EFFECTS OF SOFT FOAM INSULATION IMPACT

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by

James L. Rand

and

David J. Norton

Final Report

TEES

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prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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Contract No. NAS 9-15962

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Abstract

This report describes the results of a series of tests in which High-Temperature Reusable Surface Insulation (HRSI) tiles were impacted by a variety of foam insulation materials. The foams were typical of the debris from the main tank anticipated to strike the orbiter during the initial phases of flight. Failure of the HRSI coating was observed to be strongly dependent on the density and size of the projectile. The failure threshold was found to be as low as 140 feet per second for rubber and as high as 740 feet per second for Styrofoam. In addition, the impact pressure was measured for a variety of debris materials as a function of velocity.

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Introduction

The Orbiter thermal protection system provides thermal attenuation of aerothermal heating on the external surface of the Orbiter vehicle during atmospheric entry. The lower surface of the Orbiter will be protected by HRSI (High - Temperature Reuseable Surface Insulation) tiles which nominally measure 6 by 6 inches in planform and vary in thickness from 0.75 to 3.5 inches depending on local heating conditions. HRSI tiles comprise a low density, high purity silica fiber insulation made rigid by a ceramic bonding process. A borosilicate glass is then applied to the tile to form a black, hardened impermeable surface. Each tile is bonded to a strain isolation pad made of nomex fiber felt and the total composite is bonded directly to the Orbiter's aluminum skin structure.

During Shuttle Orbiter launch, the thermal protection system will be subjected to debris particle impact generated by the external tank attached to the Orbiter lower surface. The external tank provides the Orbiter propulsion system with liquid hydrogen and liquid oxygen and is thermally protected for prelaunch operations with a low density spray-on foam insulation (SOFI). During vertical flight, after lift-off, this protective insulation on brackets supporting flow lines and electrical cable tray is not required and can become detached from the external tank as fragments, whose weight has been estimated to vary from 0.1 to 2.5 lbs. These fragments impacting the Orbiter at free stream velocities may damage HRSI tiles and degrade tile design thermal performance during entry.

The purpose of this report is to document the damage which may be anticipated from the impact of SOFI fragments on HRSI tiles at velocities from 100 to 1800 feet per second and at angles of impact from 90° to 60°.

The materials used to characterize the debris included Dyplast Styrofoam, BX-250, CPR, Blue Styrofoam and Vitron Rubber.

Procedure

In order to obtain the necessary information, the Texas A&M University low speed air gun which is adequately described in a previous report (1) was used to accelerate the low mass projectiles to the desired velocity. In order to supplement the data from this 3/8 inch smooth bore gun, three additional barrels were fabricated with bore sizes of 1, 1½, and 2 inches. These barrels were bolted to the high pressure, house air supply and activated by rupturing a variety of thin plastic diaphragms.

Two types of tests were conducted using these four barrels. HRSI tile targets were used to determine the impact velocity which caused coating cracks. The alcohol wipe technique was used to inspect tiles both before and after each impact. The impact velocity was obtained by using light sensitive diodes to start and stop an electronic timer. The tile holder is described in reference 1 and simulates not only the tile but the nomex pad and aluminum substructure of the Orbiter.

A second series of tests utilized a ½ inch thick aluminum plate target with a flush mounted pressure transducer to obtain impact pressure as a function of velocity for a variety of projectile materials. The target material was selected since its material properties closely simulates those of the silicate coating of the HRSI tiles. The transducer was a Kristal Type 603B quartz pressure transducer for high frequency measurements. The sensor and its associated amplifiers and recording oscilloscope have a rise-time of one microsecond and a resonant frequency in excess of 400 kHz. It has a maximum measuring range of 3000 psi and may be used in a shock environment to 10,000 g's with a maximum error of 15 psi.

A number of tests were conducted at "low" temperatures. This was accomplished by floating the projectiles in a pool of liquid Nitrogen contained in a one liter Dewar. The projectile could be removed from the Dewar, loaded into the barrel, and fired against the target in less than ten seconds. Heat conduction calculations indicate that this was sufficient to maintain the centerline temperature to within 25°F of the liquid Nitrogen temperature.

Results

The results of these tests have been recorded and are presented in the accompanying figure. The pressure data was recorded on an oscilloscope and photographed. These photographs are contained in Appendix A through F. A list of the various impact parameters is contained in the accompanying tables.

The results of the alcohol wipe inspection of each HRSI tile was sketched on a data sheet. These sheets and a list of the various impact parameters is contained in Appendix G. In addition, high speed motion pictures were obtained of the impact of various materials against the targets.

Discussion

As a result of this series of tests the damage to a typical HRSI tile by the impact of foam insulation may be characterized by a relatively simple impact theory which has been documented by Wilbeck (2). In essence, the pressure generated by the impact of a "soft" material is characterized by a leading high pressure spike (sometimes called the Hugoniot pressure) followed by a lower pressure equal to the dynamic pressure of the material ($\frac{1}{2} \rho U_p^2$). The duration of the impact event may be approximated by the length of the projectile divided by the velocity, U_p.

The target of interest is the HRSI tile coating. This coating is

.015 inch thick and therefore will respond to any applied pressure locally in the time it would take for an elastic wave to propagate through the surface (~75 nanoseconds). The insulation behind the silicate is of such low impedance, it will behave effectively as a free surface. Therefore, the coating failure will be caused by the leading high pressure spike and is not influenced by the length or duration of the impact event. It is quite probable that static testing of tiles to failure will be an adequate failure criteria. Dynamic characterization of the debris material will then permit the velocity to cause failure to be predicted.

Data were obtained for both pressure and tile damage at an oblique impact of 60°. The pressure data correlates reasonably well with the $\sin^2\alpha$ theory contained in reference 2. However, tile damage threshold is indicated at the same velocity as for normal impact. It is felt that surface irregularities on the tile were sufficient to cause a portion of the projectile to be locally perpendicular. Since at the instant of impact the local stress is essentially a pressure equal in all directions for a short period of time, and since the tile responds so quickly, no attenuation due to angle of obliquity should be considered.

Data obtained at low temperatures by soaking the projectile in liquid Nitrogen are somewhat scattered but show no reduction in threshold velocity or increase in pressure. However, some projectiles were noted to increase in mass after soaking, most notable was BX-250. This material shattered on impact causing a high frequency pressure oscillation of relatively low amplitude.

A very thin sheet of Vitron rubber, which is to be used as a boot to cover a valve, was fired against both the transducer and a tile. The thin sheet was attached to a light weight styrofoam projectile with tape and cement. Due to the high impedance of this material, high pressures

were generated for a very short period of time. In addition, deep penetration into the HRSI tile was observed at a velocity of 140 feet per second.

A similar effect was noted with Styrofoam coated with a thin layer of FBL fire retardant material. The FBL coating created a high pressure at low velocities as well as coating cracks at velocities much less than the uncoated Styrofoam.

Testing of Styrofoam projectiles of increasing length at constant velocity confirmed the theory that the amplitude of the pressure is independent of length. Although the duration of impact is increased and therefore the impulse, the amplitude is unaffected.

Using four different sized barrels caused a change in the pressure velocity relation for the projectile material. This is attributed to increased time for radial release waves to propagate to the center of the larger projectiles and therefore the transducer. The limiting case of uniaxial strain was properly obtained with the 2 inch projectiles.

Conclusions and Recommendations

As a result of the testing described in this report, it is concluded that the HRSI tile coating will exhibit incipient damaged under the following circumstances:

a. Dyplast Styrofoam, uncoated, impact at 500 feet per second;

b. Dyplast Styrofoam, coated with FBL fire retardant, impact at 200 feet per second;

c. Vitron Rubber sheet impact at 100 feet per second.

Analysis indicates that the peak pressure generated during impact is the local failure criteria and equal to approximately 130 psi for a 2 inch diameter projectile. In addition, the peak pressure is the Hugoniot

pressure which may be approximated by the accoustic impedance, ρc in this velocity regime.

It is recommended that all forms of debris which may impact the Orbiter be characterized according to accoustic impedance. The threshold velocity of coating damage may then be computed for all impacts of duration in excess of 75 nanoseconds. This would apply to all debris with a dimension, h, such that:

$$\frac{2h}{c_o} > 75 \times 10^{-9} \text{ seconds}$$

In addition, the pressures and times obtained in this study may be used for gross structural response calculations where local failure does not occur.

References

1. Rand, James L.; Impact Testing of Orbiter HRSI Tiles; NASA-JSC Contract Report-PO No T-4893G, June 1979.

2. Wilbeck, James S.; Impact Behavior of Low Strength Projectiles; AFML-TR-77-134, July 1978.

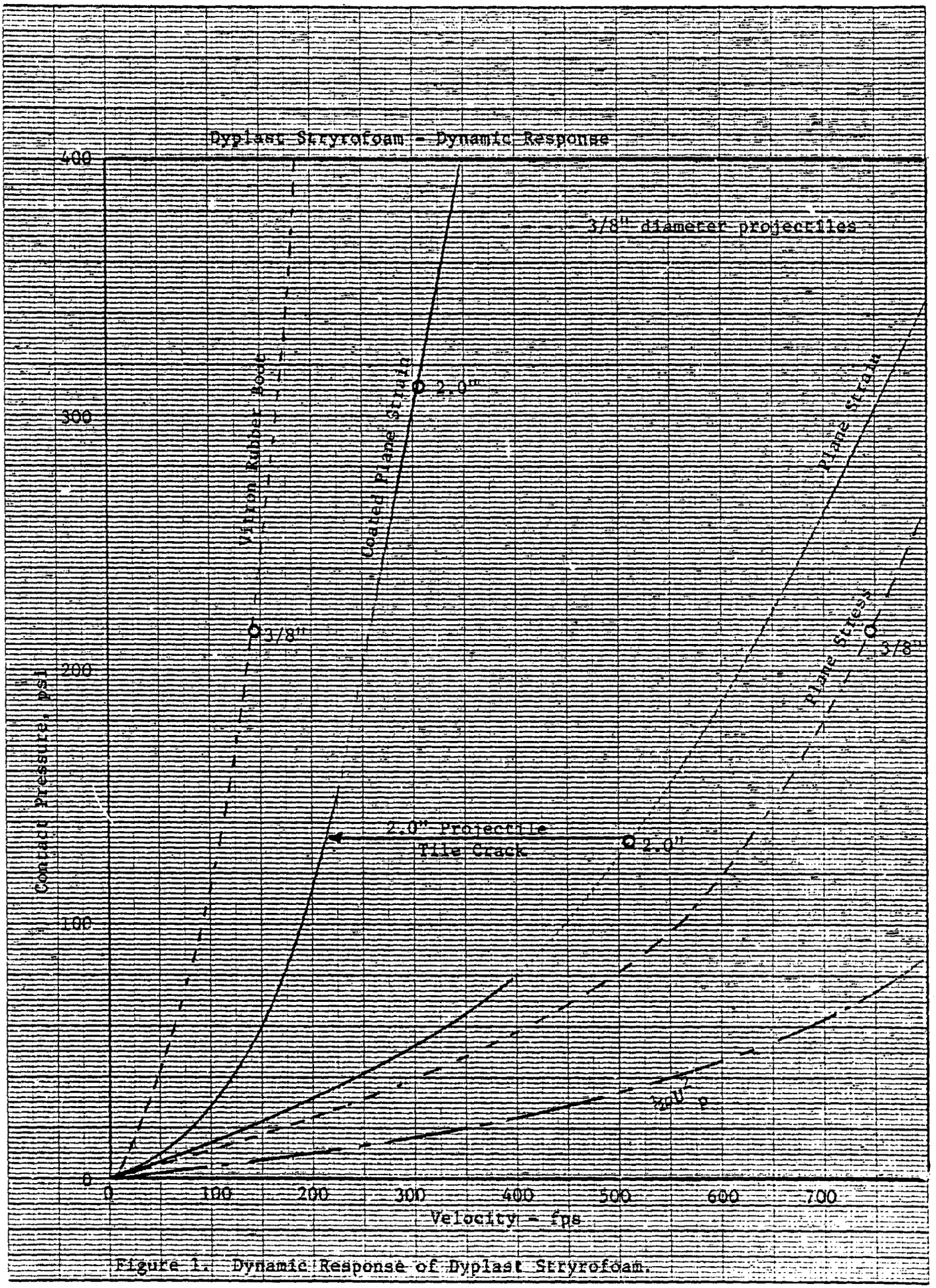


Figure 1. Dynamic Response of Dyplast Styrofoam.

