gram Fragment

A series of 19 experiments were performed on solid acceptors using the 14 gm (0.5 oz) fragment. Table 2 contains the results of these experiments. No cover plates were used for the first eight tests. The minimum velocity for detonation was found to be 1,517 m/sec (4,978 fps) while the maximum velocity without detonation was 1,343 m/sec (4,405 fps). Tests 9 through 14 used 0.318 cm thick acceptor plates which resulted in a 1,956 m/sec (6,418 fps) minimum velocity for detonation and a 1,913 m/sec (6,277 fps) maximum velocity without detonation. The steel plate increased the threshold velocity level by 439 m/sec (1,440 fps). Tests 15 through 19 used 0.635 cm thick cover plates which resulted in increasing the minimum velocity for detonation to 2,103 m/sec (6,900 fps) and likewise increasing the maximum velocity without detonation to 2,096 m/sec (6,876 fps). The extra 0.318 cm thickness increased the threshold velocity by 147 m/sec (482 fps). The difference between threshold detonation velocity for the 0.635 cm thick cover plate and an uncovered charge was 586 m/sec (1923 fps).

Molten Amatex Acceptor: 14 Gram Fragment

Table 3 presents the results of 15 tests performed on this phase of the program. The first four tests were performed on uncovered acceptors and resulted in a minimum velocity for detonation of 965 m/sec (3,167 fps) and a maximum velocity without detonation of 814 m/sec (2,669 fps). Tests 24 through 29 used the 0.318 cm thick cover plates which resulted in a minimum velocity for detonation of 937 m/sec (3,075 fps) and a maximum velocity without detonation of 821 m/sec (2,692 fps). These values are essentially the same as those measured without the cover plates. Tests 30 through 34 used the 0.635 cm thick cover plates which resulted in a minimum velocity for detonation of 1,158 m/sec (3,800 fps) and a maximum velocity without detonation of 1,037 m/sec (3,401 fps). An overall increase in threshold detonation velocity of 193 m/sec (633 fps) was observed between uncovered charges and covered (0.635 cm thick plates) charges.

Solid Amatex Acceptor: 28 Gram Fragment

Twelve experiments were performed on this phase of the program. Results of these tests are presented in Table 4. The minimum velocity for detonation of an uncovered, solid acceptor was found, after five trials to be 1,464 m/sec (4,803 fps). Maximum velocity without detonation was 1,444 m/sec (4,739 fps). Five additional tests were performed using the 0.318 cm thick, steel cover plates and resulted in a minimum velocity for detonation of 1,711 m/sec (5,614 fps) with a maximum velocity without detonation of 1,648 m/sec (5,407 fps). The steel cover plate increased the threshold detonation velocity by 247 m/sec (810 fps). Two tests were performed on 0.635 cm thick, steel cover plates at the maximum velocities attainable with the 28 gram fragment, 1,816 and 1,786 m/sec (5,957 and 5,858 fps). Both of these tests were negative, resulting in deflagrations. It was not possible to obtain a minimum velocity for detonation with the 0.635 cm thick acceptor plate because the 28 gram fragment could not be propelled above 1,816 m/sec. It is concluded that the maximum velocity without detonation is greater than or equal to 1,816 m/sec.

A comparison of minimum velocities for detonation reveals that there is a definite trend for the velocity to increase as the thickness of the cover plate increases. The difference between the no cover plate and 0.635 cm thick cover plate threshold velocities is greater than or equal to 352 m/sec (1,155 fps).

Molten Amatex Acceptor: 28 Gram Fragment

A series of 16 tests were performed using 28 gm (1.0 oz) fragments and molten acceptors. Table 5 contains the results of these experiments. No cover plates were used for the first four experiments. The minimum velocity for detonation for these tests was found to be 959 m/sec (3,146 fps) while the maximum velocity without detonation was 857 m/sec (2,813 fps). Tests 51 through 55 used 0.318 cm thick acceptor plates which resulted in a 1,122 m/sec (3,682 fps) minimum velocity for detonation and a 959 m/sec (3,146 fps) maximum velocity without detonation. The steel plate increased the threshold detonation velocity level by 163 m/sec (535 fps). Tests 56 through 62 used 0.635 cm thick cover plates which resulted in a minimum velocity for detonation of 934 m/sec (3,065 fps) and a maximum velocity without detonation of 853 m/sec (2,800 fps). The results reveal that there was very little difference in threshold detonation velocities between the uncovered and covered molten acceptor charges.

Solid Amatex Acceptor: 42 Gram Fragment

Table 6 presents the results of the ten tests performed on this phase of the program. Four tests on uncovered, solid acceptors resulted in a minimum velocity for detonation of 1,248 m/sec (4,094 fps) and a maximum velocity without detonation of 1,166 m/sec (3,825 fps). An additional four experiments performed using the 0.318 cm thick, steel cover plates resulted in a minimum velocity for detonation of 1,278 m/sec (4,194 fps) with a corresponding maximum velocity without detonation of 1,256 m/sec (4,121 fps). Two tests performed on the 0.635 cm thick, steel acceptor plates failed to yield a detonation at fragment velocities of 1,379 and 1,383 m/sec (4,524 and 4,539 fps). These were the maximum velocities attainable for the 42 gram fragment using the Composition B booster. For these experiments the difference between the threshold detonation velocities for uncovered and covered acceptors is greater than or equal to 135 m/sec (443 fps).

Molten Amatex Acceptor: 42 Gram Fragment

The last 18 experiments performed on this program are presented in Table 7. It is seen that six tests were performed on uncovered, molten acceptors. These tests resulted in a minimum velocity for detonation of 735 m/sec (2,412 fps) and a maximum velocity without detonation of 673 m/sec (2,209 fps). Five tests were performed on 0.318 cm thick, steel cover plates. These resulted in a minimum velocity for detonation of 855 m/sec (2,806 fps) and a maximum velocity without detonation of 777 m/sec (2,550 fps). Seven tests were required to establish a minimum velocity for detonation of 852 m/sec (2,794 fps) for acceptors covered with 0.635 cm thick, steel plates. The corresponding maximum velocity without detonation was 814 m/sec (2,669 fps).

It is once again interesting to note that there is very little difference between threshold detonation velocities for covered and uncovered, molten acceptor charges. Specifically, the threshold detonation velocities for the three cover plate conditions were 735, 855 and 852 m/sec. This was previously found to be the case for the 28 gram fragment and the molten acceptor.

Discussion of Results

Control of Fragment Velocity

The degree of control over fragment velocity attained on this program is evident if one analyzes the curves shown in Figure 8. It is seen that the majority of the data points were reproducible within about 61 m/sec (200 fps). The broadest spread of data is on the order of 152 m/sec (500 fps). Table 10 presents the maximum fragment velocities attained using the 7.6 cm diameter by 7.6 cm long, Composition B booster. As expected, fragment velocity decreases with increasing fragment weight.

Effect of Fragment Mass Per Unit Impact Area

A fragment traveling at a constant velocity possesses a finite quantity of kinetic energy. At impact, this energy is transferred to the acceptor charge and is distributed across the impact surface area. The spacial orientation of the fragment at impact determines the impact area through which the kinetic energy is transmitted. The distribution of the kinetic energy across the face of the acceptor charge is one of the parameters that determines whether or not a detonation will occur. Visual observations of the high speed movies, acceptor pans, and steel plates from negative tests reveal that the majority of the fragments hit the acceptor charges in an essentially flat-on impact mode.

In order to allow a reasonable comparison of threshold velocity data between the three fragments tested, all data was analyzed by comparing fragment mass per unit area to threshold detonation velocity. Use of the term, fragment mass per unit area, implies that the frontal area of the fragment is equal to the impact area. One would expect that as the magnitude of the mass per unit area term increases, the threshold velocity level would decrease. This phenomenon does occur and can be seen in the results presented in Figures 15 through 21.

Comparison of Test Results

Analysis of the data presented in Table 9 and Figure 21 reveals that the molten Amatex acceptors were much more sensitive to fragment impact than the solid Amatex acceptors. This statement is valid for both covered and uncovered acceptors. The differences in minimum velocity for detonation are significant and can not be attributed to experimental error.

Figure 21 also shows that for the solid acceptors, the threshold velocity increased significantly for the 14 and 28 gram fragments when the steel cover plates were used. The difference in threshold velocity between the two steel cover plate thicknesses, however, was not large over the range of fragment weights tested. The 42 gram fragment produced the least spread in threshold detonation velocity levels for both the molten and solid acceptor conditions and all three acceptor cover configurations.

There were two incomplete data points on this program. Detonations could not be achieved with 28 and 42 gram fragments fired at solid acceptors with 0.635 cm thick, steel cover plates. These fragments could not be propelled above 1,816 and 1,383 m/sec respectively, using the Composition B booster system established for this program. This resulted in the inability to transfer the required initiation energy through the thick plate and into the solid explosive. Attainment of higher velocities with these two fragments is possible if a larger diameter booster is used. The l/d ratio of the larger booster must be equal to one. A larger booster was not used since it was not readily available and also was not within the scope of this program.

Table 11 presents a comparison of Amatex and Composition B test results for an acceptor plate thickness of 0.318 cm. The Composition B data was taken from the previous program (ref. 2) and represents the only data that could be compared to Amatex results. Figure 22 is a plot of the data found in Table 11. It is seen that solid Composition B is more sensitive to fragment impact than solid Amatex. In addition, molten Amatex is more sensitive than molten Composition B. Finally, the difference in threshold detonation velocities is greatest for molten versus solid Amatex.

CONCLUSIONS

As a result of the 90 primary steel fragment experiments performed on this program using both molten and solid Amatex acceptors with and without steel cover plates, it is possible to conclude the following:

1. An empirical relationship has been established between fragment mass per unit impact area and threshold detonation velocity for most of the cases investigated on this program. The work conducted by previous investigators (References 1 and 3) has been extended to allow for the effects of impact area on threshold velocity.

2. The 7.6 cm (3.0 in) diameter x 7.6 cm (3.0 in) long Composition B launch system can propel 14, 28 and 42 gram (0.5, 1.0 and 1.5 oz) steel fragments at maximum velocities of 2,105, 1,816 and 1,383 m/sec (6,907, 5,957 and 4,539 fps) respectively.

3. Molten Amatex is significantly more sensitive to fragment impact than solid Amatex.

4. Threshold initiation velocities for both solid and molten Amatex are inversely proportional to fragment mass per unit impact area.

5. The minimum fragment velocity required for detonation increases as the thickness of the cover plate increases.

6. Solid Composition B is more sensitive to fragment impact than solid Amatex.

7. Molten Amatex is more sensitive to fragment impact than molten Composition B.

RECOMMENDATIONS

It is recommended that implementation of the following items be considered:

(1) Use the data generated on this program to modify the mathematical equation for boundary velocity presented in References 1 and 3 by applying the effect of fragment mass per unit impact area on threshold detonation velocity.

(2) Consider the application of this fragment explosive launch technique as a means of classifying the relative sensitivities of explosives, propellants and pyrotechnic materials to high velocity fragment impact. That is, consider this method as a standard hazards classification technique.

(3) Perform additional tests on molten and solid Amatex in order to increase the statistical validity of the data.

(4) Establish the threshold detonation velocities for molten and solid TNT. Use TNT as the baseline of comparison for all other hazardous materials.

(5) Duplicate this test effort using other solid and molten explosives and propellants at various stages of manufacture.

REFERENCES

1. D. G. McLean and D. S. Allan, "An Experimental Program to Determine the Sensitivity of Explosive Materials to Impact by Regular Fragments," Arthur D. Little, Inc., Report No. 64514.

2. G. Petino Jr. and D. De Mella, "Sensitivity of Cased Charges of Molten and Solid Composition B to Impact by Primary Steel Fragments," Technical Report 4975, Picatinny Arsenal, Dover, New Jersey, June 1976.

3. R. M. Rindner, "Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations", Report No. 2, Detonation by Fragment Impact, May 1959, Picatinny Arsenal Report DB - TR: 6 - 59.

