

R01-OH-00300

PB90100959



R1821

PROTECTION OF EYES, FACE AND BODY
AGAINST HIGH IMPACTS

Research Project OH 00300

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

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July 31, 1974

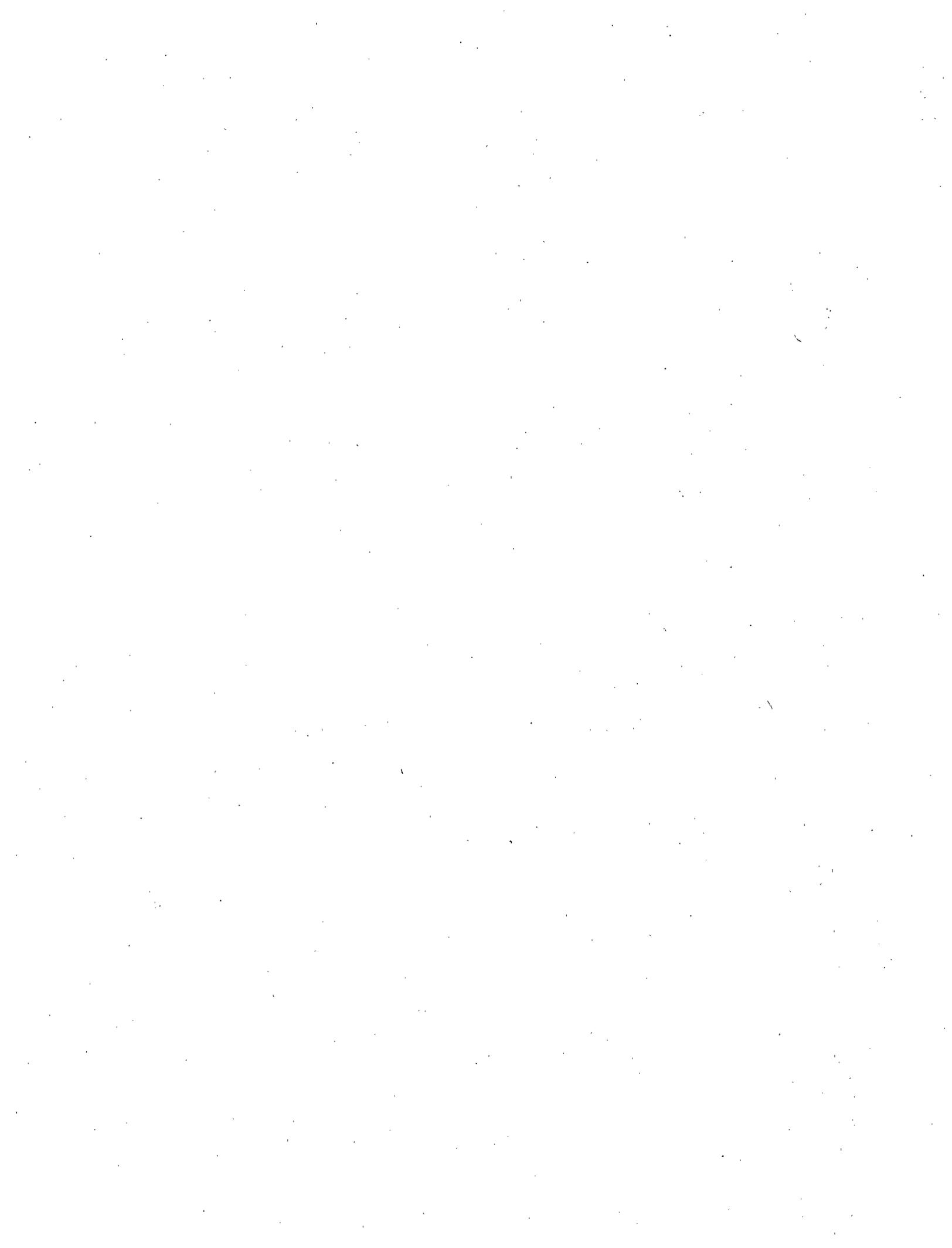
REPRODUCED BY: **NTIS**
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. PB90-100959
4. Title and Subtitle Protection of Eyes, Face and Body Against Impacts.		5. Report Date July 1974	
7. Author(s) G. Quam		6.	
9. Performing Organization Name and Address Research and Development Division Villanova University Villanova, PA 19085		8. Performing Organization Rept. No.	
12. Sponsoring Organization Name and Address NIOSH 4676 Columbia Parkway Cincinnati, OH 45226		10. Project/Task/Work Unit No.	
		11. Contract(C) or Grant(G) No. (C) (G) R01-OH-00300	
		13. Type of Report & Period Covered	
15. Supplementary Notes		14.	
16. Abstract (Limit: 200 words)			
<p>Results are presented of high impact test data yielded by safety spectacles, goggles, face shields, and body shields, currently available on the market. Details are given as to techniques for impact testing, evaluation of various plastics, and impact resistance of single and multiple targets. Evidence is presented regarding the need for strengthening of standards for eyes and face protection. Mar-resistant polycarbonate lenses are recommended over tempered glass lenses.</p>			
17. Document Analysis			
a. Descriptors NIOSH-Grant, Impact-Testing, Personal-Protective-Equipment			
b. Identifiers/Open-Ended Terms			
<p>REPRODUCED BY U.S. DEPARTMENT OF COMMERCE NATIONAL TECHNICAL INFORMATION SERVICE SPRINGFIELD, VA. 22161</p>			
c. COSATI Field/Group			
18. Availability Statement AVAILABLE TO THE PUBLIC		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 35
		20. Security Class (This Page) UNCLASSIFIED	22. Price

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PROTECTION OF EYES, FACE AND BODY

IN LABORATORIES AND SHOPS

Historical Introduction

Protection for the whole person was attempted in ancient times but chiefly in connection with warfare. Many types of helmets were designed - some quite ornate. Even the horse was provided with limited armor, Figure 1A*. Hand shields were common among ancient warriors. Today we have a similar police device sometimes called a "riot shield." The coat of mail for body protection passed through many variations and extent of coverage. Greaves were invented for leg protection, especially for the shins. In modern warfare the helmets and body shields have been revived in quite different designs and of different materials, Figure 1A. Law enforcement persons have revived protective devices from the top of the head to the soles of the feet, Figure 1B. Materials for high impacts were originally restricted primarily to metals. Modern improvements have taken us into the fields of high-impact plastics and high-impact resistant fabrics such as ballistic nylon.

In the laboratories and shops, shields for the eyes, face, and body show a remarkable evolution.

Need for Protective Devices in the Academic and Industrial Laboratories and Shops

Protective devices to be worn on the person, to be supported on work benches, and on machines have in many instances developed from ancient applications. These devices at the outset depended on glass. Development of plastics has tended to replace glass in many instances. Glass and plastics have found joint application in laminated glass, often called "shatter-proof glass."

The vast array of materials and designs has called for some control in the form of approved standards such as ANSI Z87.1-1968. In this report we hope to throw some light on the requirements for such standards - especially for the protection of eyes and face in the chemical laboratories. This requires that we consider and compare the conditions in the chemical laboratories and in the shops. In this study we must consider the most severe impacts from missiles especially - but also from sprays which may be corrosive. The chemical laboratory perhaps accounts for the highest velocities of missiles, which may be glass or metal. In shops velocity of missiles from lathes, drill presses, milling machines, grinders are comparatively of lower velocity at the source.

Survey of Current Conventional Protective Devices for Eyes, Face, and Body

At the outset we must consider the competitive atmosphere in which the manufacturer finds himself. Quite naturally appearance, comfort, and protectiveness are qualities that must be considered in seeking acceptance and sales. From the point of view of

*All figures are shown at the end of this report in Appendix I.

the consumer protectiveness should be the number one priority. The skillful industrial designer can take care of the other two secondary requirements. We will attempt to cite the typical protective devices currently on the market.

SAFETY SPECTACLES

Safety spectacles vary widely in design and lens material. Some have side shields which may be metal screens, perforated or solid plastic, Figures 2, D. Tempered glass lenses may vary in thickness and impact resistance. Plastic lenses not only vary in thickness but also in kind of plastic, e.g. acrylic, acetate, polycarbonate. Impact resistance varies greatly in terms of kinds of plastics. Frames may hold the lens feebly, Figures 2, E or very firmly, Figures 2, C.

GOGGLES

Some goggles are still equipped with tempered glass lenses, Figures 3, A & D. The plastics in use for lenses include vinyl, acrylic, acetate and polycarbonate. We will show later that the impact resistance of lenses depends not only on thickness but more especially on the kind of material. A few goggles have double lenses but again the kind of plastic used is of prime importance.

Nearly all goggles are provided with ventilation vents. Some depend on perforations, top and sides, Figures 3, C; others on turret type "buttons" opening to all sides, Figures 3, D & E, while a few have vents molded into top and sides of the frame that open only to the back, Figures 3, F. The last type prevents frontal spray from entering and reaching the eyes.

FACE SHIELDS

In face shields we also have a wide variety of designs and materials for the windows. The windows vary widely in coverage - all the way from little more than "goggles," Figures 4, B, to wide enough and long enough to cover the neck and ears, Figures 4-A, E, F. Materials used for the windows include such plastics as acetate, acrylic, polycarbonate and vinyl. Thicknesses have varied approximately from 0.020" to 0.060". The attachments for the window may vary from only a narrow head-band, Figure 4-A, to a crown that protects the top of the head, Figures 4-C, E, F.

BODY (or BENCH) SHIELDS

Contemporary body shields are manufactured in distinctive designs, Figure 5 sometimes with little regard for stability. (1, 2)**. The support for the window is usually made of metal. Some manufacturers have increased stability by adding extra weight to the "heel." Figure 5 C. The windows may be made of laminated glass, of acrylic, of polycarbonate, or of combinations. The height is usually about 30 inches and the width starts at 14 inches. The window may be curved and slanted toward the apparatus, Figure 5-A, or it may be verticle, Figure 5-B. The window may be flat and slanted toward the apparatus, Figure 5-C.

**All literature cited is listed in Appendix II.

EXPERIMENTAL

A. Techniques for Impact Testing

1. The Drop-Ball Method, Figure 6, was used to verify ANSI Z87.1-1968. In this test for lens a 1" steel ball is dropped 50" onto the center surface. The lens is approved if it does not break. Bausch and Lomb have printed a very useful table in their Catalog No. 22, Page 14.

