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An evaluation of two plastic and glass window systems subjected to projectile impacts

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16. Abstract

Impact tests were conducted at the Transportation Test Center on two glazing systems installed in railroad locomotives, passenger cars, and cabooses. A 1/4" thick extruded polycarbonate plastic and a 1/4" thick cast acrylic plastic, each installed in combinations with a 1/4" thick sheet of tempered safety glass, were subjected to standard cinder block and 22-caliber bullet impact tests. The tests were conducted in accordance with the procedures described in CFR Title 49, Part 223 - "Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses." The results derived from the tests will be used by the FRA in its research to identify which window glazing combinations will protect railroad employees and passengers from injury as the result of vandalism. This report presents details of the 18 impact tests performed by the Research and Test Department of the Association of American Railroads. It compares the impact resistance of the two plastic and safety glass system combinations and includes a comparative partial test of a double safety glass system.

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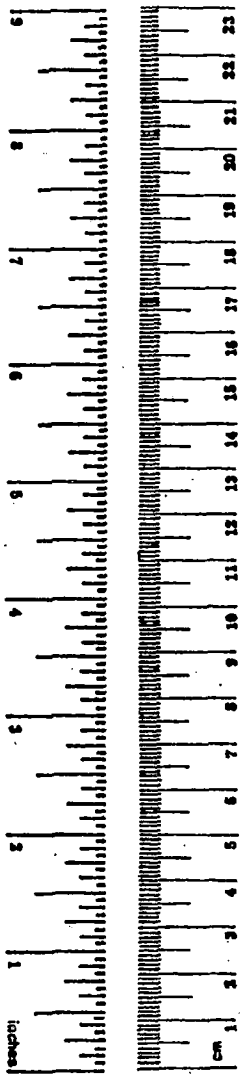
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

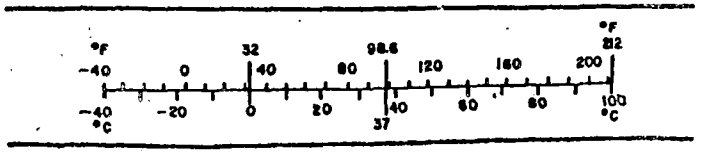
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1.0 INTRODUCTION.

The Federal Railroad Administration (FRA) has initiated a test project to examine the vulnerability of two (2) two-part window glazing systems, Margard & Safety Glass and Acriveu SA & Safety Glass to Large Object and Ballistic impact tests. These two window glazing systems are each composed of two 25"x32"x1/4" thick glazing materials having a 1/4" space between them creating a 3/4" thick specimen assembly. Typically, they are installed on locomotives, cabooses, and passenger cars in side facing locations with the safety glass on the inside position.

Results from these tests will be used by the FRA in its research to identify which window glazing combinations will protect railroad employees and passengers from injury as the result of objects striking the windows; a hazard which has become a frequent occurrence in highly populated areas of the country as the result of vandalism.

The tests described in this report were performed according to the methods and procedures prescribed in the Code of Federal Regulations, Title 49, Part 223 - "Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses." They were conducted by personnel of the Association of American Railroads at the Transportation Test Center near Pueblo, CO.

2.0 DOT PERFORMANCE STANDARDS

The series of tests covered by this report was conducted according to the methods and procedures prescribed in the regulation. It describes two types of testing regimens for safety glazing which are listed under the heading "Appendix A - Certification of Glazing Material."

The following three sections focus on the key elements:

2.1 Type I Test. This test regimen is conducted on glazing material intended for use in end facing glazing locations. It consists of the following:

A. Ballistic Impact of a standard 22-caliber long rifle lead bullet of 40 grains in weight, impacting the glazing specimen at a minimum velocity of 960 feet per second.

The Regulation states that three (3) different, consecutive test specimens must be subjected to, and pass, the ballistic portion of the Type I test.

B. Large Object Impact of a 24 pound minimum weight cinder block (8" x 8" x 16") impacting the glazing specimen at a minimum velocity of 44 feet per second (30 mph). A corner of the block must impact the glazing specimen perpendicular to, and within a 3-inch radius of its centroid.

The Regulation requires that two (2) different, consecutive test specimens must be subjected to, and pass, the Large Object Impact portion of the Type I test.

C. "Passing" a Type I impact test series constitutes the following:

"A material so tested must perform so that:

(i) there shall be no penetration of the back surfaces (side closest to Witness Plate) of the Target Material by the projectile. Partial penetration of the impact (front) surface of the Target Material does not constitute a failure; and

(ii) there shall be no penetration of particles from the back side of the Target Material through the back side of the prescribed Witness Plate." (See the following Section 2.3 for a description of the Witness Plate.)

2.2 Type II Test. This test regimen is conducted on a glazing material intended for use only in side facing locations. It consists of the following:

A. Ballistic Impact of a standard 22-caliber long rifle lead bullet of 40 grains in weight, impacting the glazing specimen at a minimum velocity of 960 feet per second.

The Regulation requires that three (3) different, consecutive test specimens be subjected to, and pass, the ballistic portion of the Type II test.

B. Large Object Impact of a 24 pound minimum weight cinder block (8"x8"x16") impacting the glazing specimen at a minimum velocity of 12 feet per second (8.2 mph). A corner of the block must impact the glazing perpendicular to, and within a 3-inch radius of its centroid.

The Regulation requires that two (2) different, consecutive test specimens must be subjected to, and pass, the Large Object Impact portion of the Type II test.

C. "Passing" a Type I impact test series constitutes the following:

"A material so tested must perform so that:

(i) there shall be no penetration of the back surfaces (side closest to Witness Plate) of the Target Material by the projectile. Partial penetration of the impact (front) surface of the Target Material does not constitute a failure; and

(ii) there shall be no penetration of particles from the back side of the Target Material through the back side of the prescribed Witness Plate." (See the following Section 2.3 for a description of the Witness Plate.)

2.3 Witness Plate and Velocity Measurement.

Each glazing test specimen is to be installed with a witness plate, positioned parallel to and 6 inches behind it. The witness plate is to be an unbacked sheet of .006 inch maximum thickness, 1100 alloy aluminum, having 0 temper. It is to be stretched across an open area of at least the size of the exposed glass. The witness plate is soft and provides easy visual confirmation of test specimen material penetrations.

Velocity measuring devices having a 10% accuracy tolerance, are to be used to measure the impact velocity of the projectiles.

2.4 "Appendix A" Test

As stated previously, the Types I and II impact tests are listed under the heading "Appendix A - Certification of Glazing Material." Therefore, for the purposes of this test report, any glazing material or system which has been subjected to both a Type I and II test regimen, shall be considered to have been subjected to a full "Appendix A" test of 49 CFR, Part 223.

The Acriveu SA & Safety and the Margard & Safety window glazing systems described within this report were both subjected to a full "Appendix A" test. The ballistic portion of the Type I and II test regimens was conducted only once on each glazing

system because the requirements for both test regimens are the same.

2.5 Additional Requirements

In addition to the requirements specified for the Type I and II test regimens as described above, one "impact to failure" test was conducted on each glazing system in accordance with the "Large Object Impact" test regimen. This test should reveal the threshold velocity at which the window glazing system being tested will fail totally.

3.0 THE TEST SETUP

3.1 Specimen Fixture, Track Vehicle, and Marksman

The glazing specimen fixture box (see Appendix A, Figures A-1 and A-3) is a frame constructed primarily of 1/4" thick steel angle and plate. This steel box contains a removable wooden frame with a 3/4" wide recess cut around its perimeter to receive the glazing specimen assembly. The face of this recess is covered with a 1/8" thick EPDM rubber strip. The back side of the wooden frame provides the surface for mounting the required witness plate, using a staple gun. The distance between the witness plate and the back surface of the glazing specimen assembly is 6 inches. A frame constructed of 2" angle iron creates a removable cover for access to the glazing specimen and internal wood frame. The cover is also lined with 1/8" thick EPDM strips which contact the glazing, thereby simulating actual installation materials.

The specimen fixture box is permanently mounted atop two steel beams which form a stable base. The assembly was used in both the Large Object Impact and Ballistic Impact tests.

For the Large Object Impact tests, the cinder blocks were hung in position from an overhead catenary cable above a railroad track and a tracked vehicle was used to transport the glazing fixture at the required velocity into the block. The vehicle used was the high-rail platform truck (see Figure A-1). The tracked vehicle provided a method for accurately controlling the impact location on the target material.

For the Ballistic Impact tests, the specimen fixture assembly was transported to the TTC Pool Fire Pit area. A 22-caliber rifle with telescopic sights was used, with the marksman seated at a portable table (see Figure A-26).

3.2 Instrumentation and Photo.

The instrumentation used in the Large Object Impact tests included an electronic tachometer with frequency conditioning and digital display, and a strip chart recorder.

The tachometer was installed on the truck's rear wheel for readout of velocity. The vehicle's velocity was continuously monitored by the instrumentation engineer from the back seat of the high-rail vehicle, and directly communicated to the driver during each impact run. This setup provided accurate control of the impact velocity.

The on-board strip chart recorder provided a hard copy record of the velocity and the concurrent impact "event mark" (See Appendix B). The velocity from each of the Large Object Impact runs is indicated on the chart in miles per hour, from 0 to 50. The manually induced event mark appears on the outer margin of the chart. Depending upon which of two different recorders were used during this test series, the event mark is expressed either as an elongated black mark on the right-hand margin, or as an interruption of a straight line in the left-hand margin. The graduations on the left-hand margin of each graph represent elapsed time in one-second intervals.

A metal foil tape is visible on the front of some of the glazing specimens (see Figure A-4) and was initially installed in an attempt to generate a self-acting event mark; the cinder block would break the conductive tape upon impact and interrupt an electrical signal displayed on the graph. However, this method proved to be unreliable and was discarded in favor of the manually induced signal.

During the Ballistic Impact tests, a ballistic chronograph (see Figures A-27 and A-28) was used for measuring bullet velocity prior to impact. Velocity is digitally displayed at the front of the unit in feet per second.

A visual record of each test was provided by a 6"x7" format camera.

3.3 Projectiles.

The projectiles used in this test series conformed to the specifications of 49 CFR, Part 223, Appendix A. The cinder blocks used in the Large Object Impact tests were 8"x8"x16" in size. The composition was as referenced in ASTM C90. These cinder blocks weigh approximately 27 pounds as purchased. Because the CFR Regulation allows the block to have a minimum

weight of 24 pounds, the back-end web of each block (opposite from impact) was cut out to reduce weight to between 24 and 24.5 pounds. The block was hung from the overhead catenary cable with cotton string, which easily breaks during impact. The block was positioned so that one corner impacted the glazing initially, in accordance with the CFR requirement. Lateral guy lines helped stabilize and position the block. Exact weights of each block are given with the specimen photographs in Appendix A of this report.

The bullets used in the Ballistic Impact portion of the tests were standard velocity 22-caliber long rifle lead bullets of 40 grains weight. They were fired from a 22-caliber rifle. The muzzle to target distances were as indicated in the test results, Appendix A of this report.

3.4 Glazing Specimens.

The two glazing specimens tested were a two-piece system comprised of one 1/4" thick sheet of plastic glazing material and one 1/4" thick sheet of laminated safety glass. The two sheets are separated by a 1/4" air gap, provided by butyl rubber auto glass tape installed around the perimeter. The plastic sheet is normally installed on the outside position in a railroad car. The 1/4" thick glazing materials tested are intended for use only in side facing glazing locations (Type II test). However, in this series of tests, they were also subjected to the more stringent test requirement for glazing materials intended for use in end facing glazing locations (Type I test).

Acriveu SA, as manufactured by Swedlow, Inc., is one of the two plastic glazing materials tested. It is composed of a stretched monolithic cast acrylic sheet containing an abrasion resistant coating on both sides. The size and thickness tested was 25"x32"x1/4".

Margard MR5 is manufactured by the General Electric Company and was the other plastic glazing material tested. It is composed of an extruded, monolithic "Lexan" polycarbonate sheet containing an abrasion resistant coating on both sides. The size and thickness tested was 25"x32"x1/4".

The FRA Type II safety glass, used in each test behind the plastic glazings, is manufactured by Viracon Inc. and marketed under Part Number VN250. It is composed of a lamination of two different thicknesses of tempered glass, using a .030 inch thick vinyl laminate between the two. The total thickness of this three-piece composite material is 1/4". The

thinnest, and therefore the weakest, side of this composite material is to be installed facing the impact (facing "outward"). This configuration puts the thicker, stronger side, which is less prone to spalling, facing the occupant inside. The material size tested was 25"x32"x1/4".

A special note on Viracon VN250 Safety Glass: This material is FRA approved for Type II side facing glazing locations only when installed as a two-component safety glass system (two pieces of 1/4" thick VN250). Because of this fact, a partial Type II test was conducted on this system as a relative comparison with the plastic/glass systems. These test results are found in Section 4.3.

4.0 TEST RESULTS.

The results of this glazing impact test series are presented and discussed in the following sections of this report.

Photographs taken from each test are exhibited in Figures A-1 through A-42 in Appendix A. These pictures show the setup activities typical of each test, and the front (glazing portion) and rear (witness plate) views of the specimen fixture following each impact.

The strip chart velocity recordings generated from the Large Object Impact tests are presented in Figures B-1 through B-11 in Appendix B.

4.1 Acriveu SA and Safety.

This glazing system was first subjected to the low speed (12 fps) Type II Large Object Impact test. Photographs of these results, along with the actual recorded impact speeds and cinder block weights, are presented in Figures A-4 through A-7 in Appendix A.

As the photographs show, the Acriveu SA glazing specimens received only localized abrasion or marring at the point of impact with the cinder blocks. No other damage was noted. The inner safety glazing from each test appeared untouched, and the aluminum witness plates were intact with no penetrations or dents visible. The Acriveu SA and Safety glazing system passed the Type II Large Object Impact test.

Results from the Type I Large Objects Impact test series (44 fps) on the Acriveu SA and Safety glazing system are presented in Figure A-12 through A-15. These photographs show complete failure in both tests, with each cinder block breaking and passing through the glazing system and witness plates. The plastic Acriveu SA material appears to have a brittle quality.

One additional Large Object (cinder block) Impact test was conducted on the Acriveu SA and Safety glazing system. This test was conducted in an attempt to find the threshold velocity at which this glazing system will fail and was not a part of the Appendix A test requirements. The impact speed was reduced from 44 fps (30 mph) in the Type I test to 37 fps (25 mph). Photographs from this test are presented in Figures A-20 and A-21. As can be seen from these pictures, the cinder block broke through the glazing specimens and the witness plate. The block appeared to break through the glazing with more difficulty than at 44 fps. It was estimated that the Acriveu SA and Safety glazing system would have survived a 29 fps (20 mph) impact.

Results from the Types I and II Ballistic Impact test series are presented in Figures A-29 through A-34. Only one specimen of Acriveu SA was available and obtainable for the ballistic portion of this test series. Because of this fact, it was decided to impact this remaining specimen with bullets in three different locations. Although this was not a legitimate test by definition of the CFR standard, the results obtained from these tests may be sufficient to derive reasonable conclusions.

The two photographs taken after the first ballistic impact (Figures A-29 and A-30) clearly show the impact area at the center of the glazing specimen, and the localized, dimpled pattern on the witness plate. The bullet passed through the plastic material and impinged onto the safety glass. Some fragments of the safety glass (approximately 6) passed through the witness plate, while others only created bumps or a dimpled effect. The cracks or crazing which are evident in the glazing material occurred primarily in the safety glass. The Acriveu SA and Safety glazing system failed the first of three ballistic impact tests.

Photographs from the second and third ballistic impacts of Acriveu SA and Safety glazing systems are presented in Figures A-31 through A-34. The two impacts were made to the left and right of the center, as shown. In both cases, the bullet passed through the plastic Acriveu SA material but was stopped at the safety glass. About a dozen small dents were created in the witness plate at each impact from fragmenting glass. However, no penetrations of the witness plate were seen. These last two impacts were not valid since they occurred a distance away from the specified 3-inch radius from the centroid. The fact that no penetrations of the witness plate were made at either location may indicate that the glazing system is stronger near the perimeter where it is supported by the frame.

In summary, the Acriveu SA and Safety glazing system failed the "Appendix A" Type I and II test regimens. It did withstand the Type II Large Object Impact test series, but not the Ballistic Impact test or the Type I Large Object Impact test. Only one specimen of Acriveu SA was available for the ballistic impact portion of these test series and was therefore impacted in three different locations.

4.2 Margard and Safety

The first test series conducted on this glazing system was the Type II Large Object Impact test (12 fps). Photographs of these results are presented in Figures A-8 through A-11 in Appendix A. Also included with these figures are the recorded impact speeds and cinder block weights.

As seen in the photographs, the first test of Margard and Safety glazing specimens resulted in localized abrasion and marring at the point of impact. No other damage was observed and the witness plate was intact with no dents or penetrations. The second test resulted in the same localized damage to the plastic glazing, but the safety glass did not survive untouched, sustaining cracks and crazing across its surface. However, no dents or penetrations were seen on the witness plate and the Margard and Safety glazing system passed the Type II Large Object Impact tests.

Results from the Type I Large Object Impact test series (44 fps) on Margard and Safety are presented in Figures A-16 through A-19. These photographs show that the cinder block deflected off the Margard material and did not break or crack it, while the rear mounted safety glass was totally cracked and crazed. In the first test, Figures A-16 and A-17, the Margard was somewhat pushed in and came out of the bottom of the mounting frame. The safety glass held together well, but 4 or 5 small punctures were noted in the witness plate, along with many small dents or dimples. In the second test, the Margard remained flat after the impact and stayed in the frame. The safety glass held together well and only 2 small penetrations were seen in the witness plate, along with several small dents. The plastic Margard material appears to have a pliant quality. However, the Margard and Safety glazing system failed the Type I Large Object Impact tests.

One additional large object impact test was conducted on the Margard and Safety glazing system to determine the impact-to-fail threshold velocity, as in the Acriveu SA and Safety test. The impact speed was increased from 44 fps to 66 fps (44 mph). It was expected that the cinder block would push the Margard out of the frame, or somehow break through it.

As seen in Figures A-22 and A-23, the cinder block deflected off the face of the Margard material but pushed it out along the top edge of the frame. Large chunks of the safety glass broke out and the witness plate tore away from the bottom and left side of the frame. It is difficult to estimate the speed at which the Margard would push through the frame; it apparently depends upon how well it is clamped into the frame.

Results from the Types I and II Ballistic Impact test series are presented in Figures A-35 through A-40. In all three tests, the bullet penetrated the plastic Margard material and impinged on the Safety glass. The cracked or crazing pattern in the Safety glass was similar in the three tests, and small penetrations were seen in each of the witness plates (between 3 and 6 were counted in each test). Several dents were also visible in each witness plate as can be seen in the photographs.

In summary, the Margard and Safety glazing system failed the Appendix A Type I and II tests. It did withstand the Type II Large Object Impact test series, but not the Ballistic Impact test.

4.3 Double Safety Glass System

As indicated in Section 3.4, a partial Appendix A test of the two-part safety glazing system was conducted as a relative comparison with the plastic/glass systems. This double safety glass system is FRA approved for Type II side facing glazing locations. Photographs from these tests are presented in Figures A-24, A-25, A-41, and A-42.

One Type II Large Object Impact test (12 fps) was conducted (see Figures A-24 and A-25). As seen in the photographs, the impact of the cinder block resulted in spalling of the outer glass and crazing of both safety glass specimens. However, no penetrations or dents were visible in the witness plate.

One Ballistic Impact test was conducted (see Figures A-41 and A-42). The bullet penetrated the outer glazing and stopped at the inner glazing. As can be seen in the photograph, the impact resulted in crazing across both glazings. No penetrations were seen in the witness plate, although many small dents were clustered together at the center. The double safety glass system passed the partial Type II impact test to which it was subjected.

4.4 Safety Glass Installed Backwards (Appendix C)

A full "Appendix A" test series of Acriveu SA/Safety and Margard/Safety glazing systems was conducted initially with the Safety glazing installed backwards. This was done mistakenly, without the knowledge that the safety glass is designed to face an impact from one designated side only. The manufacturer of the safety glass claims that installing the glazing backwards will cause it to spall and splinter much more easily when subjected to an impact. This in fact, seems to be the case.

The Type II Large Object Impact tests (12 fps) conducted on the Margard and Acriveu SA glazings with the safety glass installed backwards were all successful. It was therefore decided not to retest them and the results are used in Appendix A of this report, Figures A-4 through A-11. All other impact tests were performed again.

Except those indicated above, all other photographs taken from the impact tests conducted with the safety glass reversed are presented in Appendix C. They are included in this report as reference information only and are not to be considered as valid tests.

5.0 SUMMARY

This window glazing experiment was composed of 18 impact tests of combinations of 1/4" thick plastic glazing and 1/4" thick laminated safety class materials. They were conducted according to the procedures specified in the Code of Federal Regulations, Title 49, Part 223, "Safety Glazing Standards."