Table 1

Combinations of parameters tested

Frag. wt. gm (oz)	Fragment dimension cm x cm x cm (in x in x in)	Frag. wt/area gm/cm^2 (oz/in^2)	Acceptor plate thk. cm (in)	Acceptor condition	No. of tests
14 (0.5)	.32 x 2.36 x 2.36 (.125 x .930 x .930)	2.51 (0.58)	none none	solid molten	8 4
14 (0.5)	.32 x 2.36 x 2.36 (.125 x .930 x .930)	2.51 (0.58)	0.318 (0.125)	solid molten	6 6
14 (0.5)	.32 x 2.36 x 2.36 (.125 x .930 x .930)	2.51 (0.58)	0.635 (0.250)	solid molten	5 5
28 (1.0)	.64 x 2.36 x 2.36 (.250 x .930 x .930)	5.02 (1.16)	none none	solid molten	5 4
28 (1.0)	.64 x 2.36 x 2.36 (.250 x .930 x .930)	5.02 (1.16)	0.318 (0.125)	solid molten	5 5
28 (1.0)	.64 x 2.36 x 2.36 (.250 x .930 x .930)	5.02 (1.16)	0.635 (0.250)	solid molten	2 7
42 (1.5)	.94 x 2.40 x 2.40 (.370 x .945 x .945)	7.29 (1.67)	none none	solid molten	4 6
42 (1.5)	.94 x 2.40 x 2.40 (.370 x .945 x .945)	7.29 (1.67)	0.318 (0.125)	solid molten	4 5
42 (1.5)	.94 x 2.40 x 2.40 (.370 x .945 x .945)	7.29 (1.67)	0.635 (0.250)	solid molten	2 7

Table 2

Results of tests with 14 gram fragments: solid acceptors

Fragment: 0.32 cm x 2.36 cm x 2.36 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
1	1.214 (0.478)	none	1,939 (6,361)	Detonation	(+)
2	1.588 (0.625)	none	1,794 (5,885)	Deflagration	(-)
3	1.415 (0.557)	none	1,810 (5,938)	Detonation	(+)
4	1.605 (0.632)	none	1,703 (5,588)	Detonation	(+)
5	1.605 (0.632)	none	1,696 (5,564)	Detonation	(+)
6	2.489 (0.980)	none	1,517 (4,978)	Detonation	(+)
7	3.269 (1.287)	none	1,343 (4,405)	No reaction	(-)
8	3.269 (1.287)	none	1,312 (4,304)	No reaction	(-)
9	1.588 (0.625)	0.318 (0.125)	1,830 (6,004)	Deflagration	(-)
10	0.953 (0.375)	0.318 (0.125)	2,087 (6,846)	Detonation	(+)
11	0.953 (0.375)	0.318 (0.125)	2,105 (6,907)	Detonation	(+)
12	1.270 (0.500)	0.318 (0.125)	1,842 (6,044)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 2

Results of tests with 14 gram fragments: solid acceptors

Fragment: 0.32 cm x 2.36 cm x 2.36 cm (cont.)

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
13	1.270 (0.500)	0.318 (0.125)	1,913 (6,277)	Deflagration	(-)
14	1.069 (0.421)	0.318 (0.125)	1,956 (6,418)	Detonation	(+)
15	0.953 (0.375)	0.635 (0.250)	2,075 (6,808)	Deflagration	(-)
16	0.953 (0.375)	0.635 (0.250)	2,103 (6,900)	Detonation	(+)
17	1.588 (0.625)	0.635 (0.250)	1,810 (5,938)	Deflagration	(-)
18	1.270 (0.500)	0.635 (0.250)	1,969 (6,460)	Deflagration	(-)
19	0.953 (0.375)	0.635 (0.250)	2,096 (6,876)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 3

Results of tests with 14 gram fragments: molten acceptors

Fragment: 0.32 cm x 2.36 cm x 2.36 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
20	5.080 (2.000)	none	965 (3,167)	Detonation	(+)
21	6.350 (2.500)	none	710 (2,328)	No reaction	(-)
22	5.715 (2.250)	none	811 (2,660)	No reaction	(-)
23	5.715 (2.250)	none	814 (2,669)	No reaction	(-)
24	1.270 (0.500)	0.318 (0.125)	1,922 (6,305)	Detonation	(+)
25	2.540 (1.000)	0.318 (0.125)	1,509 (4,950)	Detonation	(+)
26	3.810 (1.500)	0.318 (0.125)	1,198 (3,932)	Detonation	(+)
27	5.080 (2.000)	0.318 (0.125)	937 (3,075)	Detonation	(+)
28	5.715 (2.250)	0.318 (0.125)	821 (2,692)	No reaction	(-)
29	5.715 (2.250)	0.318 (0.125)	821 (2,692)	No reaction	(-)
30	5.080 (2.000)	0.635 (0.250)	827 (2,714)	No reaction	(-)
31	2.540 (1.000)	0.635 (0.250)	1,582 (5,190)	Detonation	(+)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 3

Results of tests with 14 gram fragments: molten acceptors

Fragment: 0.32 cm x 2.36 cm x 2.36 cm (cont.)

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
32	3.810 (1.500)	0.635 (0.250)	1,158 (3,800)	Detonation	(+)
33	4.445 (1.750)	0.635 (0.250)	1,037 (3,401)	No reaction	(-)
34	4.445 (1.750)	0.635 (0.250)	1,036 (3,400)	No reaction	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 4

Results of tests with 28 gram fragments: solid acceptors

Fragment: 0.64 cm x 2.36 cm x 2.36 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
35	0.635 (0.250)	none	1,537 (5,044)	Detonation	(+)
36	0.953 (0.375)	none	1,464 (4,803)	Detonation	(+)
37	1.214 (0.478)	none	1,305 (4,280)	Deflagration	(-)
38	1.214 (0.478)	none	1,328 (4,356)	Deflagration	(-)
39	0.953 (0.375)	none	1,444 (4,739)	Deflagration	(-)
40	0.097 (0.038)	0.318 (0.125)	1,782 (5,846)	Detonation	(+)
41	0.318 (0.125)	0.318 (0.125)	1,711 (5,614)	Detonation	(+)
42	1.270 (0.500)	0.318 (0.125)	1,413 (4,635)	Deflagration	(-)
43	0.635 (0.250)	0.318 (0.125)	1,561 (5,122)	Deflagration	(-)
44	0.635 (0.250)	0.318 (0.125)	1,648 (5,407)	Deflagration	(-)
45	0.097 (0.038)	0.635 (0.250)	1,816 (5,957)	Deflagration	(-)
46	0.097 (0.038)	0.635 (0.250)	1,786 (5,858)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 5

Results of tests with 28 gram fragments: molten acceptors

Fragment: 0.64 cm x 2.36 cm x 2.36 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
47	3.810 (1.500)	none	857 (2,813)	No reaction	(-)
48	3.175 (1.250)	none	965 (3,167)	Detonation	(+)
49	3.493 (1.375)	none	959 (3,146)	Detonation	(+)
50	3.810 (1.500)	none	814 (2,669)	No reaction	(-)
51	0.318 (0.125)	0.318 (0.125)	1,698 (5,570)	Detonation	(+)
52	0.635 (0.250)	0.318 (0.125)	1,576 (5,172)	Detonation	(+)
53	1.[illegible]70 ([illegible]0)	0.318 (0.125)	1,344 (4,409)	Detonation	(+)
54	[illegible] ([illegible]0)	0.318 (0.125)	959 (3,146)	No reaction	(-)
55	2.540 (1.000)	0.318 (0.125)	1,122 (3,682)	Detonation	(+)
56	2.540 (1.000)	0.635 (0.250)	1,073 (3,519)	Deflagration	(-)
57	1.270 (0.500)	0.635 (0.250)	1,333 (4,373)	Detonation	(+)
58	1.905 (0.750)	0.635 (0.250)	1,158 (3,800)	Detonation	(+)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 5

Results of tests with 28 gram fragments: molten acceptors

Fragment: 0.64 cm x 2.36 cm x 2.36 cm (cont.)

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
59	2.540 (1.000)	0.635 (0.250)	1,095 (3,593)	Detonation	(+)
60	3.175 (1.250)	0.635 (0.250)	934 (3,065)	Detonation	(+)
61	3.810 (1.500)	0.635 (0.250)	841 (2,760)	No reaction	(-)
62	3.810 (1.500)	0.635 (0.250)	853 (2,800)	No reaction	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 6

Results of tests with 42 gram fragments: solid acceptors

Fragment: 0.94 cm x 2.40 cm x 2.40 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
63	0.635 (0.250)	none	1,166 (3,825)	Deflagration	(-)
64	0.318 (0.125)	none	1,270 (4,167)	Detonation	(+)
65	0.635 (0.250)	none	1,153 (3,783)	Deflagration	(-)
66	0.318 (0.125)	none	1,248 (4,094)	Detonation	(+)
67	0.097 (0.038)	0.318 (0.125)	1,346 (4,414)	Detonation	(+)
68	0.635 (0.250)	0.318 (0.125)	1,187 (3,893)	Deflagration	(-)
69	0.318 (0.125)	0.318 (0.125)	1,256 (4,121)	Deflagration	(-)
70	0.318 (0.125)	0.318 (0.125)	1,278 (4,194)	Detonation	(+)
71	0.097 (0.038)	0.635 (0.250)	1,383 (4,539)	Deflagration	(-)
72	0.097 (0.038)	0.635 (0.250)	1,379 (4,524)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 7

Results of tests with 42 gram fragments: molten acceptors

Fragment: 0.94 cm x 2.40 cm x 2.40 cm

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
73	3.175 (1.250)	none	746 (2,449)	Detonation	(+)
74	5.080 (2.000)	none	533 (1,748)	No reaction	(-)
75	3.810 (1.500)	none	673 (2,209)	No reaction	(-)
76	3.556 (1.400)	none	673 (2,209)	No reaction	(-)
77	3.556 (1.400)	none	735 (2,412)	Detonation	(+)
78	3.810 (1.500)	none	671 (2,200)	No reaction	(-)
79	0.318 (0.125)	0.318 (0.125)	1,306 (4,285)	Detonation	(+)
80	0.635 (0.250)	0.318 (0.125)	1,149 (3,771)	Detonation	(+)
81	2.540 (1.000)	0.318 (0.125)	855 (2,806)	Detonation	(+)
82	3.175 (1.250)	0.318 (0.125)	777 (2,550)	No reaction	(-)
83	3.175 (1.250)	0.318 (0.125)	777 (2,550)	Deflagration	(-)
84	2.540 (1.000)	0.635 (0.250)	814 (2,669)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 7

Results of tests with 42 gram fragments: molten acceptors

Fragment: 0.94 cm x 2.40 cm x 2.40 cm (cont.)

Test no.	Lucite thk. cm (in)	Acceptor plate thk. cm (in)	Fragment velocity m/sec (fps)	Remarks	Result*
85	1.270 (0.500)	0.635 (0.250)	1,073 (3,519)	Detonation	(+)
86	1.905 (0.750)	0.635 (0.250)	920 (3,018)	Detonation	(+)
87	2.540 (1.000)	0.635 (0.250)	823 (2,700)	Missed target	N/A
88	2.540 (1.000)	0.635 (0.250)	827 (2,714)	Missed target	N/A
89	2.540 (1.000)	0.635 (0.250)	852 (2,794)	Detonation	(+)
90	3.175 (1.250)	0.635 (0.250)	689 (2,262)	Deflagration	(-)

*(+) indicates detonation.
(-) indicates no reaction or deflagration.

Table 8

Comparison of velocity data

Frag. wt. gm (oz)	Frag. wt/area gm/cm^2 (oz/in^2)	Acceptor plate thk. cm (in)	Acceptor condition solid molten	Min. vel. for det. m/sec. (fps)	Max. vel. without det. m/sec. (fps)
14 (0.5)	2.51 (0.58)	none	solid	1,517 (4,978)	1,343 (4,405)
14 (0.5)	2.51 (0.58)	0.318 (0.125)	solid	1,956 (6,418)	1,913 (6,277)
14 (0.5)	2.51 (0.58)	0.635 (0.250)	solid	2,103 (6,900)	2,096 (6,876)
14 (0.5)	2.51 (0.58)	none	molten	965 (3,167)	814 (2,669)
14 (0.5)	2.51 (0.58)	0.318 (0.125)	molten	937 (3,075)	821 (2,692)
14 (0.5)	2.51 (0.58)	0.635 (0.250)	molten	1,158 (3,800)	1,037 (3,401)
28 (1.0)	5.02 (1.16)	none	solid	1,464 (4,803)	1,444 (4,739)
28 (1.0)	5.02 (1.16)	0.318 (0.125)	solid	1,711 (5,614)	1,648 (5,407)
28 (1.0)	5.02 (1.16)	0.635 (0.250)	solid	-	≥1,816* (5,957)
28 (1.0)	5.02 (1.16)	none	molten	959 (3,146)	857 (2,813)
28 (1.0)	5.02 (1.16)	0.318 (0.125)	molten	1,122 (3,682)	959 (3,146)
28 (1.0)	5.02 (1.16)	0.635 (0.250)	molten	934 (3,065)	853 (2,800)

*Maximum velocity attainable with the 7.6 cm dia. x 7.6 cm long booster.

Table 8

Comparison of velocity data

(cont.)

Frag. wt. gm (oz)	Frag. wt/area gm/cm² (oz/in²)	Acceptor plate thk. cm (in)	Acceptor condition solid molten	Min. vel. for det. m/sec. (fps)	Max. vel. without det. m/sec. (fps)
42 (1.5)	7.29 (1.67)	none	solid	1,248 (4,094)	1,166 (3,825)
42 (1.5)	7.29 (1.67)	0.318 (0.125)	solid	1,278 (4,194)	1,256 (4,121)
42 (1.5)	7.29 (1.67)	0.635 (0.250)	solid	-	≥1,383* (4,539)
42 (1.5)	7.29 (1.67)	none	molten	735 (2,412)	673 (2,209)
42 (1.5)	7.29 (1.67)	0.318 (0.125)	molten	855 (2,806)	777 (2,550)
42 (1.5)	7.29 (1.67)	0.635 (0.250)	molten	852 (2,794)	814 (2,669)

*Maximum velocity attainable with the 7.6 cm dia. x 7.6 cm long booster.