KINETIC ENERGY OF STEEL BALLS

Ball Dia.	Weight Pounds	Ratio to 0.50" Ball	Striking Energy 50" Drop	
			Ergs.	Ft. Pounds
1/2"	0.01874		1.058×10^6	0.0780
5/8"	0.03660	1.953	2.092×10^6	0.1542
3/4"	0.06173	3.294	3.486×10^6	0.2571
7/8"	<u>0.09898</u>	5.282	5.590×10^6	<u>0.4122</u> A
1"	<u>0.14726</u>	7.859	8.317×10^6	<u>0.6133</u>
1 1/8"	0.20921	11.165	11.815×10^6	0.8713
1 1/4"	0.28726	15.329	16.347×10^6	1.2055
1 3/8"	0.38249	20.412	21.601×10^6	1.5930
1 1/2"	0.49625	26.482	28.025×10^6	2.0667
1 5/8"	0.63073	33.658	35.620×10^6	2.6268 B
1 3/4"	0.77513	41.365	43.774×10^6	3.2282
1 7/8"	0.96032	57.247	54.232×10^6	3.9994
2"	1.16644	62.247	65.886×10^6	4.8588
2 1/8"	1.39969	74.694	79.157×10^6	5.8376

A ANSI Spec. Lens 0.6133 ft./lb. B B&L Average (3.2168 ft./lb.)

The ANSI specifications refer to 7/8" ball for the face shield (ANSI Z87.1-1968, p. 26, section 6342). Bausch and Lomb, however, has required a higher standard for its Bal-SAFE lens with an average of 3.2168 ft./lb. as opposed to ANSI 0.6133 ft./lb. Stated in another way B-L requires over five times the standard impact for its Bal-SAFE lens.

We will refer back to the Drop-Ball Method when we will consider steel balls of diameters up to 2 1/8" and drops up to 8 ft.

2. Our ballistic tests were made with a Sheridan air-gun, Figure 7 A, a Remington 22-caliber rifle, Figure 7 B, and a "Glass Missile Cannon," Figure 7 C. The ballistic data was supplied by the manufacturer of each weapon.

(a) SHERIDAN AIR-GUN (16 GRAIN PELLET) FIGURE 7-A

Strokes of piston	2	3	4	5	6	7	8
Ft./lb. impact	3.6	6.2	7.5	9.0	10.2	11.3	12.4
Muzzle velocity ft./sec.	325	421	470	527	550	582	609

(b) REMINGTON RIFLE - 22 CALIBER. FIGURE 7-B

Cartridges	Bullet Grains	Ft./lb. Impact	Muzzle vel. ft./sec.
Minicaps	30	35	720
22 short	29	81	1125
22 long	29	99	1240
22 long rifle	40	158	1325

(c) "GLASS MISSILE CANNON" FIGURE 7-C

The need for some control of missile flight was amply shown by the charting of missile patterns for the sound-color movie (1). No two charts were alike. The wide spaces between hits in many charts explained why so many of us have escaped. To make this study meaningful we had to control the flight of missiles to a high degree. The "cannon" was our attempt to simulate impacts from an exploding flask-under some control. Obviously we were guided into this approach by experience with a straight bore shot-gun.

The "cannon" barrel was a 1 1/2" diameter steel pipe 10" long and capped at one end. The cap had two holes for the ignition wires. The missiles of broken glass varied greatly in weight as would be true of an exploding flask or bottle. The charges of $KClO_3$ and granular Mg were made in stoichiometric proportions and classified as #2 charge based on 0.02 mole $KClO_3$; #3 charge based on 0.03 mole $KClO_3$; #4 charge based on 0.04 mole $KClO_3$. The explosion was initiated by a modified Parr igniter.

The Drop-Ball Method of measurement has served well for establishing standards for relatively low velocity missiles such as may originate from shop machinery.

Explosions in a chemical laboratory on the other hand often result in very high velocity missiles approaching those of a bomb or a grenade. The velocity at the source may be extremely high and the impacts at two to ten feet from the explosion center may far exceed the Z87.1 standard of 0.6133 ft./lb. - in fact it may be at least ten times that value. This estimate is based on the simulated impact required to duplicate the damage to a lens worn by the victim of an accidental laboratory explosion. Several illustrations will be cited later. THESE OBSERVATIONS AND MANY OTHERS DEVELOPED IN THIS PROJECT, DESIGNATED AS OH 00300, STRONGLY SUGGEST UPGRADING THE REQUIREMENTS OF ANSI Z87.1-1968.

Since the steel balls cannot positively indicate the kinds of impacts caused by high velocity irregularly shaped missiles of metals, glasses, ceramics or plastics we added the air gun, rifle, and glass missiles "cannon" to our devices for delivering the missile.

B. EVALUATION OF PLASTICS

Shields for eyes and face are currently made of a variety of materials, chiefly plastics. Our preliminary studies of plastics indicated a wide range of impact resistance (3). The missile for this study was a 22 caliber short hi-speed Remington bullet. The bullet registered an 80 ft./lb. impact on a 10 ft. range. The target plates of nine different plastics were each of 0.062" thickness. Twenty seven plates of each plastic were placed in a target holder, Figure 8, and held firmly by two threaded rods. The target selector allowed four shots - unless the first caused extensive fractures.

TABLE I

BALLISTIC TESTS USING 22-CALIBER SHORT BULLETS,
0.062-INCH PLATES IN TARGET FRAME---10 FEET FROM
MUZZLE TO TARGET

Plastic in Target Frame	0.062" Plates Penetrated	Bullet Defeated by
1. Vinyl	21 all shattered	22nd (dented)
2. Acetate	6 radial cracked	7th (slightly cracked)
3. Acrylic	22 all shattered	23rd (cracked)
4. Polycarbonate I (1)	4 no cracks	5th (dented)
5. Polycarbonate II (1)	4 no cracks	5th (dented)
6. Cyclic (ABC) (2)	8 no cracks	9th (dented)
7. Fiber Glass I (2)	8 frosted	9th (dented)
8. Fiber Glass II (2)	12 frosted	13th (slightly dented)
9. Styrene (2)	13 radial cracked	14th (dented)

(1) Lexan or Merlon; (2) None are transparent.

Table I shows that 21 plates of vinyl and 22 plates of acrylic were penetrated and shattered. Six acetate plates were penetrated and showed radial cracks. The two kinds of polycarbonate plates were penetrated but not cracked. The fifth plate of each was slightly dented. Plas-

tics were opaque and were included for possible use in a body shield to be worn (to be discussed later). The results indicate that plastics are not necessarily alike in terms of impact resistance. Table I shows that polycarbonate is a vastly superior plastic.

Acrylic and polycarbonate sheets were also tested to determine the minimum thickness of a single plate required to stop the 22 caliber hi-speed short bullet.

TABLE II

THICKNESS REQUIRED TO STOP A 22 SHORT BULLET

Plastic	0.250"	0.375"	0.500"	0.625"	0.750"	0.875"
Acrylic	Pen. Sh.	Pen. Sh.	Pen. Sh.	Stopped Sh.	Stopped one crack	Stopped No crack
Polycarbonate	Pen.	Stopped Imbedded	Stopped Imbedded			

Pen. - penetrated, Sh. - shattered.

A 0.875" (or 7/8") acrylic plate stopped the bullet and registered no break, whereas only a 0.375" (or 3/8") polycarbonate plate was required to stop a 22 short without penetration. This demonstrates that for a given level of protection less weight of polycarbonate is required. This suggests that in terms of protection the cost may prove to be about equal.

 NOTE: Our studies with 1/8" and 1/4" plates of coors porcelain indicated this was very effective for defeating the bullets but was only a one-shot protection. The plates were so fractured that it was of doubtful effectiveness for a second impact. We abandoned this type of ceramic for laboratory safety shields.

C. IMPACT RESISTANCE OF SINGLE AND MULTIPLE TARGETS OF POLYCARBONATE

In earlier investigations we had become aware of higher impact resistance of loosely laminated glass or plastic sheets compared to a single sheet of the same total thickness. In the study reported here single and multiple polycarbonate target plates were placed in the first space, or spaces, of the target-holder, Figure 8.

TABLE III

EVALUATION OF SINGLE AND MULTIPLE
POLYCARBONATE TARGETS.
22 CAL. SHORT - 10 FT. RANGE

Thickness of P. C. Targets		0.062" test plates penetrated	22 shorts	
Single	Multiple		defeated by	dented
0.040"	-	4	5th	3/32"
-	2 x 0.020"	4	5th	3/32"
0.062"	-	3	4th	5/32"
-	2 x 0.030"	3	4th	5/32"
0.093"	-	3	4th	4/32"
-	0.030" + 0.062"	3	4th	2/32"
0.125"	-	2	3rd	4/32"
-	2 x 0.062"	2	3rd	3/32"
-	0.030" + 0.093"	1	2nd	3/32"
0.187"	-	1	2nd	2/32"
-	2 x 0.093"	1	2nd	2/32"
-	0.062" + 0.125"	1	2nd	2/32"
0.250"	-	0	1st	4/32"
-	2 x 0.125"	0	0	second 0.125" dented 3/32"

*PC - polycarbonate (Lexan or Merlon)

This was followed by six 0.062" polycarbonate test plates designed to register the energy remaining in the 22 short bullet after penetrating the target plate or plates. Table III shows the results for total thicknesses 0.040" to 0.250" (3). The third column shows the number of 0.062" test plates penetrated after the bullet passed through the target plate or plates. The last entry show that the second target plate (0.125") stopped the bullet. The plate which defeated the bullet is listed in the fourth column and the depth of dent is recorded in the fifth or last column. In the Table 0.093" and 0.030" + 0.062" were the first targets to show measurable differences. The differences in impact resistance as the thicknesses increase become quite dramatic.

D. TESTING OF CONTEMPORARY PROTECTIVE DEVICES (4).

The person, or persons, delegated to purchase safety glasses, goggles, and face shields for laboratory workers should know what specifications are important and what may be critical. Suppliers use such expressions as "shatter-proof glass," "plastic," "light weight," and "style." The consumer selects his shields for eyes and face for protection against missiles and sprays. Face shields should provide suitable coverage also.

Table I demonstrated clearly that transparent plastics vary widely in impact resistance. The supplier should state in sales literature complete specifications - especially the kind of material used for lenses and windows, and also thicknesses.

In the evaluations that follow in Tables IV, V and VI we have made standard the impacts of 7.5 and 10 ft./lb. (3). We also observed the protection against spray by goggles and roughening of face shields by glass missiles. We have deliberately omitted the manufacturer's name in each case.