The following glazing "systems", as installed in locomotives, passenger cars, and cabooses, were subjected to the cinder block and 22-caliber bullet impacts specified in the Code of Federal Regulations:

* Acriveu SA and Safety Glass,
* Margard and Safety Glass, and
* Double Safety Glass System.

The Acriveu SA plastic glazing and Safety Glass system did not pass either the Type I or Type II "Appendix A" impact test series. The system did pass the Large Object Impact test portion of the Type II test series, but failed the Ballistic Impact portion of the test. Acriveu SA is a plastic acrylic material and has a comparatively brittle quality. The Margard plastic glazing and Safety Glass system also did not pass either the Type I or Type II "Appendix A" impact test series. The system did pass the Large Object Impact test portion of the Type II test series, but failed the Ballistic Impact portion of the test. Margard is a plastic polycarbonate material and has a comparatively pliant quality.

The double Safety Glass system is FRA approved for use in a Type II (side facing glazing) installation. It was subjected to a partial Type II impact test (1 - cinder block and 1 - ballistic impact) for comparative purposes only. This system passed both impacts.

APPENDIX A

PHOTOGRAPHS FROM GLAZING IMPACT TESTS

Figure A-1. Type I Large Object Impact Test at moment of impact.

Figure A-3. View down RTT East Tangent section where the Large Object Impact runs were conducted.

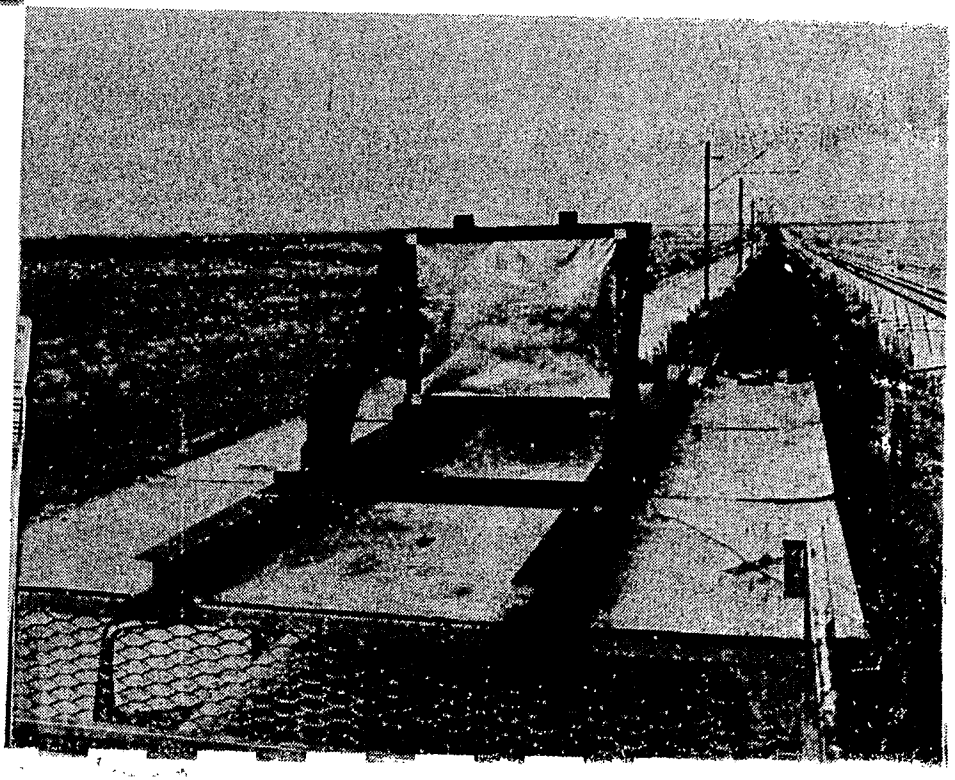
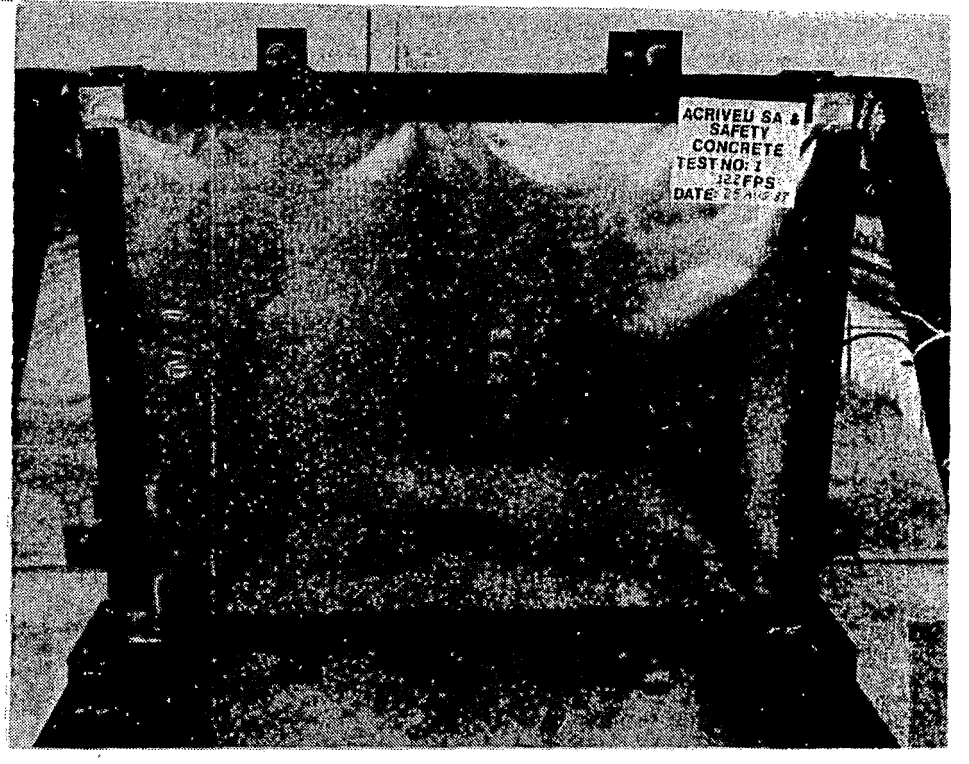


Figure A-2. Setup activities for hanging cinder blocks from overhead catenary cable.

Figure A-4. Front view of Acriveu SA & Safety glazing system after the first 12 fps cinder block impact run.

Points of Impact.



ACRIVEU SA & SAFETY

- Test Type: Type II Large Object Impact (Test #1)
- Recorded Impact Velocity 8.3 mph (12.2 fps)
- Cinder Block Weight: 24.1 lbs

Figure A-5. Rear View of the witness plate -- no penetrations or dents.

Point of Impact

Figure A-6. Front view of Acriveu SA & Safety glazing system after the second 12 fps cinder block impact run.

ACRIVEU SA & SAFETY

- Test Type: Type II Large Object Impact (Test #2)
- Recorded Velocity: 8.7 mph (12,8 fps)
- Cinder Block Weight: 24.2 lbs

Figure A-7. Rear view of the witness plate -- no penetrations or dents.

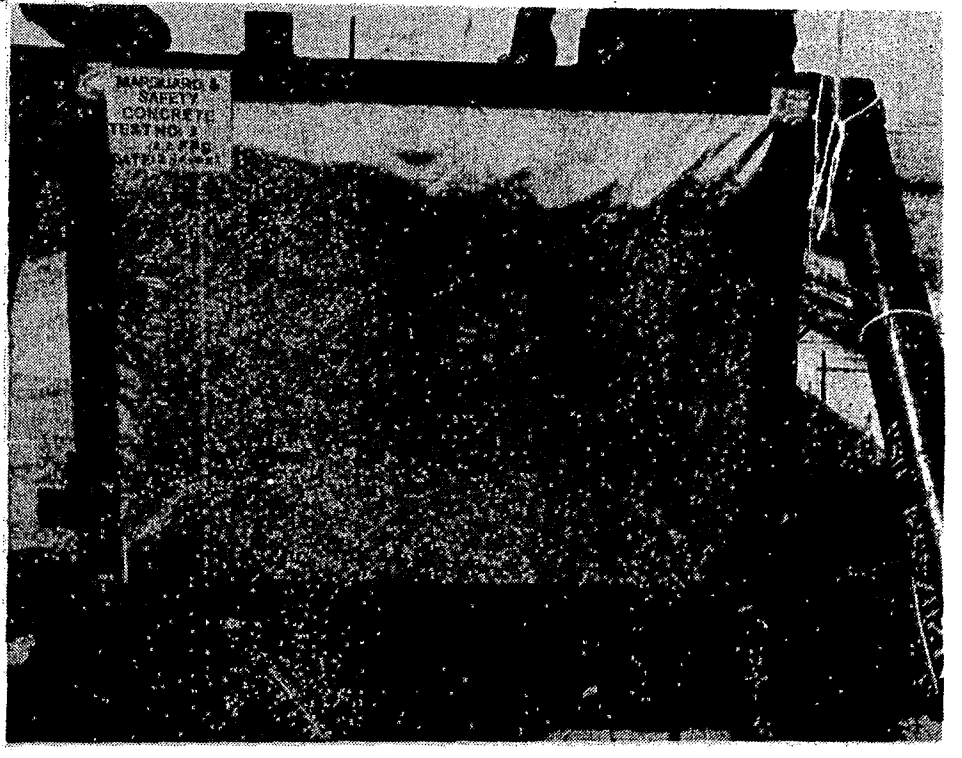
MARGARD & SAFETY

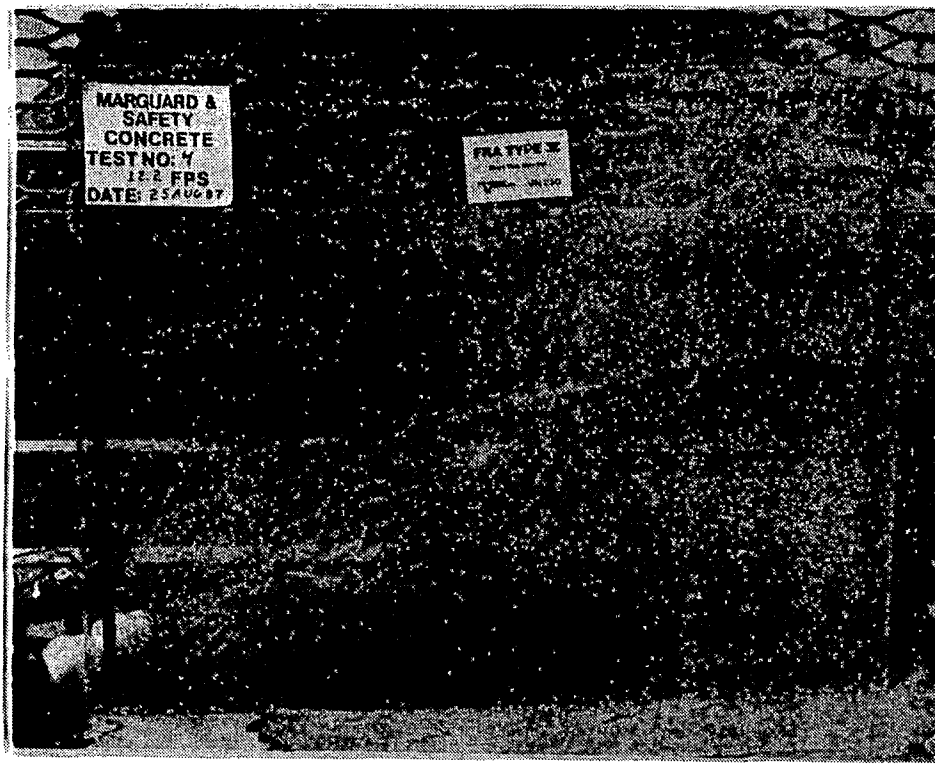
- Test Type: Type II Large Object Impact (Test #1)
- Recorded Velocity: 8.2 mph (12 fps)
- Cinder Block Weight: 24.3 lbs

Figure A-9. Rear view of the witness plate -- no penetrations or dents.

Figure A-8. Front view of a Margard & Safety glazing system after the first 12 fps cinder block impact run.

Point of Impact





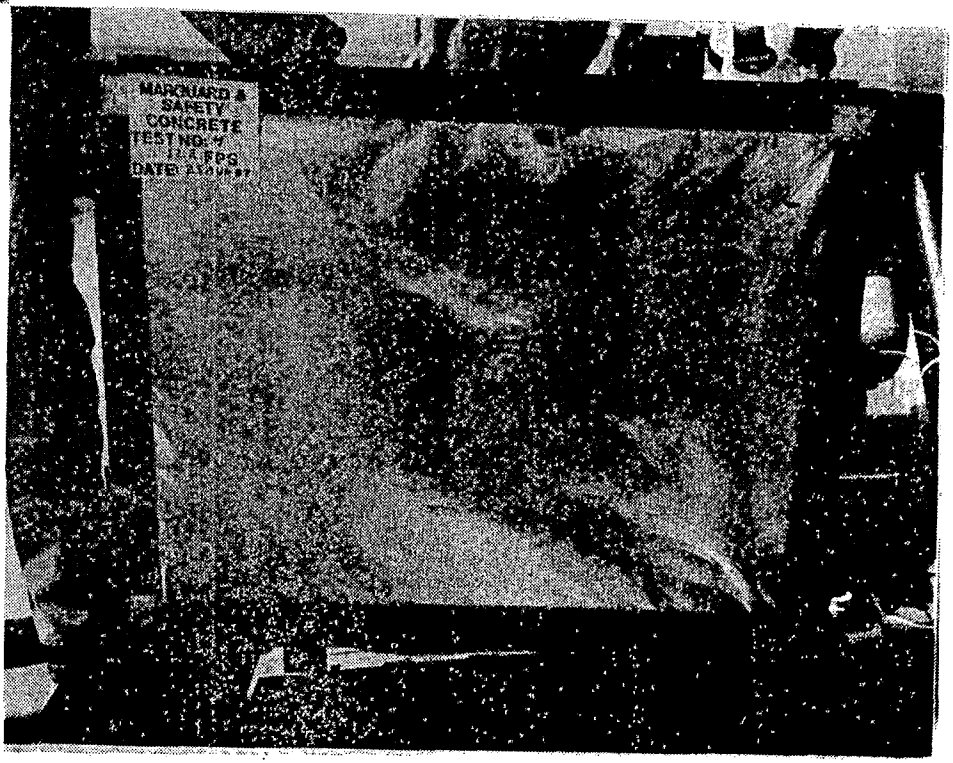
MARGARD & SAFETY

- Test Type: Type II Large Object Impact (Test #2)
- Recorded Velocity: 8.6 mph (12.6 fps)
- Cinder Block Weight: 24.4 lbs

Figure A-11. Rear view of the witness plate -- no penetrations or dents.

Figure A-10. Front view of a Margard & Safety glazing system after the second 12 fps cinder block impact run.

Point of Impact



ACRIVEU SA & SAFETY

- Test Type: Type I Large Object Impact (Test #1)
- Recorded Velocity: 30.9 mph (45.3 fps)
- Cinder Block Weight: 24.2 lbs

Figure A-13. Rear view of the witness plate -- cinder block passed through.

Figure A-12. Front view of Acriveu SA & Safety glazing system after the first 44 fps cinder block impact run.

Area of Impact

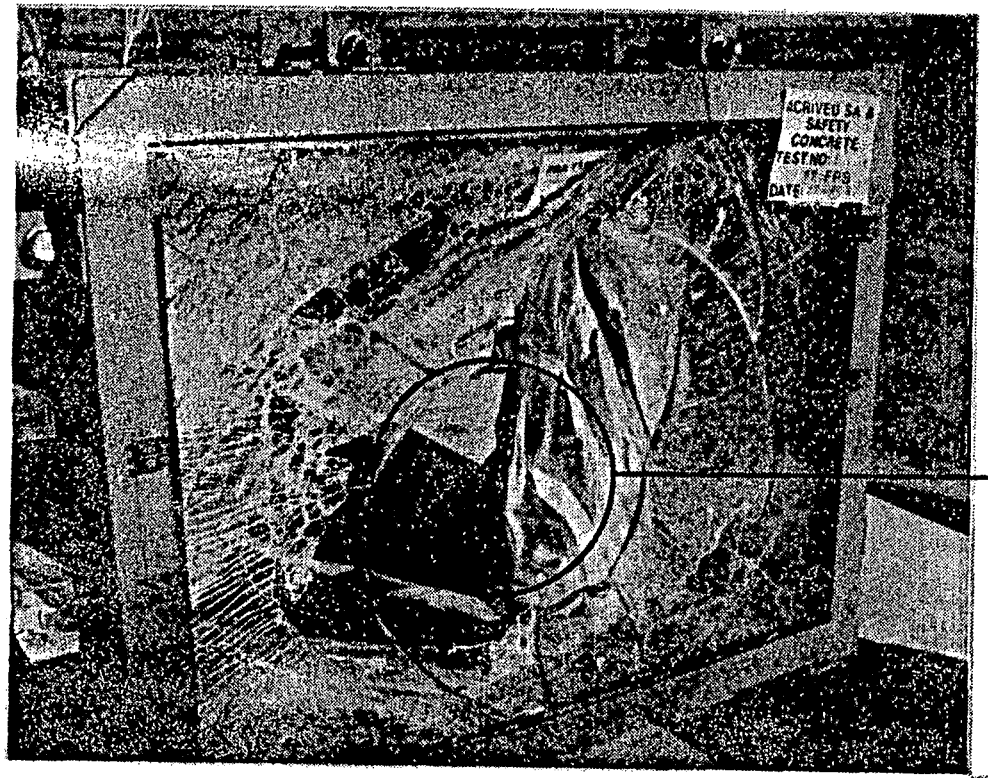
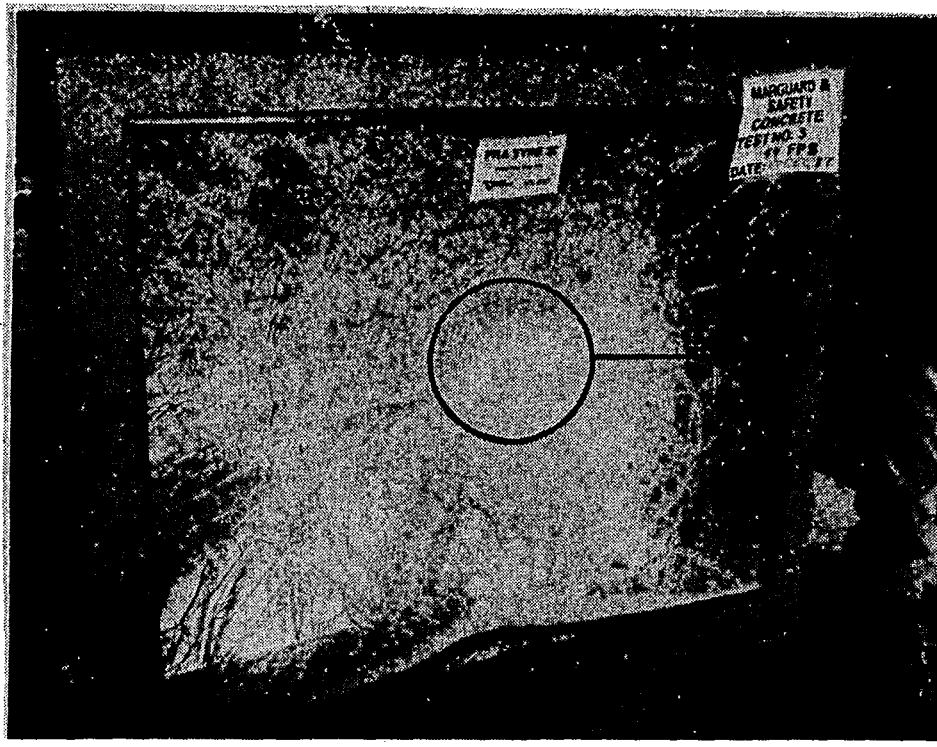


Figure A-14. Front view of Acriveu SA & Safety glazing system after the second 44 fps cinder block impact run.

Area of Impact

ACRIVEU SA & SAFETY
- Test Type: Type I Large Object Impact (Test #2)
- Recorded Velocity: 31.2 mph (45.8 fps)
- Cinder Block Weight: 24 lbs

Figure A-15. Rear view of the witness plate -- [illegible] passed through.