Appendix A

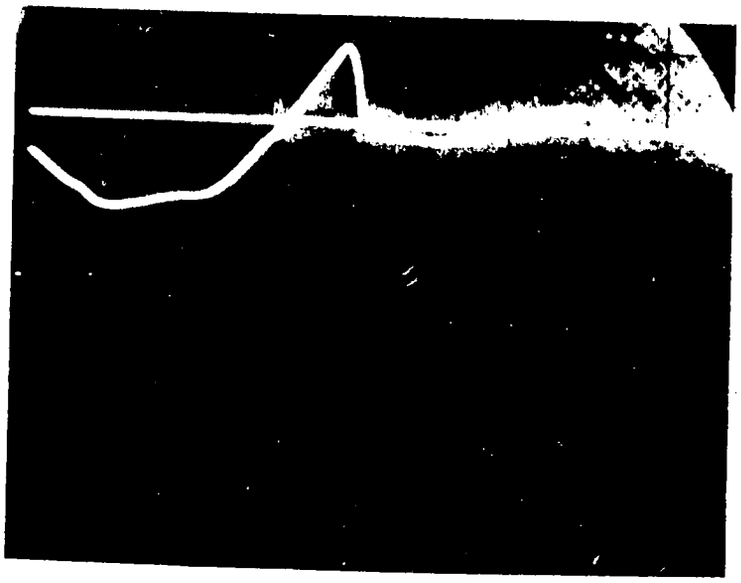
Table A-1

Dyplast Styrofoam - 2 Inch Projectile

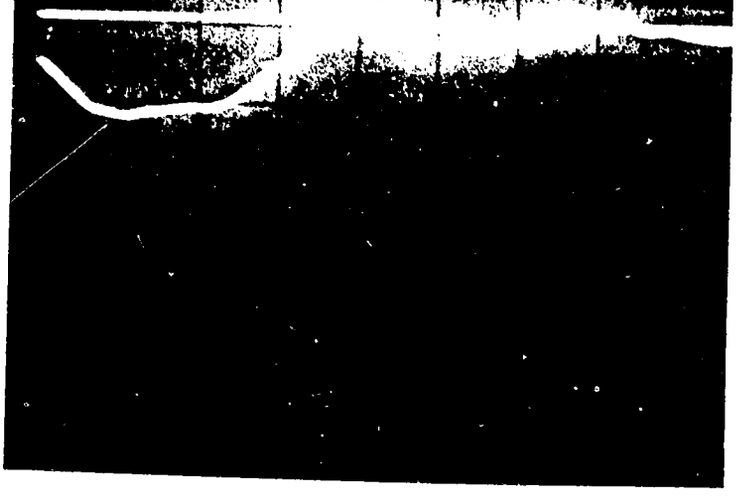
Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
A-4	2	2	57	90	RT
A-5	2	2	52	90	RT
A-6	2	2	336	90	RT
A-7	2	2	367	90	RT
A-8	2	2	163	90	RT
A-11	2	2	698	90	RT
A-12	2	2	546	90	RT
A-13	2	2	508	90	RT
A-17	2	2	550	90	RT
A-18	2	2	341	90	RT
A-19	2	2	130	90	RT
A-20	2	2	24	90	RT
A-21	2	2	44	90	RT
A-22	2	2	659	90	RT
		Dyplast Styrofoam with Fire Retardant Coasting			
A-24	2	2	542	90	RT
A-25	2	2	474	90	RT
A-26	2	2	295	90	RT
A-27	2	2	365	90	RT
A-29	2	2	262	90	RT
A-30	2	2	244	90	RT
A-40*	2	2	488	90	RT
A-41**	2	2	539	90	RT

* Coating on rear surface

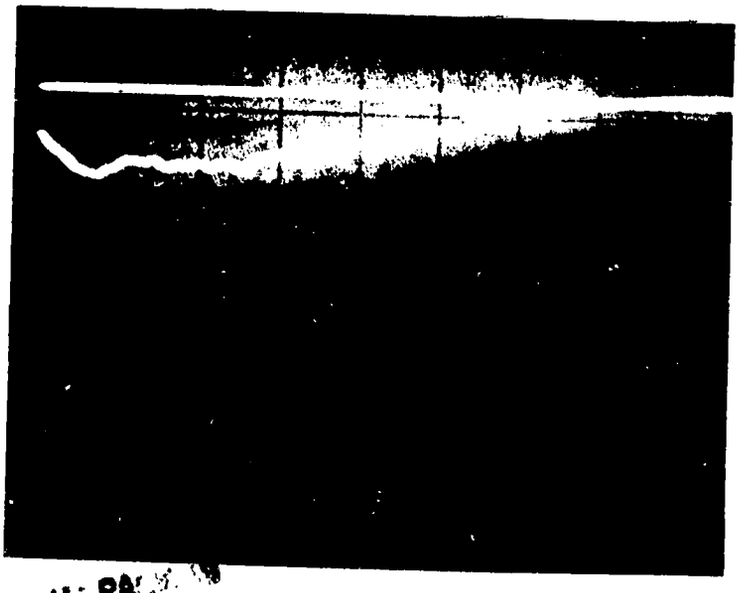
** Coating on rear surface-tapered impact surface



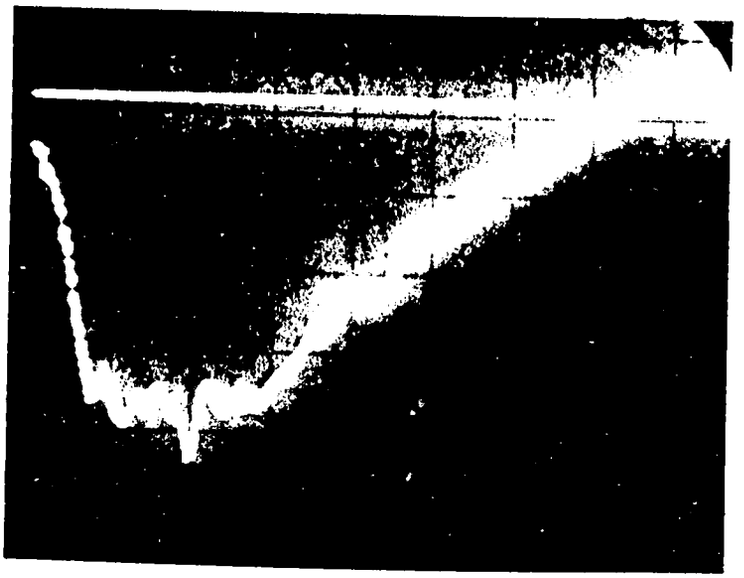
Shot No A-4 - 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 2901.6 (μsec)
Velocity 57.4 (ft/sec) 16 psi
Scale 13.65 (psi/cm)



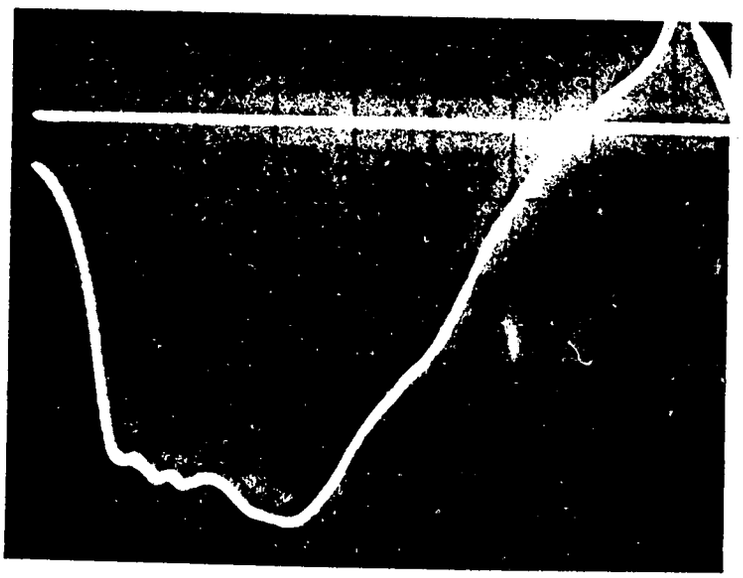
Shot No A-5 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 3165.4 (μsec)
Velocity 52.6 (ft/sec) 17 psi
Scale 13.65 (psi/cm)



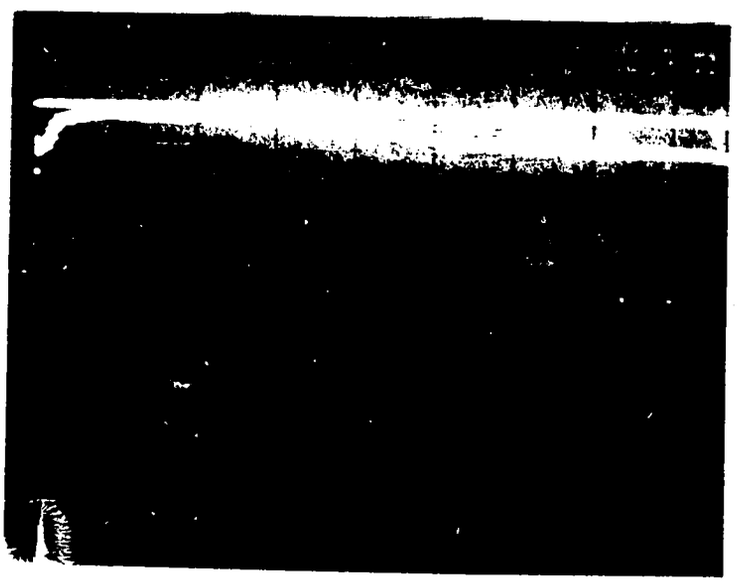
Shot No A-6 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 494.8 (μsec)
Velocity 336.8 (ft/sec) 60 psi
Scale 54.62 (psi/cm)



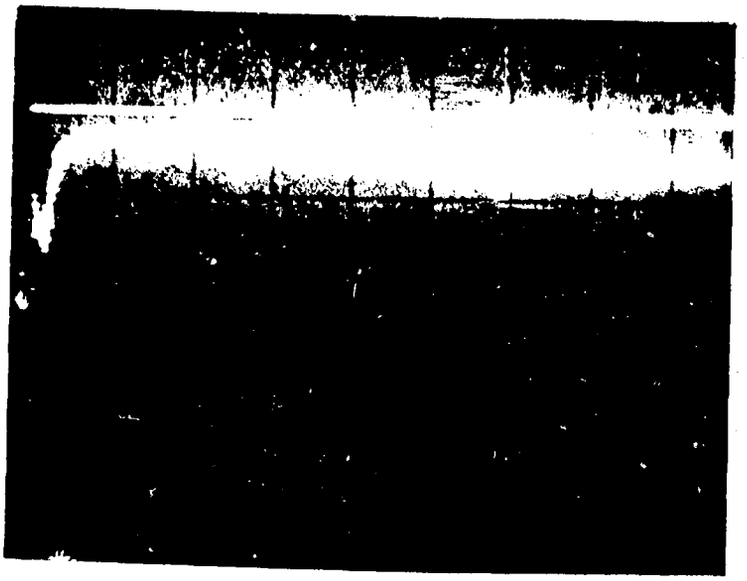
Shot No A-7 2" dia
DYPLAST
Material STYROFOAM
Mass 1853 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 453.2 (μsec)
Velocity 367.8 (ft/sec) 63 psi
Scale 13.65 (psi/cm)



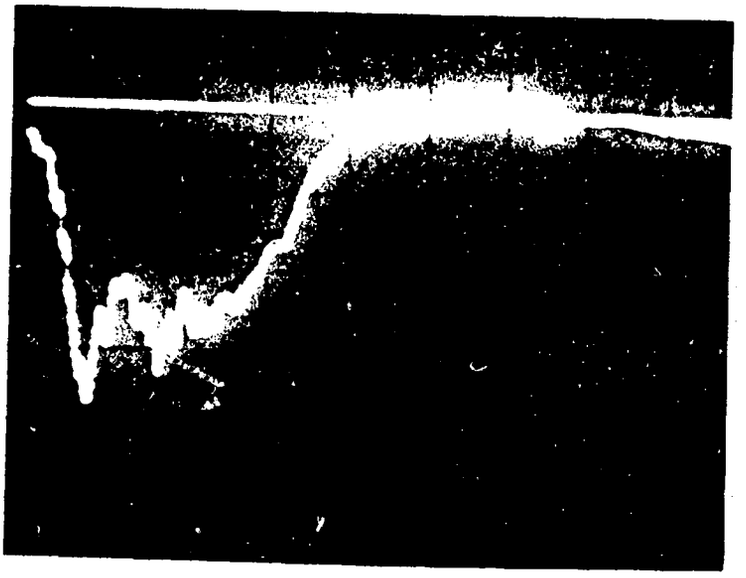
Shot No A-8 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .02 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 1022.5 (μsec)
Velocity 163.0 (ft/sec) 25.25 ps
Scale 5.462 (psi/cm)



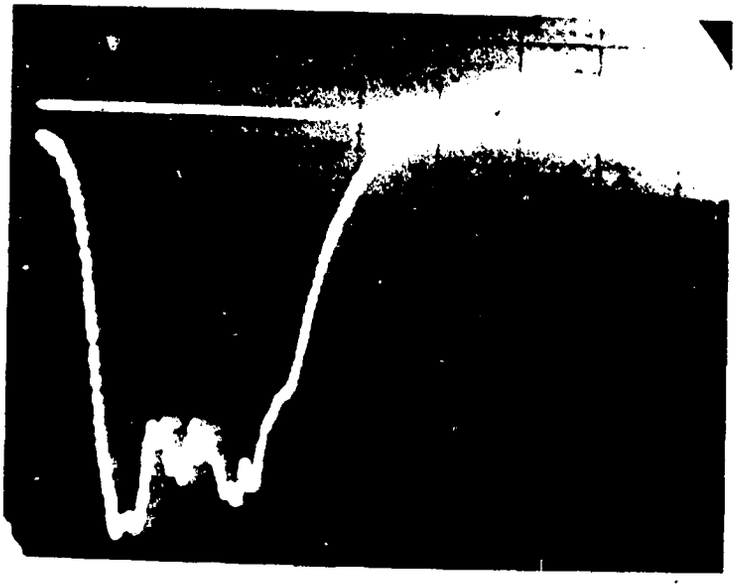
Shot No 9 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 200.5 (μsec)
Velocity 831.2 (ft/sec)
Scale ____ (psi/cm)