Table 9

Summary of fragment impact test results

Frag. wt. gm (oz)	Acceptor plate thk. cm (in)	Min. vel. for det. solid m/sec. (fps)	Min. vel. for det. molten m/sec. (fps)	Max. vel. without det. solid m/sec. (fps)	Max. vel. without det. molten m/sec. (fps)
14 (0.5)	none	1,517 (4,978)	965 (3,167)	1,343 (4,405)	814 (2,669)
28 (1.0)	none	1,464 (4,803)	959 (3,146)	1,444 (4,739)	857 (2,813)
42 (1.5)	none	1,248 (4,094)	735 (2,412)	1,166 (3,825)	673 (2,209)
14 (0.5)	0.318 (0.125)	1,956 (6,418)	937 (3,075)	1,913 (6,277)	821 (2,692)
28 (1.0)	0.318 (0.125)	1,711 (5,614)	1,122 (3,682)	1,648 (5,407)	959 (3,146)
42 (1.5)	0.318 (0.125)	1,278 (4,194)	855 (2,806)	1,256 (4,121)	777 (2,550)
14 (0.5)	0.635 (0.250)	2,103 (6,900)	1,158 (3,800)	2,096 (6,876)	1,037 (3,401)
28 (1.0)	0.635 (0.250)	-	934 (3,065)	≥1,816* (5,957)	853 (2,800)
42 (1.5)	0.635 (0.250)	-	852 (2,794)	≥1,383* (4,539)	814 (2,669)

*Maximum velocity attainable with the 7.6 cm dia. x 7.6 cm long booster.

Table 10

Summary of maximum fragment velocities

Fragment weight gm (oz)	Fragment dimension cm (in)	Max. fragment velocity m/sec. (fps)
14 (0.5)	.32 x 2.36 x 2.36 (.125 x .930 x .930)	2,105 (6,907)
28 (1.0)	.64 x 2.36 x 2.36 (.250 x .930 x .930)	1,816 (5,957)
42 (1.5)	.94 x 2.40 x 2.40 (.370 x .945 x .945)	1,383 (4,539)

Table 11

Comparison of Amatex and Composition B test results

Acceptor plate thickness: 0.318 cm (0.125 in)

Frag. wt. gm (oz)	Acceptor condition* solid/molten	Min. vel. for det. Comp B m/sec (fps)	Min. vel. for det. Amatex m/sec (fps)	Max. vel. without det. Comp B m/sec (fps)	Max. vel. without det. Amatex m/sec (fps)
14 (0.5)	solid	1,767 (5,798)	1,956 (6,418)	1,587 (5,206)	1,913 (6,277)
14 (0.5)	molten	1,571 (5,155)	937 (3,075)	1,410 (4,626)	821 (2,692)
28 (1.0)	solid	1,651 (5,418)	1,711 (5,614)	1,377 (4,518)	1,648 (5,407)
28 (1.0)	molten	1,247 (4,090)	1,122 (3,682)	1,308 (4,292)	959 (3,146)

*Refer to Table 1 for number of trials for each acceptor condition.

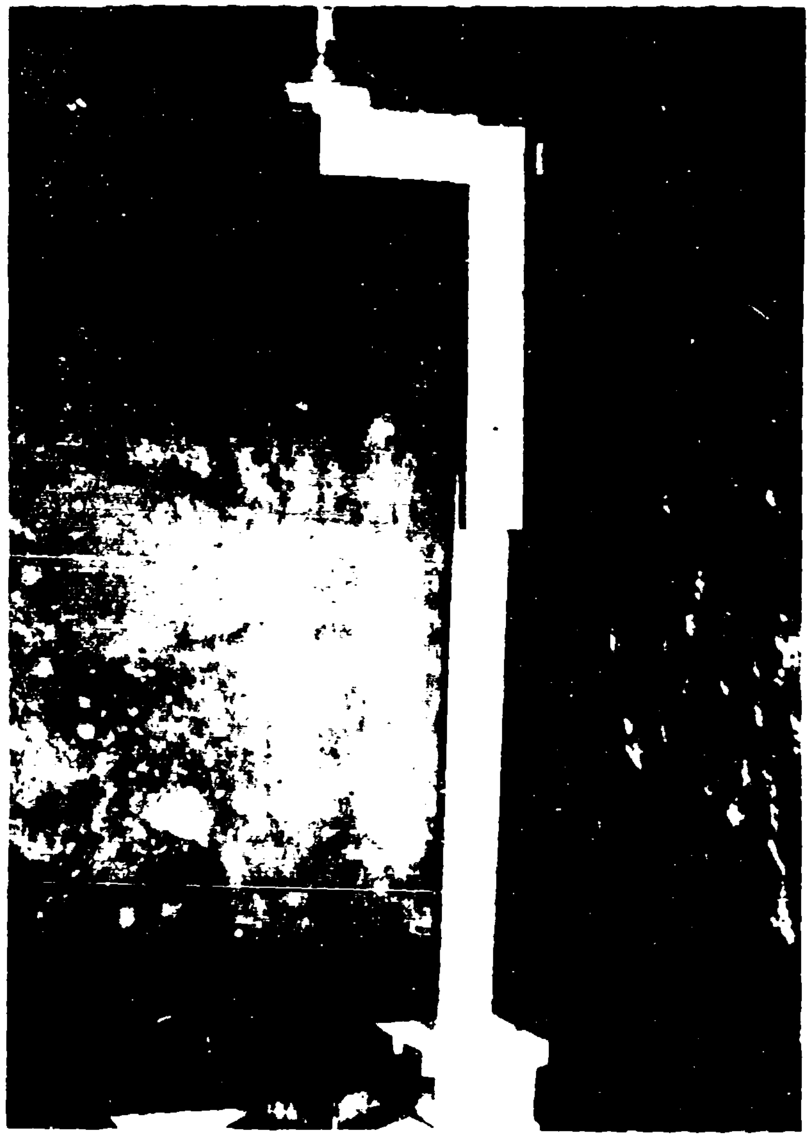
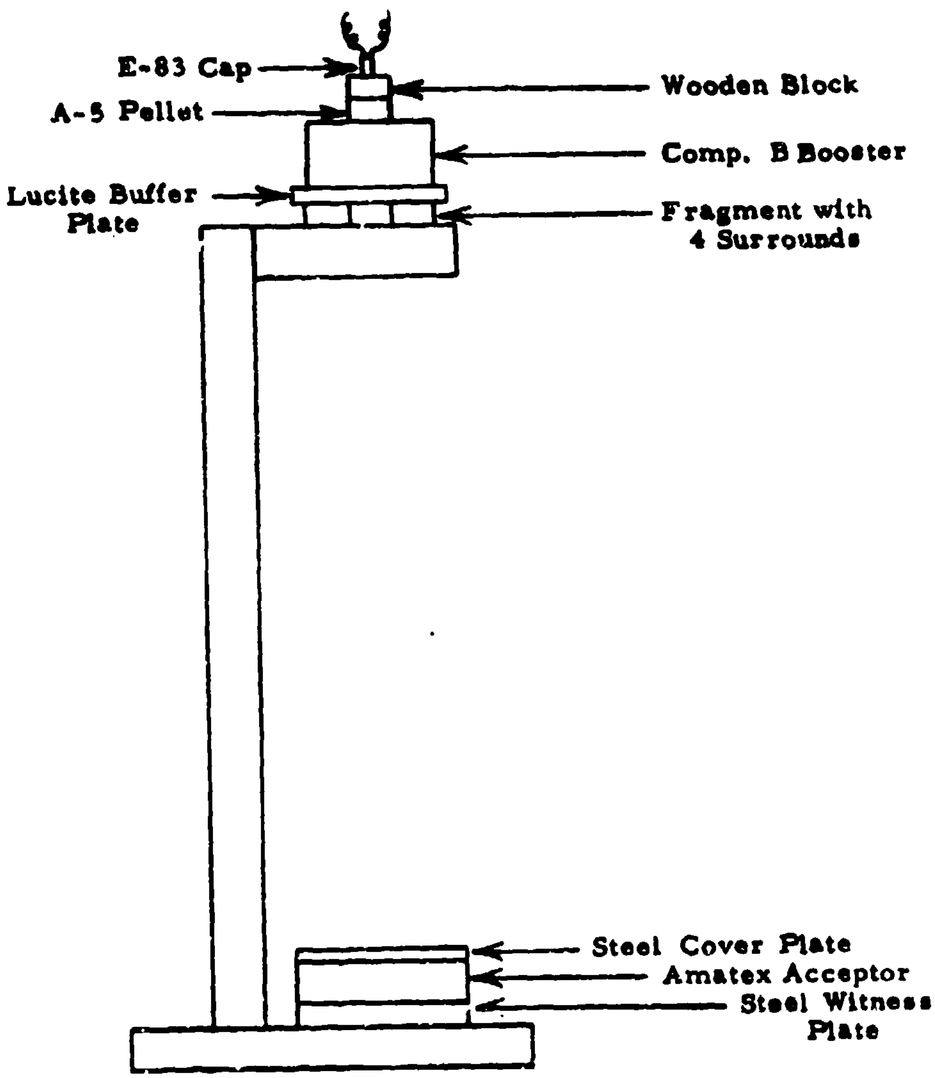