MARGARD & SAFETY

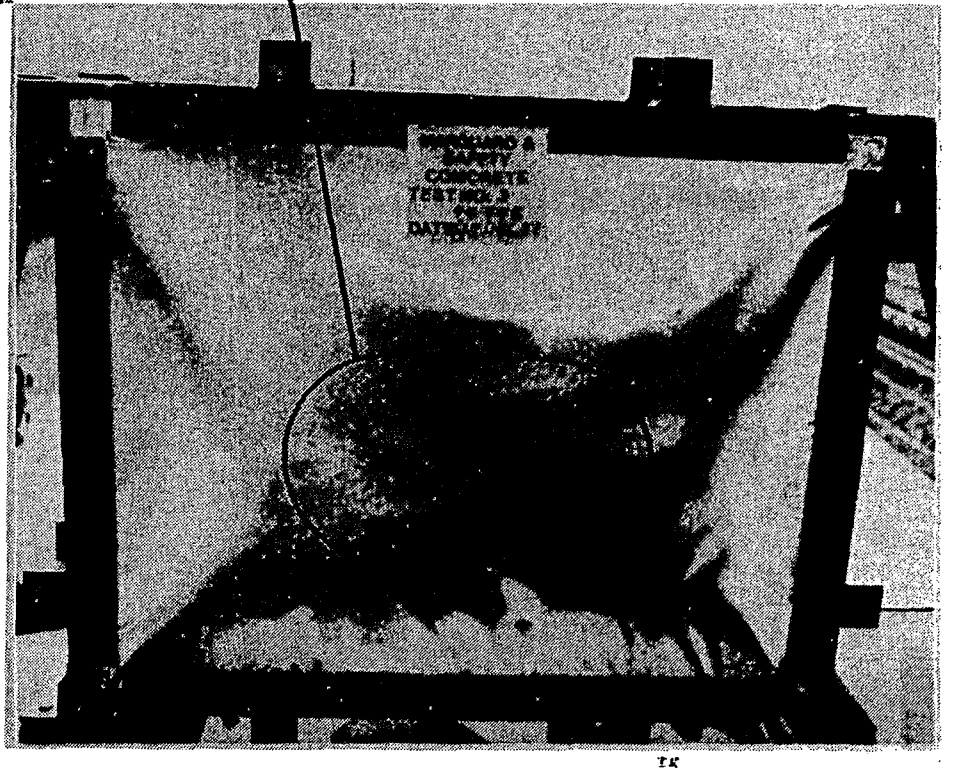
- Test Type: Type I Large Object Impact (Test #1)
- Recorded Velocity: 31.1 mph (45.6 fps)
- Cinder Block Weight: 24 lbs

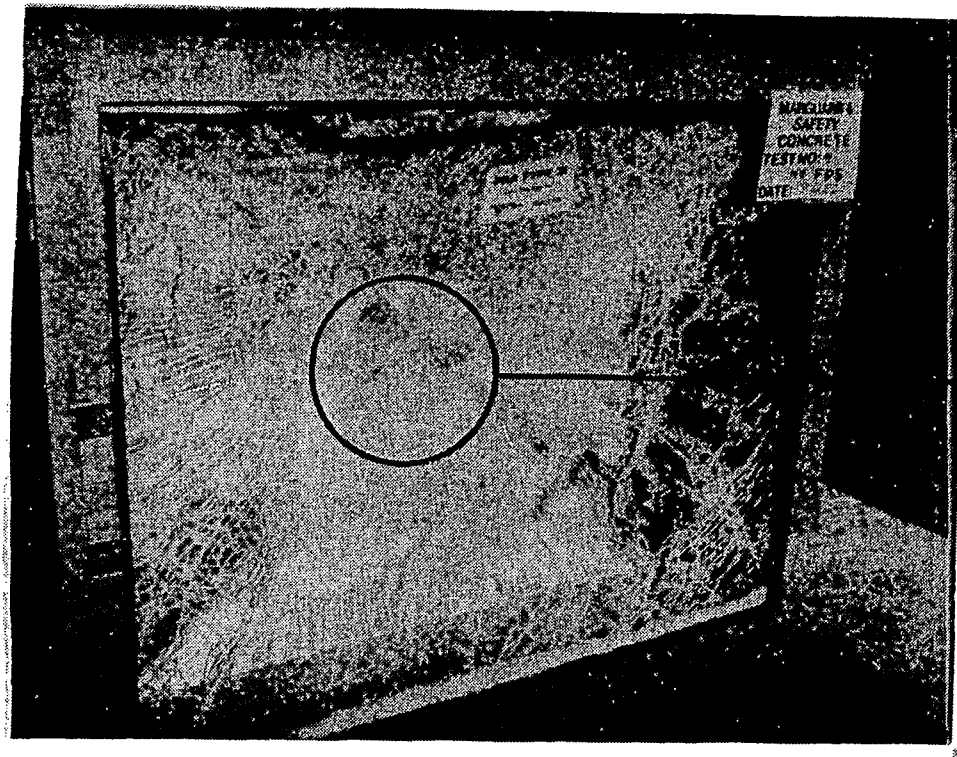
Figure A-17. Rear view of the witness plate -- small penetrations and dents as indicated.

Figure A-16. Front view of a Margard & Safety glazing system after the first 44 fps cinder block impact run.

Point of Impact

5 small penetrations, several dents.





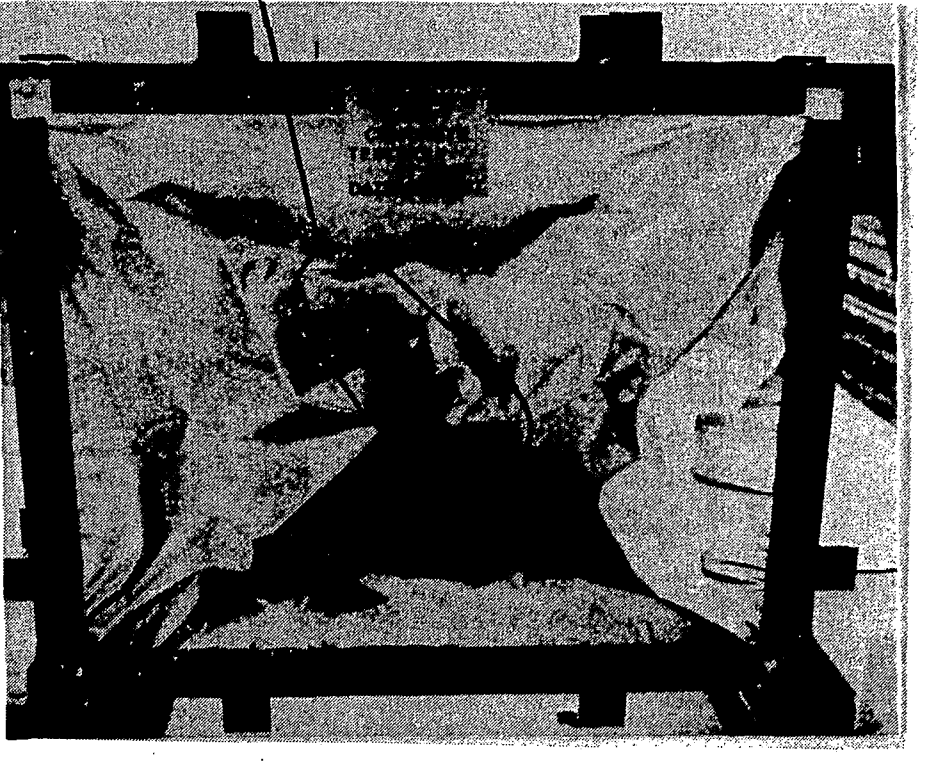
MARGARD & SAFETY
- Test Type: Type I Large Object Impact (Test #2)
- Recorded Velocity: 31.7 mph (46.5 fps)
- Cinder Block Weight: 24 lbs

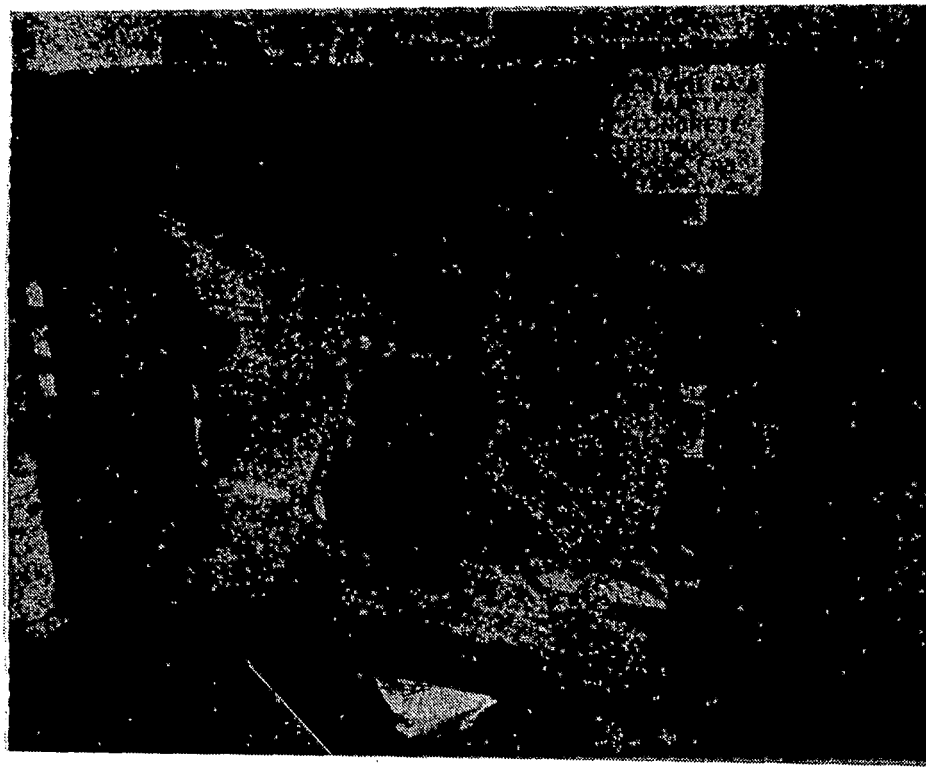
Figure A-19. Rear view of the witness plate -- small penetrations and dents as indicated.

Figure A-18. Front view of a Margard & Safety glazing system after the second 44 fps cinder block impact run.

Point of Impact

2 small penetrations, several dents



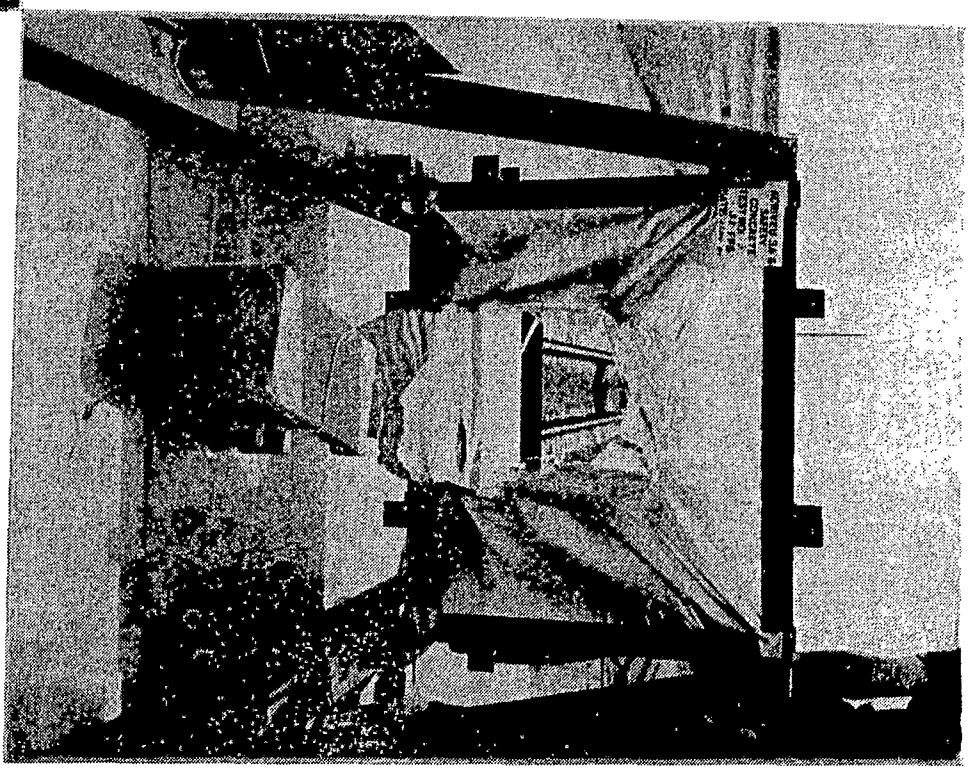


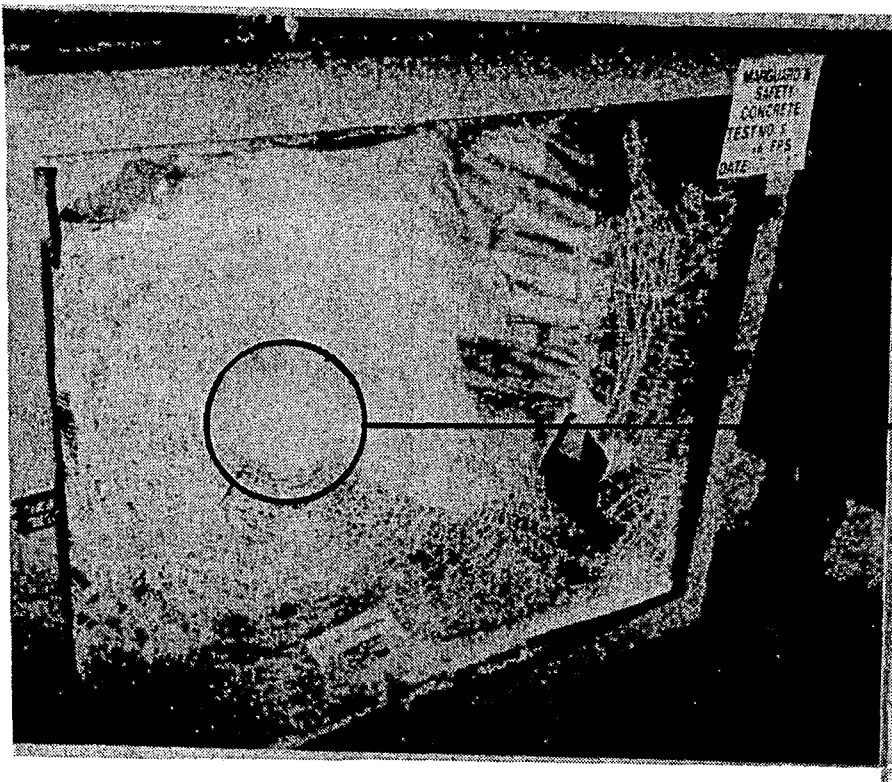
ACRIVEU SA & SAFETY
- Test Type: Impact-to-Fail (one test only)
- Recorded Velocity: 25.1 mph (36.8 fps)
- Cinder Block Weight: 24 lbs

Figure A-21. Rear view of the witness plate -- block passed through glazing and rested where shown.

Figure A-20. Front view of Acriveu SA & Safety glazing system after the "impact-to-fail" cinder block impact run.

Area of Impact





MARGARD & SAFETY
- Test Type: Impact-to-Fail (one test only)
- Recorded Velocity: 46.4 mph (68.1 fps)
- Cinder Block Weight: 24 lbs.

Figure A-23. Rear view of the witness plate -- safety glass broken, pieces gone, witness plate torn; Margard intact.

Figure A-22. Front view of a Margard & Safety glazing system after the "impact-to-fail" cinder block impact run.

Point of Impact

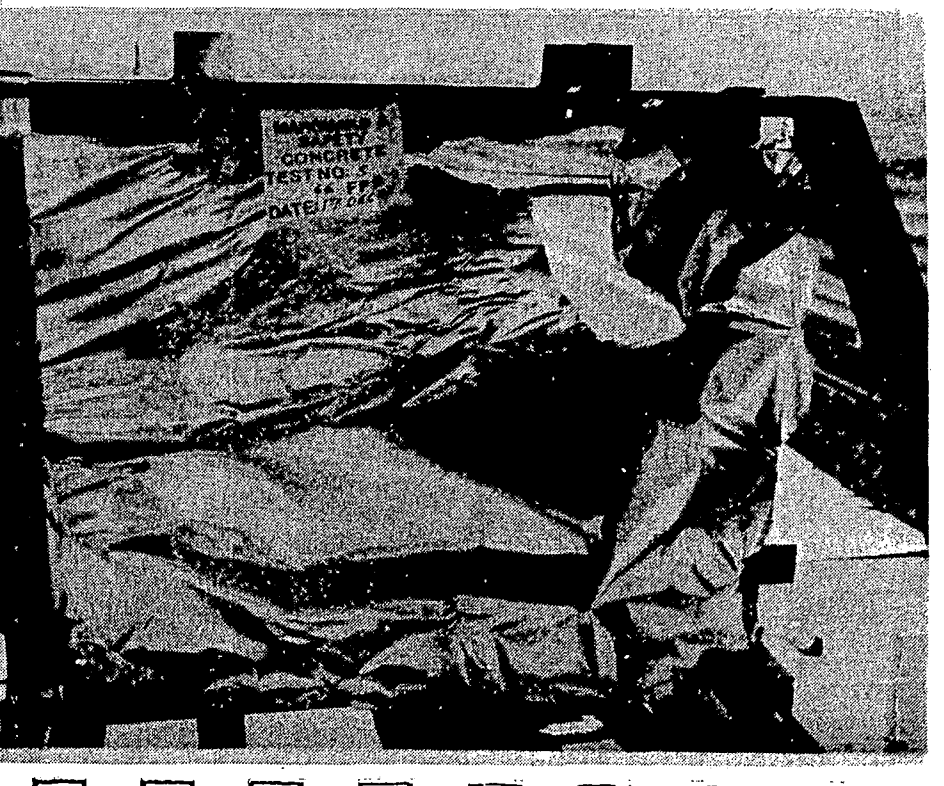


Figure A-24: Front view of a Safety & Safety glazing system after the single 12 fps cinder block impact run.

SAFETY & SAFETY
- Test Type: Type II Large Object Impact (single test)
- Recorded Velocity: 8.4 mph (12.3 fps)
- Cinder Block Weight: 24 lbs

Figure A-25. Rear view of the witness plate -- no penetrations or dents.

Figure A-26. Marksman taking aim prior to a Type I & II Ballistic Impact Test.

Figure A-28. View showing digital readout and target cards of the ballistic chronograph.

Figure A-27. Changing the glazing system and witness plate between ballistic impact tests.

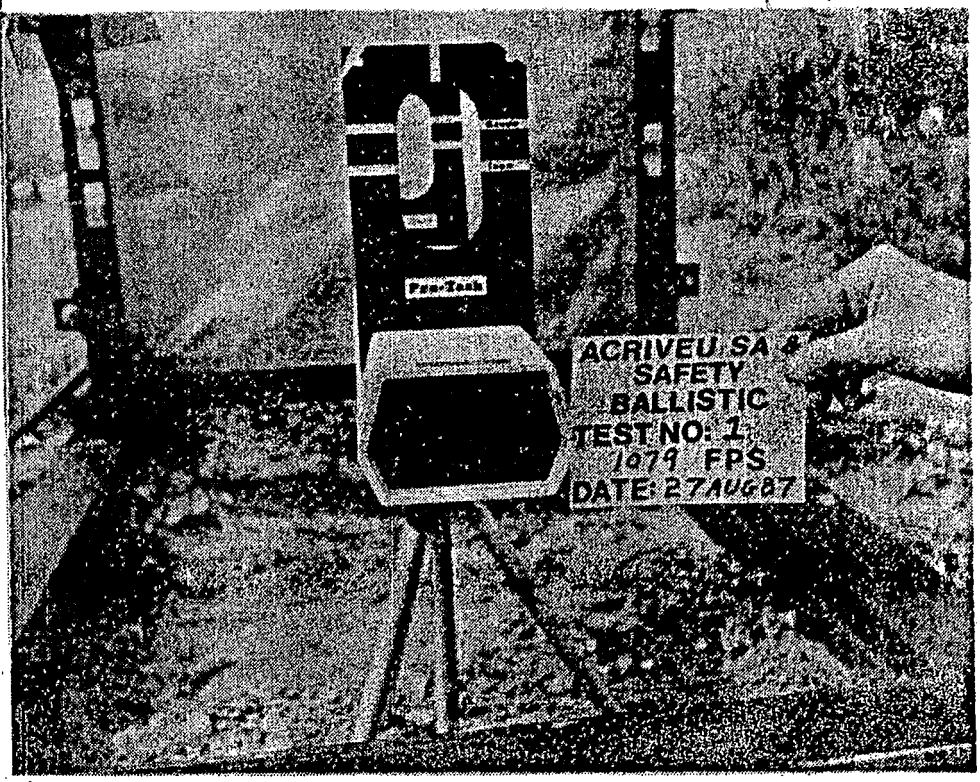
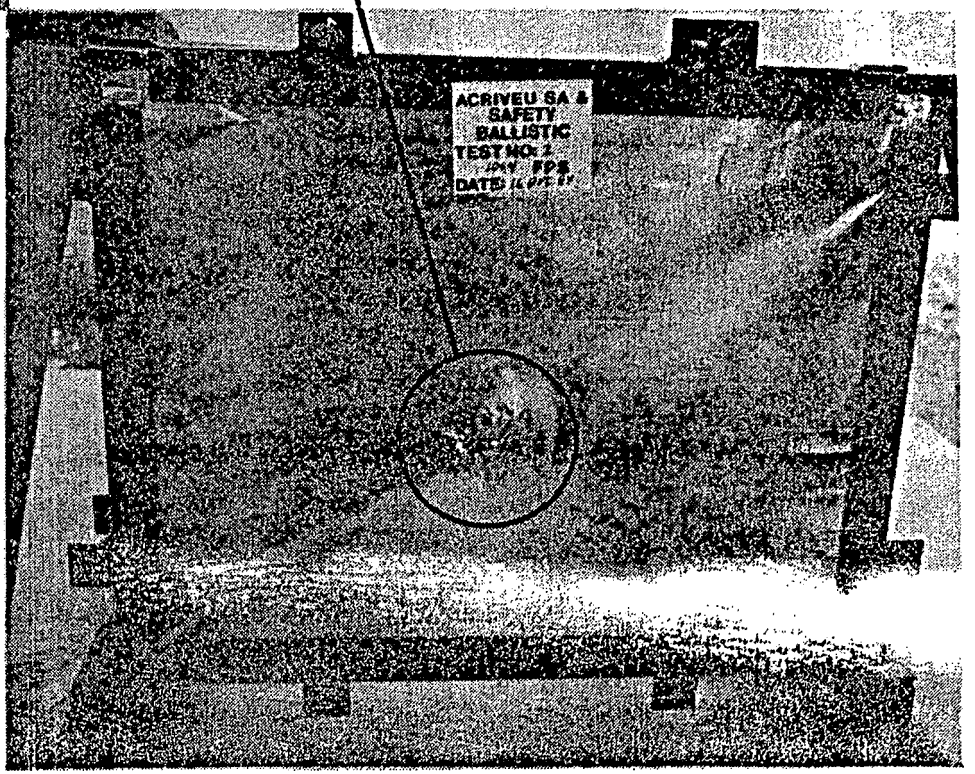


Figure A-29. Front view of the Acriveu SA & Safety glazing system after the first bullet impact.