TABLE IV

COMMERCIAL SAFETY GLASSES

Lens Material and Thickness	Impact at 10 ft	
	7.5 ft./lb.	10 ft./lb.
1. Acrylic "Clip-on" 0.070"	Lens cracked and broke loose	
2. Acrylic "Visitors" 0.100"	Lens shatter Part broke loose	
3. Glasses 0.140"	Lens shattered and broke loose	
4. Glasses 0.145"	Pellet flattened No cracks	No cracks (12.4 ft./lb. shattered)
5. Glasses 0.155"	Pellet flattened No cracks	Lens shattered did not break loose
6. Polycarbonate 0.130" mar resistant	Pellet flattened No cracks	Pellet flattened No cracks (12.4 ft./lb. - slight dent No cracks)

Number 4 (tempered glass) withstood both 7.5 and 10 ft./lb. impacts but not 12.4 ft./lb. Number 6 showed a slight dent from a 12.4 ft./lb. impact. Number 4 was completely pulverized by a 22 mimicap (35 ft./lb) while Number 6 was cracked into only three large pieces.

The effects of 7.5 and 10 ft./lb. pellet impacts on commercial goggles in Table V are self-explanatory. All but Number 6 provided some kind of ventilation. Numbers 9 and 10 had molded vents open to the back only thus preventing entry of spray from the front. The highest impact resistance lenses were Numbers 8, 9, and 10 - all were polycarbonate.

TABLE V

COMMERCIAL GOGGLES

Materials and Thickness	Impact at 10 ft.		Protection against spray
	7.5 ft./lb.	10 ft./lb.	
1. Glass lens 0.120"	Pellet flattened	Lens shattered but held by frame	vents open to all sides
2. "Multiply" lens 0.052"	Dented	Dented and three cracks	vents open to all sides
3. Vinyl 0.052"	Penetrated. Rapid cracks.	Penetrated. Larger hole and cracks.	Vents open to all sides.
4. Acrylic 0.085"	Penetrated. Cracked edge to edge.	-	Vents open to all sides.
5. Acetate 0.060"	Deep dent	Penetrated Radial cracks	Vents open to all sides.
6. Acetate double 0.030" and 0.060"	Both were penetrated. Radial cracks.	Larger holes. Cracked.	No ventilation provided.
7. Acetate 0.040"	Penetrated. Cracked.	-	Vents open to all sides.
8. Polycarbonate 0.060"	Sl. dent No cracks	Deeper dent	Perforations of top and sides
9. Polycarbonate double 0.040"	Dent in first and slight bulge in second.	Deeper dent	Vents open to back only.
10. Polycarbonate 0.062"	Slight dent	Deeper dent	Vents open to back only - top and sides.

Face shields tests, Table VI, recommended polycarbonate, acetate of at least 0.060" thickness, and "multiply".

TABLE VI

COMMERCIAL FACE SHIELDS

Material and Thickness	Impact at 10 ft.		Effect of Glass Missiles
	7.5 ft. lb.	10 ft. lb.	
1. Acetate 0.020"	Penetrated Many cracked	-	Badly shattered
2. Acetate 0.040"	Penetrated and cracked	-	Torn long cracks
3. Acetate 0.060"	Deep dent	Penetrated and cracked	Roughened
4. Acrylic 0.100"	Penetrated and split edge to edge	-	Cracked and roughened
5. "Multiply" 0.045"	Dented and cracked very slightly	-	Roughened. One slight circular crack.
6. Vinylite 0.045"	Penetrated. Radial cracks.	-	Cracked and roughened.
7. Polycarbonate 0.062"	Slight dent.	Deeper dent	Roughened only.

In addition to the high impact resistance of Numbers 3 and 7 the buyer should insist on windows wide enough to protect the ears from side attack and long enough to protect the neck - as demonstrated in our sound-color movie (1).

Conventional body shields (or bench shields) (5) are available with approximately 14" x 30" windows of 1/4" laminated glass, acrylic, or polycarbonate. Stability was measured for the sound-color movie (1). Portable shields supported on the work space are looked upon as sturdy barricades for a given laboratory set-up. We expect its impact resistance and stability to afford high degree of protection. Stability of some shields have been greatly improved by increasing the weight of the base at the heels (Figure 5 C). For the windows laminated glass and acrylic have been much favored in the past. Both types used in our tests have been reinforced with a 1/8" secondary polycarbonate window on the apparatus side as illustrated in the sound-color movie (1). The tests recorded in Table VII were made to determine the relative effectiveness of laminated glass and plastics. We subjected the conventional body shields to the 35 ft. lb. impact (22 caliber minicap) and 80 ft. lb. impact (22 caliber hi-speed short) on a 10 ft. range from the apparatus side.

TABLE VII

COMMERCIAL BODY SHIELDS

Window Material and Thickness	Impact at 10 ft.	
	35 ft. lb.	80 ft. lb.
1. Laminated glass - 1/4"	Penetrated. Radial and concentric cracks.	Penetrated. Radial and concentric cracks.
2.* 1/4" laminated glass and 1/8" polycarbonate	Polycarbonate Dented and laminated glass cracked.	Penetrated both. Laminated glass cracked - radial and concentric.
3.* 1/4" acrylic and 1/8" polycarbonate	Polycarbonate Dented	Penetrated both. Acrylic - several long radial cracks.
4. Polycarbonate double - 3/16" each	Dented first sheet	Penetrated first layer and dented the second.
5.** Polycarbonate double 1/4" and 1/8" on apparatus side	Dented first Dented first	Penetrated 1/8" and Penetrated 1/8" and slightly dented the 1/4" layer

*Polycarbonate on apparatus side.

**Custom built-based on suspended shield (6).

The laminated glass, Number 1, performed very badly for both 35 ft./lb. and 80 ft./lb. impacts. When reinforced with a 1/8" polycarbonate, Number 2, it remained intact for the 35 ft./lb. impact but for the 80 ft./lb. the shield failed. The shield with the basic acrylic window, Number 3, also performed badly. The two double polycarbonate windows, Numbers 4 and 5, performed well in both tests. For milder laboratory impacts, Numbers 2 and 3 have served well. Later in this report we will describe our body shield to be worn.

The wide variation of impact resistance among commercial safety glasses, goggles and bench shields forces us into a strange conclusion. Since all met ANSI Z87.1-1968 requirements obviously the weakest shielding devices have the minimum requirements with little or no margin. Our tests show that many manufacturers have forged ahead to produce shields that far exceed current standards. For example: Table IV showed that Numbers 1, 2, and 3 failed our 7.5 ft./lb. test while 4, 5, and 6 passed it. The tempered glass lens #4 also withstood the 10 ft./lb. impact. The polycarbonate lens, #6, withstood impact of 7.5, 10, and 12.4 ft./lb. Tables V and VI show similar results.

EVIDENCE FOR NEEDED STRENGTHENING OF OUR STANDARD FOR EYES AND FACE

We have observed that several safety glasses and goggles recovered from accidental laboratory explosions did protect the eyes of the victim even though the safety glasses shattered but did not fall out of the frame toward the eyes. We must add, however,

that we have recovered some "protective devices" which utterly failed to protect the eyes. Figure 9 shows two "safety glasses" that met the minimum American Standards requirements at the time of each accident. The one on the left was worn by a graduate organic student 1940. His left eye was so damaged by the explosion that it had to be removed and the right eye was under close observation for about two years. The safety glasses on the right manikin head was recovered from a 1964 accident. The erratic nature of the missile pattern resulted in a hit on the left lens but not on the right. In this case the left lens was shattered but was held by the frame. Quite obviously the margin of safety was very limited indeed.

We attempted to determine the actual impact withstood by the 1964 tempered glass lens. A similar tempered glass lens of the same catalog number was subjected to a series of impacts of pellets from a Sheridan air-gun. The 7.5 ft./lb. impact produced practically identical results - but a 10 ft./lb. impact shattered and knocked out the other lens. This demonstration indicates qualitatively that a safety lens for a chemist should withstand at least a 7.5 ft./lb. impact.

A similar test with the 1940 type "safety glasses" resulted in complete shattering and demonstrated that it was far short of withstanding the impact registered by the 1964 safety glasses and should not be classed as a safety device for the chemist. We are forced to conclude that the minimum standard requirement of 0.6133 ft./lb. should be raised to at least ten times its present value.

Figure 10 shows a 0.040" acetate window that failed badly for a first year graduate student of 1964. This met the standard minimum requirement by being 0.040" "plastic." A Number 3 charge in our "glass missile cannon" damaged a 0.040" acetate window in a quite similar manner - but a polycarbonate window under the same impact was merely roughened. We can standardize the charge but we have not learned to measure the overall impact. To specify 0.040" plastic ANSI Z87.1-1968, top p.12, #5.2.6.1 is not specific enough as clearly demonstrated by evaluation of plastics in Table I. We must recommend and name the highest impact resistant plastic. To date that plastic is polycarbonate.

COMPARISON OF TEMPERED GLASS AND HARD-SURFACE POLYCARBONATE LENSES

A TEMPERED GLASS - 0.146" THICK

(1) Steel ball dropped 50 inches

Diameter of ball	Energy ft./lb.	Results
1"	0.6133	No break
1 1/4"	1.205	Shattered (two tests)

(2) Sheridan Air-gun

Stroke of piston	Energy ft./lb.	Results
2	3.6	shattered (two tests)

MAR-RESISTANT POLYCARBONATE LENS - 0.130" THICK

(1) Steel Ball

Diameter of ball	Drop	Energy ft./lb.	Results
1"	50"	0.6133	No break
2 1/8"	50"	5.83	No break
2"	6'	6.99	No break
2 1/8"	6'	8.4	Sl. crack evidence strain
2 1/8"	7'	9.74	Sl. crack evidence strain

(2) Sheridan Air-gun

Stroke of piston	Energy ft./lb.	Results
4	7.5	No break
6	10.0	No break
8	12.4	No break

(3) 22 Caliber Minicap

	Energy ft./lb.	Results
	35 ft./lb.	Cracked into three pieces

NOTE: We wish we could fill in between 12.4 and 35 ft./lb. impacts.

The mar-resistant polycarbonate proved to be of greater impact resistance than the superior tempered glass. By the drop-ball method polycarbonate withstood about ten times the maximum impact for tempered glass. For the air gun the polycarbonate is vastly superior.

From the standpoint of safety we strongly advocate 0.130" mar-resistant polycarbonate lenses for laboratory or shop safety glasses.

GOGGLES

Table V showed a variety of goggles with respect to lens impact resistance and ventilation. Number 10, with a polycarbonate lens, resisted impacts up to 7.5 and 10 foot pounds. The ventilation vents opened only to the back thereby preventing spray from entering directly.