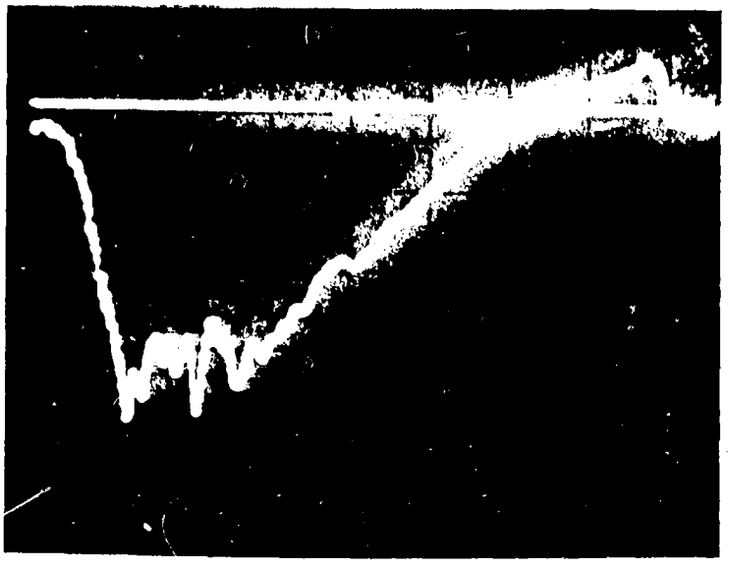
Shot No 10 2" dia
DYPLAST
Material STYROFOAM
Mass ____ (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time ~ (μsec)
Velocity ~ (ft/sec)
Scale 13.65 (psi/cm)



Shot No A-11 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 238.6 (μsec)
Velocity 698.6 (ft/sec) 200 psi
Scale 54.62 (psi/cm)



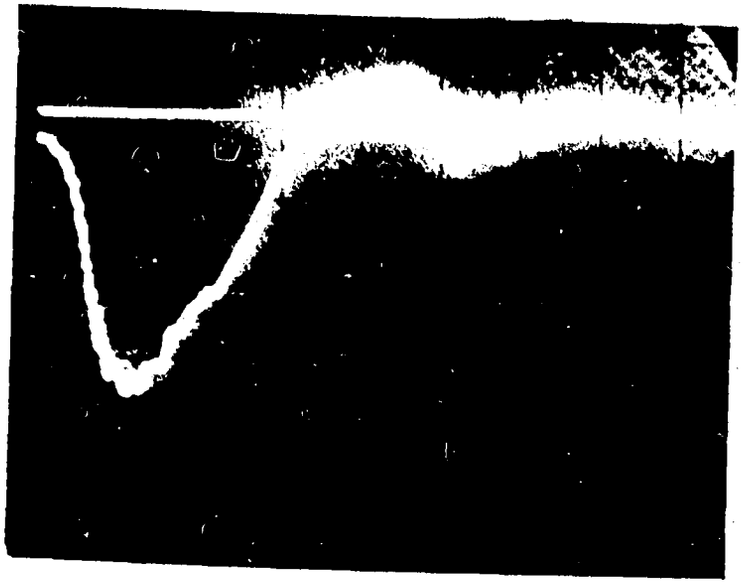
Shot No A-12 2" dia
DYPLAST
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 305 (μsec)
Velocity 546 (ft/sec) 152 psi
Scale 27.31 (psi/cm)



Shot No A-13 2" dia
Material STYROFOAM
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 327.8 (μsec)
Velocity 509.4 (ft/sec) 108psi
Scale 27.31 (psi/cm)

Shot No _____
Material _____
Mass _____(milligrams)
Temperature _____
Vert. Sens. _____(Volts/cm)
Horiz. Sens. _____(μsec/cm)
Time _____(μsec)
Velocity _____(ft/sec)
Scale _____(psi/cm)

Shot No _____
Material _____
Mass _____(milligrams)
Temperature _____
Vert. Sens. _____(Volts/cm)
Horiz. Sens. _____(μsec/cm)
Time _____(μsec)
Velocity _____(ft/sec)
Scale _____(psi/cm)



Shot ~~No~~ -17

Material STYROFOAM 2"x1"

Mass 925 (milligrams)

Temperature RT

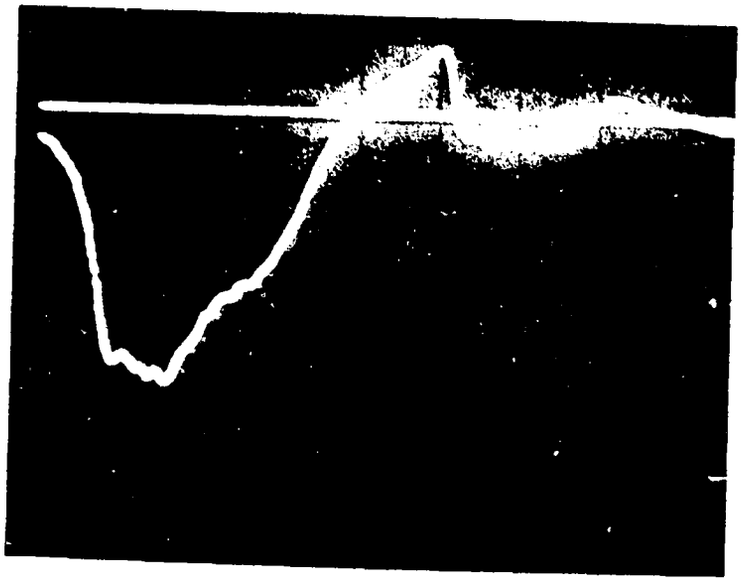
Vert. Sens. .1 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

Time 302.8 (μsec)

Velocity 550 (ft/sec) 92

Scale 27.31 (psi/cm)



Shot ~~No~~ -18

Material STYROFOAM

Mass 925 (milligrams) 2"x1"

Temperature RT

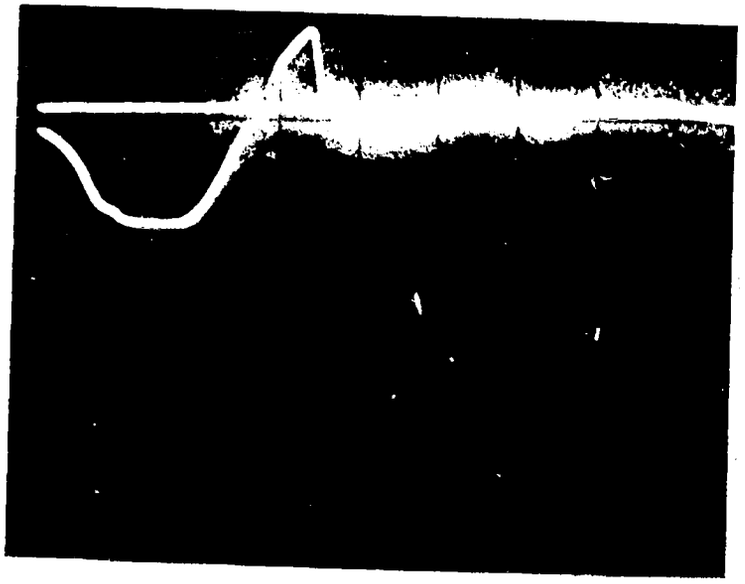
Vert. Sens. .05 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

Time 488.6 (μsec)

Velocity 341 (ft/sec) 47

Scale 13.65 (psi/cm)



Shot ~~No~~ -19

Material STYROFOAM 2"x1"

Mass 925 (milligrams)

Temperature RT

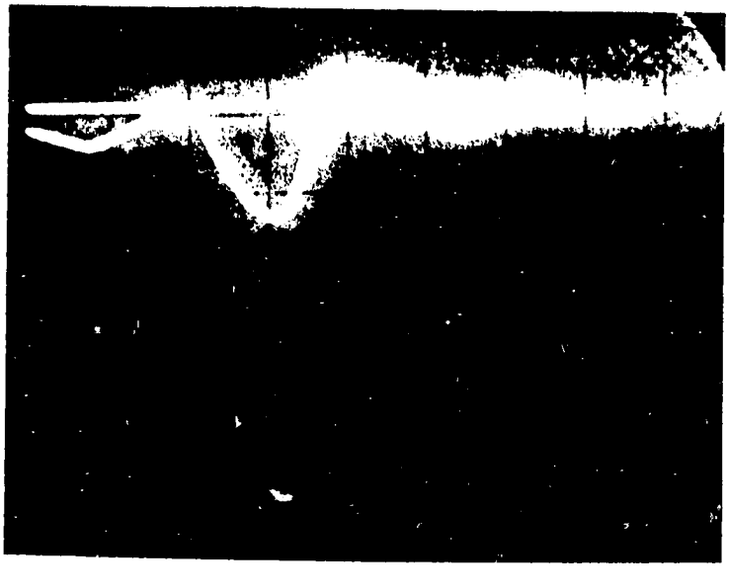
Vert. Sens. .05 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

Time 1277.3 (μsec)

Velocity 130 (ft/sec) 20

Scale 13.65 (psi/cm)



Shot No -20

Material STYROFOAM 2"x1"

Mass 925 (milligrams)

Temperature RT

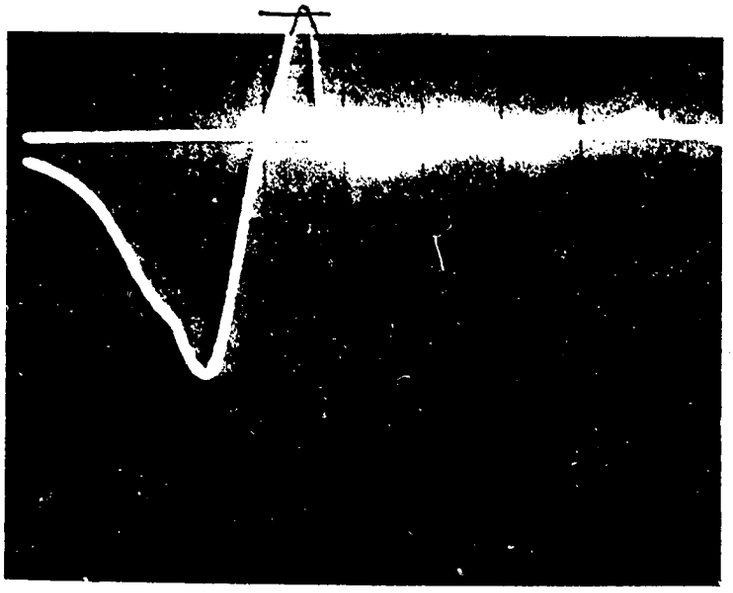
Vert. Sens. .02 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

Time 6757 (μsec)

Velocity 24.6 (ft/sec) 7.5

Scale 5.46 (psi/cm)



Shot No -21

Material STYROFOAM 2"x1"

Mass 925 (milligrams)

Temperature RT

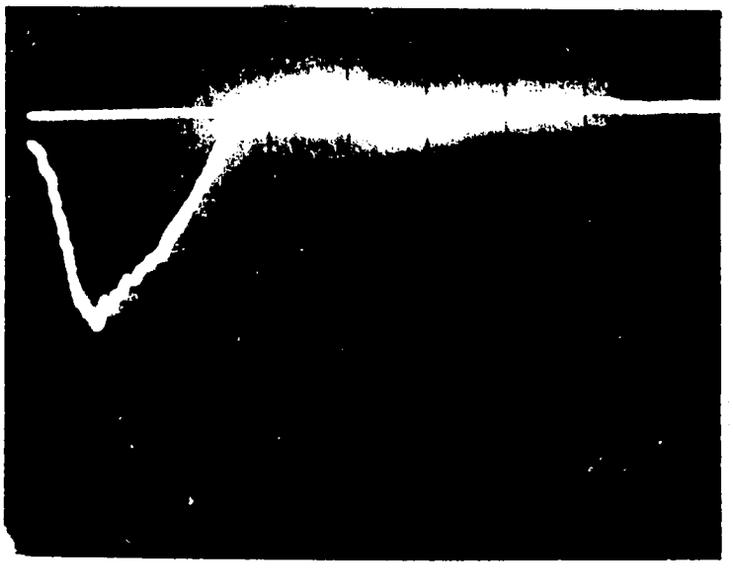
Vert. Sens. .05 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

Time 3764.9 (μsec)

Velocity 44.3 (ft/sec) 41 ≈ 16.4

Scale _____ (psi/cm)



Shot No -22

Material STYROFOAM 2"x1"

Mass 925 (milligrams)

Temperature RT

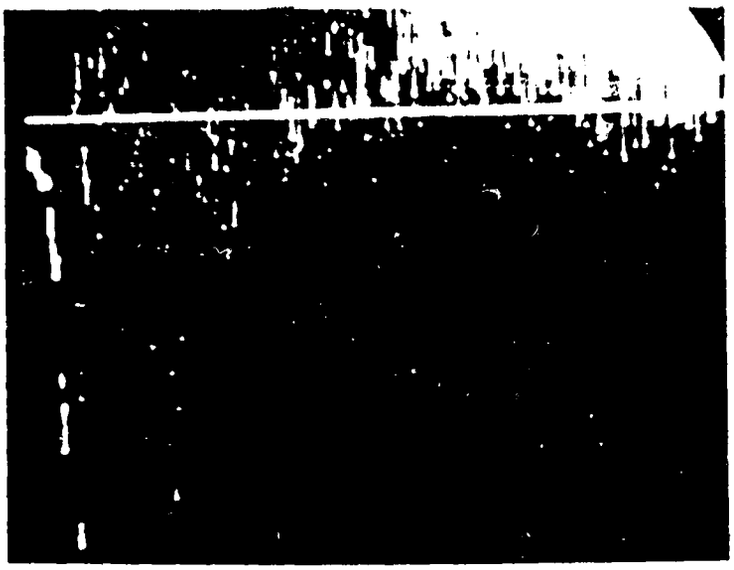
Vert. Sens. .2 (Volts/cm)

Horiz. Sens. 100 (μsec/cm)