Point of Impact

Cluster of small penetrations and dents



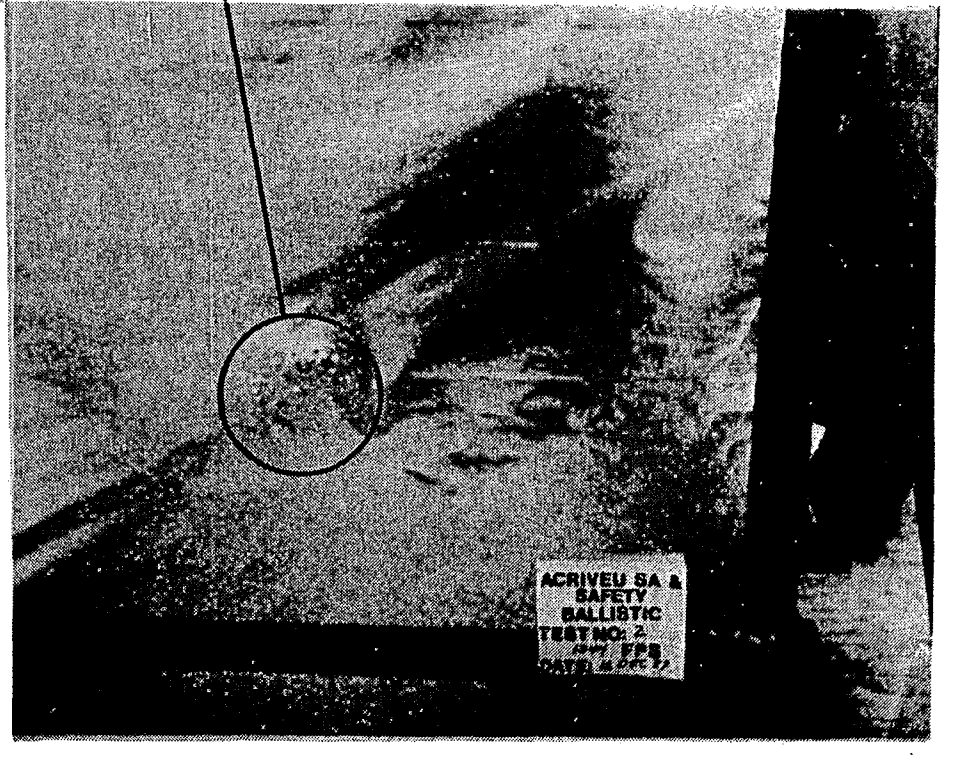
ACRIVEU SA & SAFETY
- Test Type: Types I & II Ballistic Impact (Test #1)
- Indicated Velocity: 1064 fps
- Muzzle to Target Distance: 78.5 feet

Figure A-30. Rear view of the witness plate -- several small penetrations and dents from glass fragments.

Figure A-31. Front view of the Acriveu SA & Safety glazing specimen after incurring the second (left of center) bullet impact.

Point of Impact

Cluster of small dents only.



ACRIVEU SA SAFETY
- Test Type: Types I & II Ballistic Impact (Test #2)
- Indicated Velocity: 1044 fps
- Muzzle to Target Distance: 78.5 feet

Figure A-32. Rear view of the witness plate -- several small dents but no penetrations.

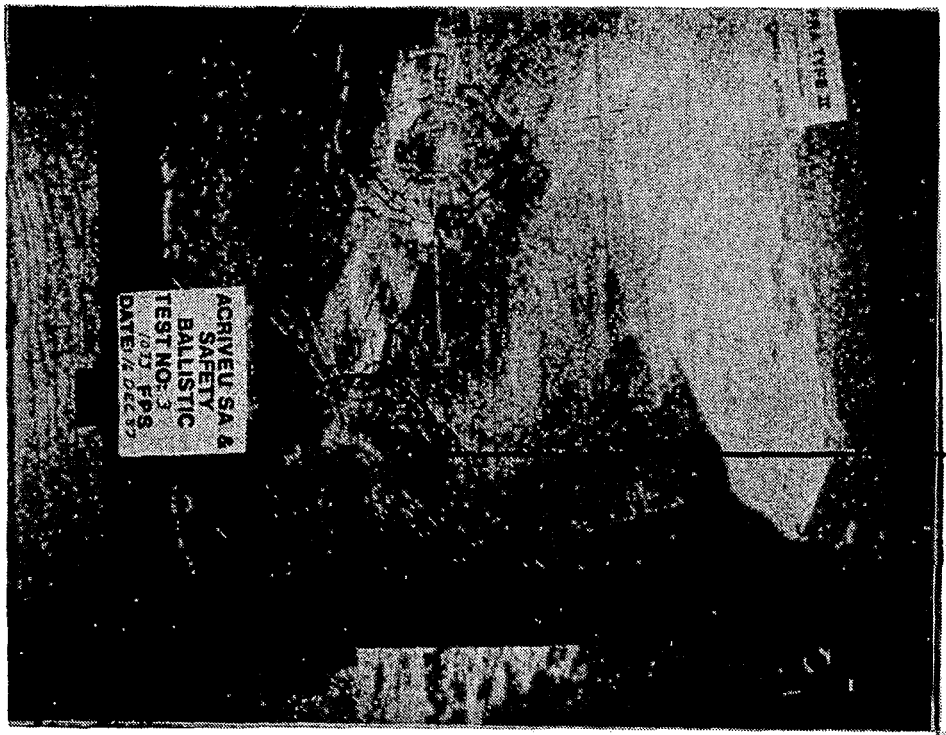
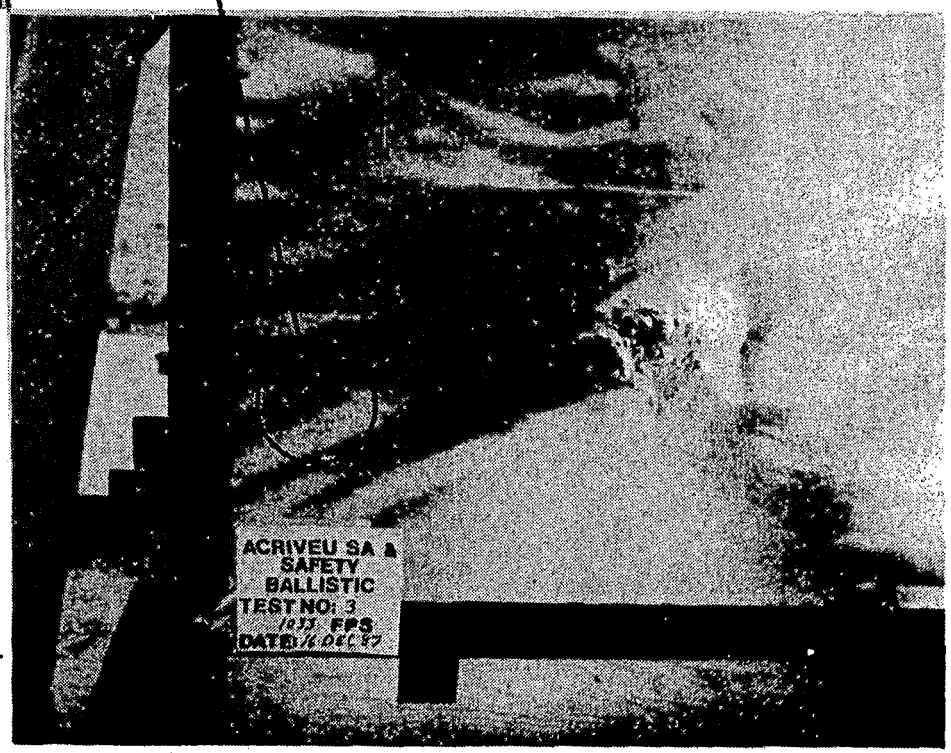


Figure A-33. Front view of the Acriveu SA & Safety glazing specimen after incurring the third (right of center) bullet impact.

Point of Impact

Small dents (12 places)



ACRIVEU SA & SAFETY

- Test Type: Types I & II Ballistic Impact (Test #3)
- Indicated Velocity: 1033 fps
- Muzzle to Target Distance: 78.5 feet

Figure A-34. Rear view of the witness plate -- 12 small dents but no penetrations.

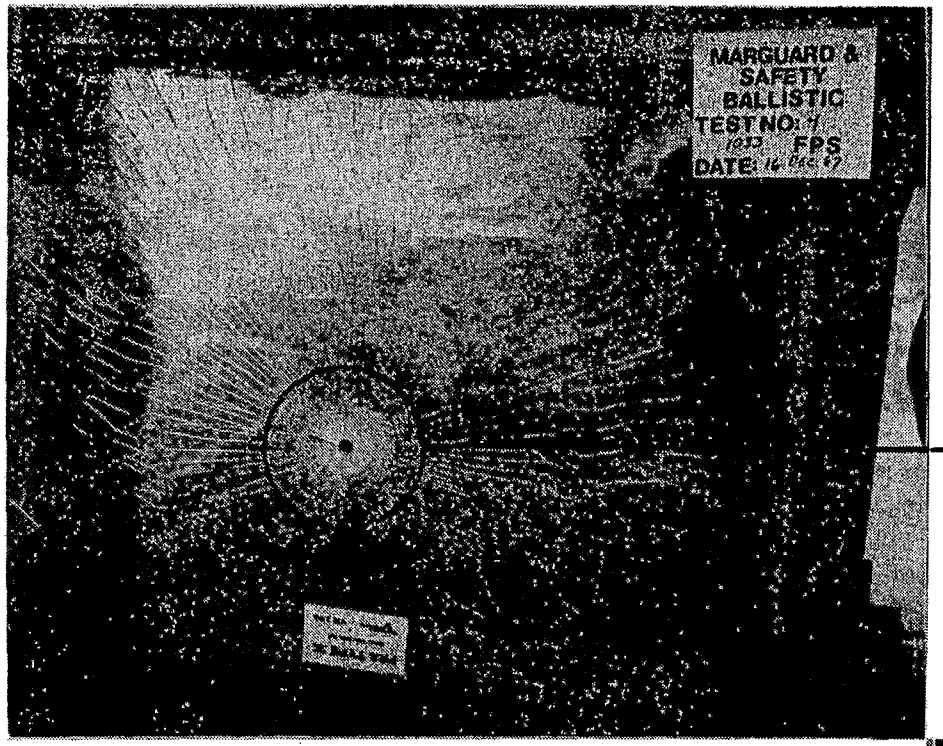


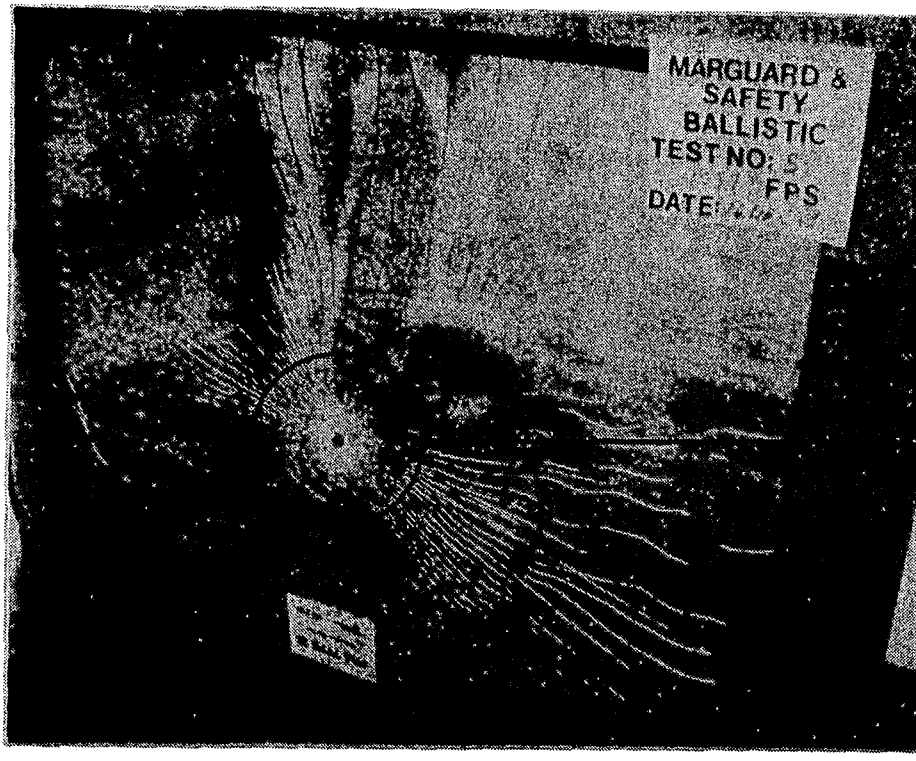
Figure A-35. Front view of a Margard & Safety glazing system after the first ballistic impact test.

Point of Impact

Few small penetrations, several dents.

MARGARD & SAFETY
- Test Type: Types I & II Ballistic Impact (Test #1)
- Indicated Velocity: 1033 fps
- Muzzle to Target Distance: 78.5 feet

Figure A-36. Rear view of the witness plate -- 3 or 4 small penetrations and several dents.

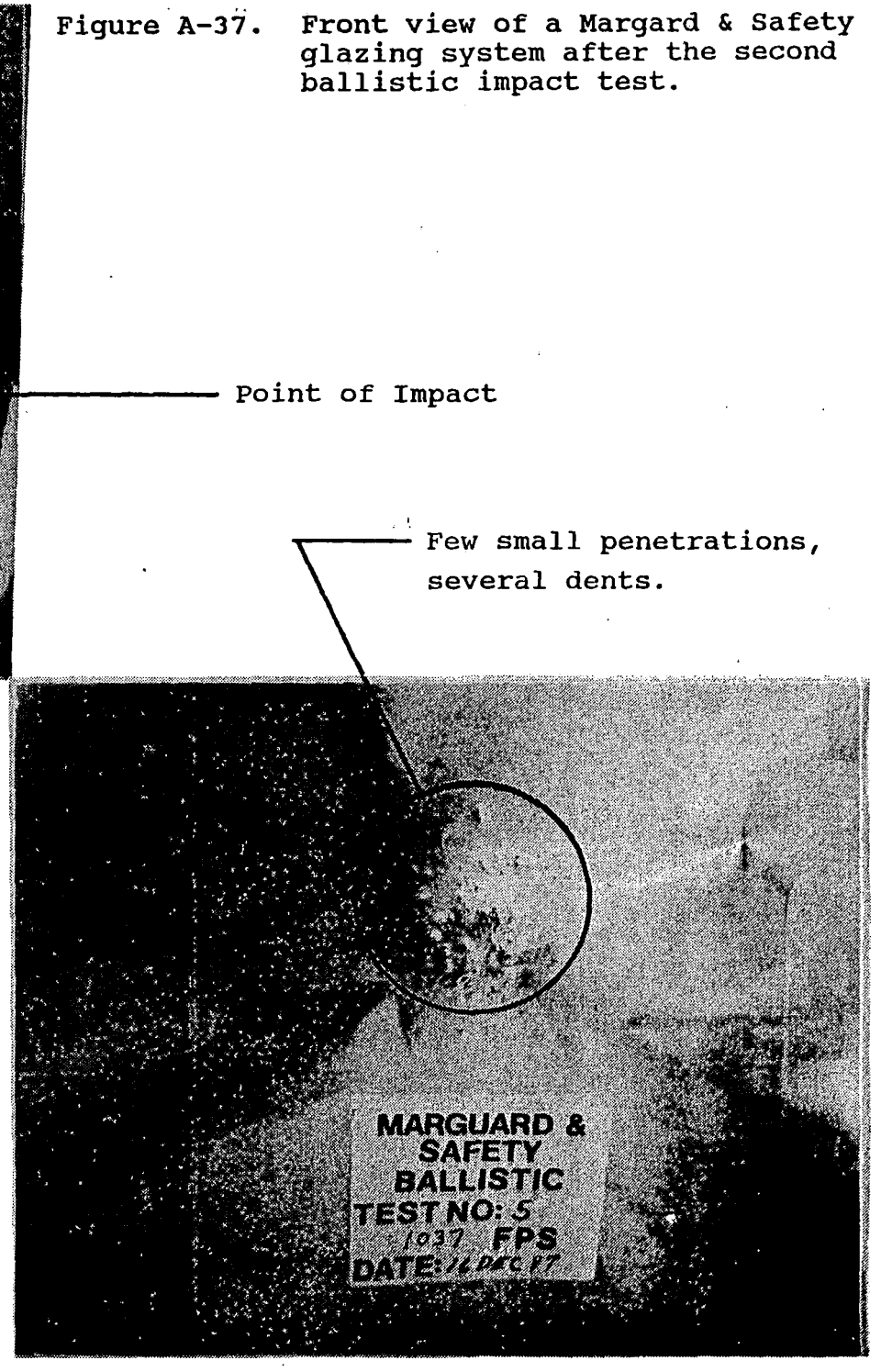


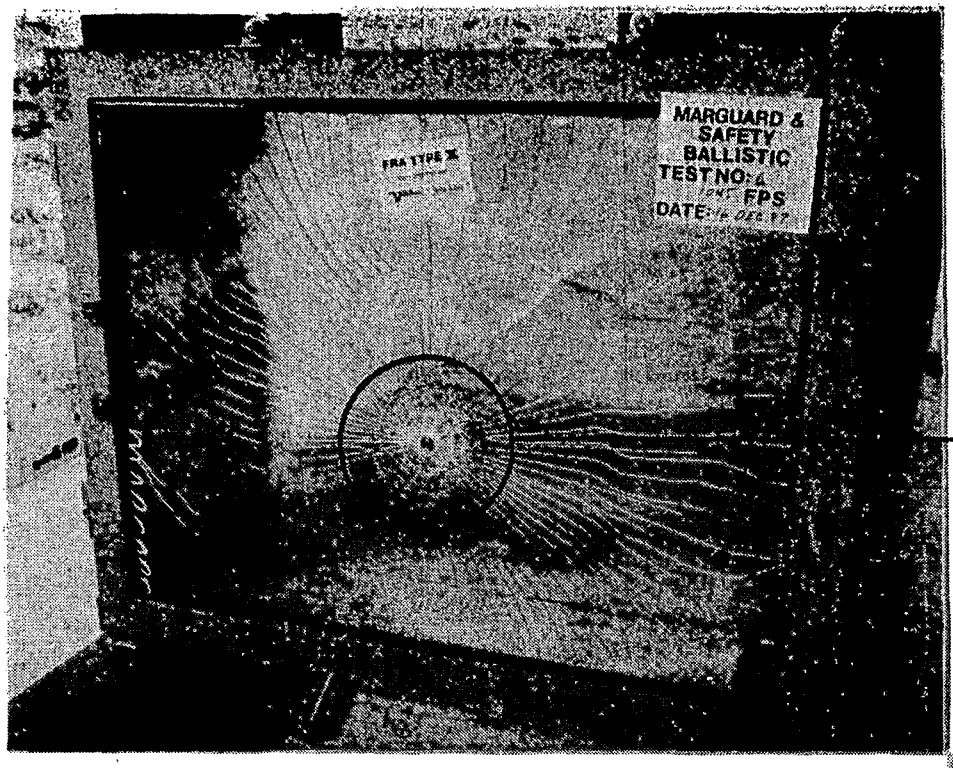
MARGARD & SAFETY

- Test Type: Types I & II Ballistic Impact (Test #2)
- Indicated Velocity: 1037 fps
- Muzzle to target Distance: 78.5 feet

Figure A-38. Rear view of the witness plate -- 2 or 3 small penetrations and several dents.