Number 10 was modified to afford still greater protection by replacing the 0.060" lens with a 0.093". In front of this lens was added a reinforcing 0.187" polycarbonate lens of slightly oversize. A small brass bolt above the nose held it in place, Figure 11, and two plastic blocks were cemented above each eye to keep the outer lens from turning to either side. The two 2" x 5" plates of 0.093" and 0.187" thicknesses were used for ballistic tests. Two 22 short bullets penetrated the 0.187" plate and slightly dented the 0.093" plate. The purpose of this reinforcement was to produce a lens combination equal to the reinforced face shield window discussed below.

FACE SHIELDS

Table VII showed data for seven typical face shields. Number 7 withstood the 7.5 and 10 foot pounds impacts and was only roughened, but not cracked, by the glass missile cannon blast. Polycarbonate face shield windows of thicknesses 0.060" and above require thermal shaping for suitable fit and without strain. A Mandrel, Figure 12, was required for uniform results. The shape of the templets was controlled by the curvature of the crown attachment edge. Sheet aluminum was fastened to the templets and then covered with a layer of flannel, to prevent the adherence of warm plastic to warm aluminum. After the hot soft polycarbonate was quickly pressed onto the pre-heated mandrel a second layer of flannel was placed on it before adding the final weighted aluminum cover. The whole assembly was returned to the oven for final complete shaping. Before the shaping procedure, polycarbonate must be dried at 125°C - the time of heating depends on thickness. When dry the temperature is raised to the shaping temperature - about 163°C. When the shaped window is cool holes are drilled for attachment to the crown band. For normal laboratory protection a single 0.062", or a 0.093", window is considered quite satisfactory. For possible high impacts a reinforced window is recommended.

To make a reinforced window (e. g. 0.187") several layers of flannel are placed on the mandrel under the window blank in order to increase the curvature. This window is fastened to the basic window with two brass bolts on each side with an extra nut as a separator thus allowing about 1/8" separation space, Figure 13. You will note

that the outer reinforcing window extends upward about 2 1/2" to reinforce the crown. The basic window is 20" wide and 10" long. The outer reinforcing window may be removed when not needed - thereby making the shield lighter to wear for routine laboratory work.

BODY SHIELDS

Bench Shields. Table VII gave data on four commercial and one modified custom built shields. The superior performance of a double polycarbonate window, 0.250" and 0.125", caused us to urge replacement of laminated glass and acrylic with a sheet of 0.250" polycarbonate. The rectangular 14" x 30" window of Number 2 made this test very simple - in line with our previous double polycarbonate suspended shield (6). The modified shield, Figure 14, allowed a 22 caliber short bullet to penetrate the 0.125" window and dent the 0.250" window. Recently Number 4 has come onto the market with the possibility of a single or double polycarbonate window of 0.1875" thickness. The second window may be removed by unbolting much like the reinforced face shield described above.

Suspended Shield. Our double sheet glass suspended shield was custom built and successfully used as early as 1952. The double polycarbonate windows, 0.250" and 0.125", was reported 1965 (6) and in the color sound movie (1). Figure 15 shows a 20" x 30" shield suspended from rods attached to the edge of the work space. Suspension also may be made from a track on the ceiling as shown in color-sound film (1). Such a shield may be stored near the ceiling by tying-in. If the apparatus side of a suspended shield is damaged that window may be removed and replaced by a new one. The suspended shields swing out at the bottom rather than tipping toward the face - as is true of the bench type.

BODY SHIELDS TO BE WORN (7)

For the person delegated to remove and destroy a sensitive explosive chemical or for the person who has chosen to do research with a very active chemical (e.g. azo compounds, peracids, azides or peroxides) body shielding should be furnished to wear in order to free both hands. The usual body, or bench, shield is too clumsy to handle and requires the use of at least one hand. Our chemical literature cites several fatalities that could have been avoided by a body shield firmly attached to the body.

FACE PROTECTION

Face protection may be provided by a reinforced double window and crown as described above, Figure 13. The 10" x 20" windows of 0.093" and 0.187" polycarbonate offer good protection. Reinforced goggles, Figure 11, should be a part of the complete face protection.

HANDS

Hands may be protected by pliable but heavy work gauntlets.

ARMS AND LEGS

Arms and legs may be protected by leather sleeves and chaps available in almost any safety equipment company. For further impact resistance each may be lined with ballistic nylon.

THE CHEST OR "RIB CAGE"

The chest or "rib cage," requires a high impact resistant sturdy shield. To make a shield to be worn over the chest area and held by hooks over the shoulders requires thermal shaping of the polycarbonate blank on a Mandrel, Figure 16. The shape of the Mandrel was arrived at by making a "hardware cloth" pattern on a sturdy volunteer. This required much cutting, fitting and soldering. This pattern determined the shape of the templets. The sheet aluminum was fitted and fastened as was done in making the simple face shield Mandrel, Figure 12.

The outer aluminum cover was weighted and additional pressure for final shaping was accomplished with fiber straps and springs. Each Polycarbonate blank was dried and heated to shaping temperature. After the two 3/16" blanks were shaped eight layers of ballistic nylon were cut to the same pattern. The eight layers were held together with rows of button stitches and finally the edges flamed to prevent unravelling. The shield was assembled on the Mandrel by placing first a shaped 3/16" polycarbonate sheet, then the eight layers of ballistic nylon, and finally a second 3/16" polycarbonate on top. When this was covered and fastened down the whole assembly was placed in the oven for final heating, shaping and annealing. When cool the assembly was carefully removed and fastened with brass bolts at the lower corners, at the sides and at the ends of the hooks. The shield was then ready to wear as shown in Figure 17. This chest shield is held firmly by suspender straps and a belt secured with velcro fasteners.

THE GROIN SHIELD

The groin shield consisted of twelve layers of ballistic nylon held by rows of button stitches. The edges were fused by a torch. The groin shield was held in place by an adjustable neck strap.

Adjustments were made to allow overlap of face shield, chest shield, and groin shield. The choice of composition of each element was based on a series of ballistic tests of 5" x 5" targets with 22 caliber shorts. Each target was firmly held in a target holder, Figure 19, made to hold a single package. Figure 21 shows a typical series of targets.

EXPLOSION BLANKET

If a bottle contains a deteriorated chemical which may explode when disturbed (e.g. an ether peroxide) it should be covered with an "explosion blanket" as a first step in picking it up and transporting it. Our blanket was made of ten 3' x 3' layers of ballistic nylon. Two one foot square 0.125" sheets of polycarbonate were placed in the exact center - one between the 2nd and 3rd and one between the 3rd and 4th layers of ballistic nylon. The

plates were held firmly centered by two rivets through four sheets of ballistic nylon at each side of the plates. The assembly of ten layers of ballistic nylon are held together by rows of button stitches. All edges are flamed to avoid unravelling. Two 9 ft. nylon straps are riveted along each side of the plates. These assist in safely handling the blanket and may also be used to make secure.

This blanket may be used as a protective cover over a potential explosive or over the explosion cask while it is being transported.

EXPLOSION CASK

Explosion casks for high explosion requiring detonation have been made (8). In this laboratory we proceeded to make a small reinforced cask based on the targets used to determine the composition of the chest shield (7). A five gallon benzene can (13 1/2" high and 11" diameter) was used for the outside support. The cover already equipped with a handle was cut along the edge. Two handles were riveted to the opposite sides for ease in carrying. The composition chosen for the top and bottom circular impact resistant package read from the inside were layers: one 0.250" polycarbonate, two ballistic nylon, one 0.125" polycarbonate, eight ballistic nylon, one 0.500" energy absorption sheet, ten ballistic nylon, and one 0.500" energy absorption sheet. The diameter was the diameter of the can - 11" for the bottom and 10.75" for the top after cutting to fit loosely. The top was fixed with four bolts.

The wall was of the same composition thus leaving inner space of 7.5" diameter and 9.5" high for a container of explosive or explosive suspect. The inner 0.250" polycarbonate was shaped on a cylindrical mandrel and riveted. Each ballistic nylon segment was left in a continuous piece thus helping to hold the assembly firm until it was inserted down to the top of the bottom layer and far enough down to allow the cover to seat.

The ballistic test was made in a fume hood with our #4 charge in a 1 lb. wide mouth supply bottle wrapped in towels inside a plastic carrying case. Before igniting the charge the explosion blanket was draped over the top. The #4 charge consisted of 0.04 mole KClO_3 and 0.12 mole granular magnesium. We can assume from our preparation of the sound-color film (1) and literature reports that the #4 charge simulated quite well the most forceful laboratory explosion. The Parr ignition wire was imbedded in the charge. The 8 mm camera was started just before activating the igniter. The explosion lifted the cover and blanket. Glass fragments recovered in the cask weighed 163 grams and 60 grams were recovered on the hood floor near the cask. The blanket prevented the 60 grams of glass fragments from scattering. The liner of the cask withstood two explosions very effectively as shown in Figure 19.

From our preliminary experiences we recommend a larger cask for general practice - perhaps a 10 gallon can as the outside support.

ADDENDUM

EXTENSION TO POLICE PROTECTION

Our unique complete safety gear to be worn by the chemist suggested further development of chest and groin shields that would effectively meet the requirements of police. A standard bullet proof vest, of greater weight, shows questionable coverage, Figure 20. The fiber shoulder straps allow sagging thus exposing much of the body between top of chest and lower edge of a rather weak helmet visor. The Villanova chest protector holds its high position by virtue of the plastic shoulder hooks which are a continuous part of the chest protector. The reason for the fabrication - "polycarbonate sheet - ballistic nylon multiple pad - polycarbonate sheet" was to distort the missile (bullet in this case) by the first layer of hard tough polycarbonate, then slow it down to a stop by the many layers of ballistic nylon and finally distribute the impact force over the entire chest area by the second inner polycarbonate sheet. This composition was designed to avoid a concentrated hit on a very limited area which could result in a severe bruise or fracture of a rib or the sternum. This effect has been surmised in the body armor reported in Industrial Research, June 1944 and was reported June 10, 1974 as a real experience of a California State Traffic Officer. The latter was wearing a bullet-proof vest but required hospital treatment for a localized chest bruise from a bullet fired at him by a motorist. We believe our composition can be made to head-off localized damage to the chest area by standard lead bullet weapons.

To determine the suitable composition of the visor, groin, and chest shields 5" x 5" targets were prepared, Figure 21. The elements of Figure 21 were selected from preliminary ballistic targets developed for Philadelphia Police Pistol Range, June 1, 1973, Pennsylvania State Police (Harrisburg), September 4, 1973 and Willistown Township Police (Pa.), September 27, 1973.

The weight of a chest shield of the composition of Figure 21 would be about 13 pounds.