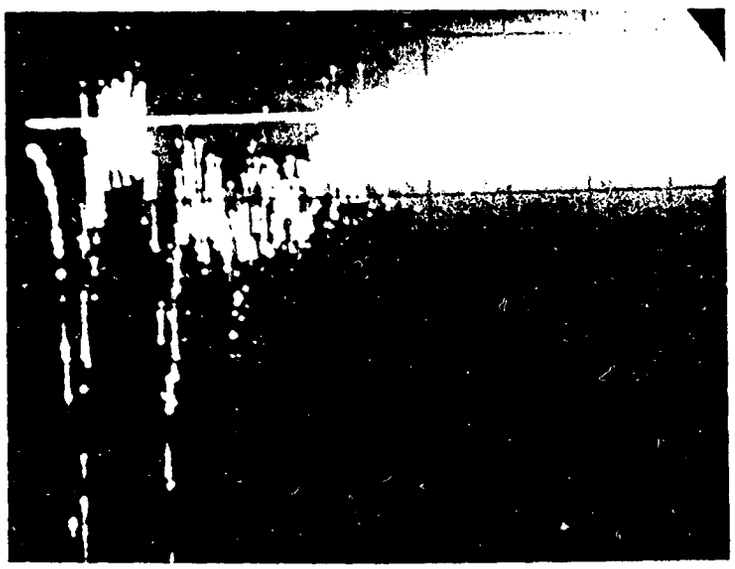
Time 252.9 (μsec)

Velocity 659 (ft/sec) 145

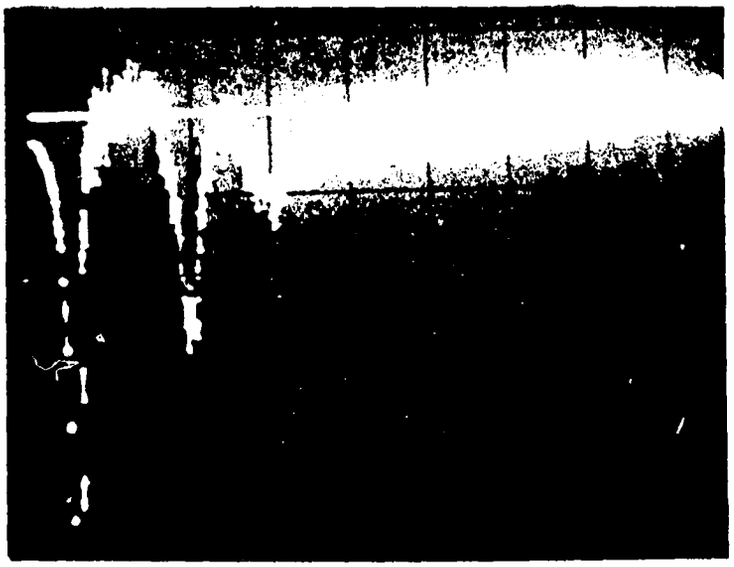
Scale 54.62 (psi/cm)



Shot No 24
Material COATED STYROFOAM 2" x 2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 307.3 (μsec)
Velocity 542 (ft/sec) 295?
Scale 54.62 (psi/cm)

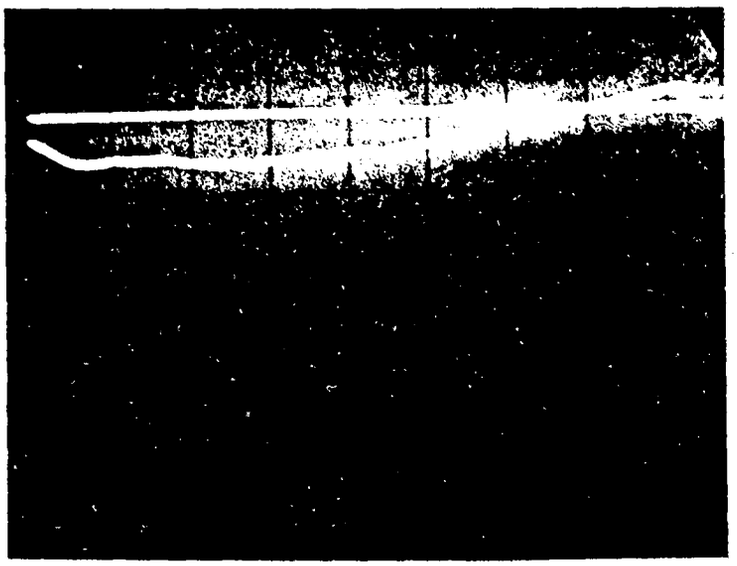


Shot No 25
Material COATED STYROFOAM 2" x 2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 351.9 (μsec)
Velocity 474 (ft/sec) >300
Scale 54.62 (psi/cm)



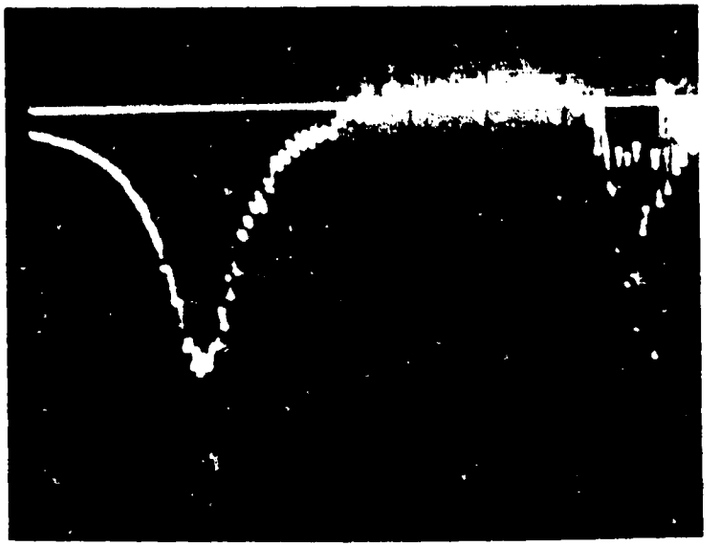
Shot No 26
Material COATED STYROFOAM 2" x 2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 565.1 (μsec)
Velocity 295 (ft/sec) 320
Scale 54.62 (psi/cm)

Shot No A-27
Material COATED STYROFOAM 2"x2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 456.9 (μsec)
Velocity 365 (ft/sec) 465
Scale 136.5 (psi/cm)



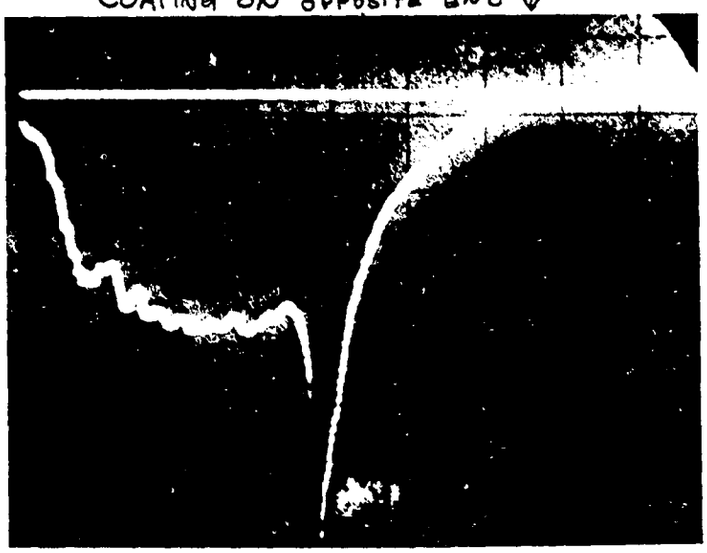
Shot No 28
Material (NOT COATED) STYROFOAM 2" x 2"
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 649.5 (μsec)
Velocity 257 (ft/sec) 32
Scale 54.62 (psi/cm)

Shot No A-29
Material COATED STYROFOAM 2"X2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 636.9 (μsec)
Velocity 262 (ft/sec) 240
Scale 54.62 (psi/cm)



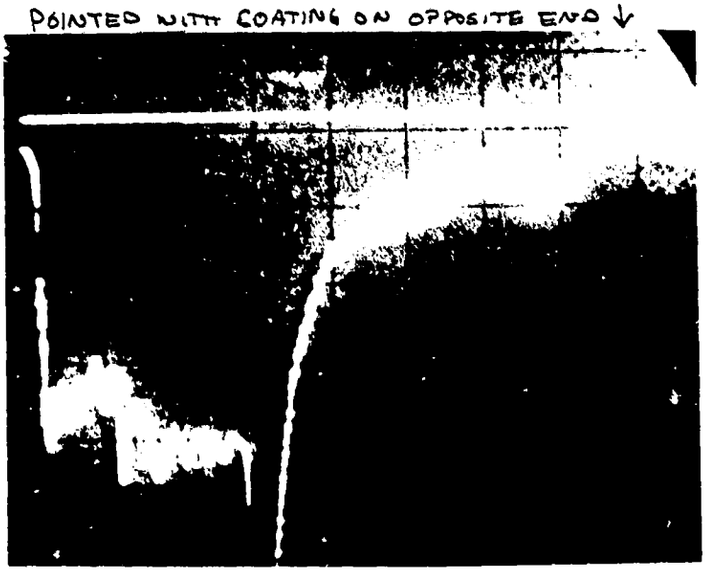
Shot No. A-30
Material COATED STYROFOAM 2"x2"
Mass ? (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 20 (μsec/cm)
Time 683.4 (μsec)
Velocity 244 (ft/sec) 185
Scale 54.62 (psi/cm)

COATING ON OPPOSITE END ↓



Shot No. A-40
Material COATED 2"x2" STYROFOAM
Mass ? (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 341.7 (μsec)
Velocity 488 (ft/sec) ~~462~~ 81
Scale 27.31 (psi/cm)

POINTED WITH COATING ON OPPOSITE END ↓



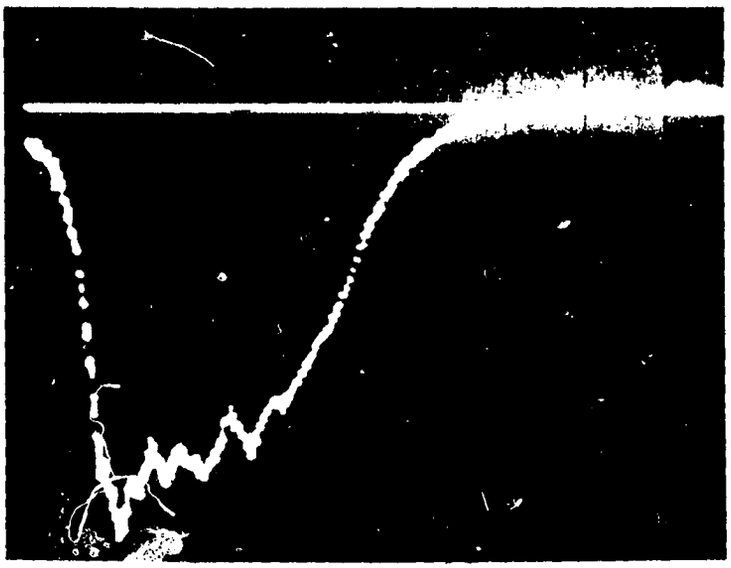
Shot No. 41
Material COATED 2"x2" STYROFOAM
Mass ? (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 100 (μsec/cm)
Time 309.3 (μsec)
Velocity 539 (ft/sec) 120
Scale 27.31 (psi/cm)

Appendix B

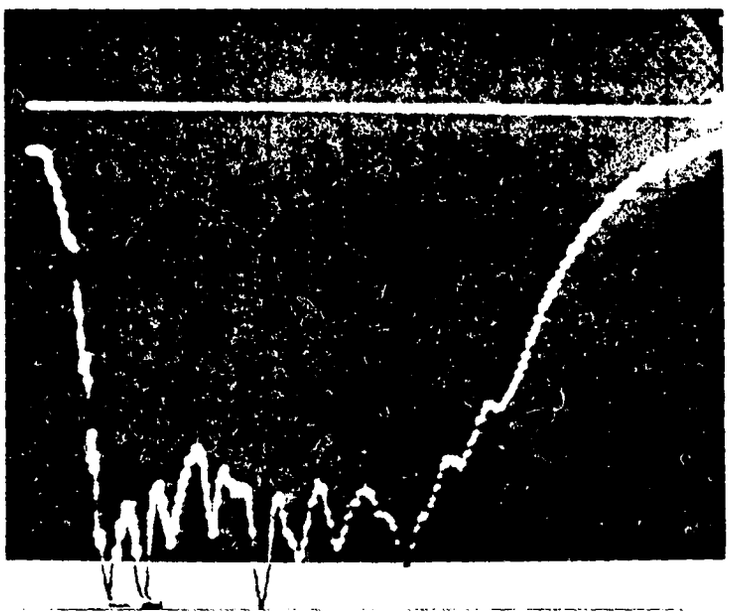
Table B-1

Normal Impact - 1.5

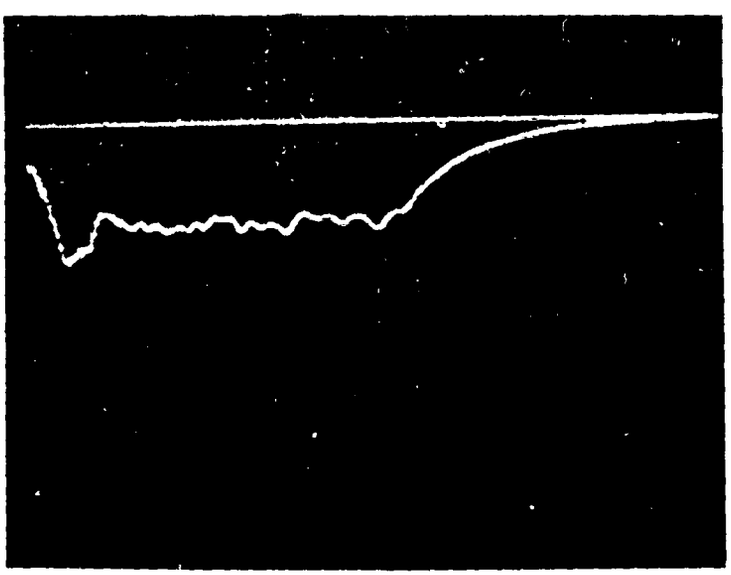
Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
B-42	1.5	2	605	90	RT
B-43	1.5	2	673	90	RT
B-44	1.5	2	747	90	RT
B-45	1.5	2	468	90	RT
B-46	1.5	2	423	90	RT
B-47	1.5	2	237	90	RT