Figure A-37. Front view of a Margard & Safety glazing system after the second ballistic impact test.





MARGARD & SAFETY

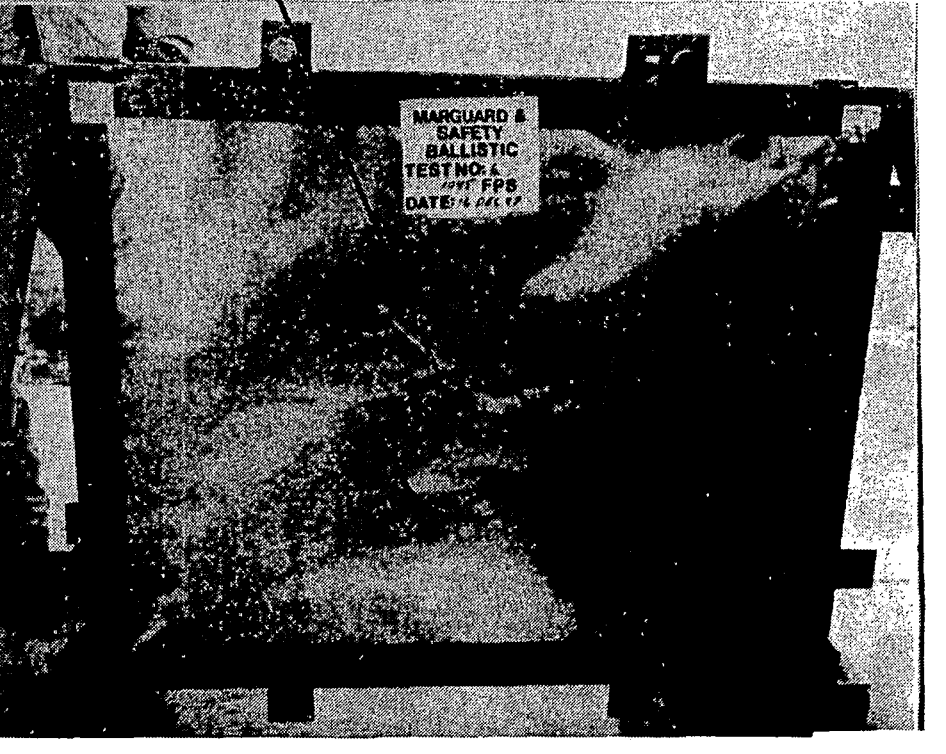
- Test Type: Types I & II Ballistic Impact (Test #3)
- Indicated Velocity: 1045 fps
- Muzzle to Target Distance: 78.5 feet

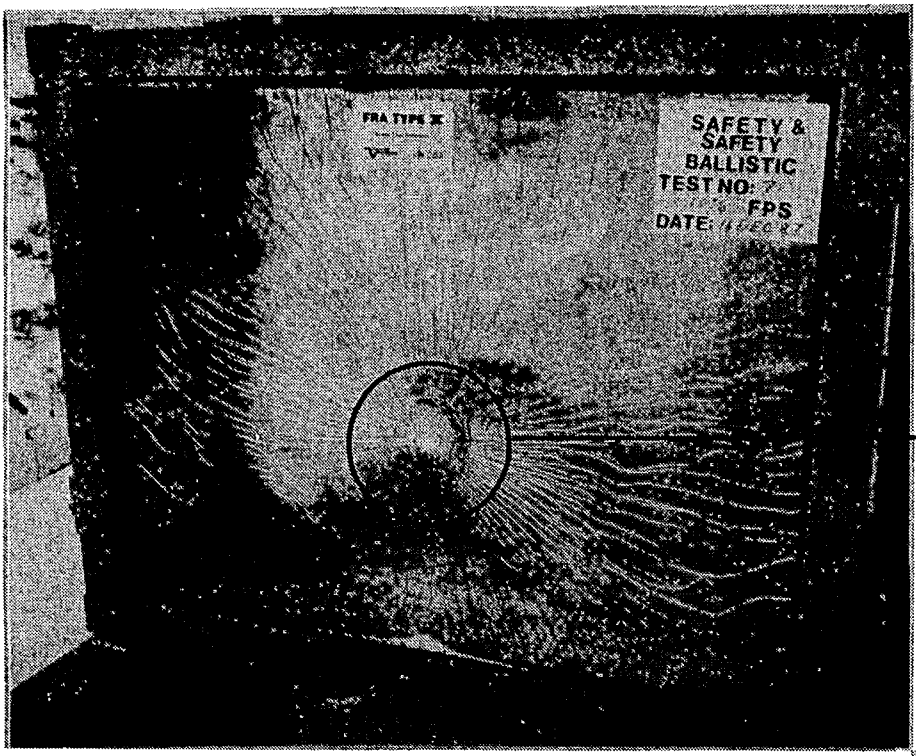
Figure A-40. Rear view of the witness plate -- penetrations and dents as indicated.

Figure A-39. Front view of a Margard & Safety glazing system after the third ballistic impact test.

Point of Impact

Two small penetrations, several dents.



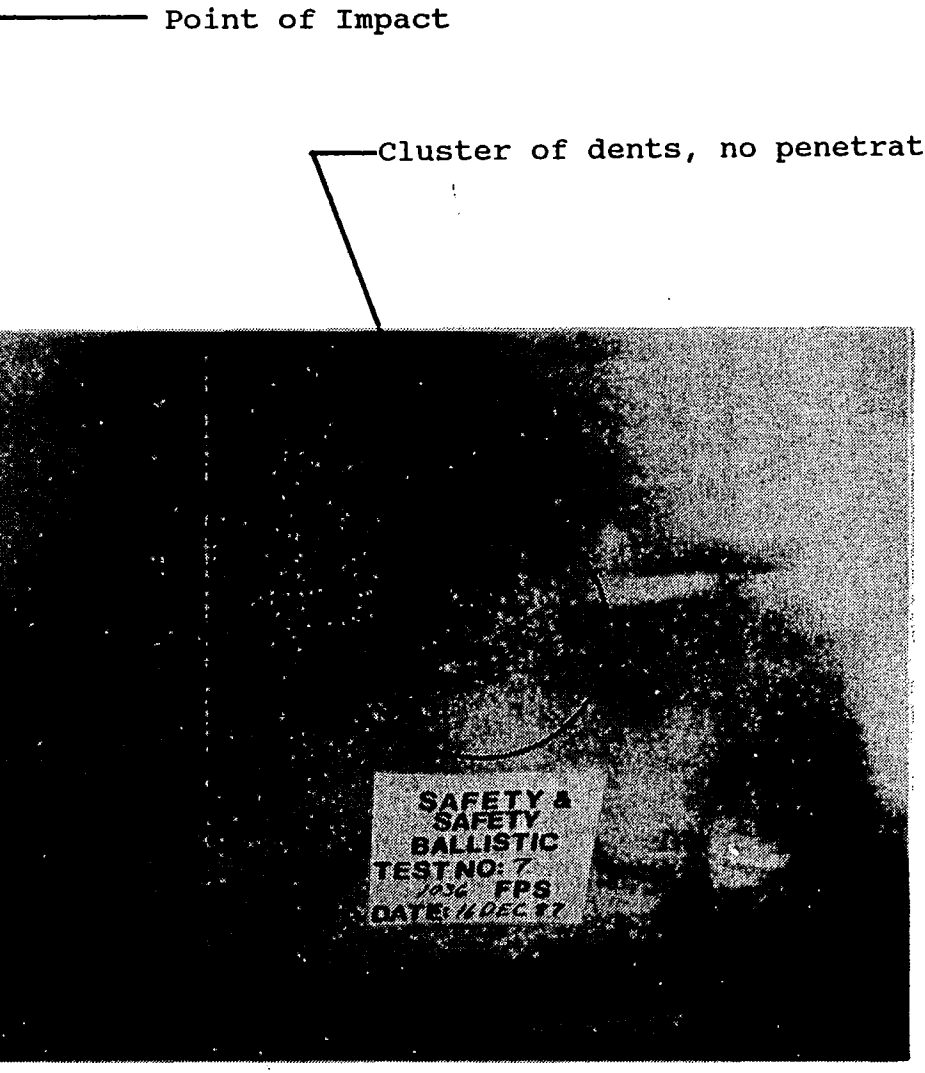


SAFETY & SAFETY

- Test Type: Types I & II Ballistic impact (single test)
- Indicated Velocity: 1036 fps
- Muzzle to Target distance: 78.5 feet

Figure A-42. Rear view of the witness plate -- no penetrations, many small dents.

Figure A-41. Front view of a Safety & Safety glazing system after the single ballistic impact test.