Fig 1 Experimental set-up



F.g 2 Schematic of experimental set-up

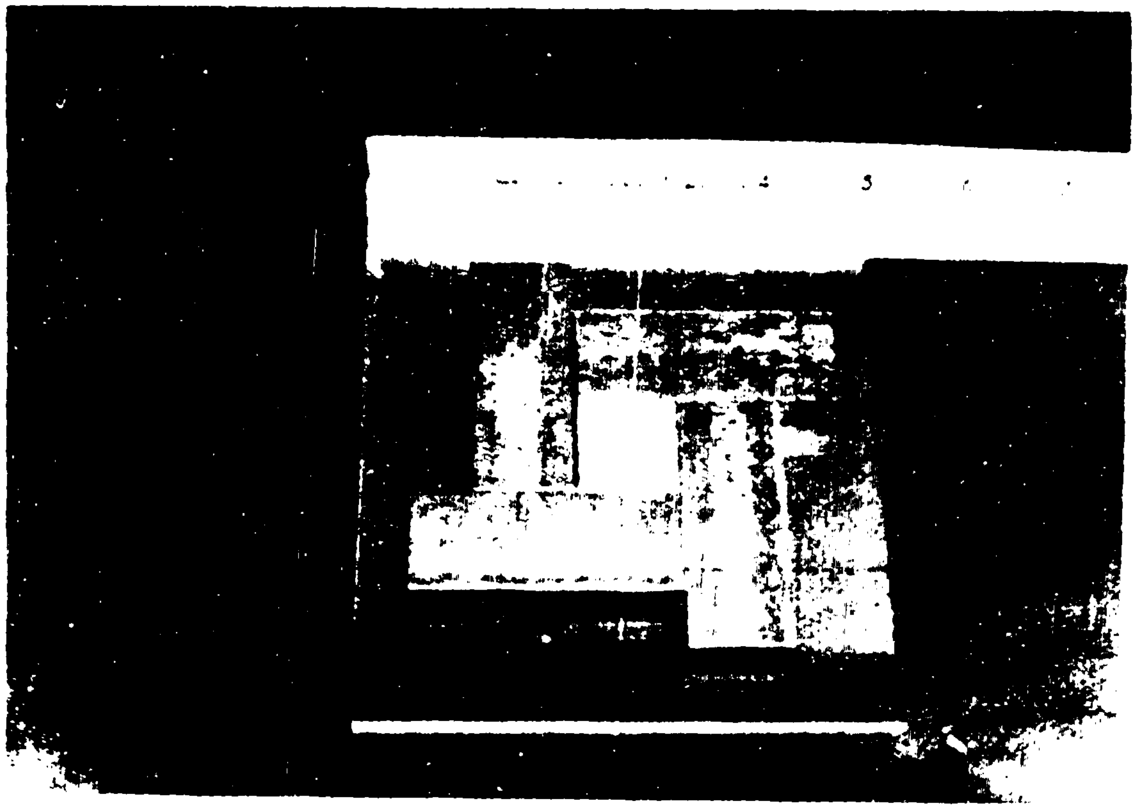


Fig 3 Forty-two gram steel fragment, four surrounds, and Lucite buffer plate

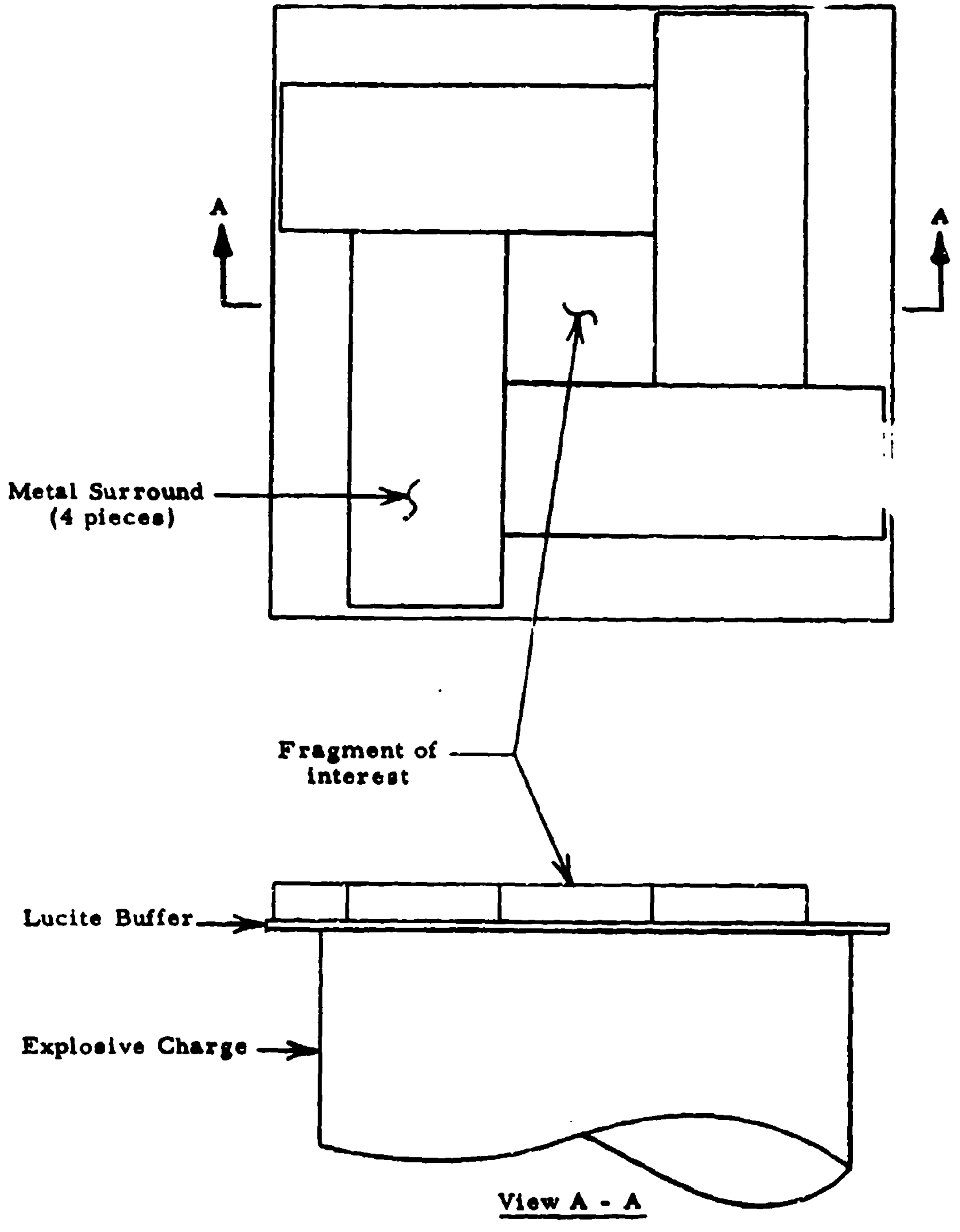


Fig 4 Schematic of fragment propulsion system

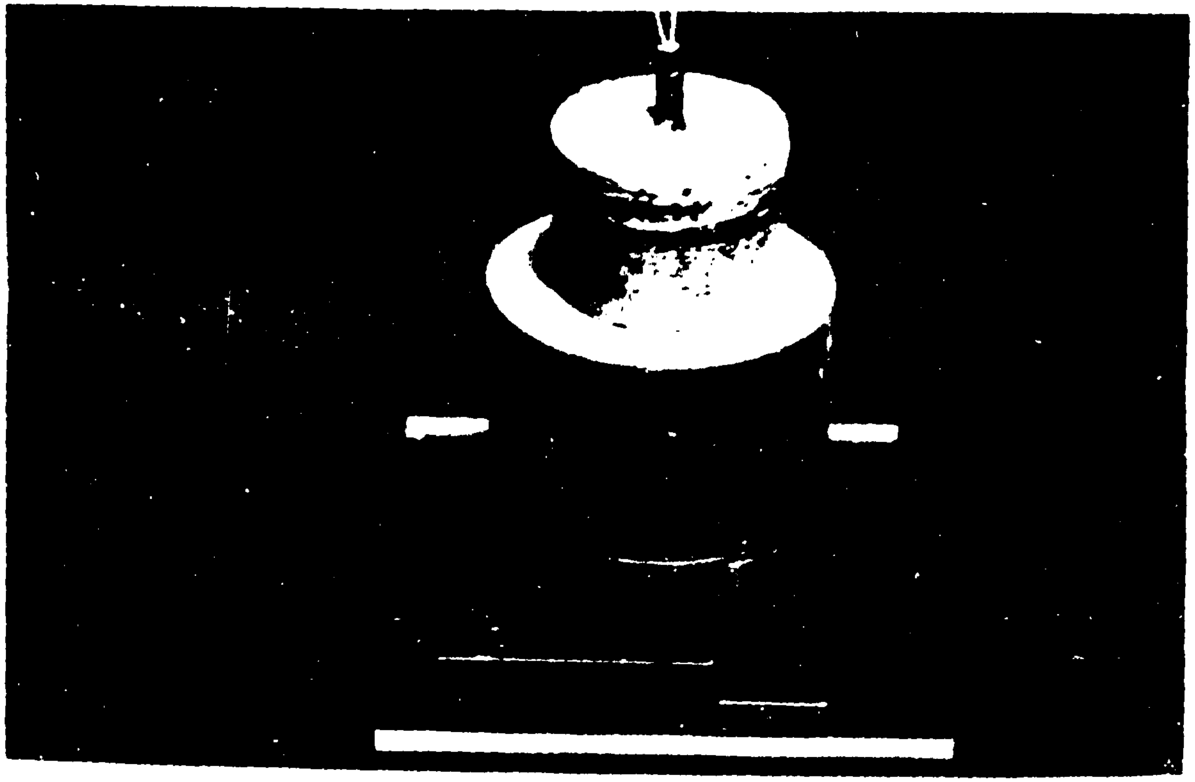


Fig 5 Composition B booster configuration

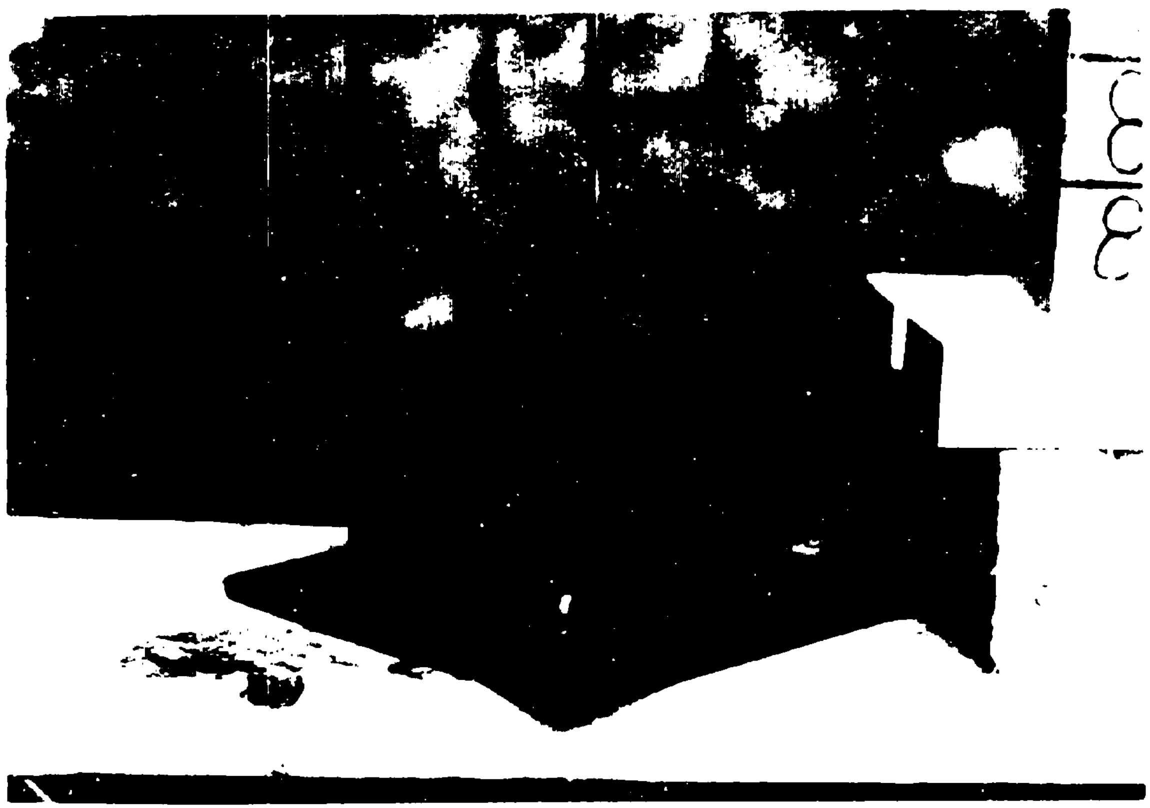


Fig 6 Molten Amatex acceptor charge with 0.635 cm thick steel acceptor plate and 0.953 cm thick steel witness plate