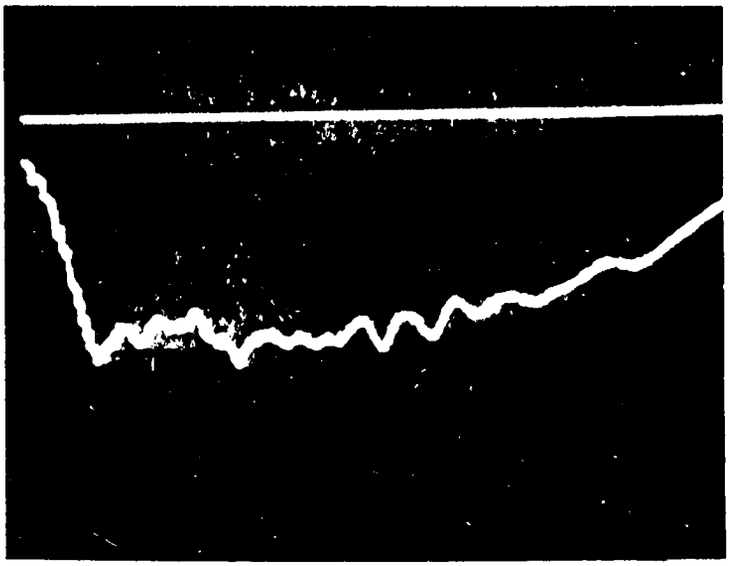
Shot No B-42 1½" dia
Material DYPLAST STYROFOAM
Mass 1040 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 275 (μsec)
Velocity 605 (ft/sec) 150 psi
Scale 27.31 (psi/cm)



Shot No B-43 1½" dia
Material DYPLAST STYROFOAM
Mass 1040 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 247.6 (μsec)
Velocity 673 (ft/sec) 170 psi
Scale 27.31 (psi/cm)



Shot No B-44 1½" dia
Material DYPLAST STYROFOAM
Mass 1040 (milligrams)
Temperature RT
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 222.9 (μsec)
Velocity 747.7 (ft/sec) 240 psi
Scale 36.55 (psi/cm)



Shot B-45

Material STYROFOAM 1½" X 2"

Mass 1040 (milligrams)

Temperature RT

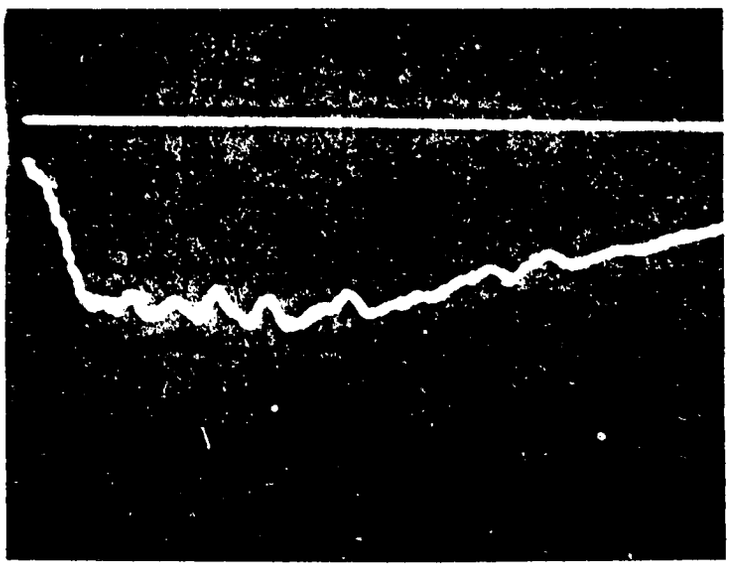
Vert. Sens. .1 (Volts/cm)

Horiz. Sens. 50 (μsec/cm)

Time 352.8 (μsec)

Velocity 468 (ft/sec) 83 psi

Scale 27.31 (psi/cm)



Shot B-46

Material STYROFOAM 1½" X 2"

Mass 1040 (milligrams)

Temperature RT

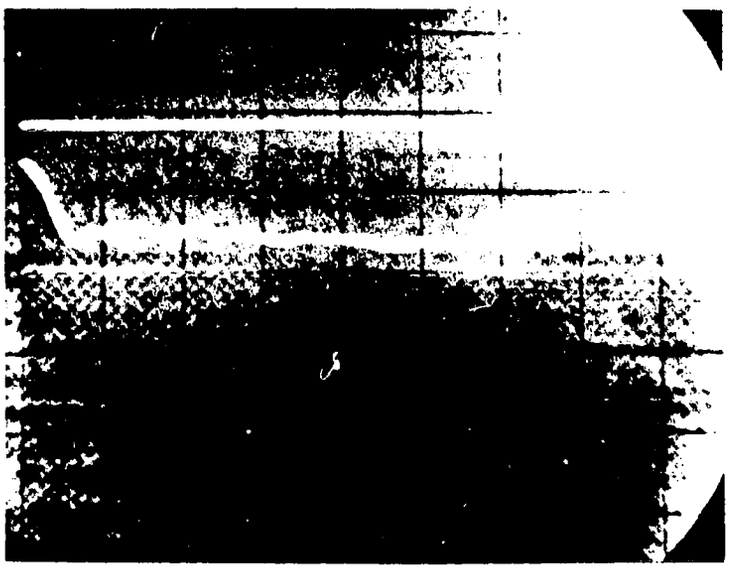
Vert. Sens. .1 (Volts/cm)

Horiz. Sens. 50 (μsec/cm)

Time 394.2 (μsec)

Velocity 423 (ft/sec) 63 psi

Scale 27.31 (psi/cm)



Shot B-47

Material STYROFOAM 1½" X 2"

Mass 1040 (milligrams)

Temperature RT

Vert. Sens. .1 (Volts/cm)

Horiz. Sens. 50 (μsec/cm)

Time 702.5 (μsec)

Velocity 237 (ft/sec) 40 psi

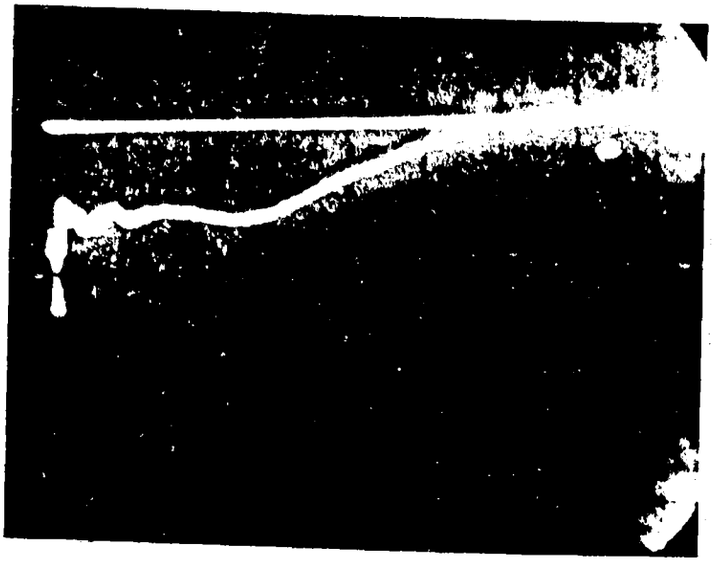
Scale 27.31 (psi/cm)

Appendix C

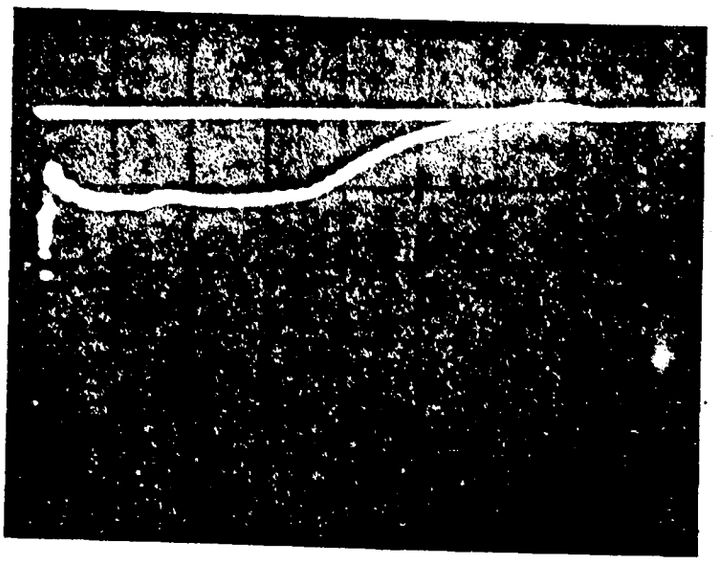
Table C-1

Normal Impact - 3/8

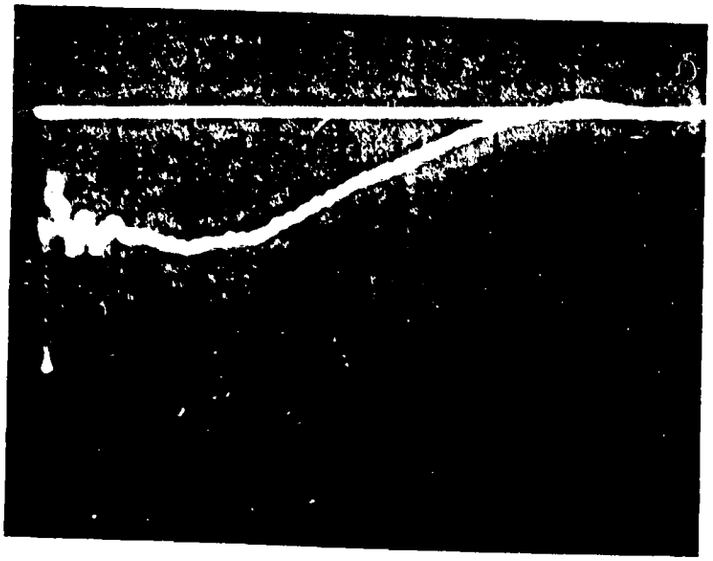
Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
C-3	.375	1	315	90	RT
C-4	.375	1	221	90	RT
C-5	.375	1	198	90	RT
C-6	.375	1	166	90	RT
C-7	.375	1	250	90	RT
C-8	.375	1	651	90	RT
C-10	.375	1	470	90	RT
C-11	.375	1	451	90	RT
C-13	.375	1	823	90	RT
C-14	.375	1	806	90	RT
C-15	.375	1	77	90	RT



Shot No C-5
Material STYROFOAM (AYPLAST)
Mass 36 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 537.4 (μsec)
Velocity 198.5 (ft/sec) 35
Scale 27.31 (psi/cm)

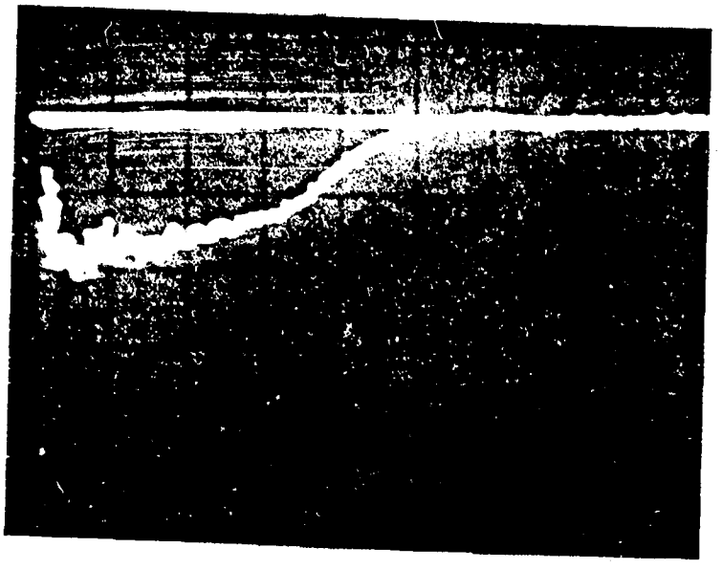


Shot No C-6
Material STYROFOAM (AYPLAST)
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 640.7 (μsec)
Velocity 166.5 (ft/sec) 32
Scale 27.31 (psi/cm)

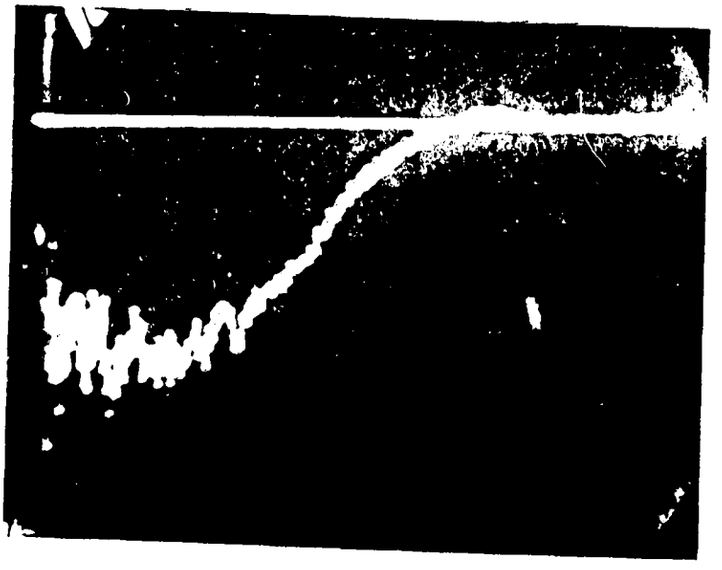


Shot No C-7
Material STYROFOAM (AYPLAST)
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 426.8 (μsec)
Velocity 250.0 (ft/sec) 40
Scale 27.31 (psi/cm)