APPENDIX B

IMPACT VELOCITY GRAPHS FROM LARGE OBJECT IMPACT TESTS

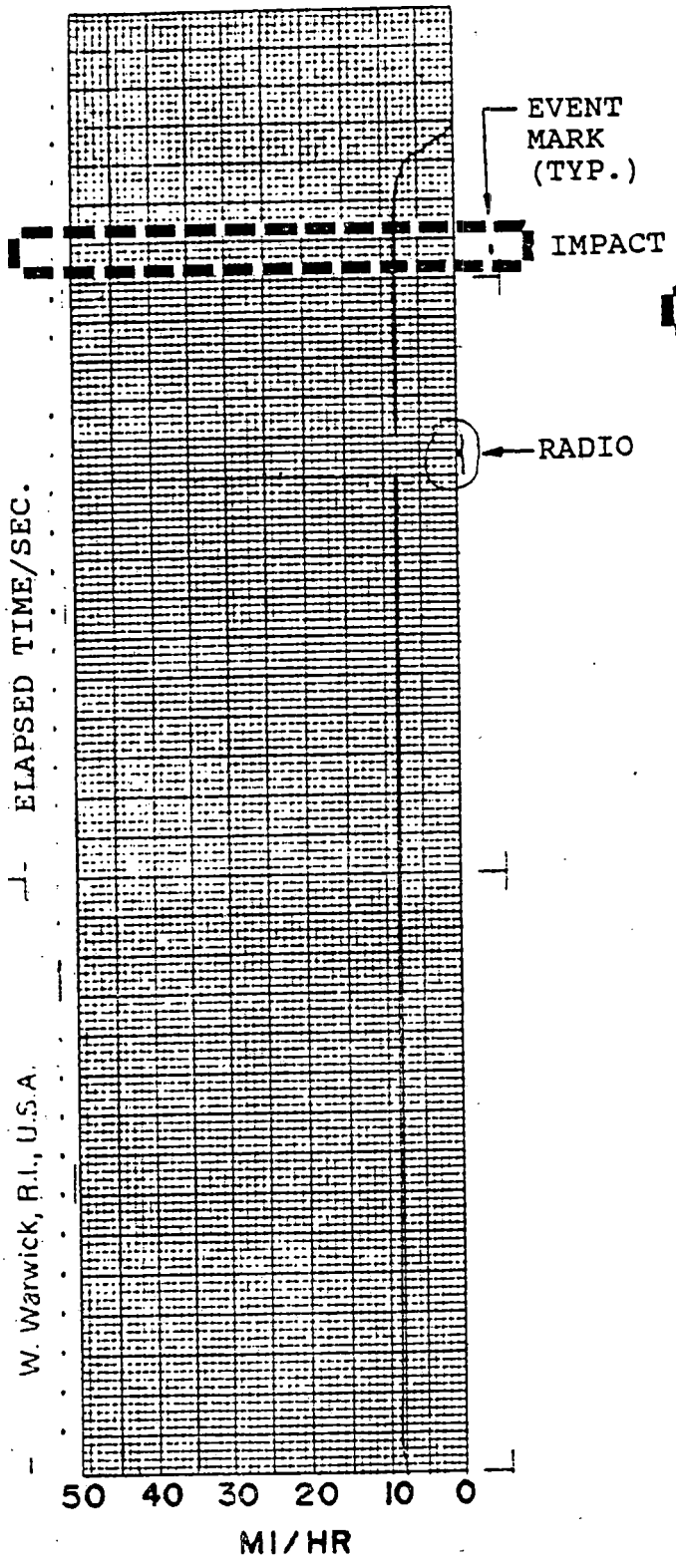


Figure B-1
ACRIVEU SA & SAFETY
Type II Large Object
Impact Test #1

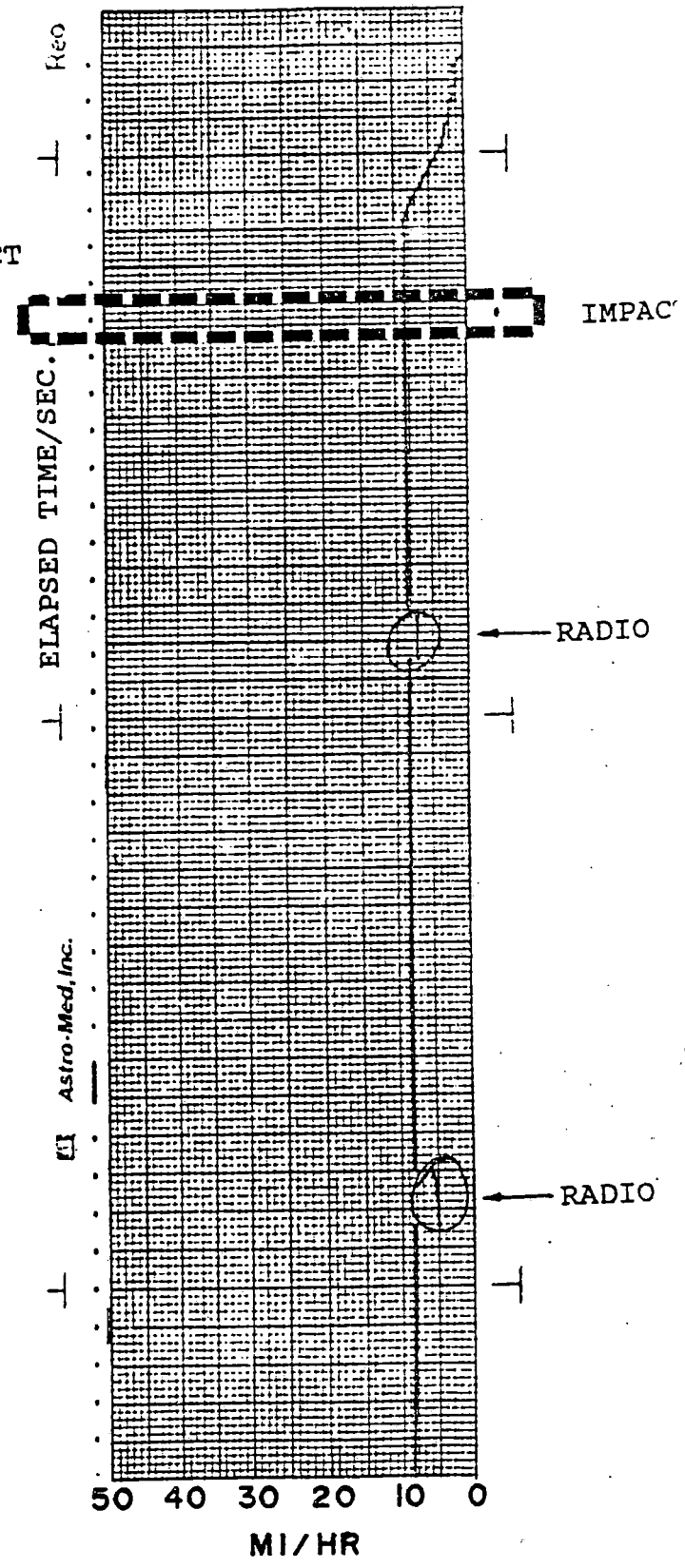


Figure B-2
ACRIVEU SA & SAFETY
Type II Large Object
Impact Test #2

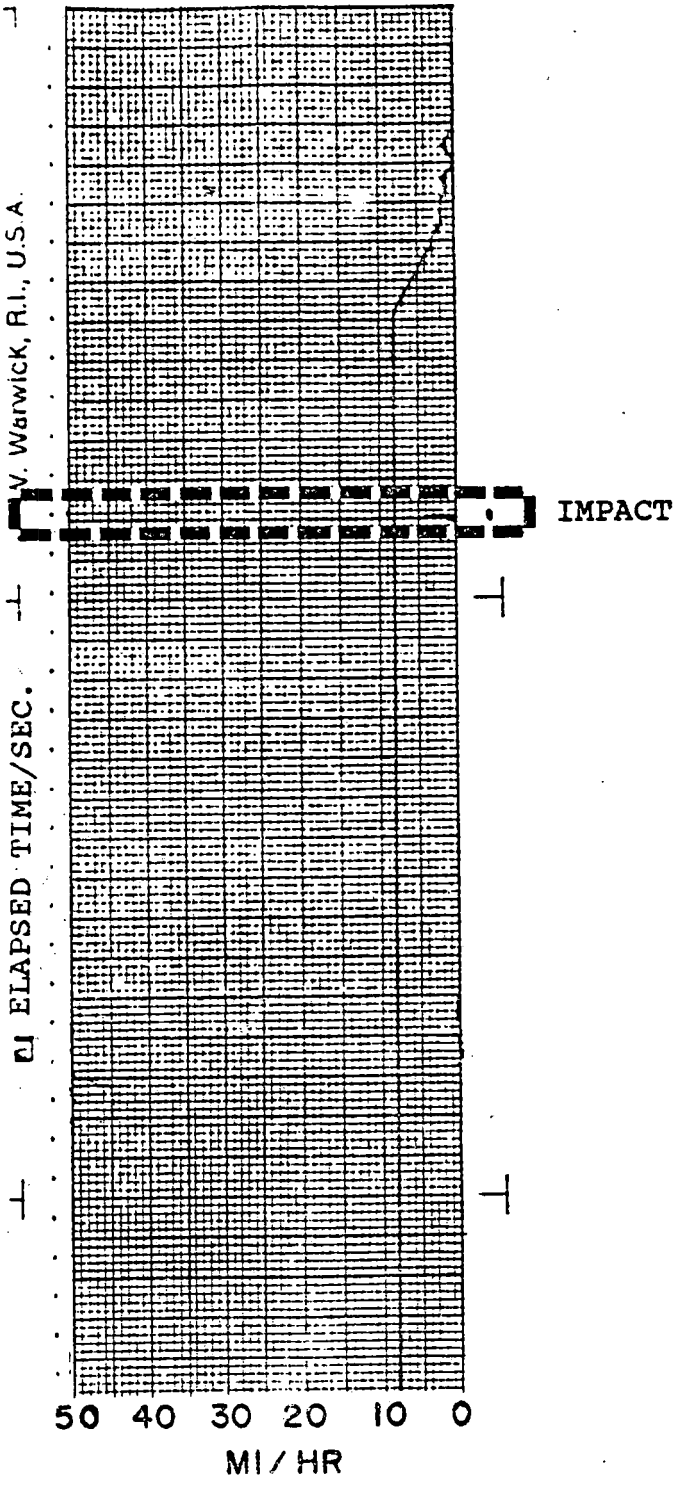


Figure B-3
MARGARD & SAFETY
Type II Large Object
Impact Test #1

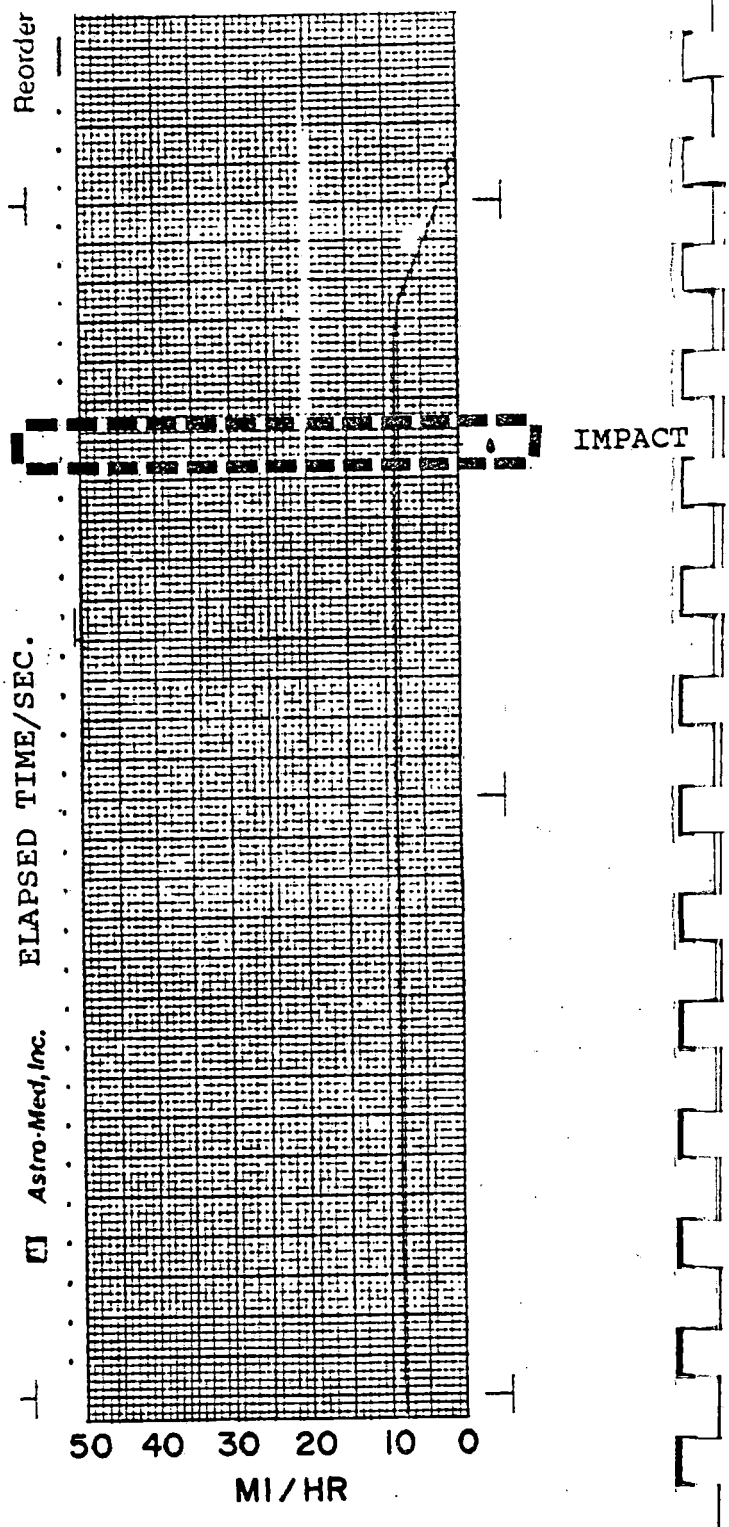


Figure B-4
MARGARD & SAFETY
Type II Large Object
Impact Test #2

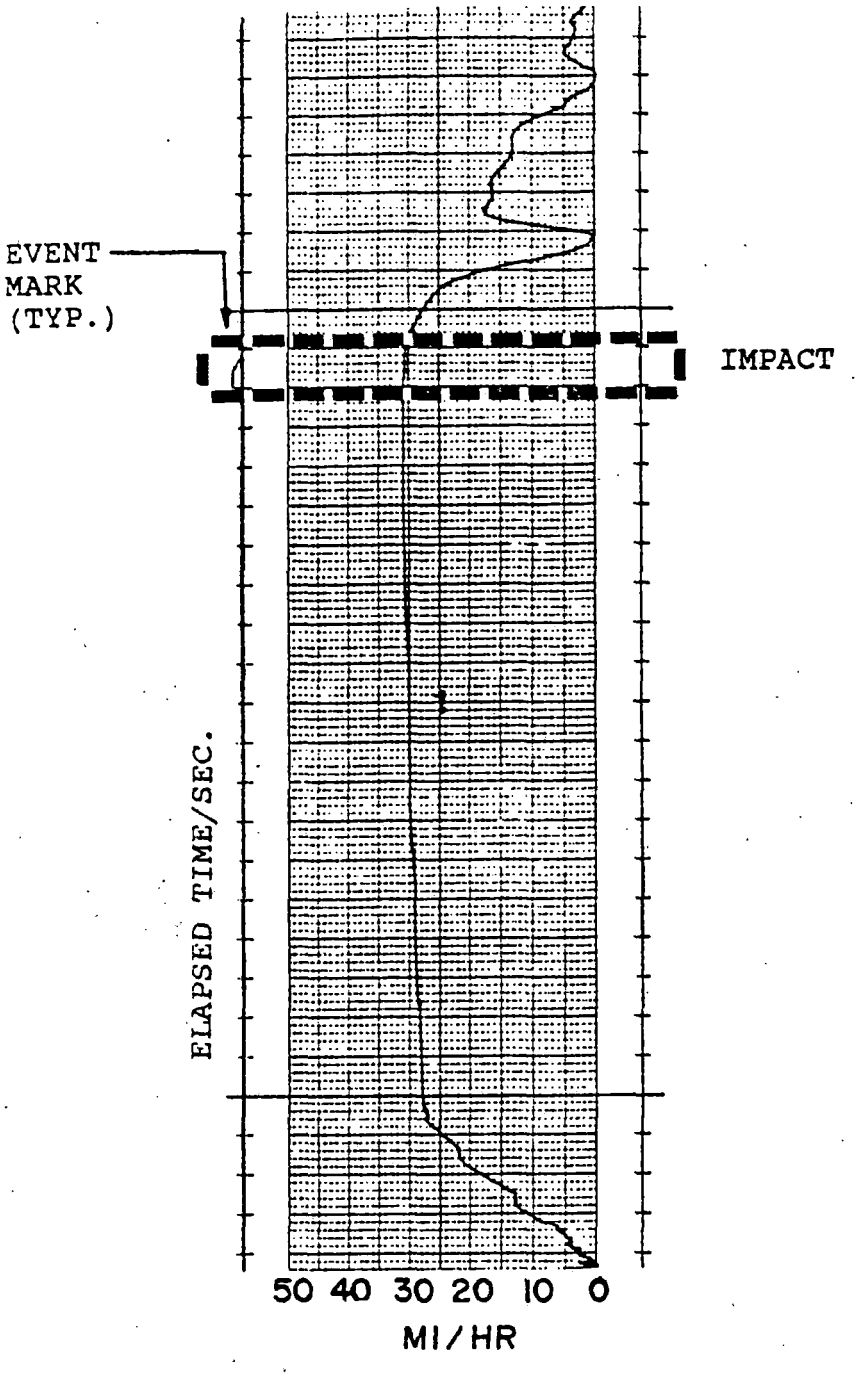


Figure B-5
ACRIVEU SA & SAFETY
Type I Large Object
Impact Test #1

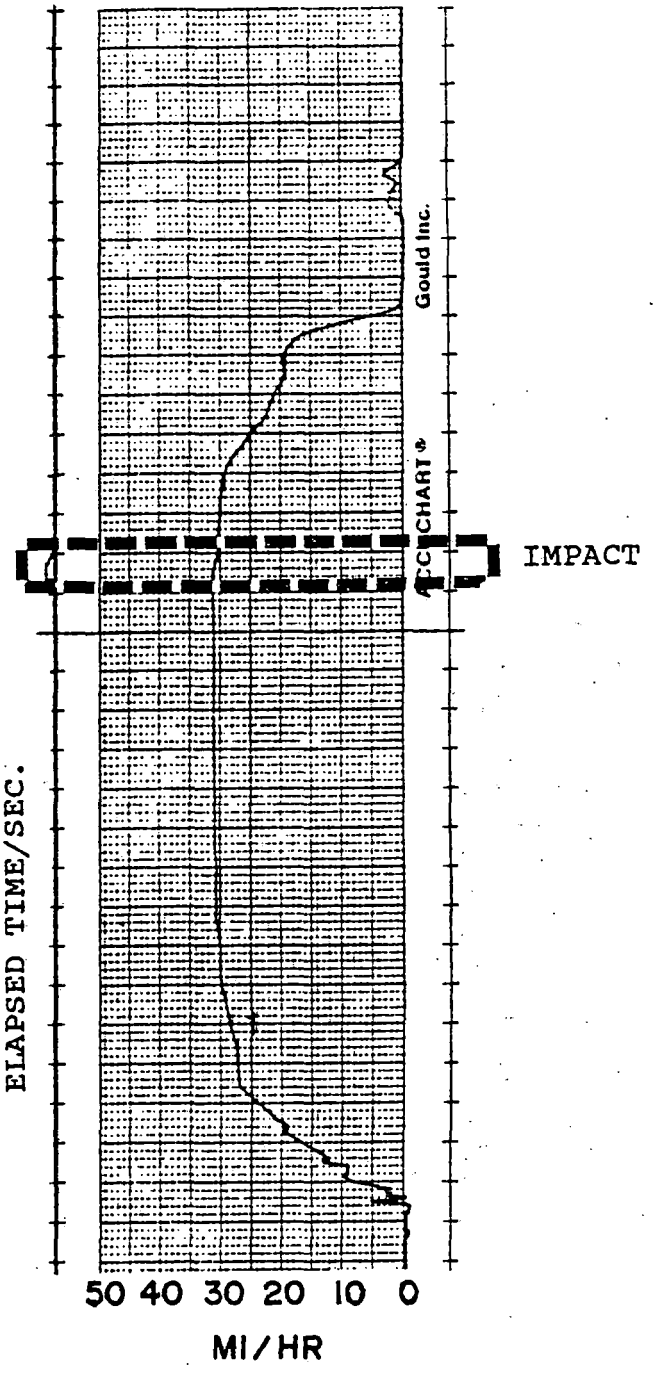


Figure B-6
ACRIVEU SA & SAFETY
Type I Large Object
Impact Test #2

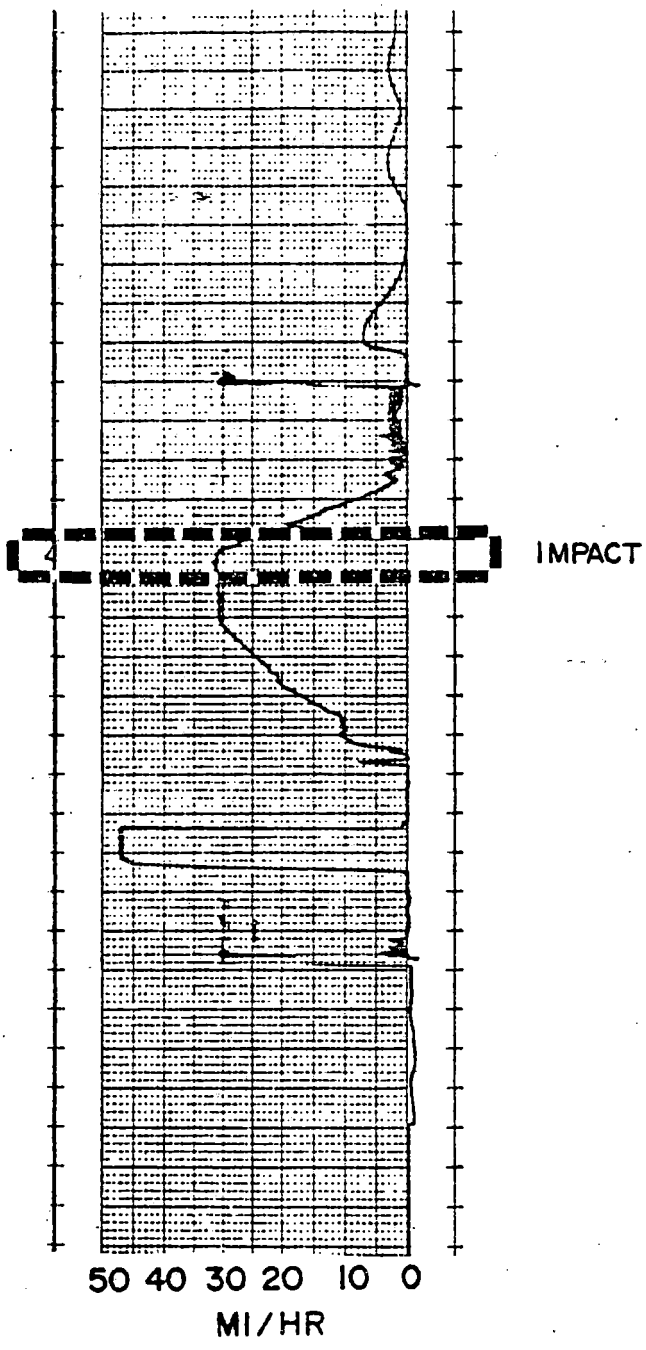


Figure B-7
MARGARD & SAFETY
Type I Large Object
Impact Test #1

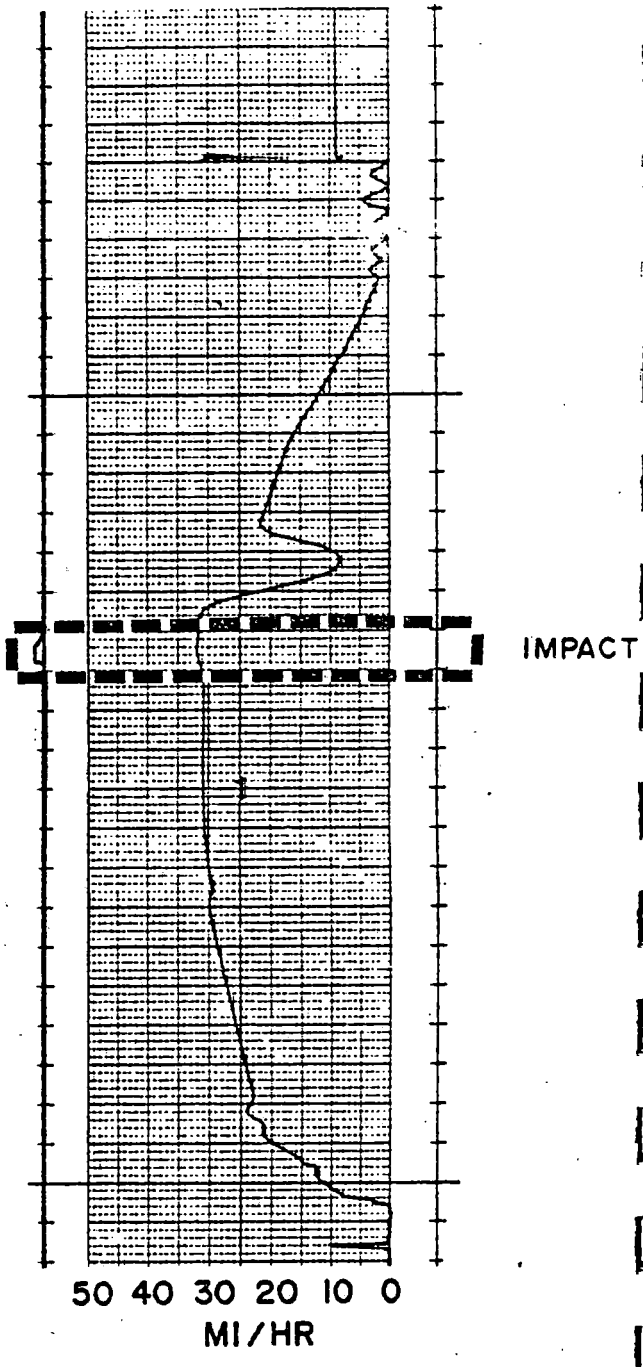


Figure B-8
MARGARD & SAFETY
Type I Large Object
Impact Test #2

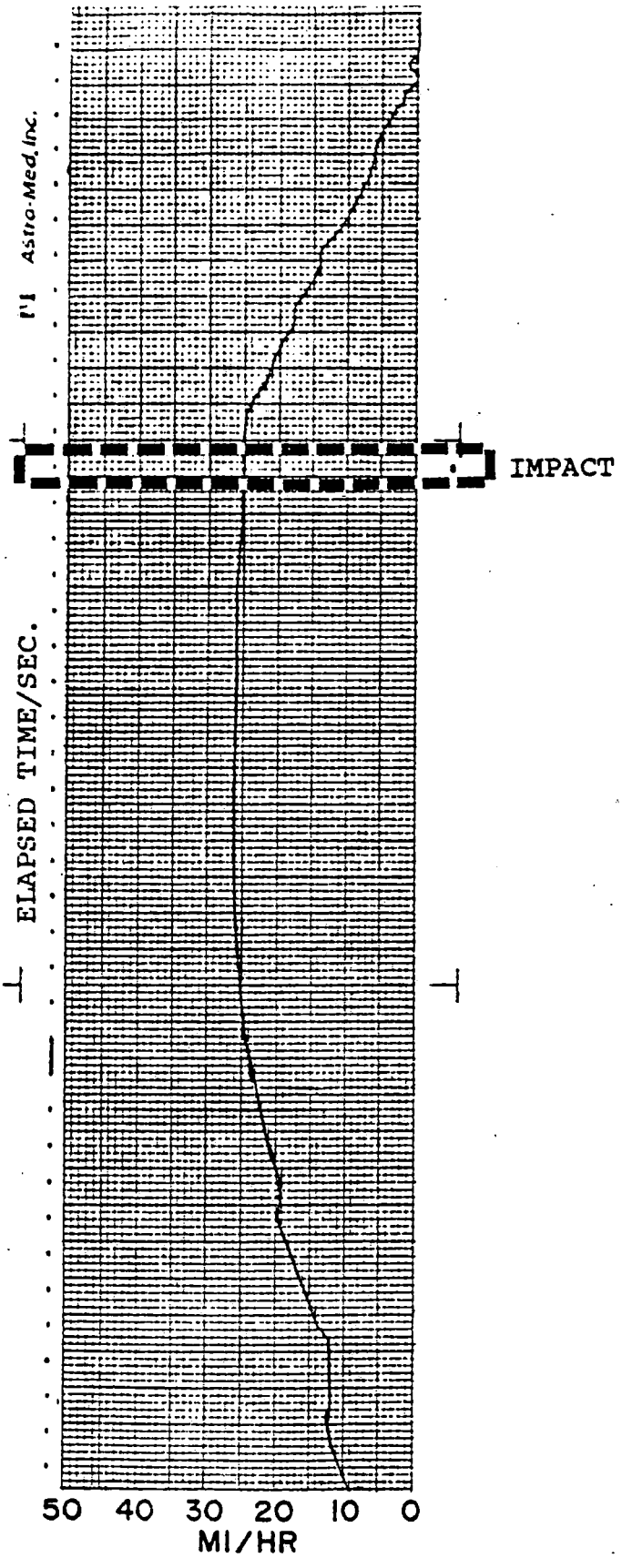


Figure B-9
ACRIVEU SA & SAFETY
Impact-to-Failure Test

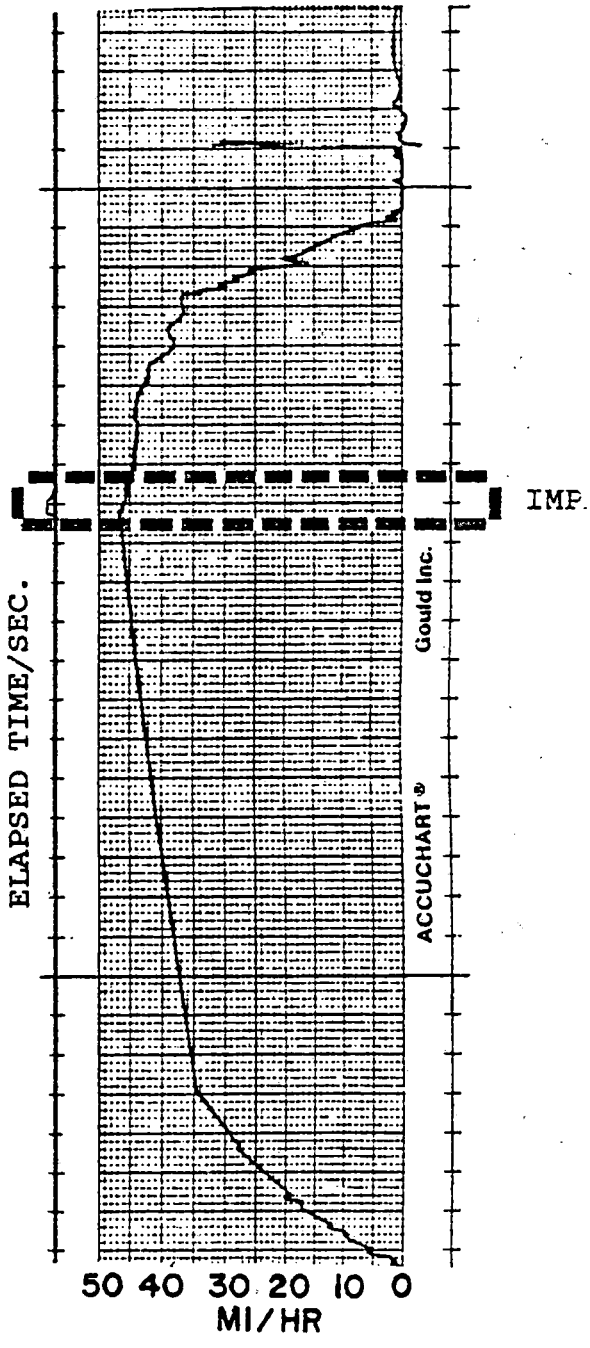


Figure B-10
MARGARD & SAFETY
Impact-to-Failure Test

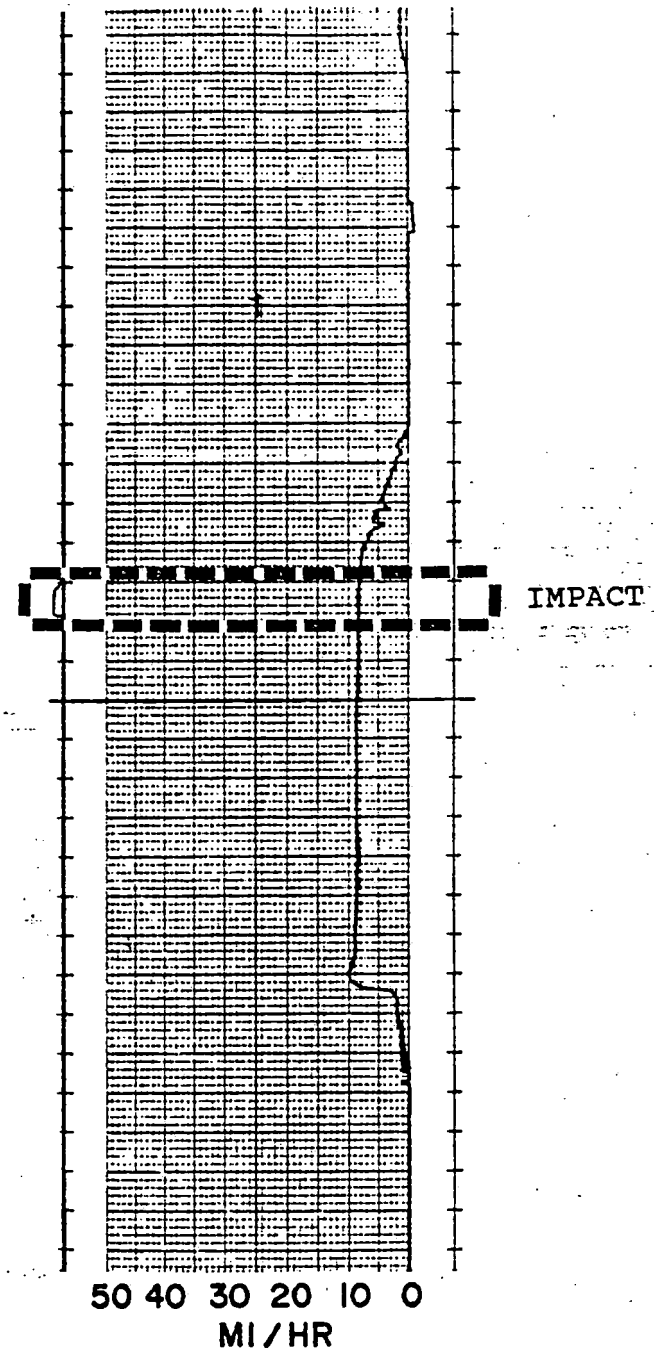
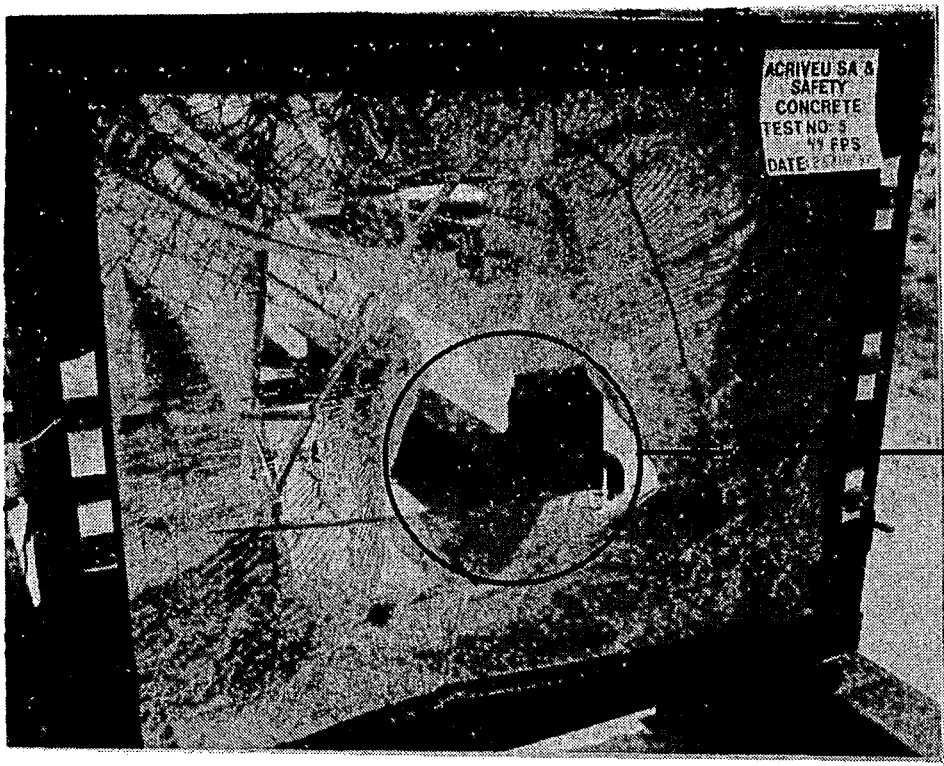


Figure B-11
SAFETY & SAFETY
Type II Large Object
Impact Test

APPENDIX C

PHOTOGRAPHS FROM GLAZING IMPACT TESTS, SAFETY GLASS INSTALLED BACKWARDS



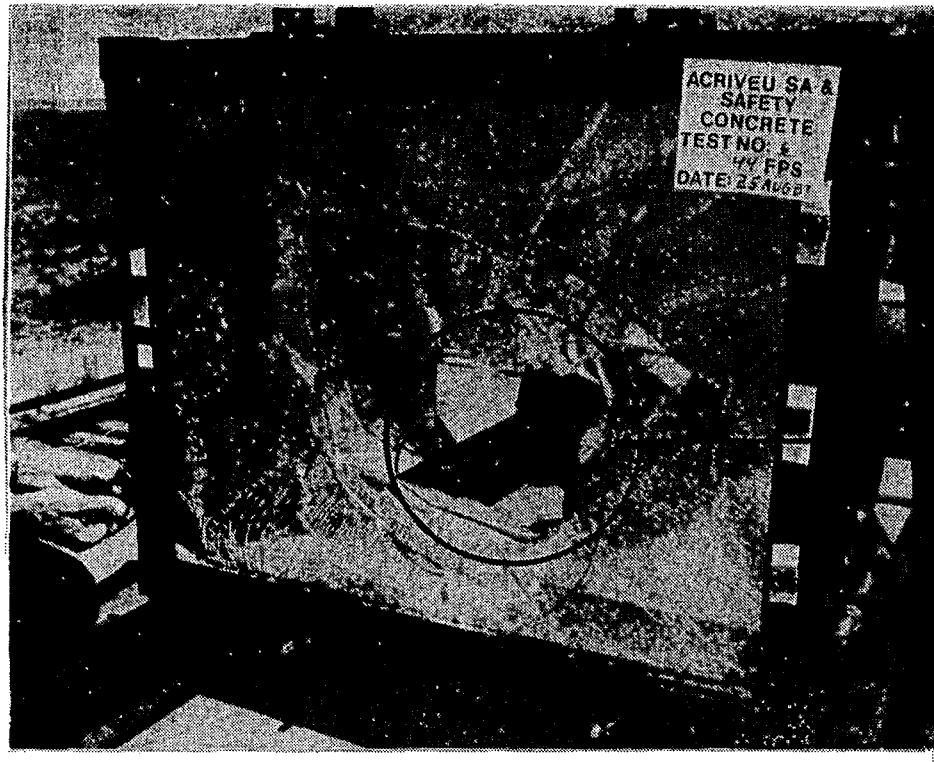
ACRIVEU SA & SAFETY - REVERSED

- Test Type: Type I Large Object Impact (Test #1)
- Recorded Velocity: 32.7 mph (48.0 fps)
- Cinder Block Weight: 24.2 lbs

Figure C-2. Rear view of the witness plate -- cinder block passed through.

Figure C-1. Front view of an Acriveu SA & Safety glazing system, Safety Glass installed backwards, after the first 44 fps cinder block impact run.

——————— Area of Impact



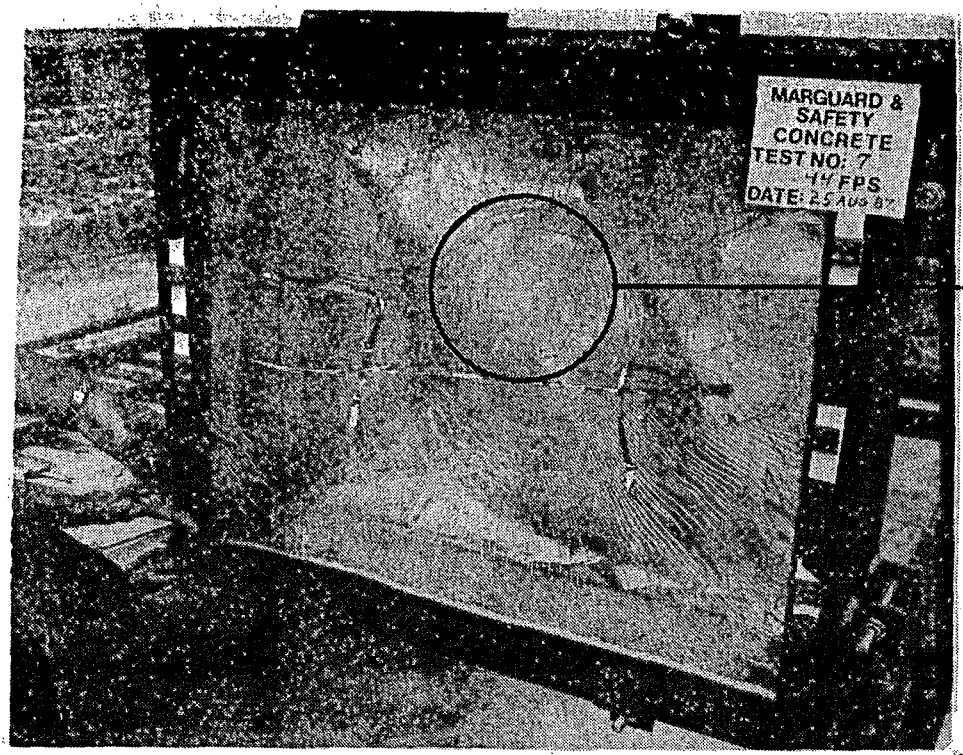
ACRIVEU SA & SAFETY - REVERSED

- Test Type: Type I Large Object Impact (Test #2)