The 22 caliber long rifle tests were made on the Villanova University Campus but police officers supplied the tests with 38 special, 357 magnum and 9 mm Luger. Figure 21 shows that the composition for the chest shield allowed the 22 long rifle bullet to penetrate the first 3/8" polycarbonate and was stopped by the first layer of ballistic nylon; the 38 special only dented the first polycarbonate sheet; the 357 magnum lead bullet was stopped by the eighth layer of ballistic nylon; and the 9 mm Luger "metal case" bullet was stopped by the twelfth layer of ballistic nylon. This composition was obviously far more protective than the California Traffic Officer's bullet proof vest.

This preliminary exploration has created much interest among police and encouraged continuation of this study beyond NIOSH OH 00300. In this preliminary effort to develop more sturdy and greater coverage body shields to meet the police requirements we have been encouraged by the following police representatives who have assisted us in ballistic tests:

Inspector Robert Martin - Armor Unit, Philadelphia Police Department.

Lieutenant James Sagans - Ballistic Section - Crime Laboratory
and Sargent Deffley Pa. State Police, Harrisburg, Pa.

Major Sidney Deyo - Director, Bureau of Research and Development
Pa. State Police, Harrisburg, Pa.

Chief William Tarr - Willistown Township Police Department
Chester County, Pa.

Figure 18 was the target holder used to hold single package targets of which Figure 21 was typical.

The following summary of targets for ballistic tests are polycarbonate combinations (PC), ballistic nylon layers (BN) and the combinations of PC and BN. The police of Philadelphia (P), Harrisburg State Police (H) and Willistown Township (W) made ballistic tests with the four types of ammunition in the order indicated in Figure 21. The following targets are listed in the order of increasing impact resistance. The police organization is indicated by letter.

PC PLATES ONLY

1/8" + 1/8" + 2/8" (W)	3/8" + 3/8" + 2/8" (H)
2/8" + 2/8" (P)	3/8" + 3/8" + 3/8" (P)
2/8" + 2/8" + 1/8" (W)	4/8" + 2/8" + 2/8" (H)
3/8" + 2/8" + 1/8" (P)	4/8" + 3/8" (W)
3/8" + 3/8" + 3/16" (P)	4/8" + 3/8" + 3/8" (H & W)

BN LAYERS ONLY

12 (H), 16 (W), 20 (H), 24 (P), 28 (H), 32 (P)

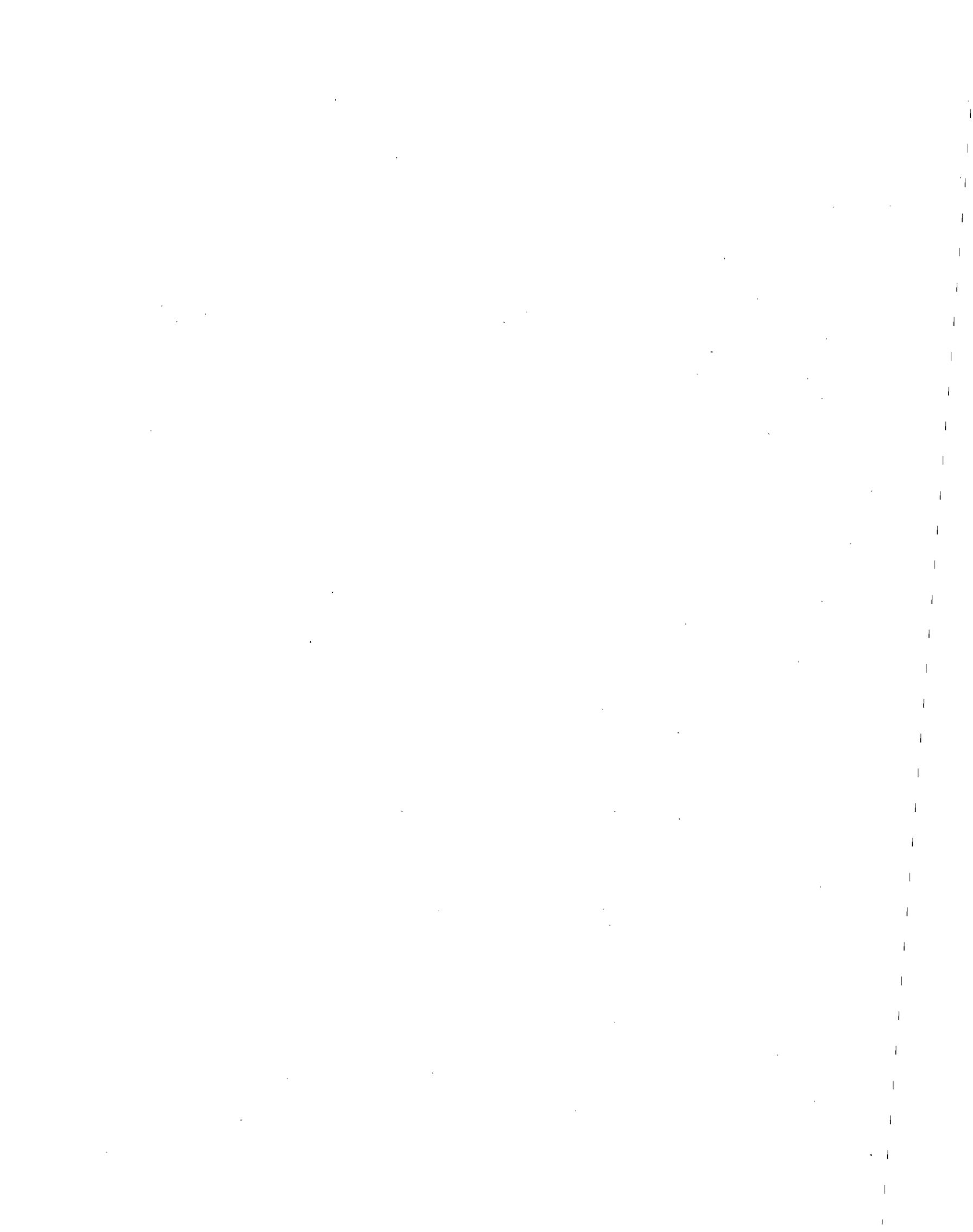
PC + BN + PC LAYERS

3/8" + 10 + 3/16" (P)	3/8" + 20 + 3/8" (W)
3/8" + 10 + 3/8" (P)	3/8" + 24 + 3/8" (P)
3/8" + 14 + 2/8" (P)	3/8" + 28 + 3/8" (H)
3/8" + 20 + 2/8" (P)	4/8" + 24 + 3/8" (H & W)

ACRYLIC ONLY

(All targets were shattered by 357 magnum)

2/8" + 2/8" + 2/8" (H)	4/8" + 4/8" (W & H)
3/8" + 3/8" + 3/8" (W & H)	5/8" + 5/8" (W & H)

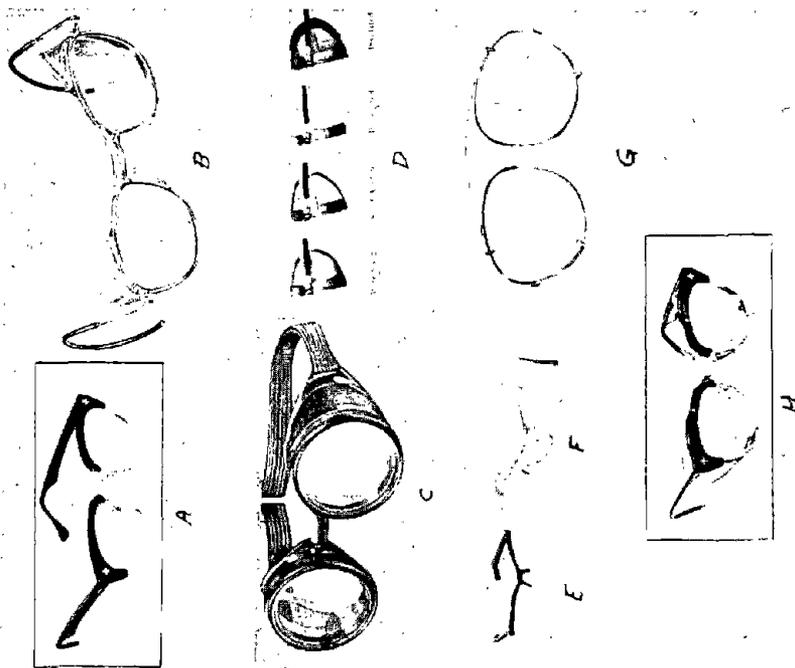


APPENDIX I

Figures 1 and 2



Figure 1.



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Figure 2.

Figures 3 and 4

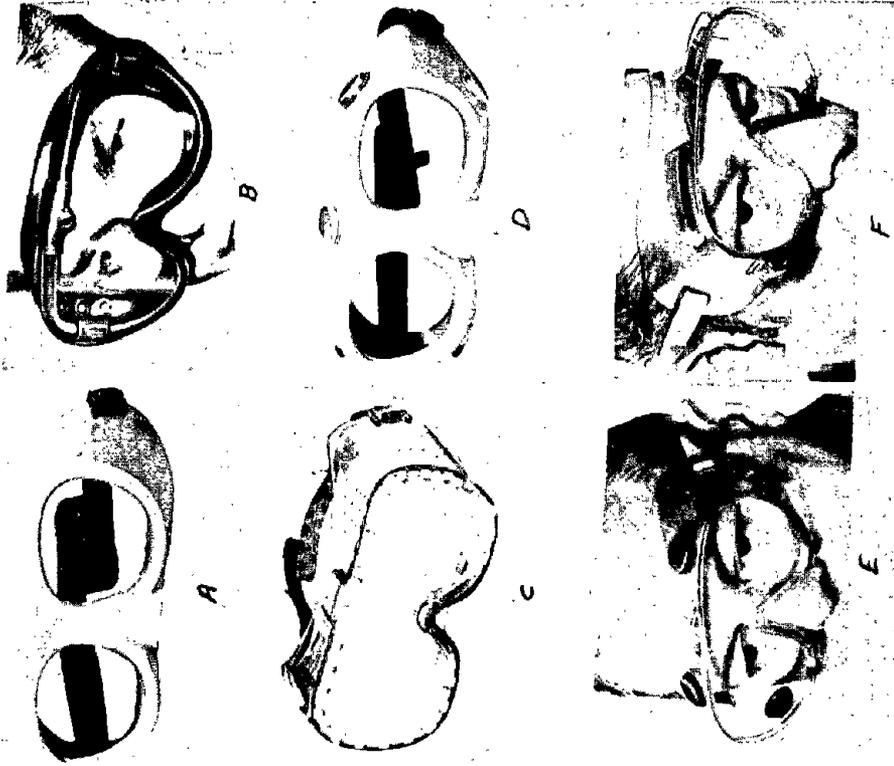


Figure 3.