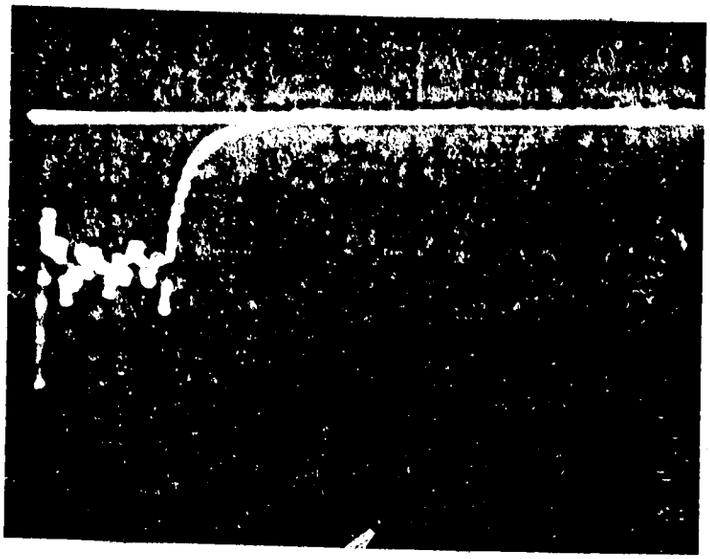
Shot No C-8
Material DYPLAST STYROFOAM
Mass 35 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 163.8 (μsec)
Velocity 651.2 (ft/sec) 140
Scale 54.62 (psi/cm)



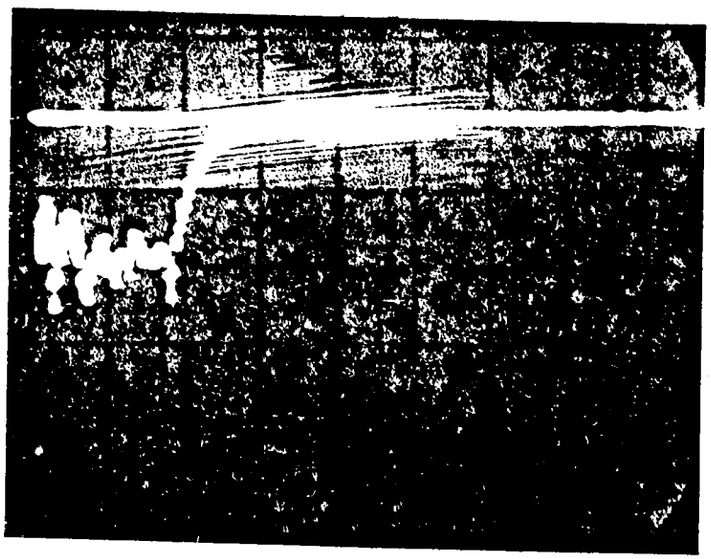
Shot No C-10
Material DYPLAST STYROFOAM
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 226.8 (μsec)
Velocity 470.3 (ft/sec) 103
Scale 54.62 (psi/cm)



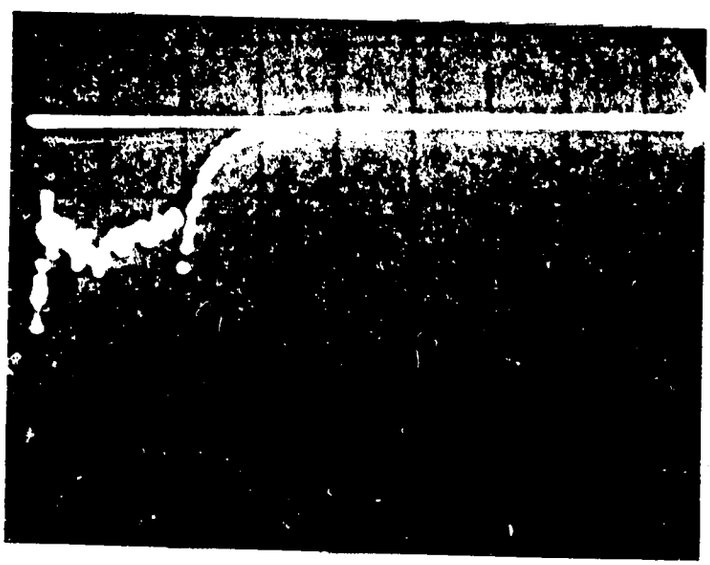
Shot No C-11
Material DYPLAST STYROFOAM
Mass 35 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 236.0 (μsec)
Velocity 451.9 (ft/sec) 475 83
Scale 27.31 (psi/cm)



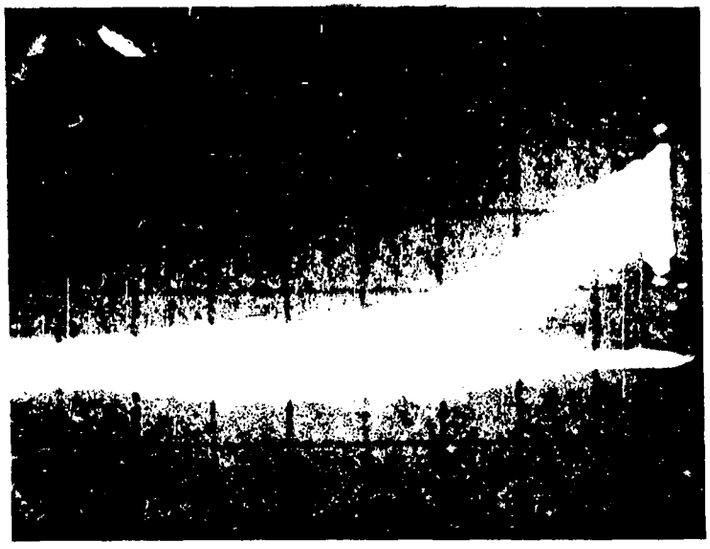
Shot No C-13
DYPLAST
Material STYROFOAM
Mass 38 (milligrams)
Temperature RT
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 129.5 (μsec)
Velocity 823.6 (ft/sec) 310
Scale 136.55 (psi/cm)



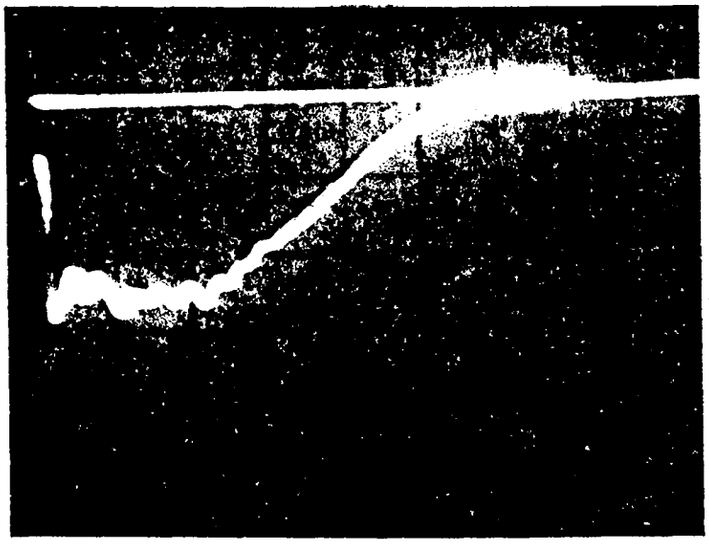
Shot No C-14
DYPLAST
Material STYROFOAM
Mass 36 (milligrams)
Temperature RT
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 132.3 (μsec)
Velocity 806.2 (ft/sec) 295
Scale 136.55 (psi/cm)



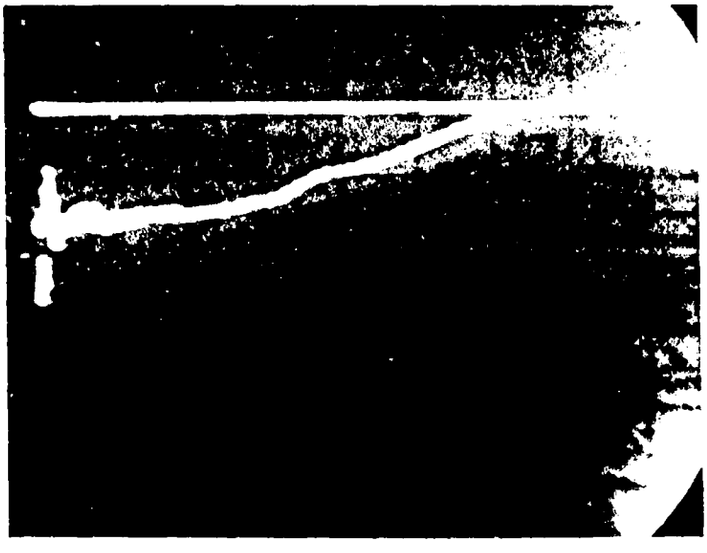
Shot No C-15
DYPLAST
Material STYROFOAM
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 137.2 (μsec)
Velocity 777.2 (ft/sec) 250
Scale 136.55 (psi/cm)



Shot No 27
Material BX-250
Mass 55 (milligrams)
Temperature CRYO
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 182.7 (μsec)
Velocity 583.2 (ft/sec)
Scale 136.55 (psi/cm)



Shot No C-3
Material DYPLAST STYROFOAM
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 338.5 (μsec)
Velocity 315.1 (ft/sec) 75 psi
Scale 27.31 (psi/cm)



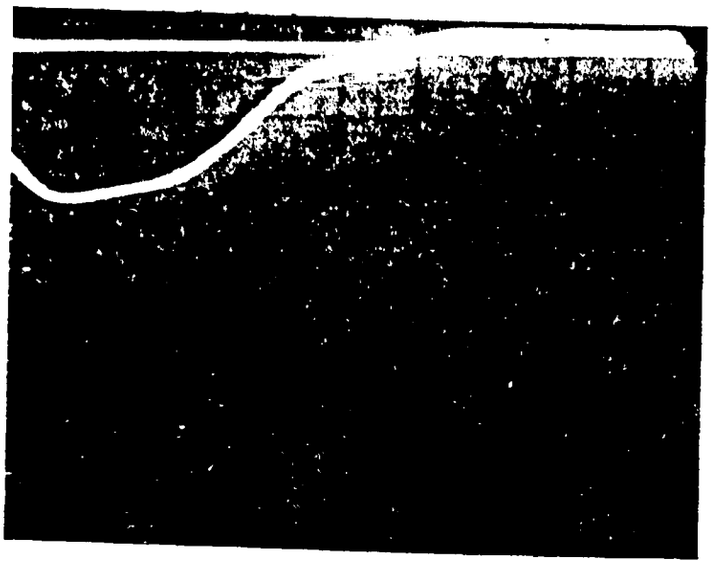
Shot No C-4
Material DYPLAST STYROFOAM
Mass 35 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 482.3 (μsec)
Velocity 221.3 (ft/sec) 43
Scale 27.31 (psi/cm)

Appendix D

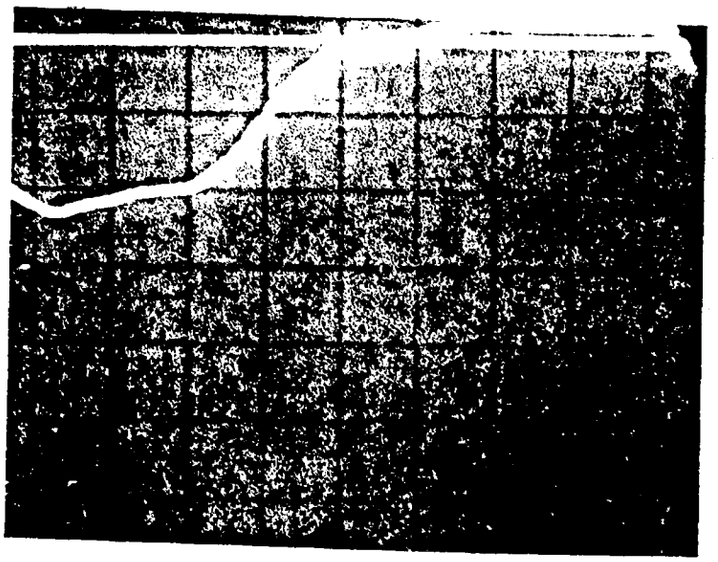
Table D-1

Oblique Impact

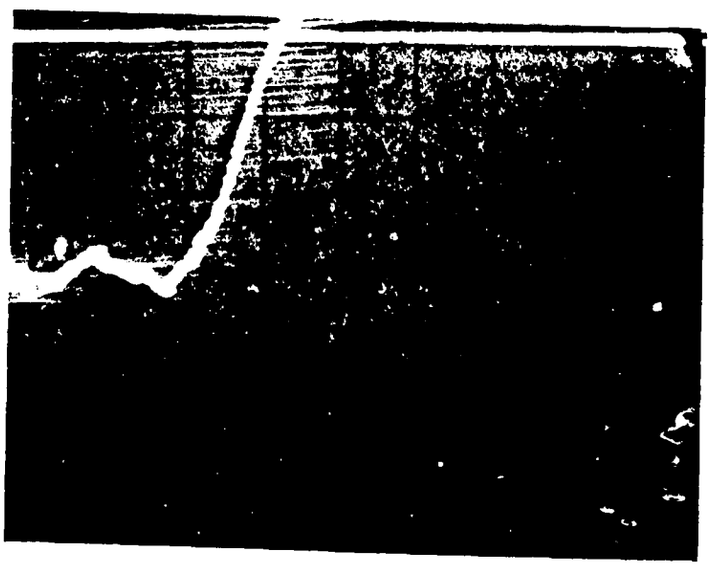
Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
D-26	.375	1	154	60	RT
D-27	.375	1	205	60	RT
D-28	.375	1	281	60	RT
D-29	.375	1	237	60	RT
D-31	.375	1	487	60	RT
D-32	.375	1	477	60	RT
D-33	.375	1	493	60	RT
D-34	.375	1	934	60	RT
D-37	.375	1	121	60	RT
D-39	.375	1	752	60	RT
D-40	.375	1	740	60	RT