- Recorded Velocity: 31 mph (45.5 fps)
- Cinder Block Weight: 24.3 lbs

Figure C-4. Rear view of the witness plate -- cinder block passed through.

Figure C-3. Front view of an Acriveu SA & Safety glazing system, Safety Glass installed backwards, after the second 44 fps cinder block impact run.

Area of Impact



MARGARD & SAFETY - REVERSED

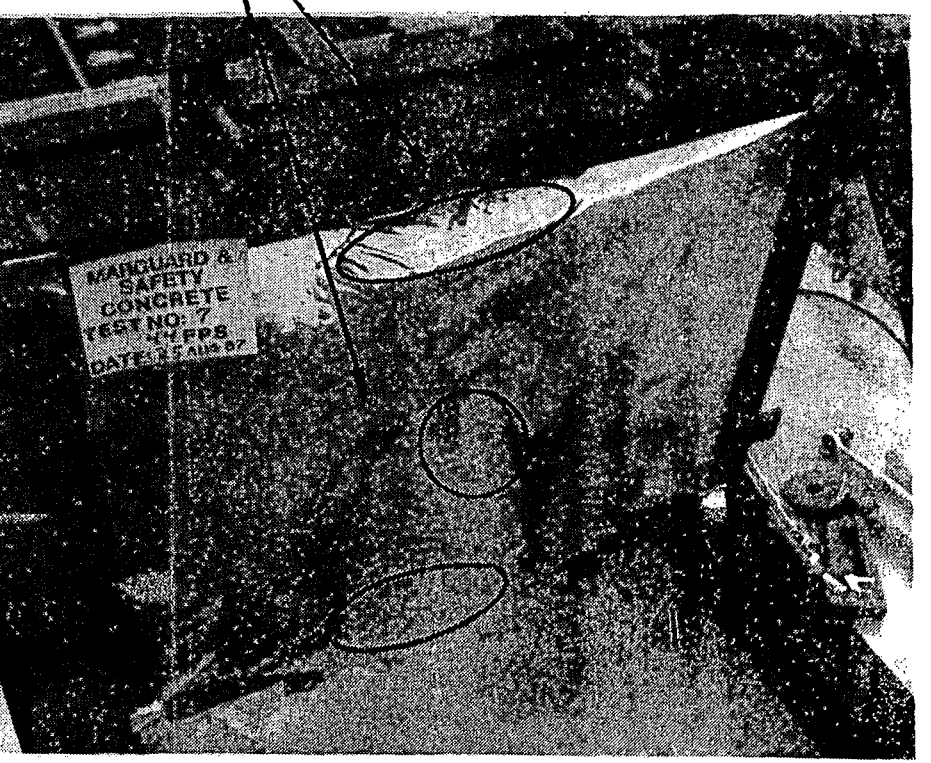
- Test Type: Type I Large Object Impact (Test #1)
- Recorded Velocity: 30.8 mph (45.2 fps)
- Cinder Block Weight: 24.2 lbs

Figure C-6. Rear view of the witness plate -- several small penetrations and dents in different areas. Margard bowed inwards, but remained intact. Witness plate was torn out at the bottom of the frame.

Figure C-5. Front view of a Margard & Safety glazing system, Safety Glass installed backwards, after the first 44 fps cinder block impact run.

——— Point of Impact

——— Areas of dents and penetrations.



MARGARD & SAFETY - REVERSED

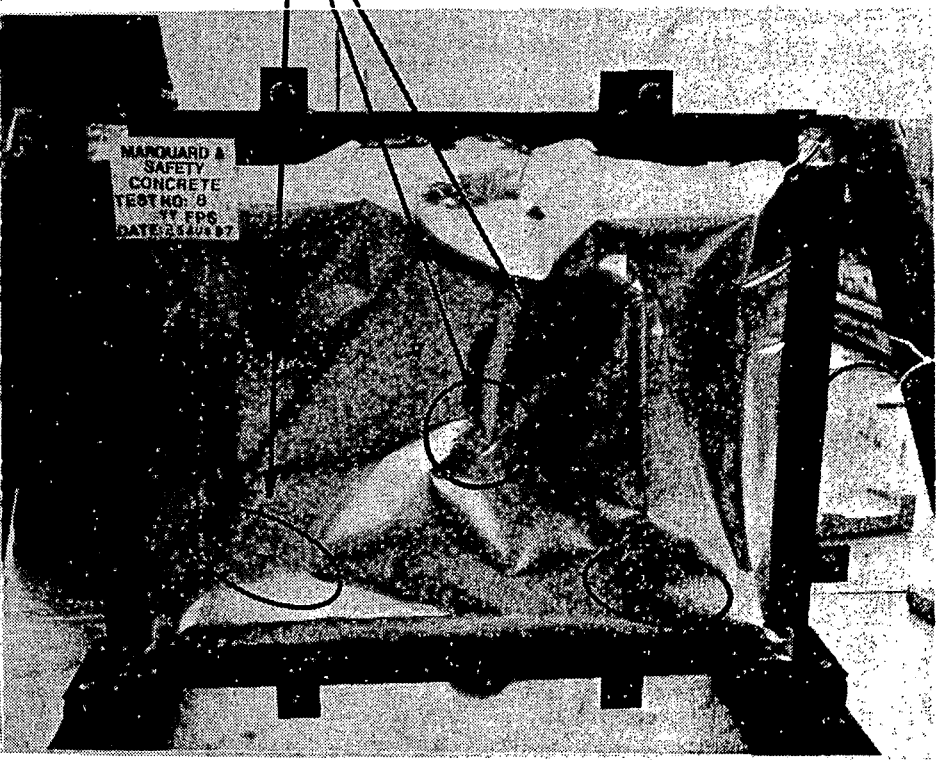
- Test Type: Type I Large Object Impact (Test #2)
- Recorded Velocity: 30.8 mph (45.2 fps)
- Cinder Block Weight: 24.5 lbs

Figure C-8. Rear view of the witness plate -- small penetrations and dents in areas shown. Aluminum torn out along top of the frame. Margard bowed inwards, but remained intact.

Figure C-7. Front view of a Margard & Safety glazing system, Safety Glass installed backwards, after the second 44 fps cinder block impact run.

Point of Impact

Areas of dents and penetrations.



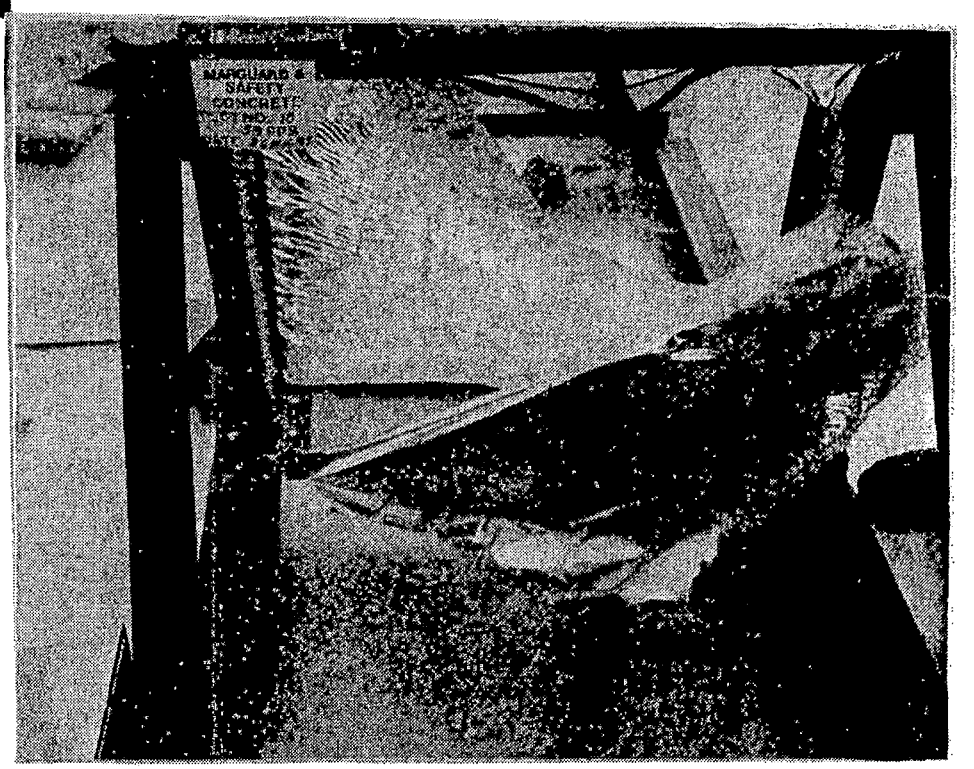
MARGARD & SAFETY - REVERSED

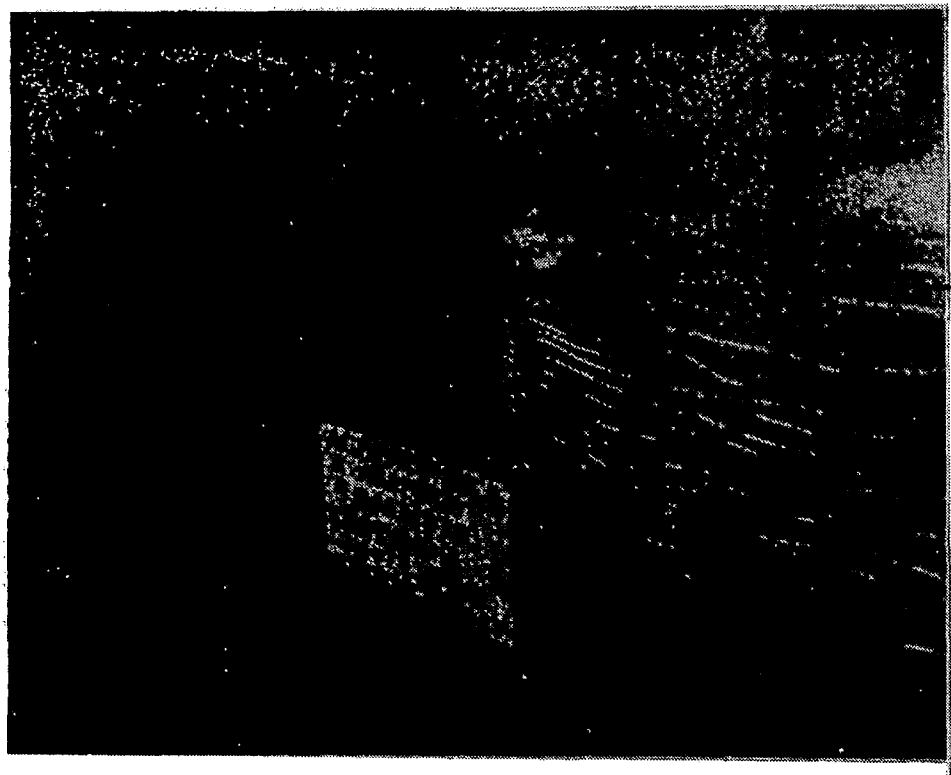
- Test Type: Impact-to-Fail (one test only)
- Recorded Velocity: 43.8 mph (64.3 fps)
- Cinder Block Weight: 24.0 lbs

Figure C-10. Rear view of the witness plate -- safety glass broken apart and witness plate almost torn away. Margard remained intact but was pushed out of the frame at the top and left side.