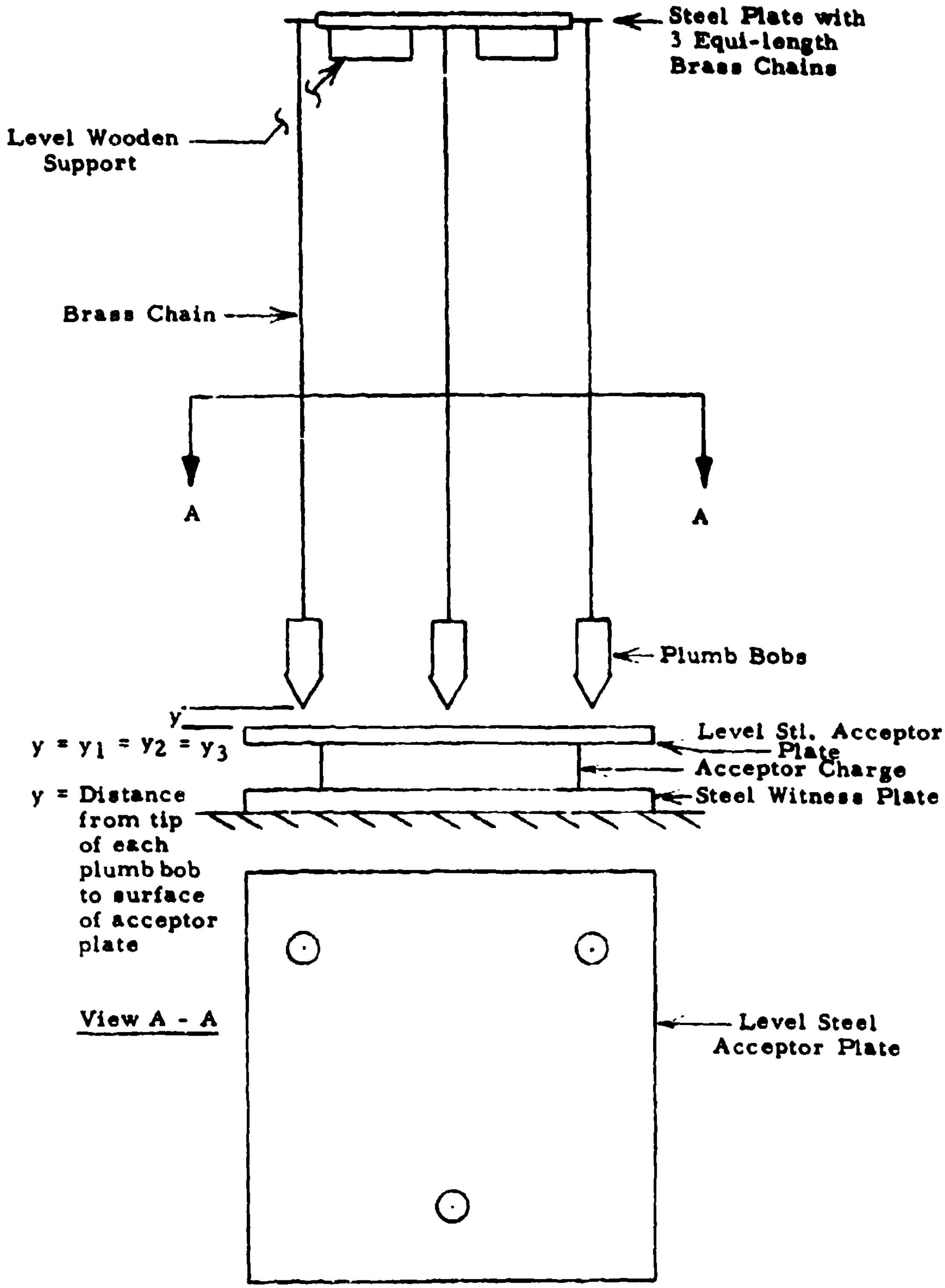
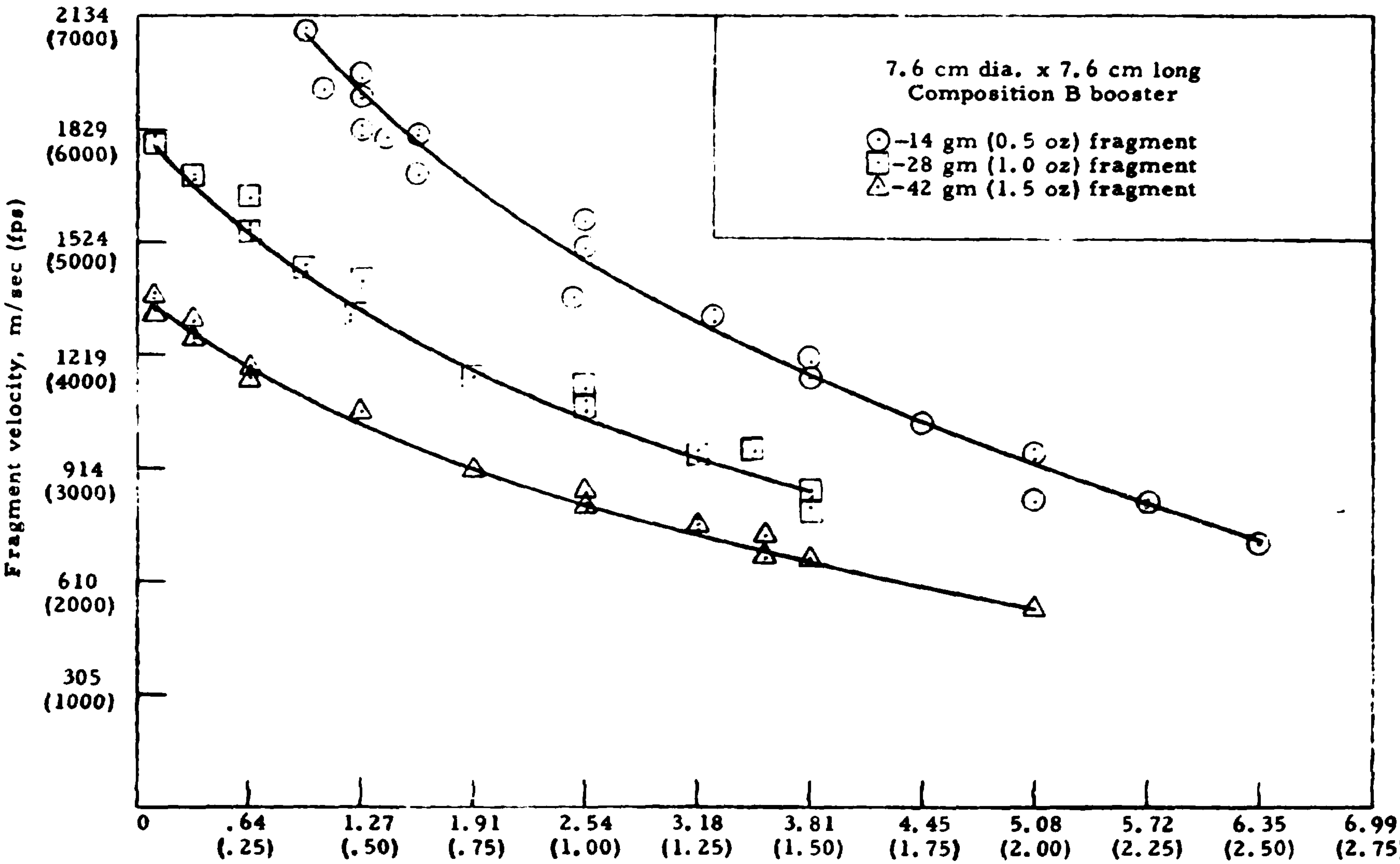


Fig 7 Fragment aiming technique



Lucite buffer plate thickness, cm (in)

Fig 8 Fragment velocity vs Lucite thickness

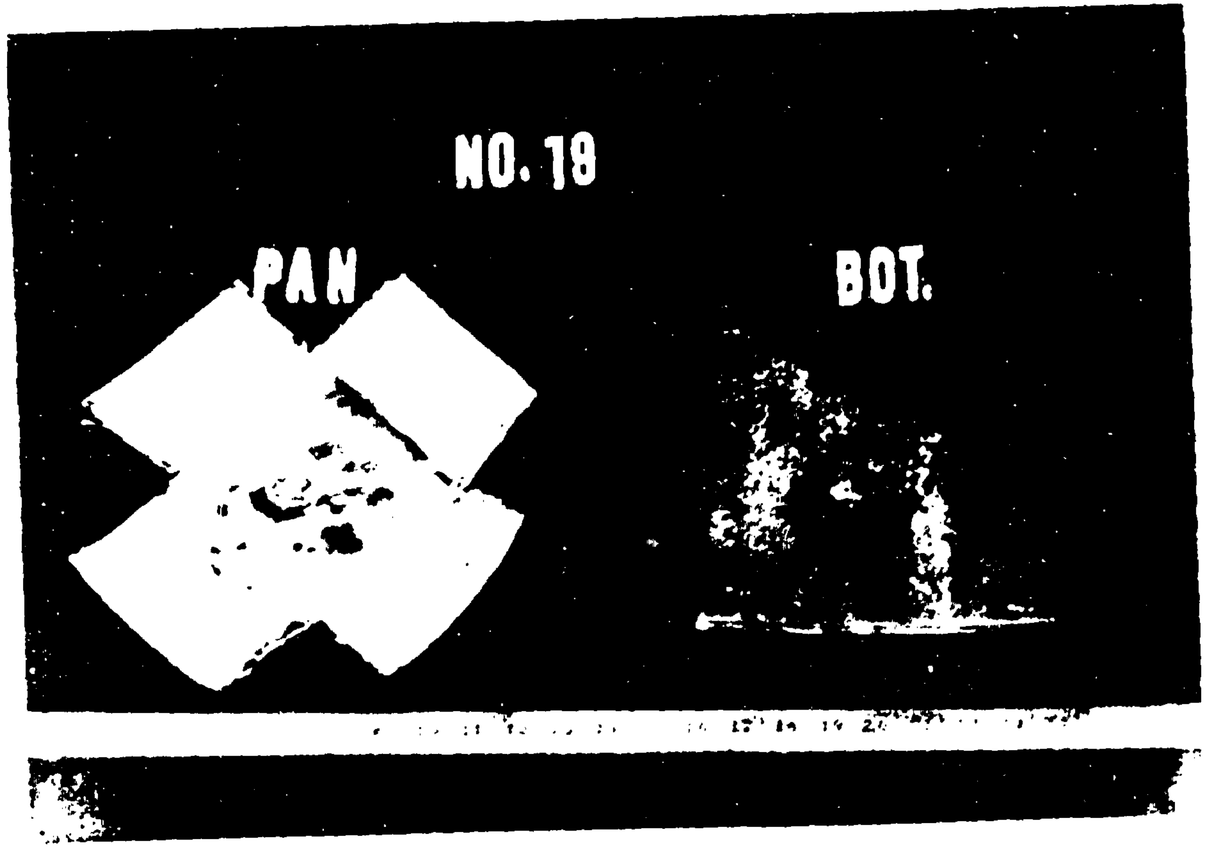


Fig 9 Post-run condition of typical witness plate, pan, and fragment after a negative test result on an uncovered, solid acceptor

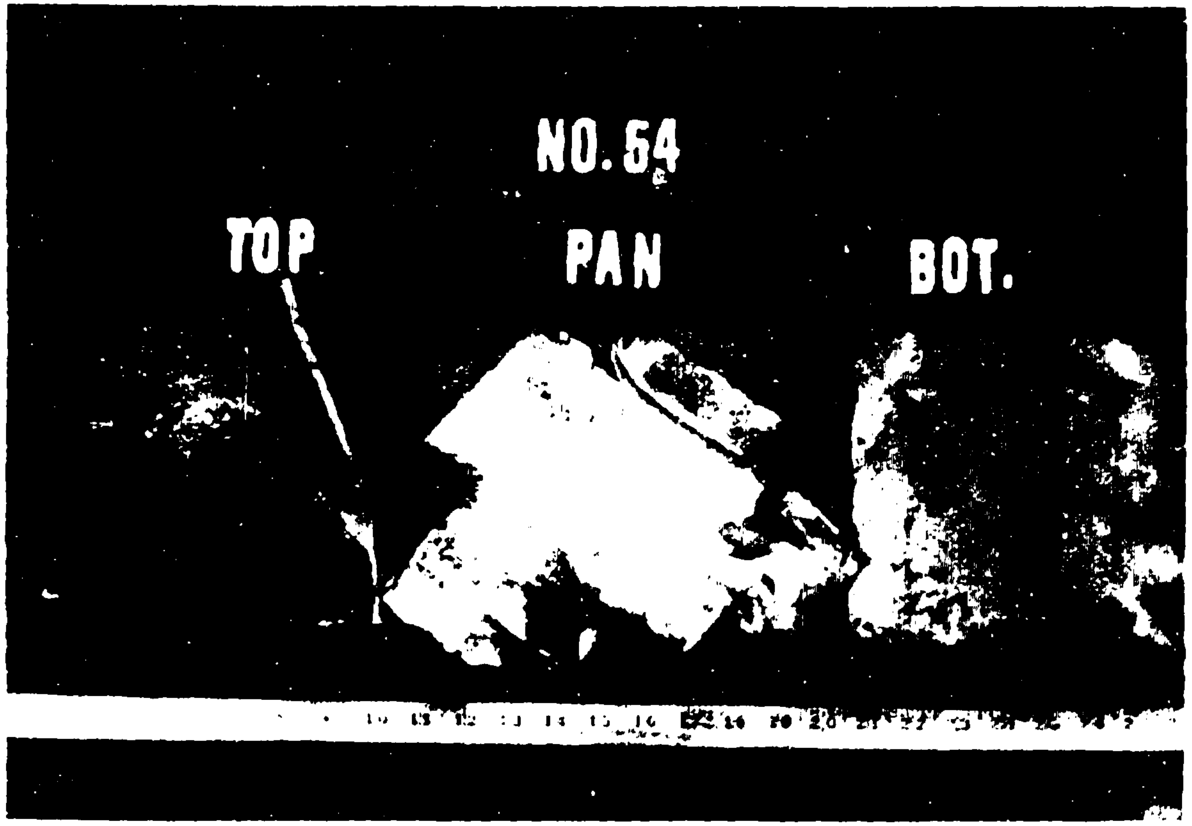


Fig 10 Post-run condition of typical witness plate, pan, acceptor plate, and fragment *after* a *negative* test result on a solid acceptor

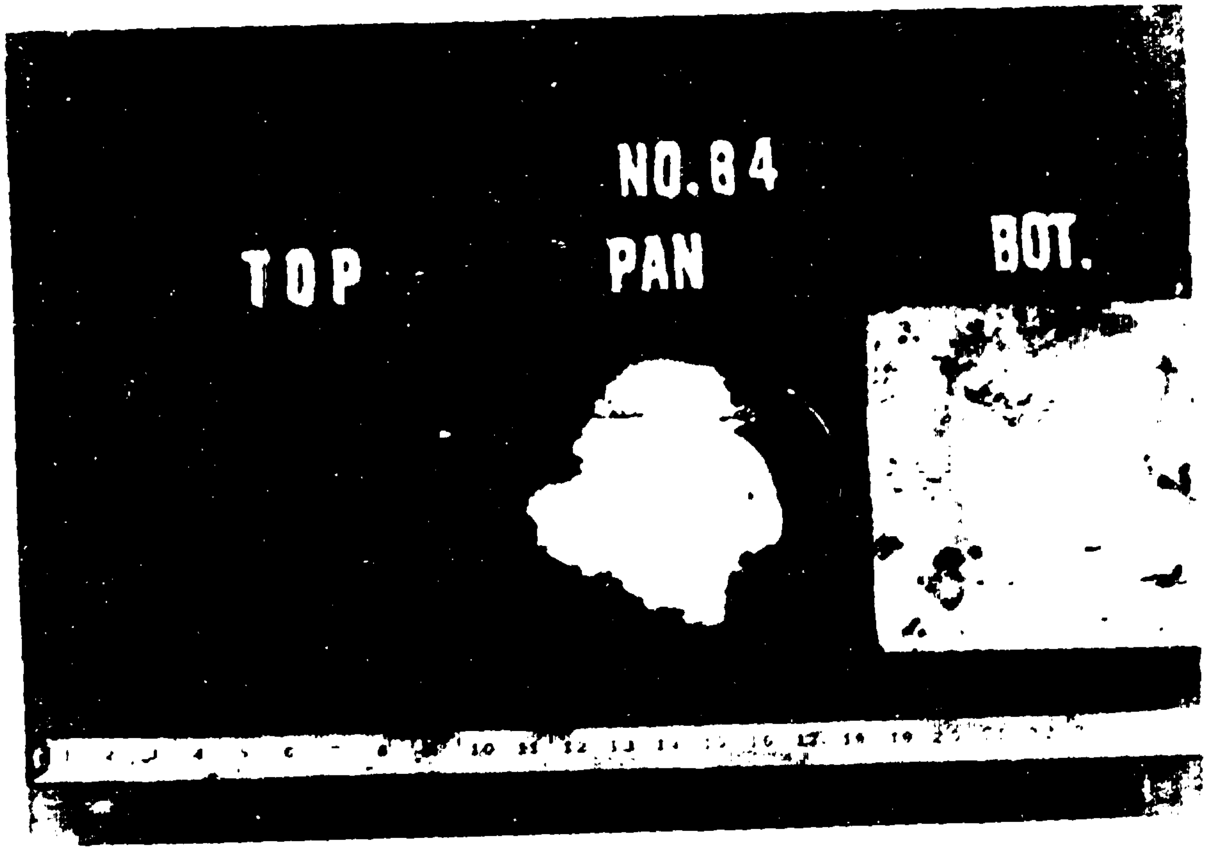


Fig 11 Post-run condition of typical witness plate, pan, and fragment after a negative test result on an uncovered, molten acceptor