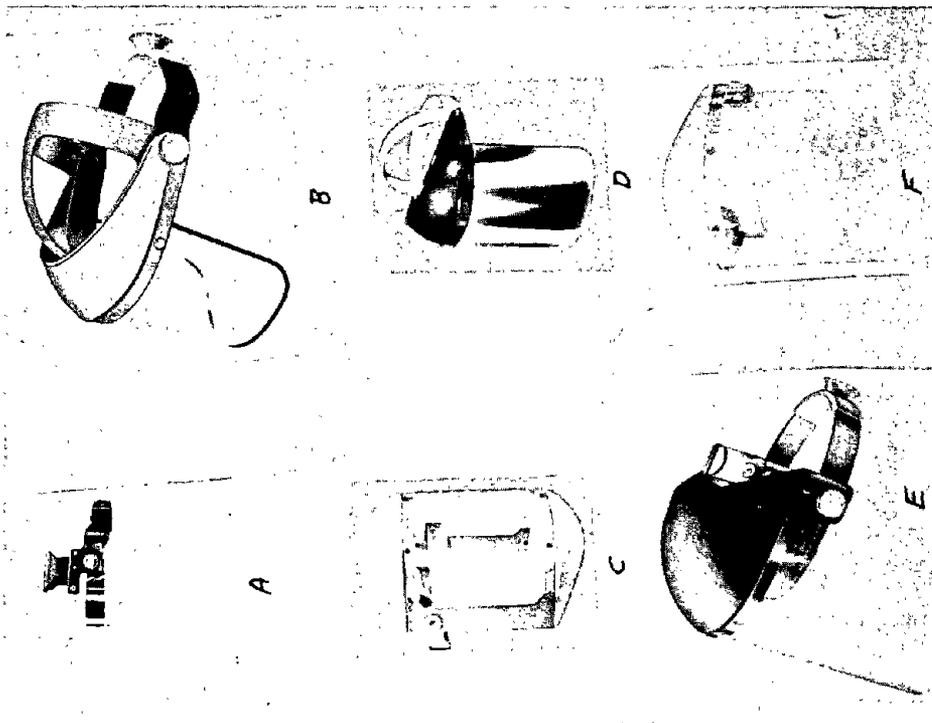


Figure 4.

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Figures 5A, B, C

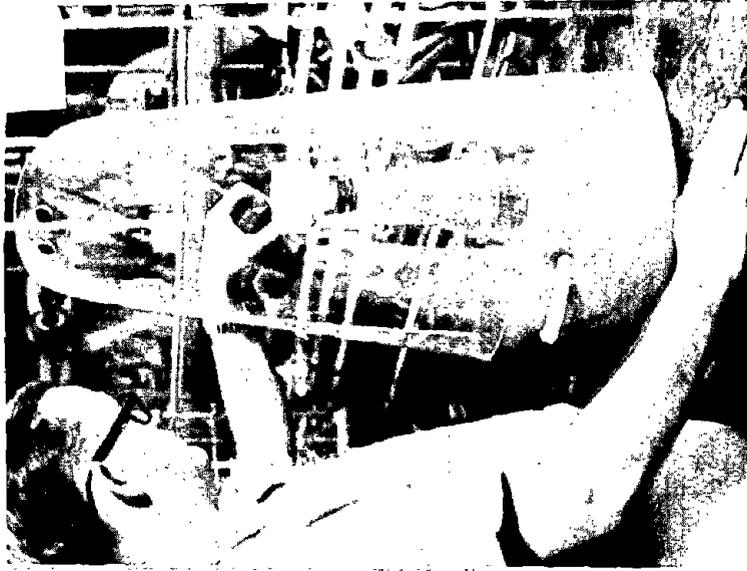


Figure 5A.

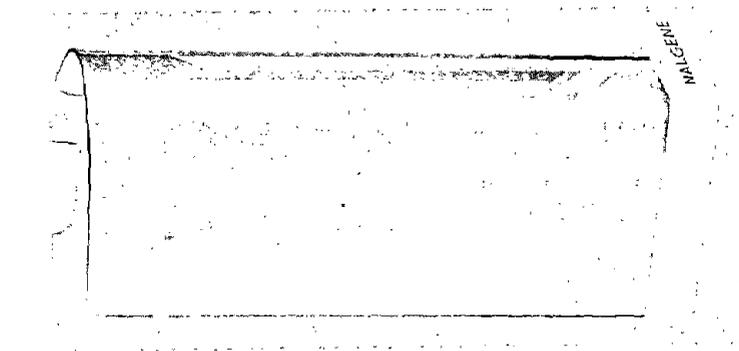


Figure 5B.

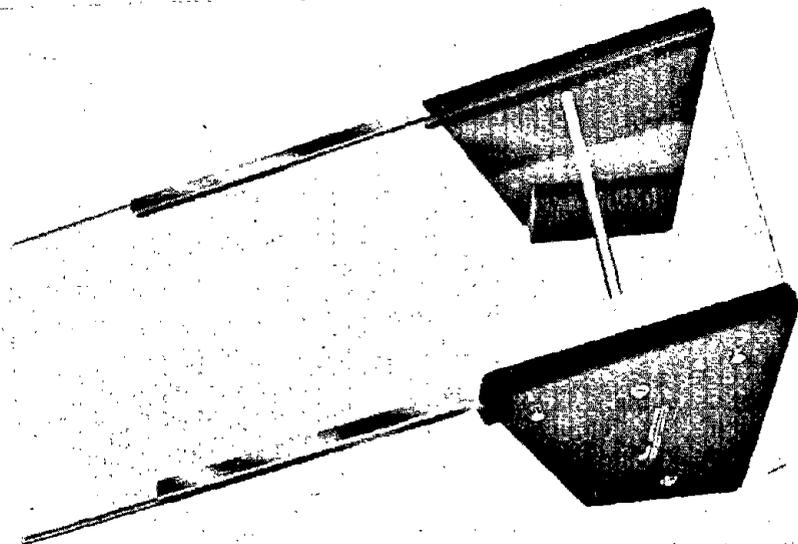


Figure 5C.

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Figures 6 and 7

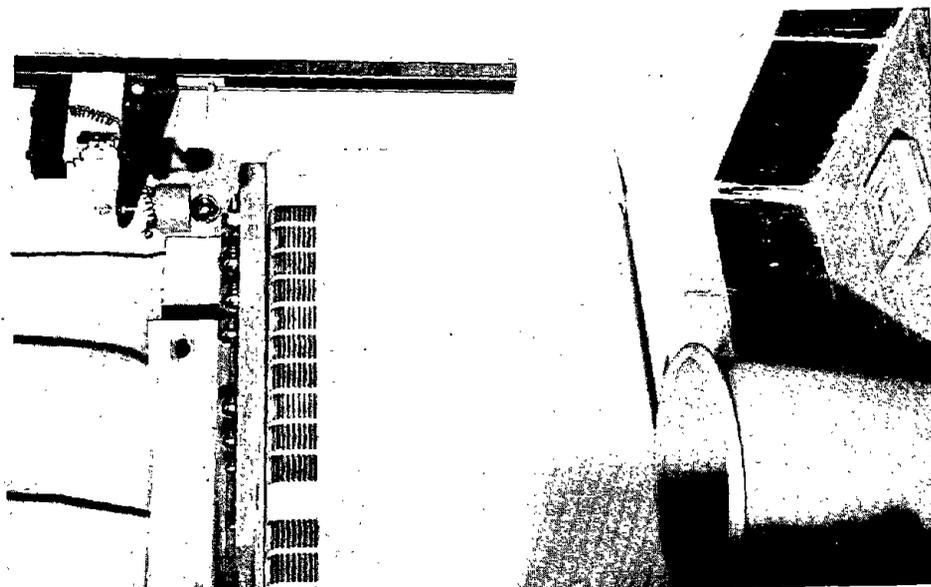


Figure 6.

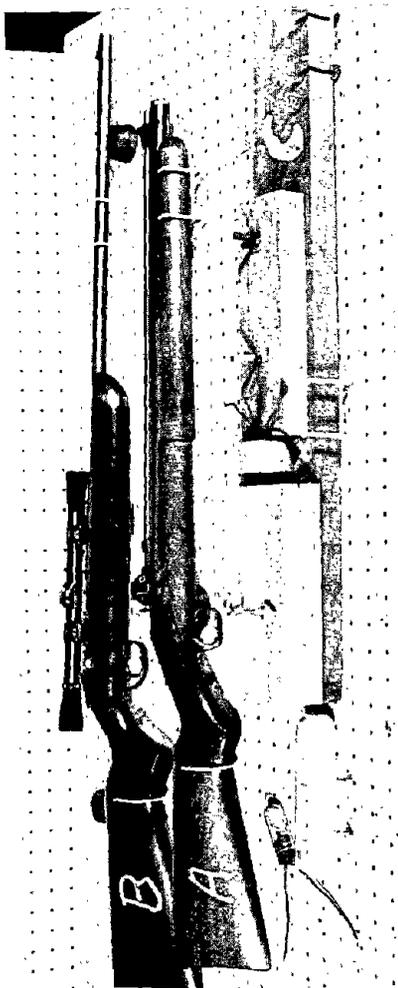


Figure 7.

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Figures 8 and 9

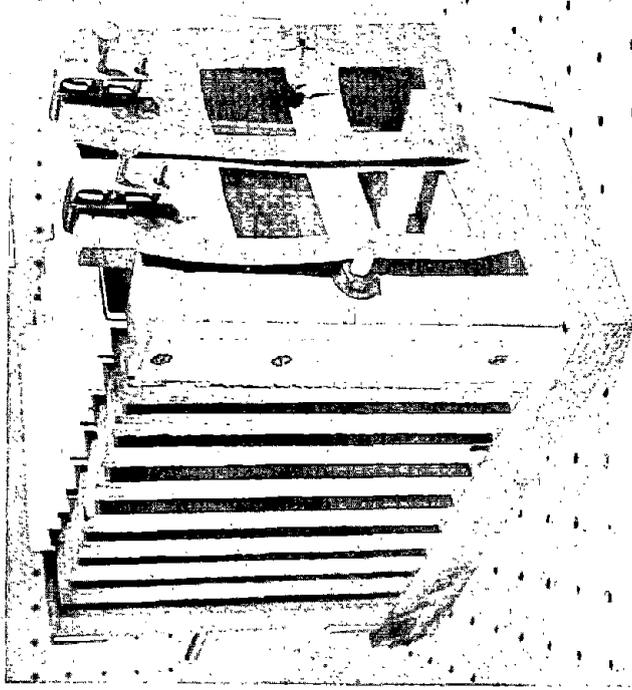


Figure 8.