Figure C-9. Front view of a Margard & Safety glazing system, Safety Glass installed backwards, after the "impact-to-fail" cinder block impact run.

Point of Impact





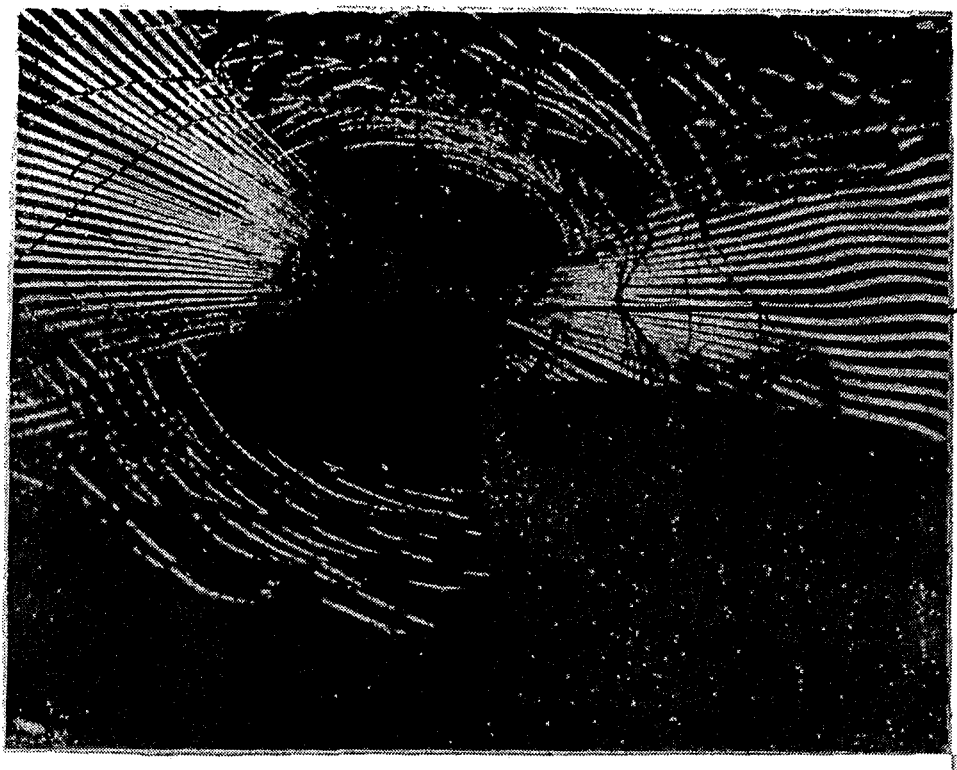
ACRIVEU SA & SAFETY - REVERSED
- Test Type: Types I & II Ballistic Impact (Test #1)
- Indicated Velocity: 1079 fps
- Muzzle to Target Distance: 63 feet

Figure C-12. Rear view of the witness plate -- holes and dents as indicated, but bullet impinged onto the Safety Glass; did not pass through.

Figure C-11. Front view of an Acriveu SA & Safety glazing system, Safety Glass installed backwards, after the first bullet impact test.

Point of Impact

3/4" +/- diameter hole with cluster of small penetrations and dents.



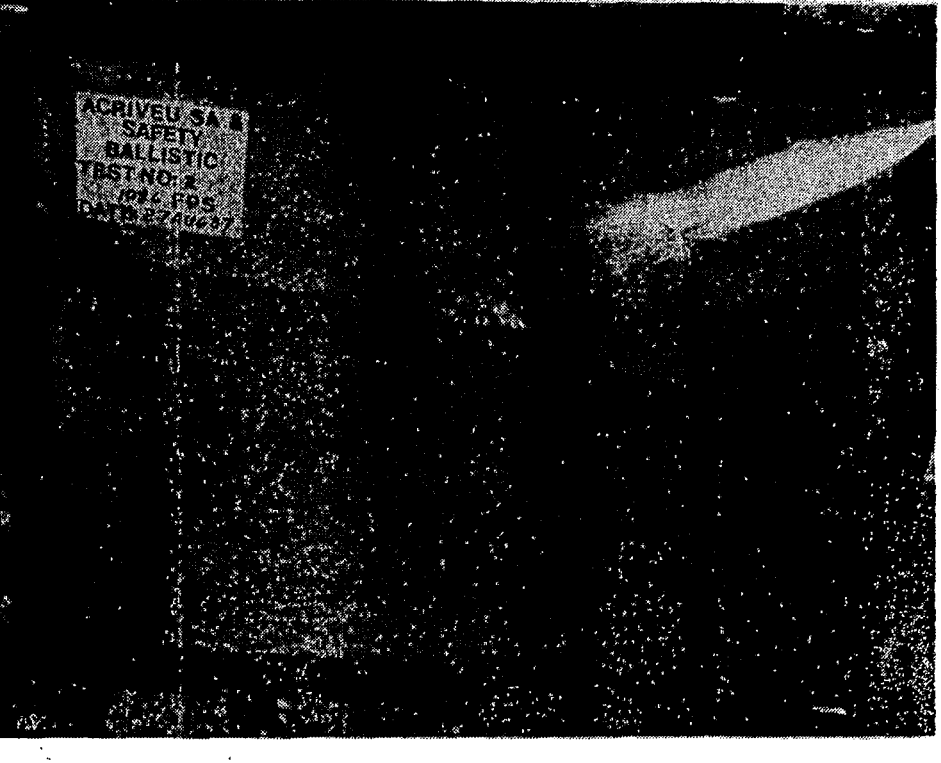
ACRIVEU SA & SAFETY - REVERSED
- Test Type: Types I & II Ballistic Impact (Test #2)
- Indicated Velocity: 1086 fps
- Muzzle to Target Distance: 63 feet

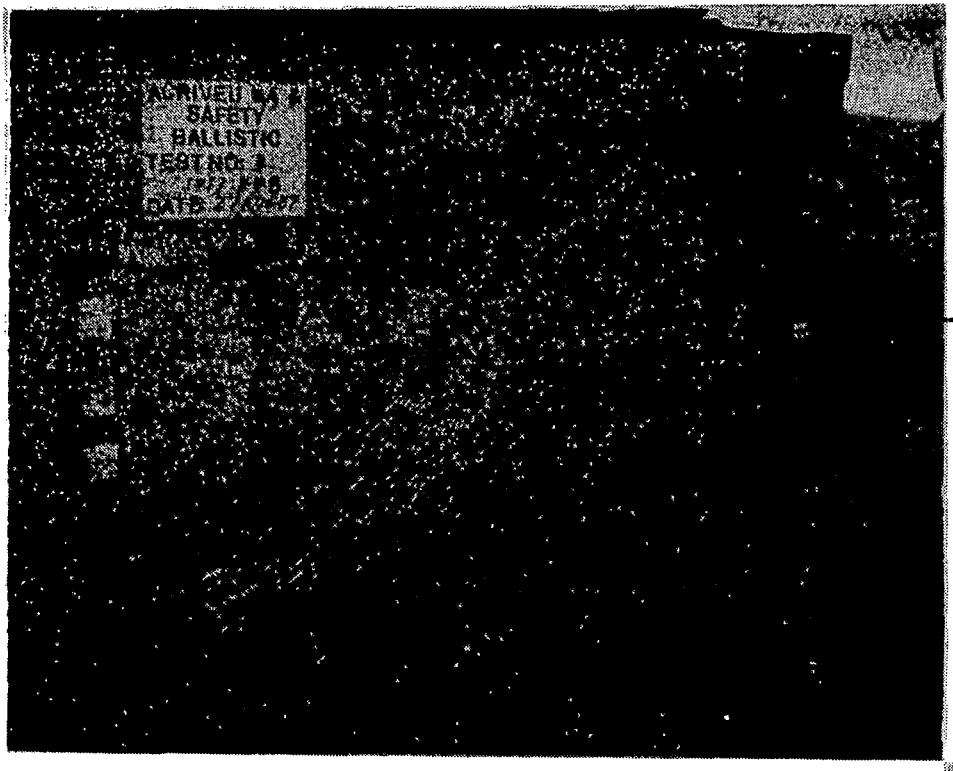
Figure C-14. Rear view of the witness plate -- bullet impinged onto Safety Glass, small glazing penetrations and dents as shown.

Figure C-13. Front view of an Acriveu SA & Safety glazing system, Safety Glass installed backwards, after the second bullet impact test.

Point of Impact

Cluster of small penetrations and dents.





ACRIVEU SA & SAFETY - REVERSED

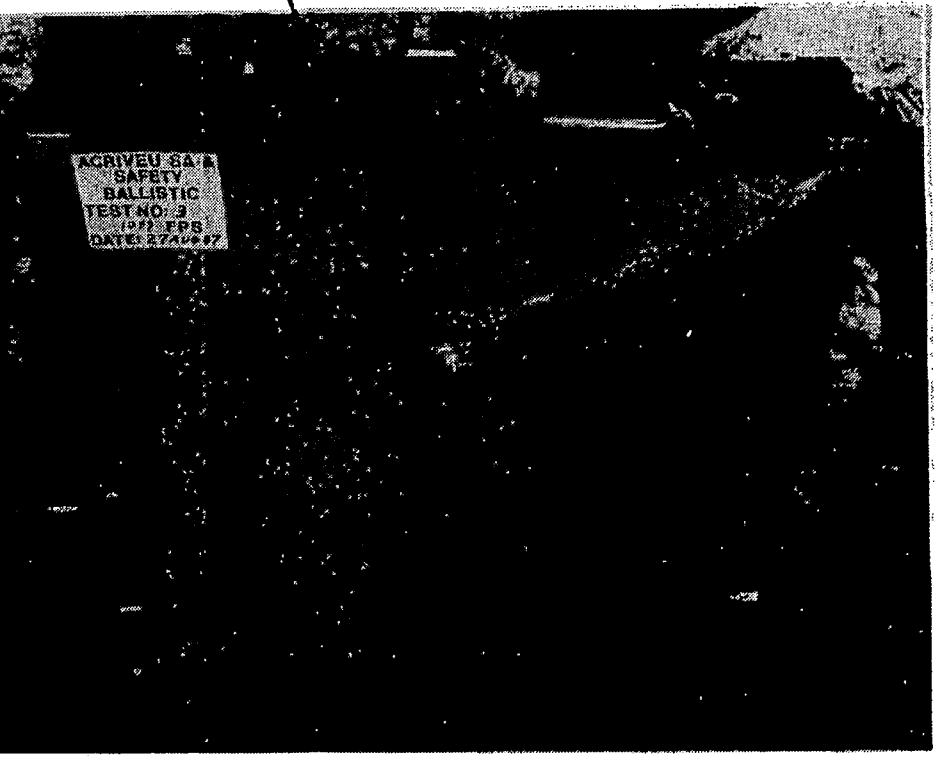
- Test Type: Types I & II Ballistic Impact (Test #3)
- Indicated Velocity: 1077 fps
- Muzzle to Target Distance: 63 feet

Figure C-16. Rear view of the witness plate -- bullet stopped at safety Glass and fell down between the glazings. Small penetrations and dents as indicated.

Figure C-15. Front view of an Acriveu SA & Safety glazing system, Safety Glass installed backwards, after the third bullet impact test.

Point of Impact

Cluster of small penetrations and dents.



MARGARD & SAFETY - REVERSED

- Test Type: Types I & II Ballistic Impact (Test #1)
- Indicated Velocity: 1080 fps
- Muzzle to Target Distance: 63 feet

Figure C-18. Rear view of the witness plate -- bullet passed through as indicated.

Figure C-17. Front view of a Margard & Safety glazing system, Safety Glass installed backwards, after first bullet impact test.

Point of Impact

Bullet and glass pieces passed through, leaving 1 1/2" diameter hole and smaller penetrations and dents.

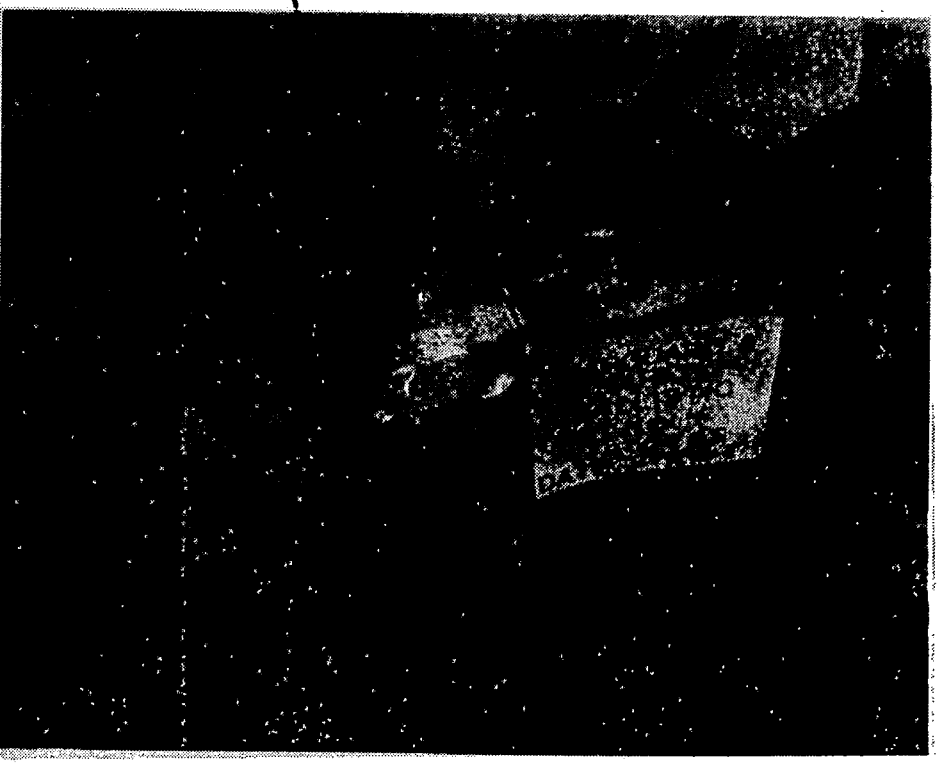
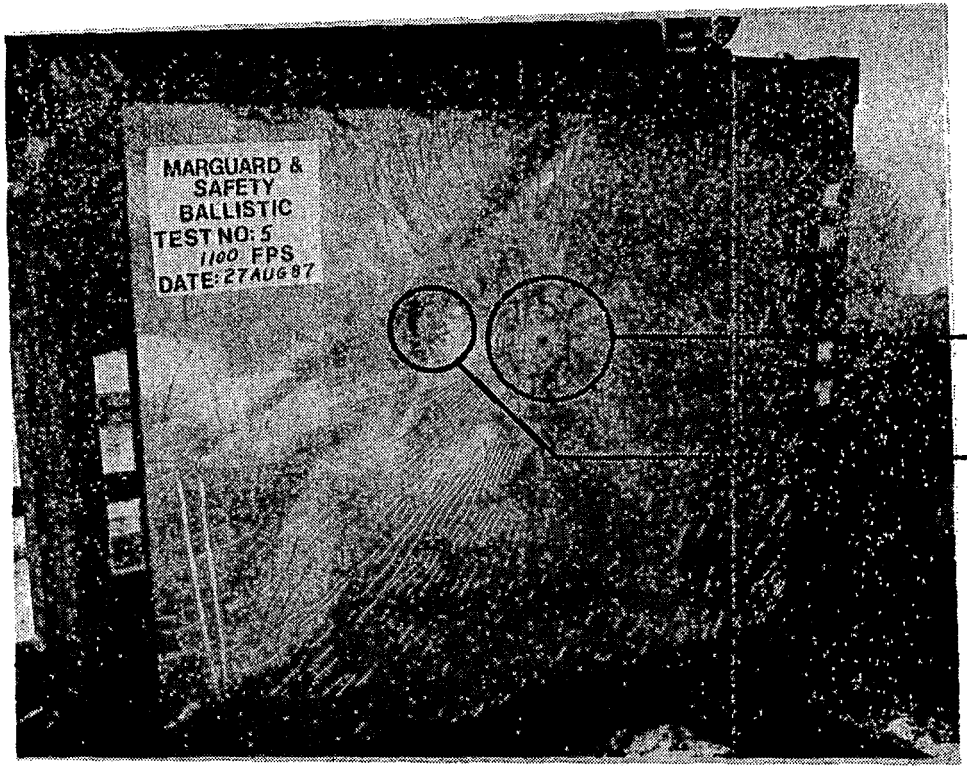
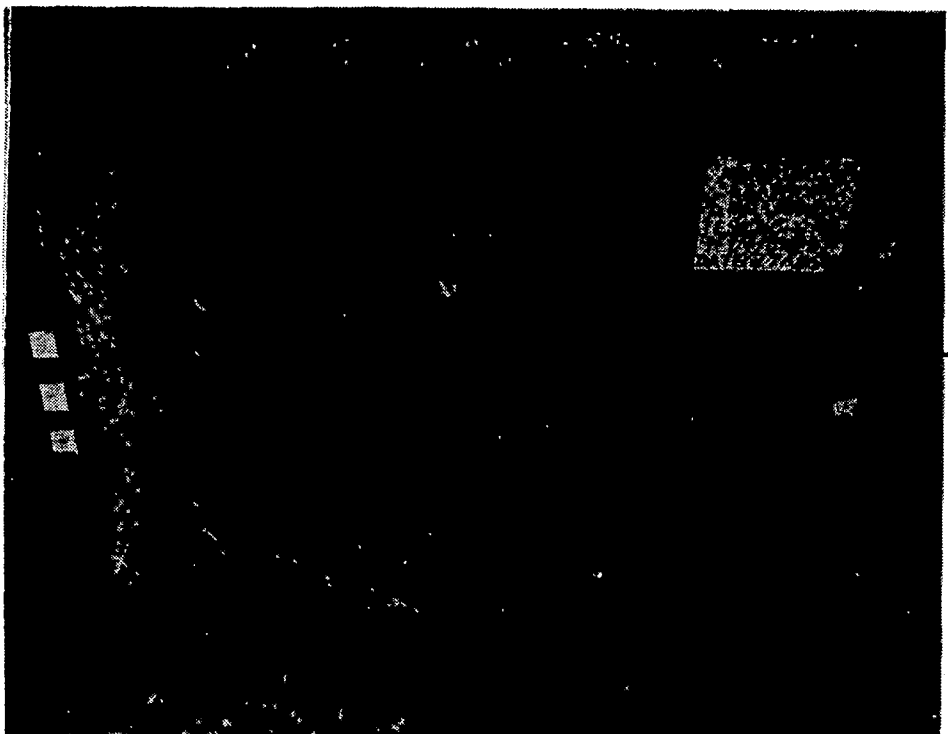


Figure C-19. Front view of a Margard and Safety glazing system, Safety Glass installed backwards, after second bullet impact test.



MARGARD & SAFETY - REVERSED

- Test Type: Types I & II Ballistic Impact (Test #2)
- Indicated Velocity: 1100 fps
- Muzzle to Target Distance: 63 feet



MARGARD & SAFETY - REVERSED

- Test Type: Types I & II Ballistic Impact (Test #3)
- Indicated Velocity: 1091 fps
- Muzzle to Target Distance: 63 feet

Figure C-21. Rear view of the witness plate -- bullet passed through as indicated.

Figure C-20. Front view of a Margard & Safety glazing system, Safety Glass installed backwards, after third bullet impact test.

Point of Impact

Bullet and glass pieces passed through, leaving 1 1/2" diameter hole and smaller penetrations and dents.