Fig 12 Post-run condition of typical witness plate, pan, acceptor plate and fragment after a negative test result on a molten acceptor

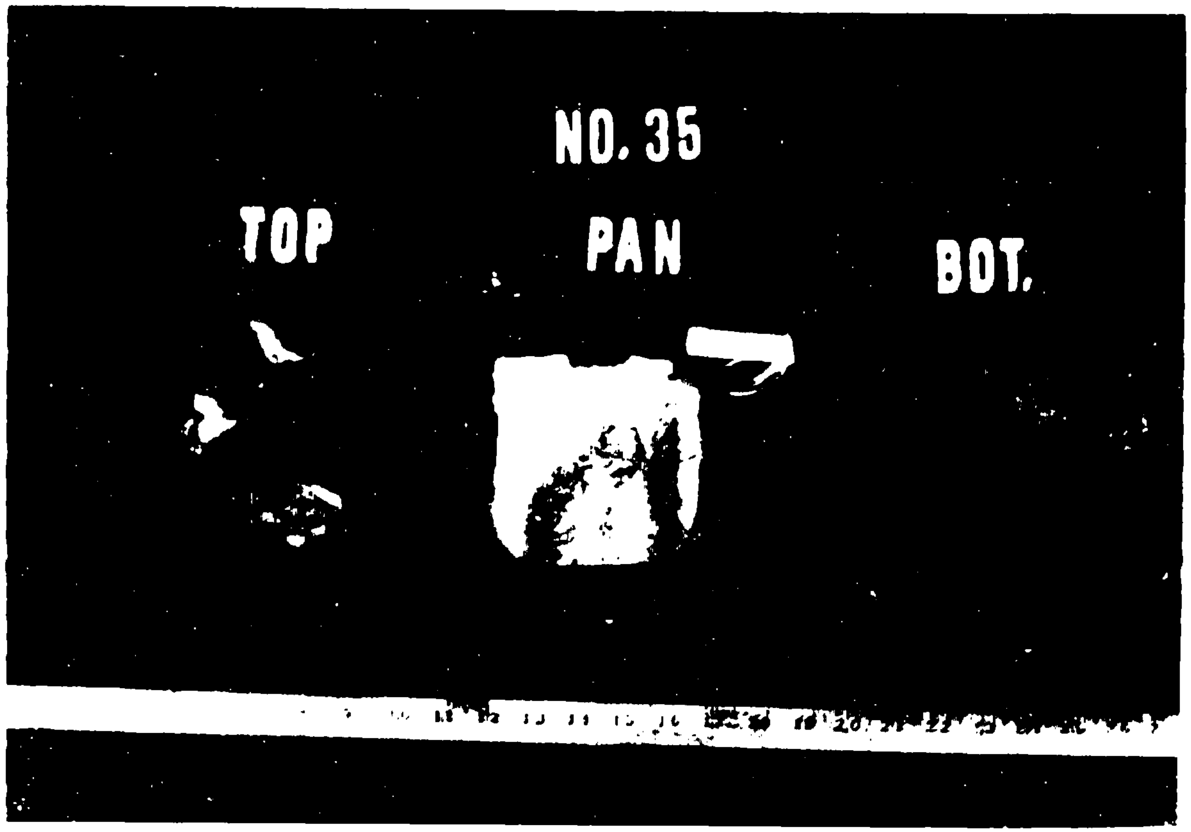


Fig 13 Post-run condition of typical witness plate, pan, acceptor plate, and fragment after a low order detonation of a molten acceptor

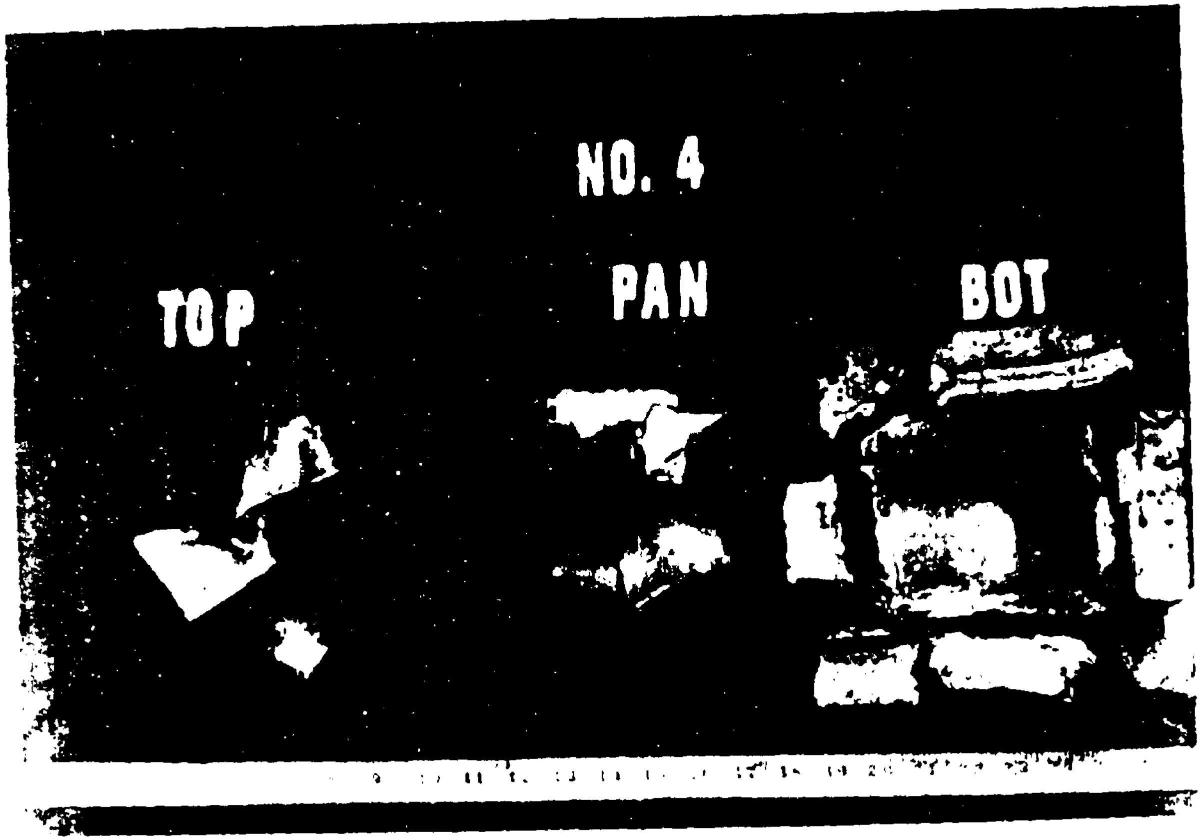


Fig 14 Post-run condition of typical witness plate, pan, and acceptor plate after a high order detonation of a solid acceptor