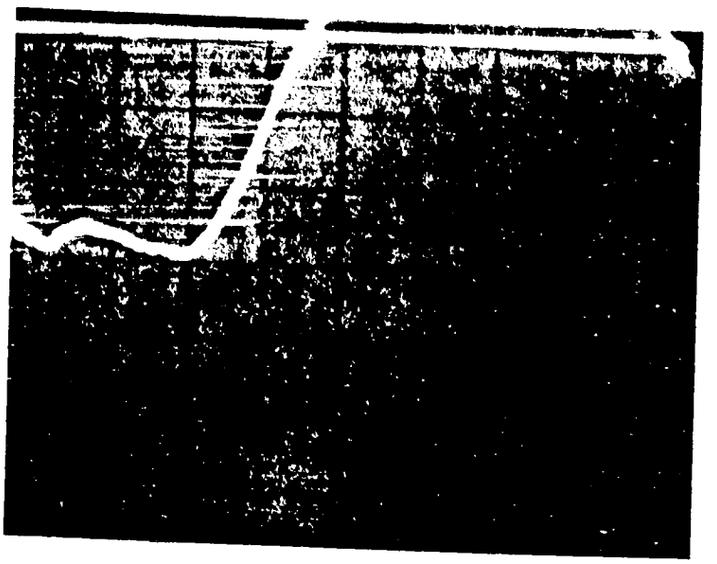
Shot No D-26 60°
DYPLAST
Material STYROFOAM
Mass 34 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 692.1 (μsec)
Velocity 154.1 (ft/sec) 27
Scale 13.65 (psi/cm)



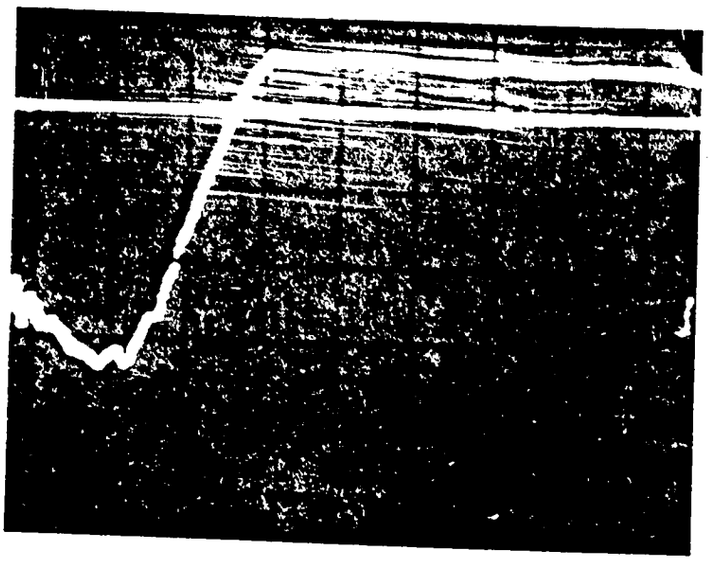
Shot No D-27 60°
DYPLAST
Material STYROFOAM
Mass 34 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 518.5 (μsec)
Velocity 205.7 (ft/sec) 26
Scale 13.65 (psi/cm)



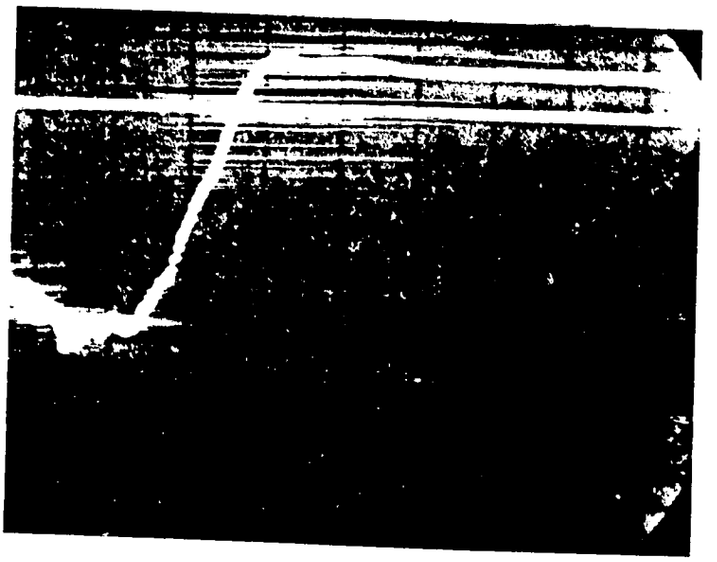
Shot No D-28 60°
DYPLAST
Material STYROFOAM
Mass 34 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 379.3 (μsec)
Velocity 291.2 (ft/sec) 25
Scale 13.65 (psi/cm)



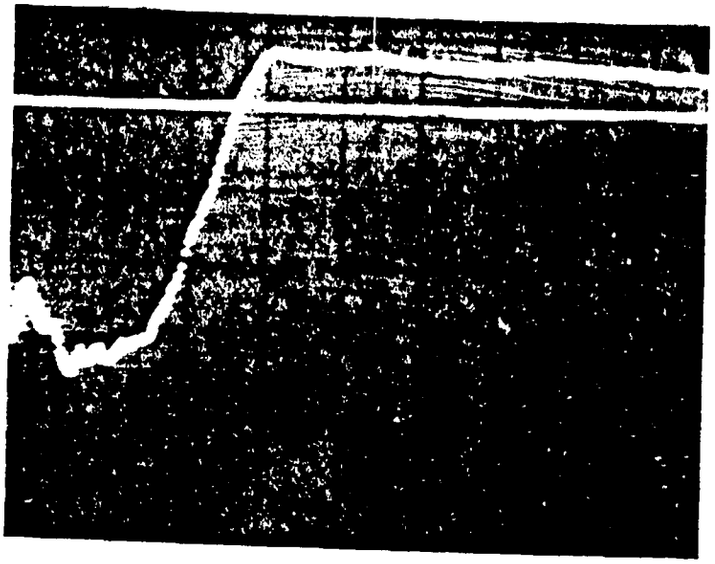
Shot No D-29 60°
DYPLAST
Material STYROFOAM
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .05 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 449.0 (μsec)
Velocity 237.5 (ft/sec)
Scale 13.65 (psi/cm)



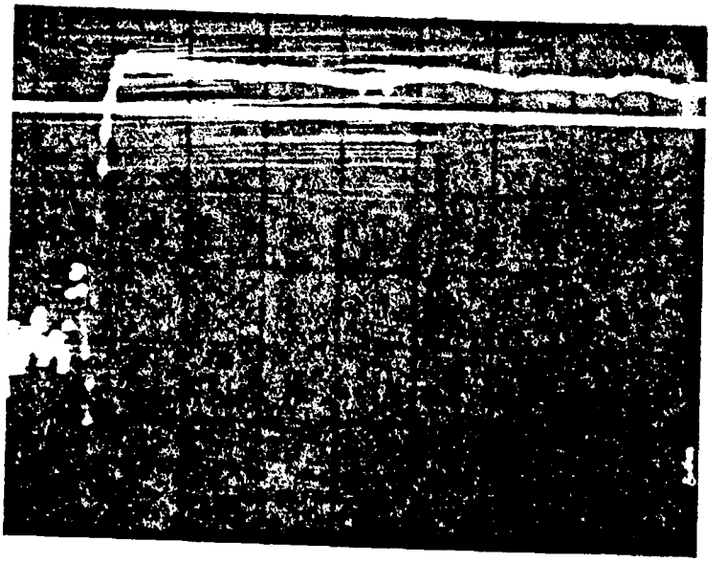
Shot No D-31 60°
DYPLAST
Material STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 219.0 (μsec)
Velocity 487.1 (ft/sec)
Scale 27.31 (psi/cm)



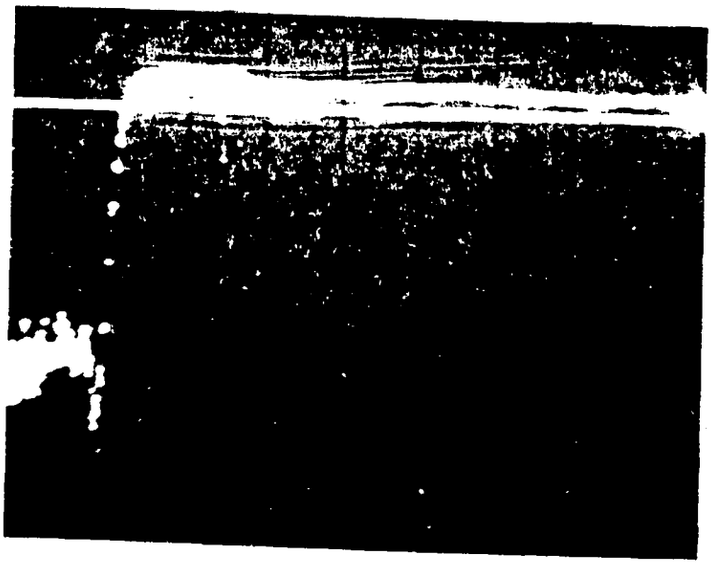
Shot No D-32 60°
DYPLAST
Material STYROFOAM
Mass 32 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 223.2 (μsec)
Velocity 477.8 (ft/sec)
Scale 27.31 (psi/cm)



Shot No 33 60°
DYPLAST
Material STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .1 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 216.3 (μsec)
Velocity 493.1 (ft/sec)
Scale 27.31 (psi/cm)

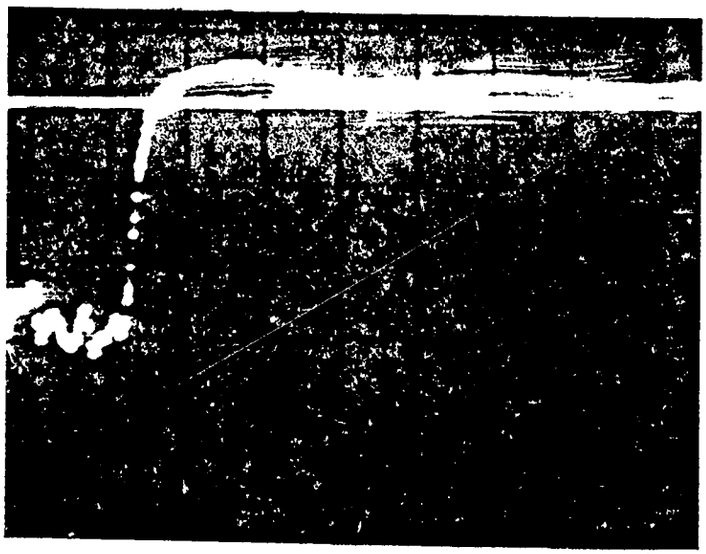


Shot No 34 60°
DYPLAST
Material STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 114.1 (μsec)
Velocity 934.8 (ft/sec)
Scale 54.62 (psi/cm)

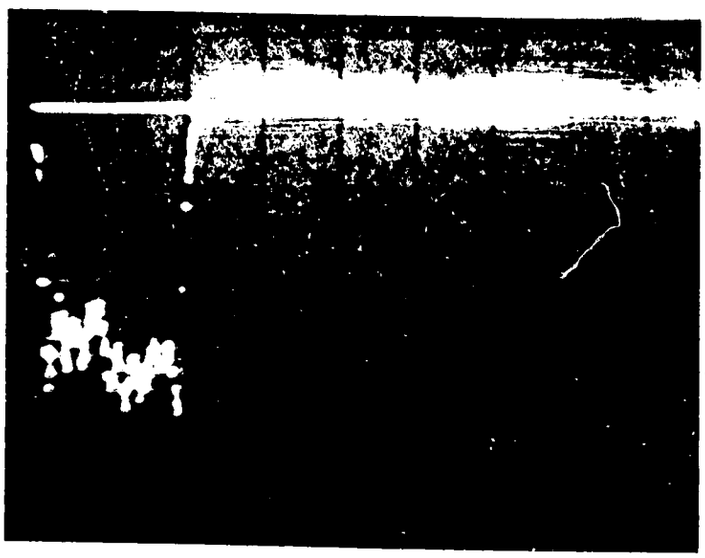


Shot No 37 60°
DYPLAST
Material STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 121.7 (μsec)
Velocity 876.5 (ft/sec)
Scale 54.62 (psi/cm)

Shot No - 39 60°
Material DYPLAST STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 141.8 (μsec)
Velocity 752.2 (ft/sec) 120
Scale 54.62 (psi/cm)



Shot No - 40 60°
Material DYPLAST STYROFOAM
Mass 33 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 144.1 (μsec)
Velocity 740.2 (ft/sec) 120
Scale 54.62 (psi/cm)