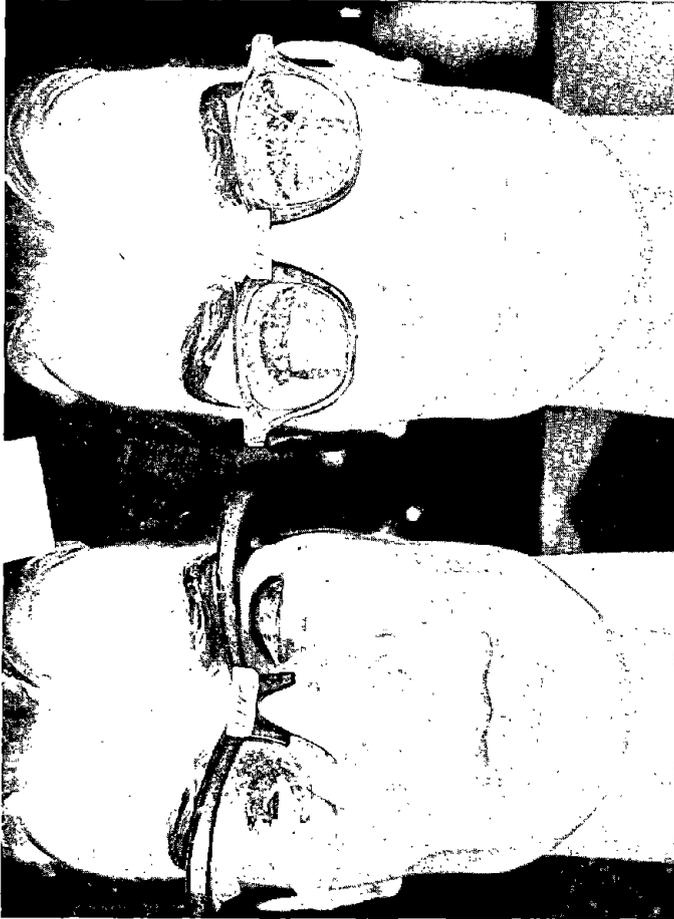


Figure 9.

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Figures 10 and 11

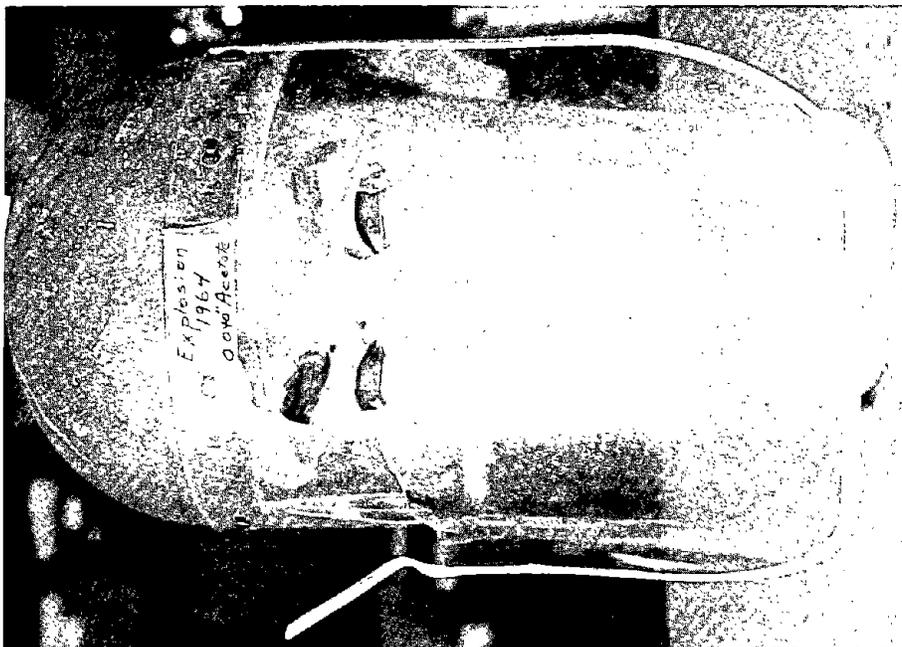


Figure 10.



Figure 11.

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Figures 12 and 13

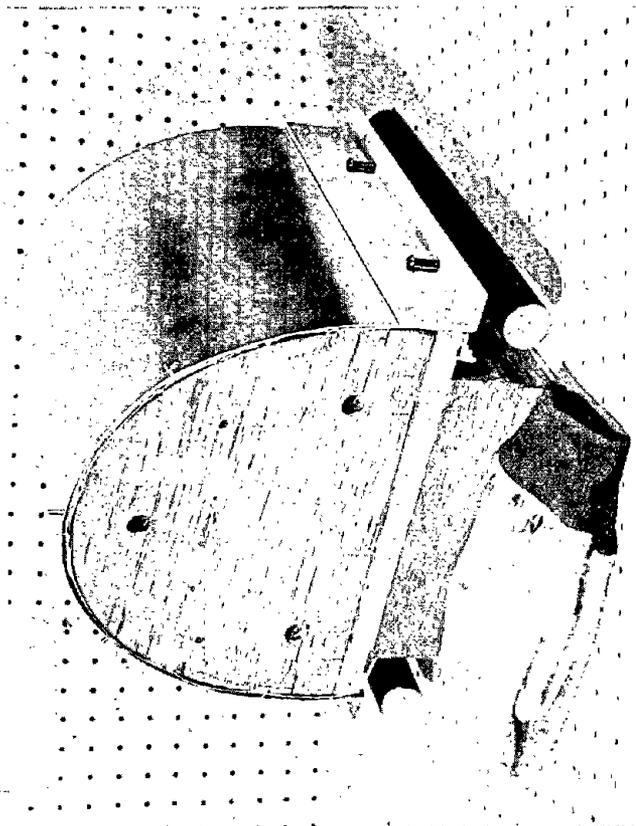


Figure 12.

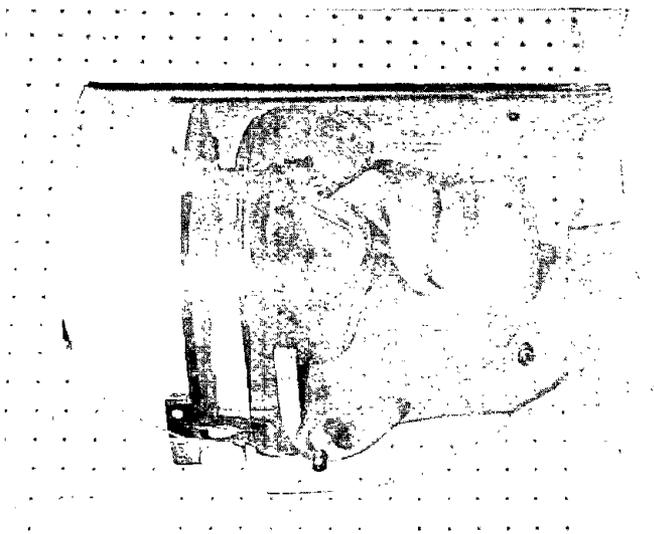


Figure 13.

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Figures 14 and 15.

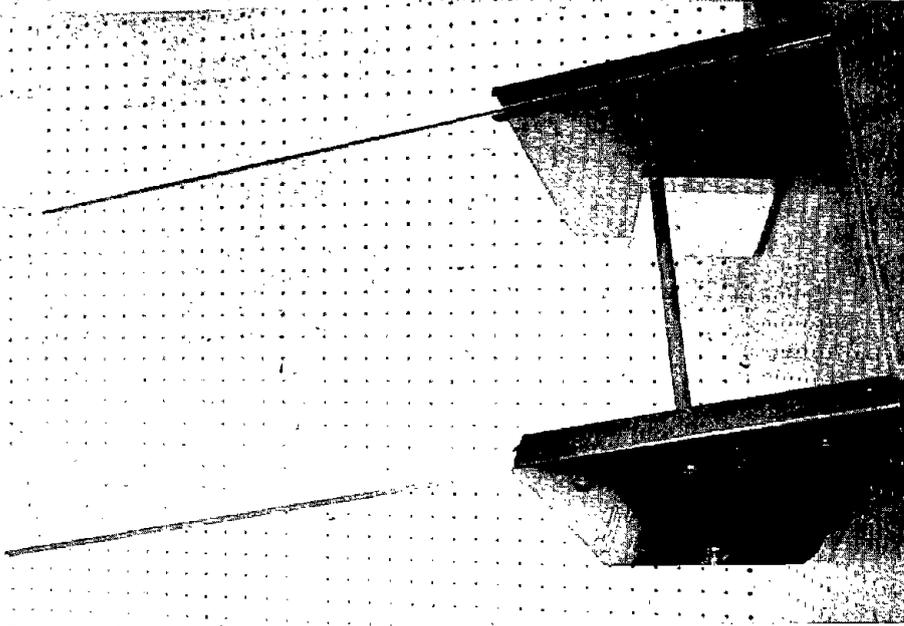


Figure 14.

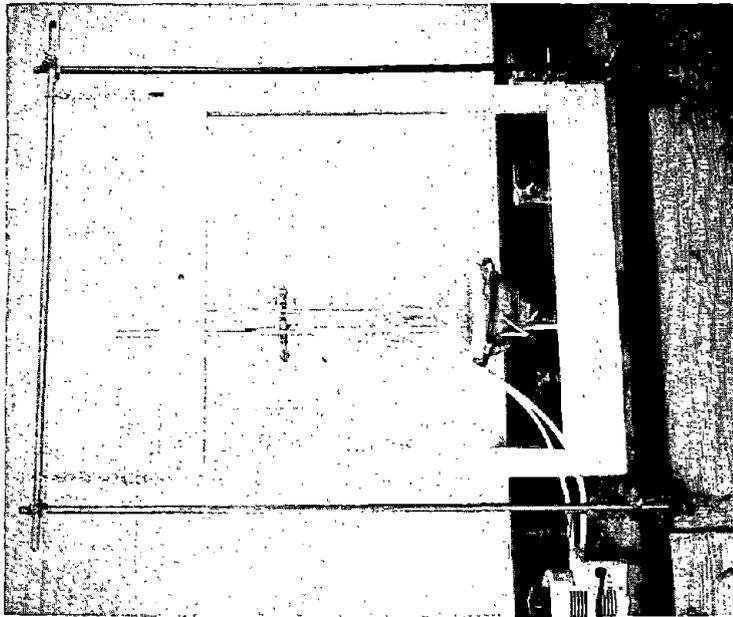
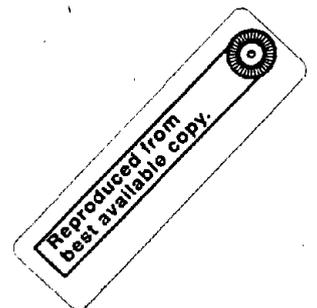


Figure 15.