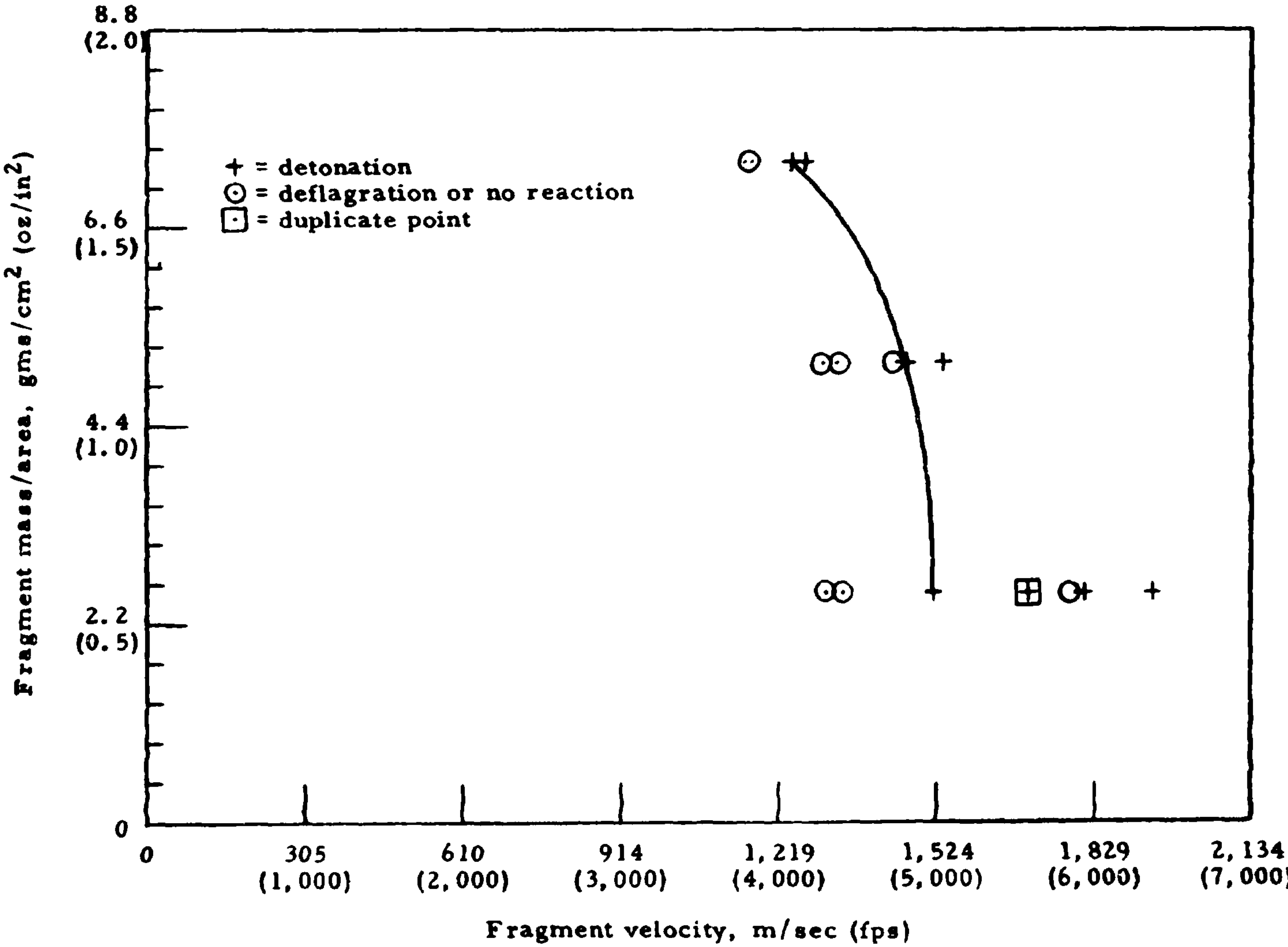


Fig 15 Plot of test results for uncovered, solid Amatex

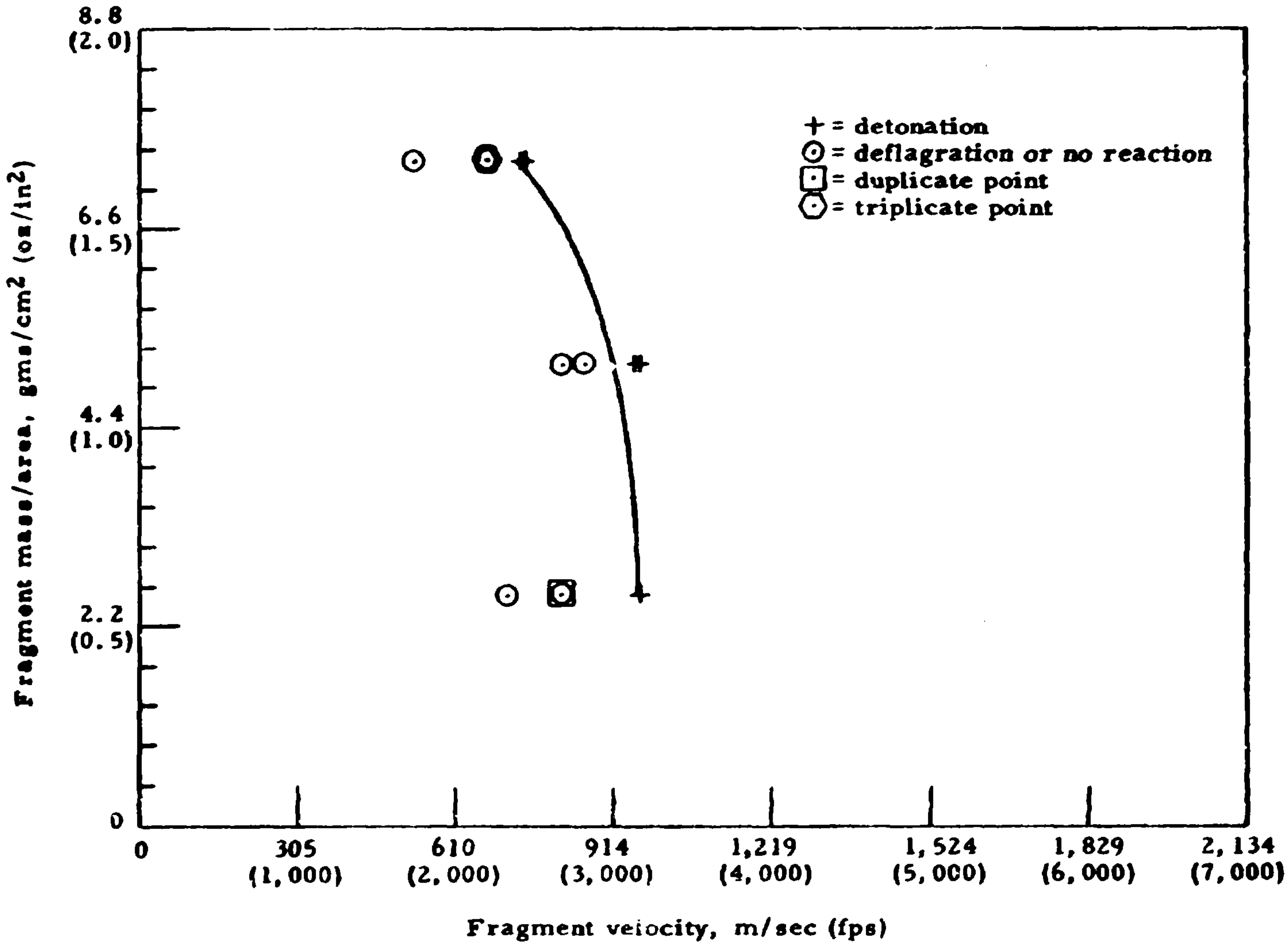


Fig 16 Plot of test results for uncovered, molten Amatex

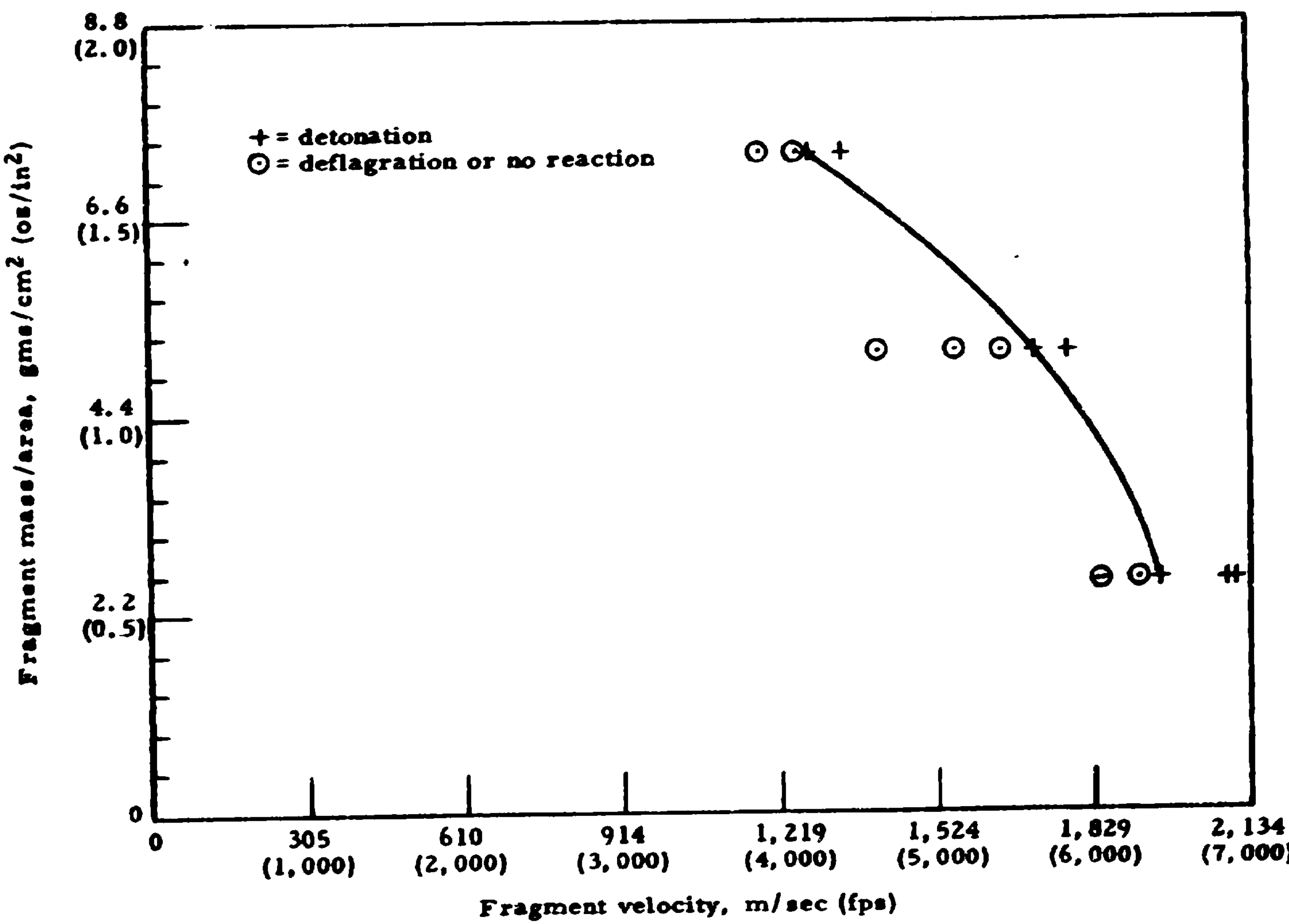


Fig 17 Plot of test results for solid Amatex with 0.318 cm thick acceptor plate

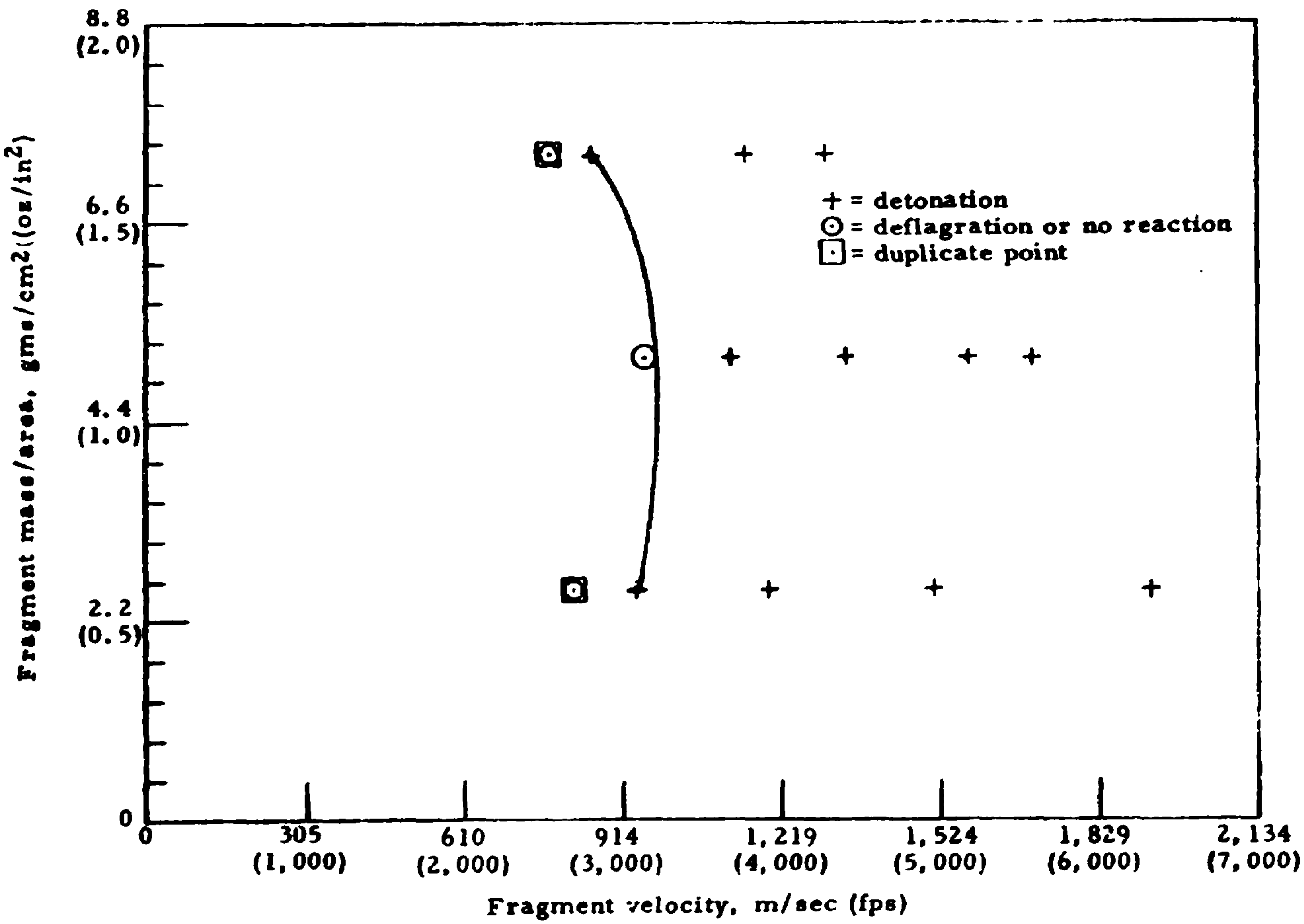


Fig 18 Plot of test results for molten Amatex with 0.318 cm thick acceptor plate

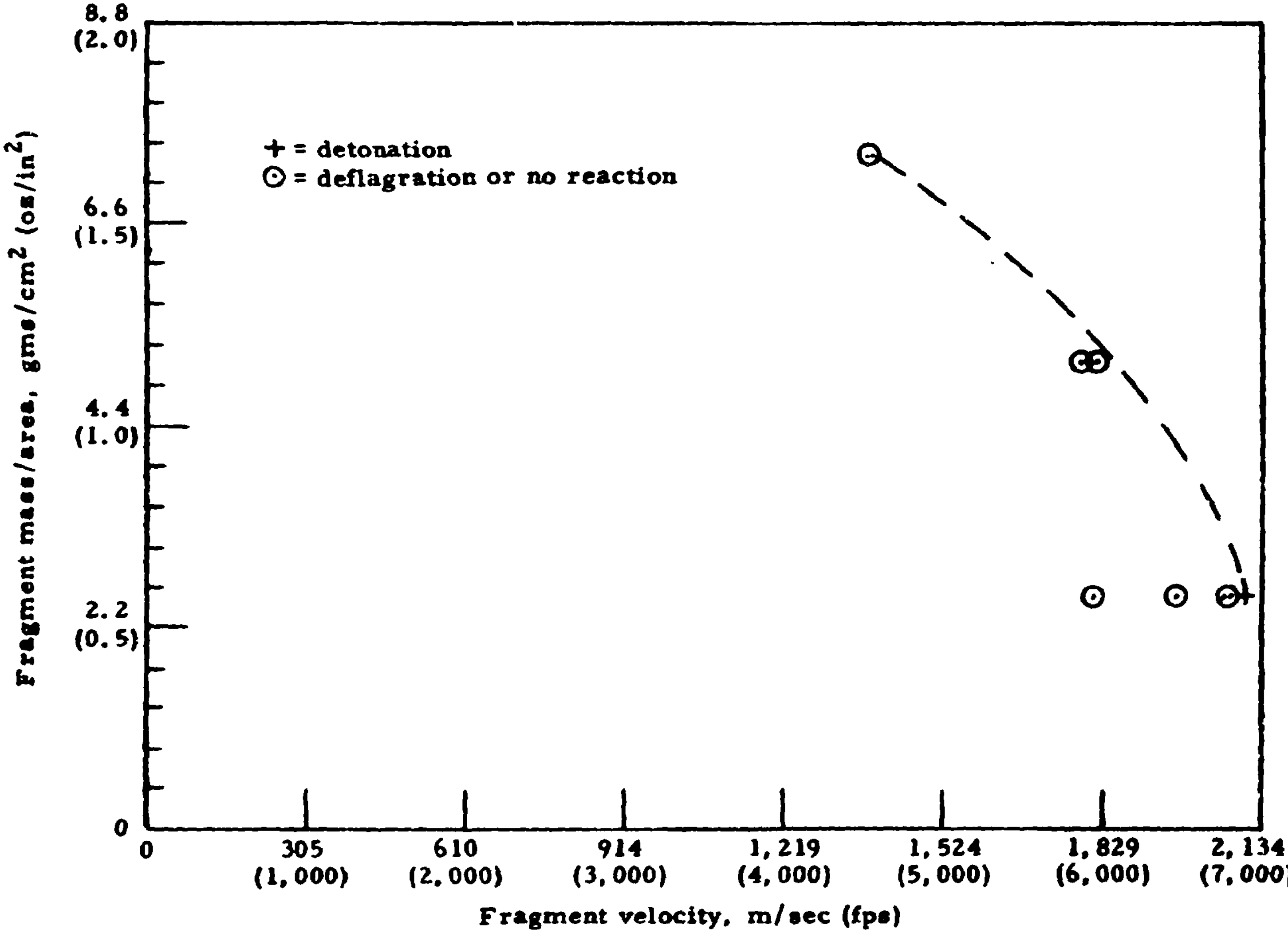


Fig 19 Plot of test results for solid Amatex with 0.635 cm thick acceptor plate

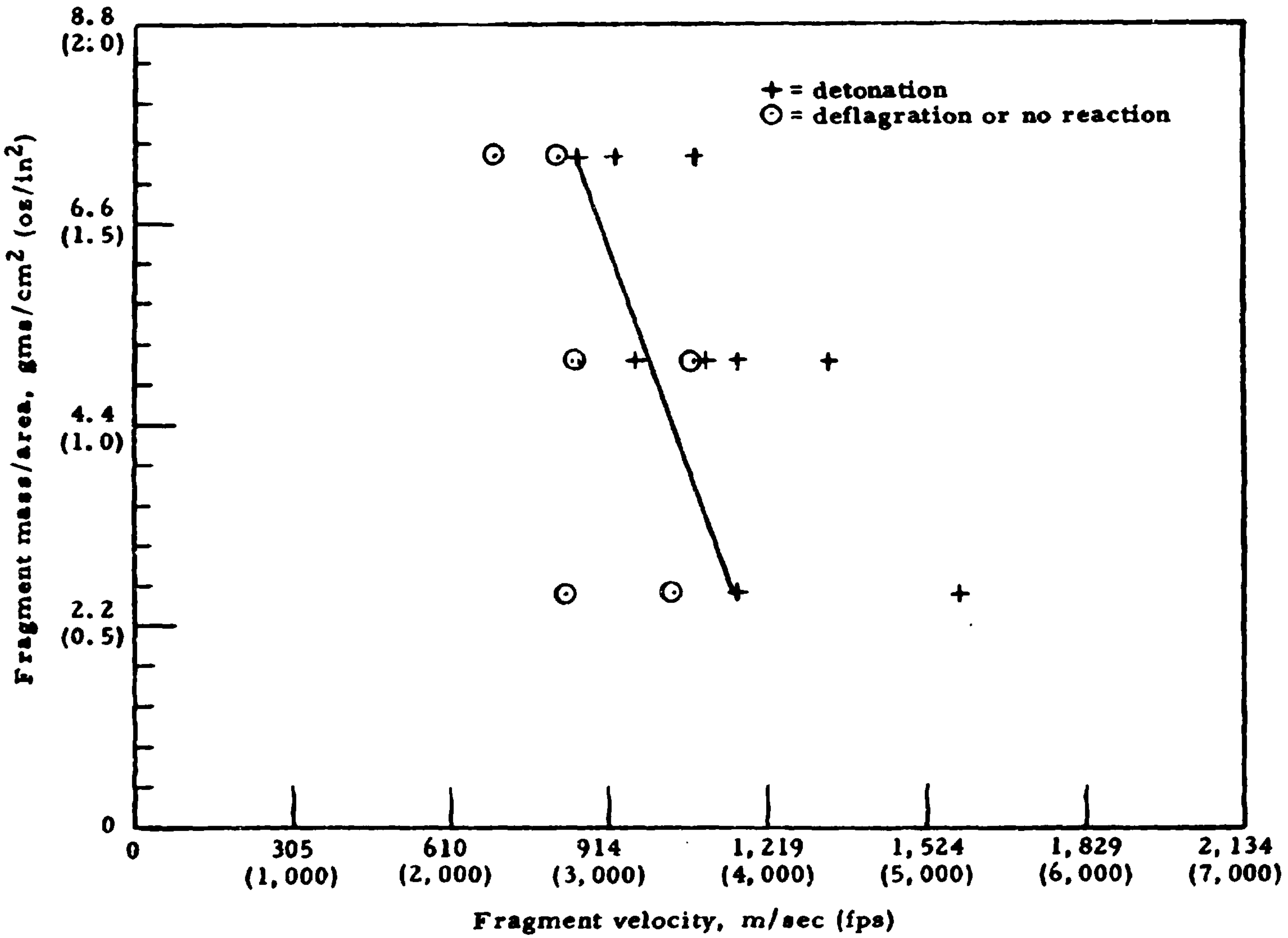


Fig 20 Plot of test results for molten Amatex with 0.635 cm thick acceptor plate

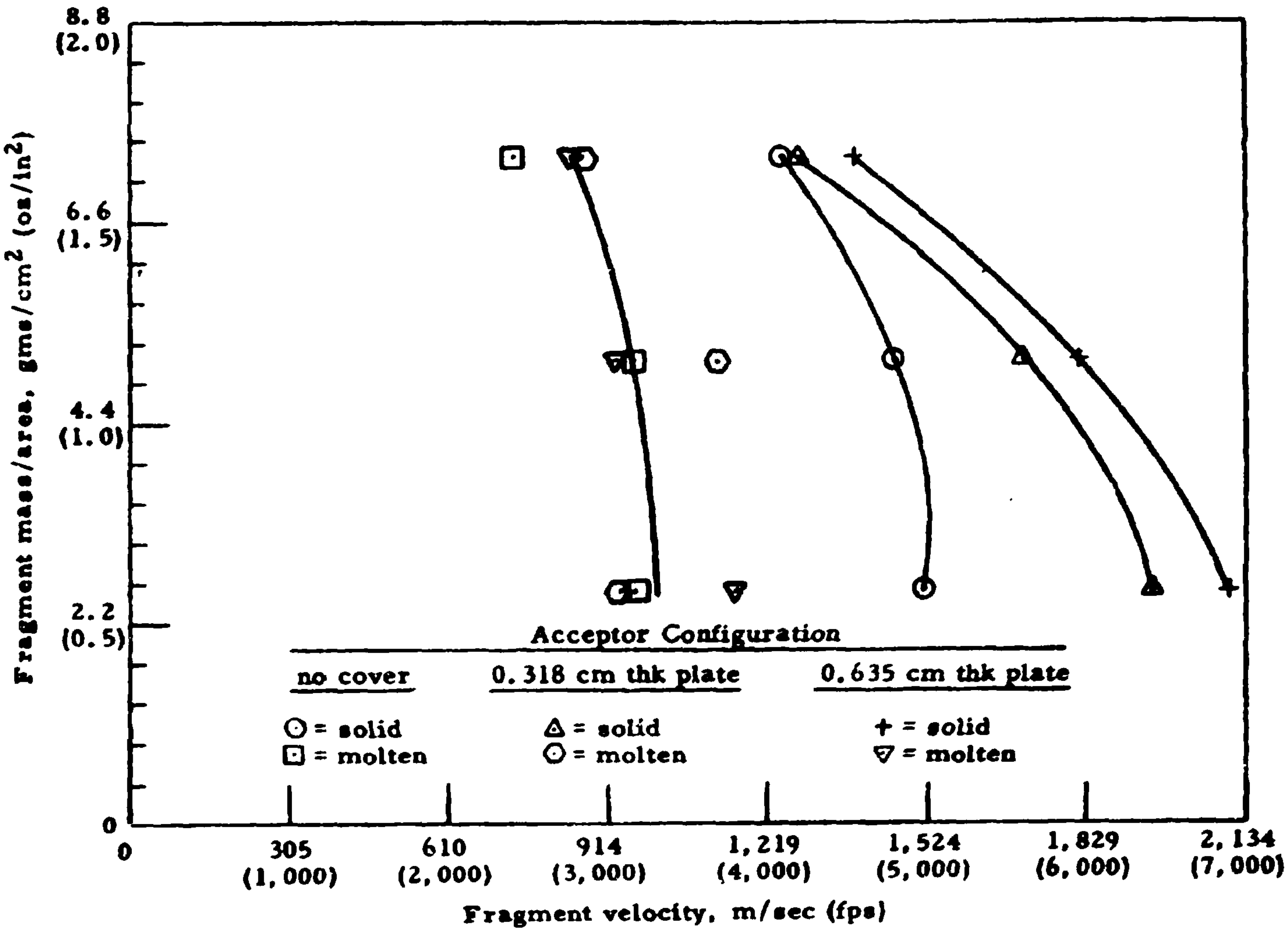


Figure 21 Comparison of minimum velocity for detonation of molten and solid Amatex as a function of fragment mass per unit area

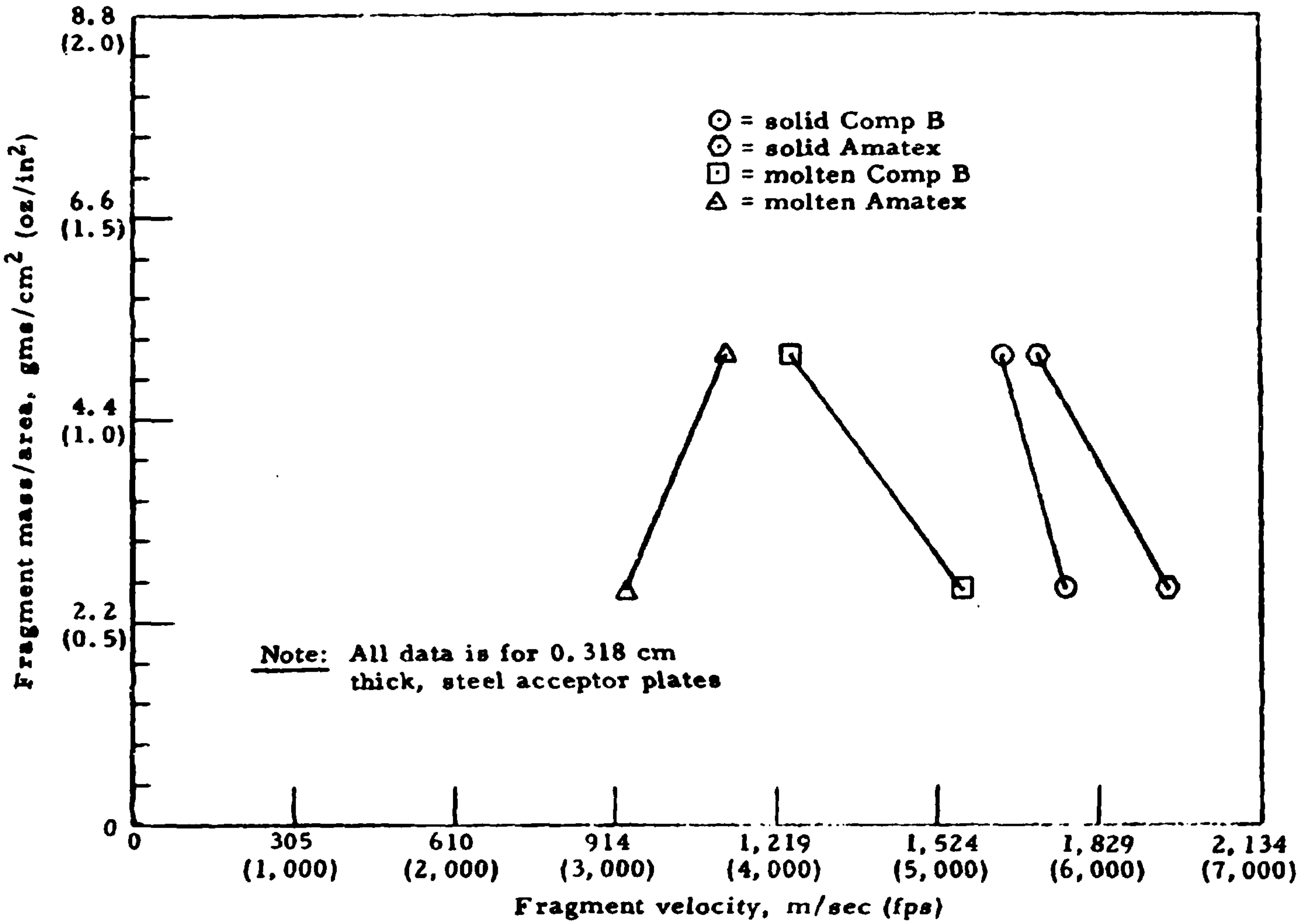


Fig 22 Comparison of minimum velocity for detonation of molten and solid Amatex and Composition B as a function of fragment mass per unit area

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