Figures 16 and 17

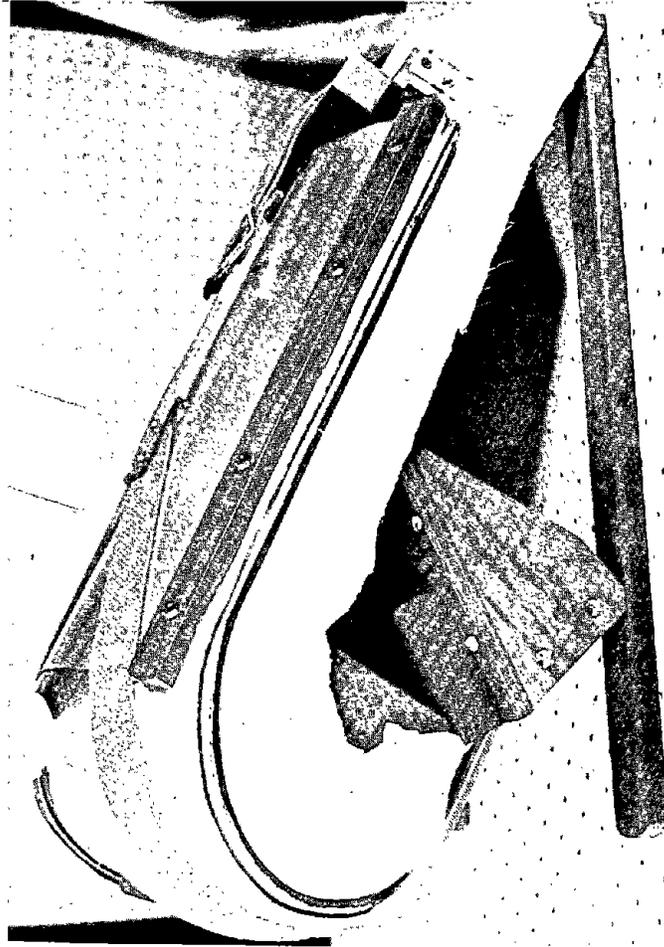


Figure 16.

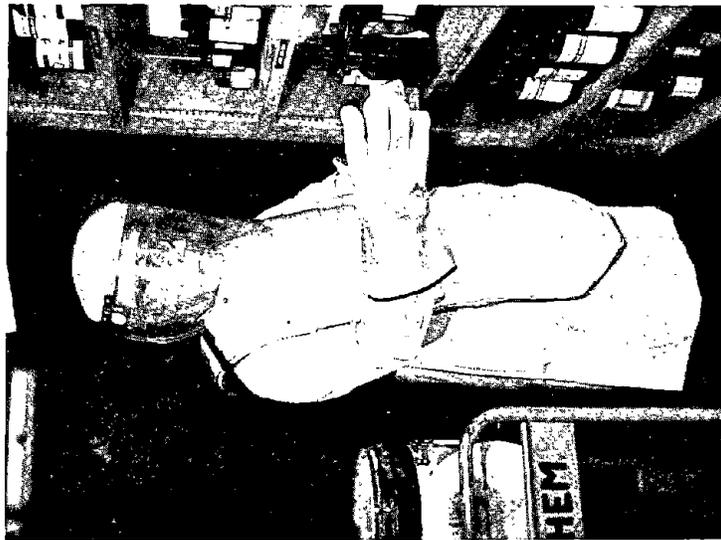


Figure 17.

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Figures 18 and 19

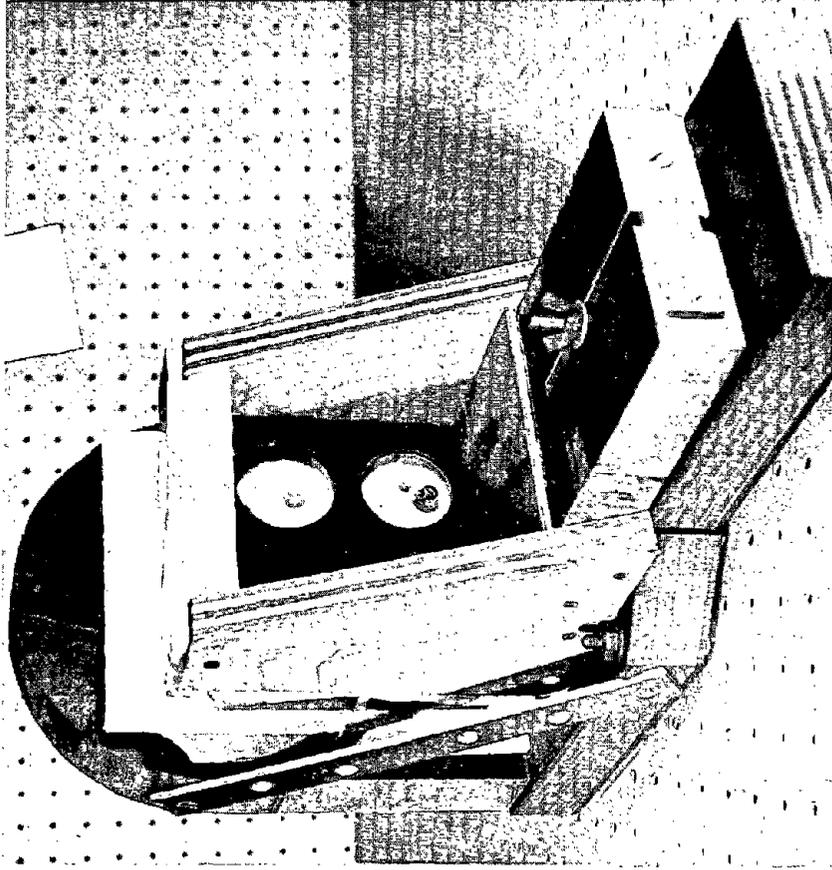


Figure 18.

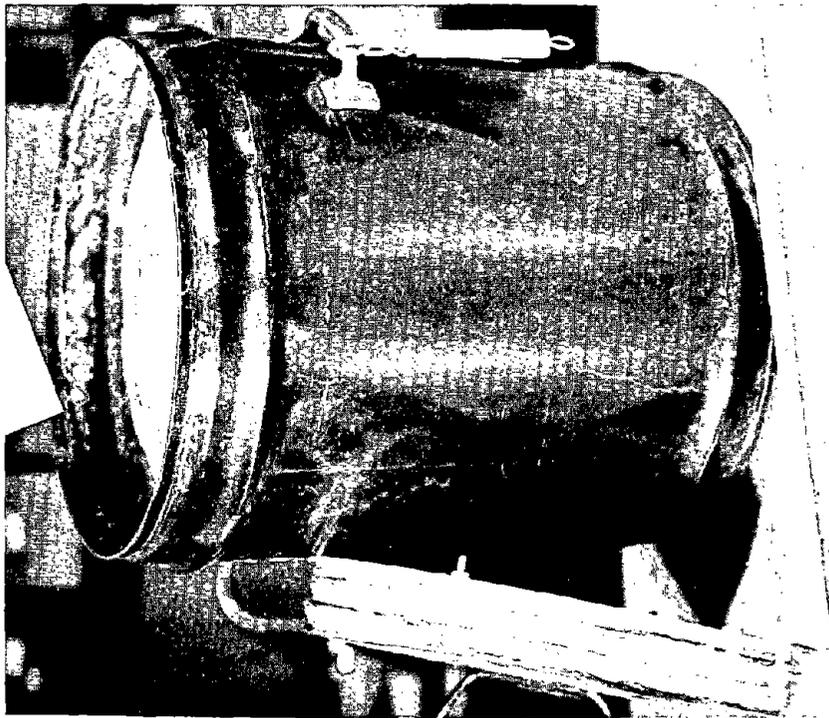


Figure 19.

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Figures 20 and 21

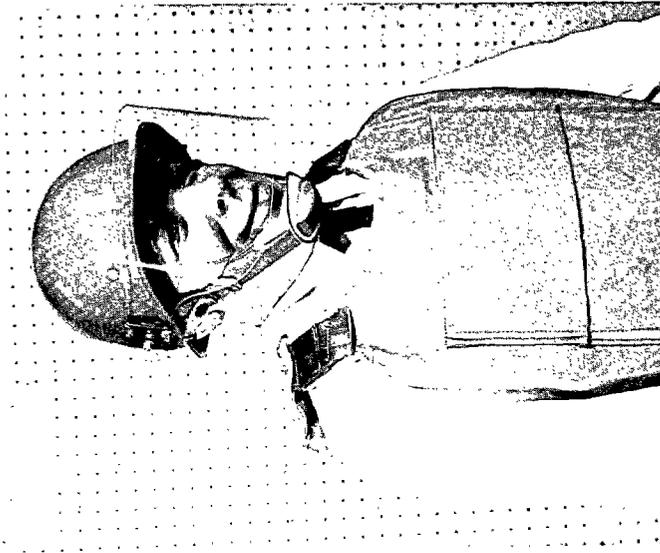
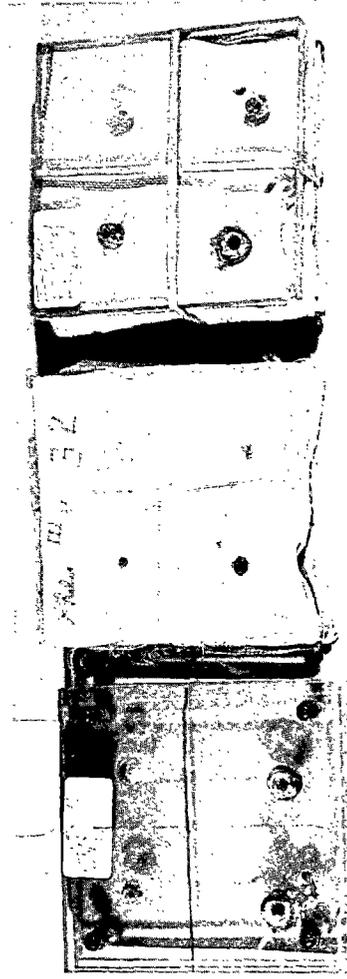


Figure 20.



Philadelphia Police Pistol Range			
1	2	3	4
PC - 24 BN - 2 nd PC	PC - 24 BN - 2 nd PC	PC - 24 BN - 2 nd PC	PC - 24 BN - 2 nd PC
Pen 1 st PC			
Dent 1 st PC 7/8"			
Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"
Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"	Pen 1 st PC Dent 2 nd 7/8"

Figure 21.

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APPENDIX II

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