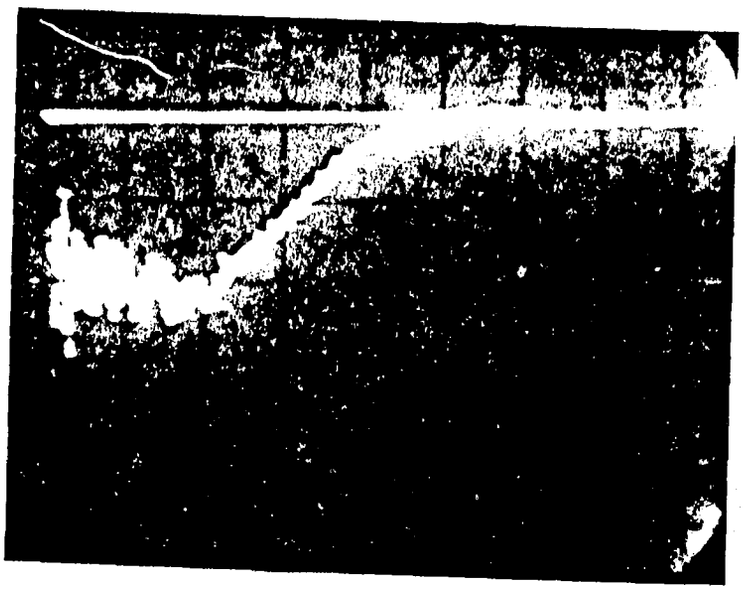
Shot No - 41 - 60°
Material DYPLAST STYROFOAM
Mass 34 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 129.1 (μsec)
Velocity 826.2 (ft/sec)
Scale 54.62 (psi/cm)

Appendix E

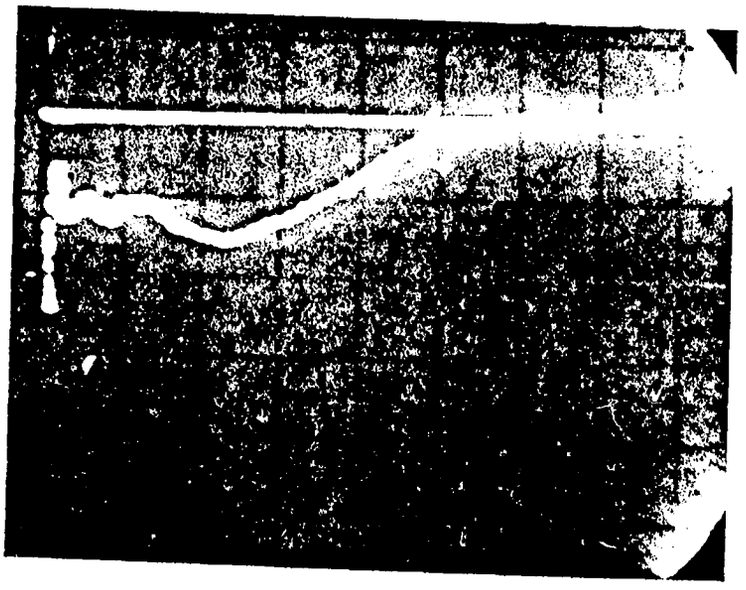
Table E-1

Cryogenic Temperatures

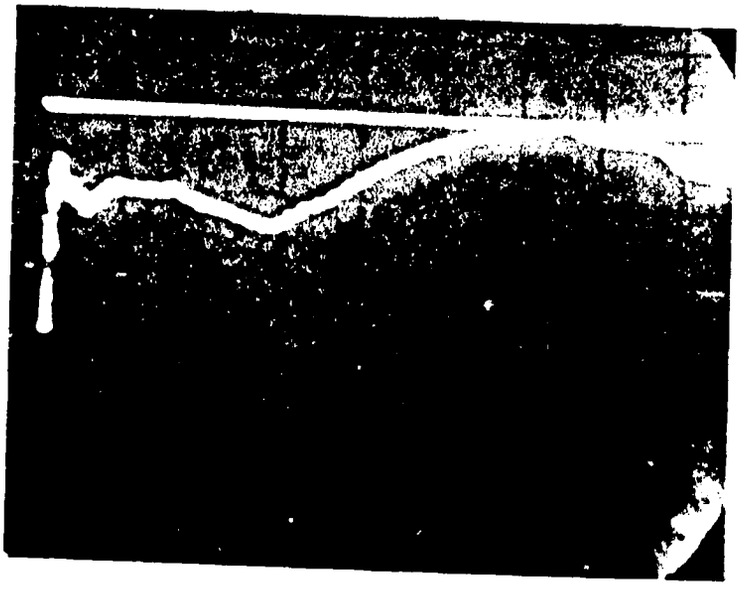
Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
E-16	.375	1	232	90	CRYO
E-17	.375	1	755	90	CRYO
E-18	.375	1	859	90	CRYO
E-19	.375	1	538	90	CRYO
E-20	.375	1	354	90	CRYO
E-21	.375	1	318	90	CRYO



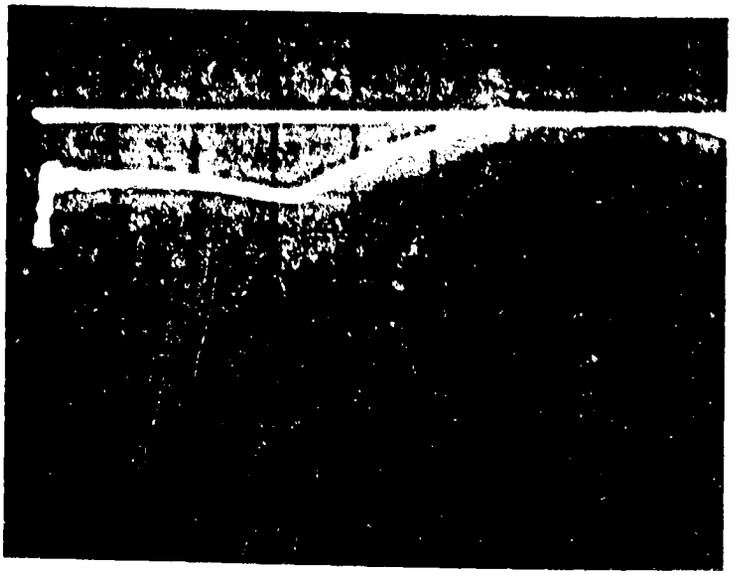
Shot No E-19
Material DYPLAST STYROFOAM
Mass 37 (milligrams)
Temperature CRYO
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 198.0 (μsec)
Velocity 538.7 (ft/sec) 120
Scale 54.62 (psi/cm)



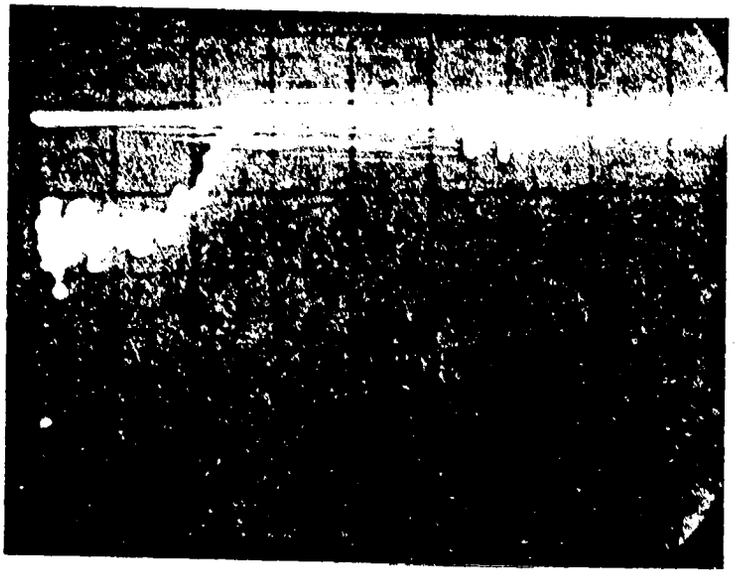
Shot No E-20
Material DYPLAST STYROFOAM
Mass 37 (milligrams)
Temperature CRYO
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 300.5 (μsec)
Velocity 354.9 (ft/sec) 80
Scale 54.62 (psi/cm)



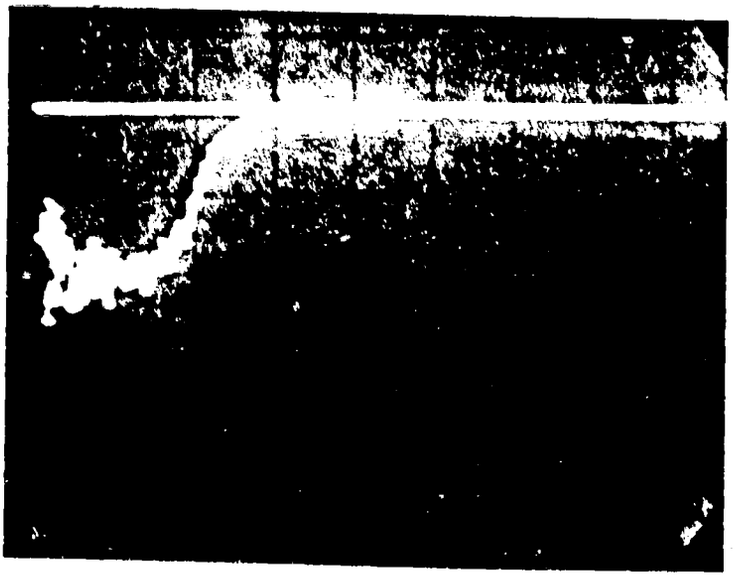
Shot No E-21
Material DYPLAST STYROFOAM
Mass 32 (milligrams)
Temperature CRYO
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 334.5 (μsec)
Velocity 318.9 (ft/sec) 75
Scale 54.62 (psi/cm)



Shot No E-16
Material DYPLAST STYROFOAM
Mass 30 (milligrams)
Temperature CRYO
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 459.6 (μsec)
Velocity 232.1 (ft/sec) 52
Scale 54.62 (psi/cm)



Shot No E-17
Material DYPLAST STYROFOAM
Mass 37 (milligrams)
Temperature CRYO
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 141.2 (μsec)
Velocity 755.4 (ft/sec) 230
Scale 136.55 (psi/cm)



Shot No E-18
Material DYPLAST STYROFOAM
Mass 32 (milligrams)
Temperature CRYO
Vert. Sens. .5 (Volts/cm)
Horiz. Sens. 50 (μsec/cm)
Time 124.1 (μsec)
Velocity 859.5 (ft/sec) 260
Scale 136.55 (psi/cm)

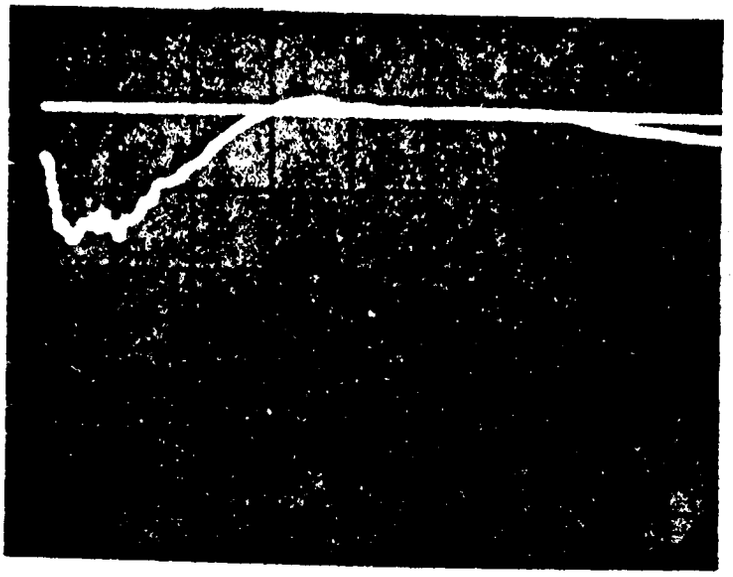
Appendix F

Table F-1

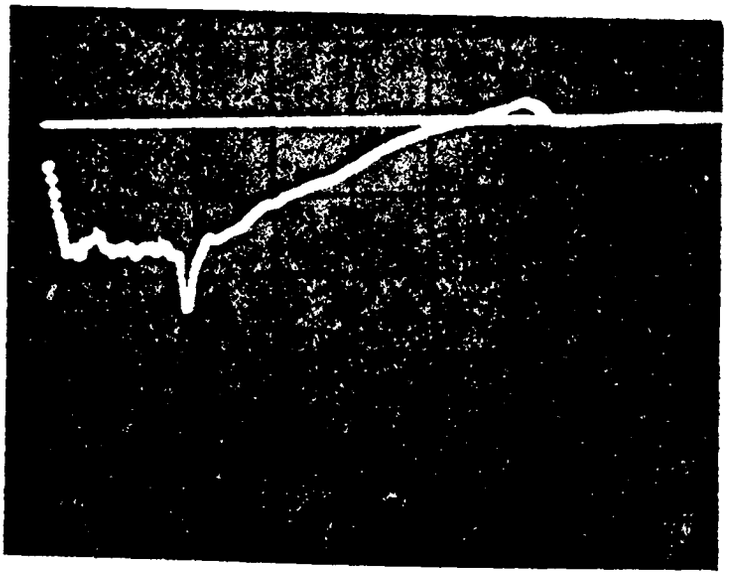
Multiple Projectile Data

Shot No	Diam(inch)	Length(inch)	Velocity (ft/sec)	Impact Angle	Temp
F-2	4	2	642	90	RT
F-3	4	2	517	90	RT
F-4	6	2	485	90	RT
F-5	8	2	646	90	RT
F-6	4	2	530	90	RT
F-7	4	2	470	90	RT
F-8	2	2	494	90	RT
F-9	2	2	500	90	RT
F-10	4	2	504	90	RT
F-11	8	2	427	90	RT

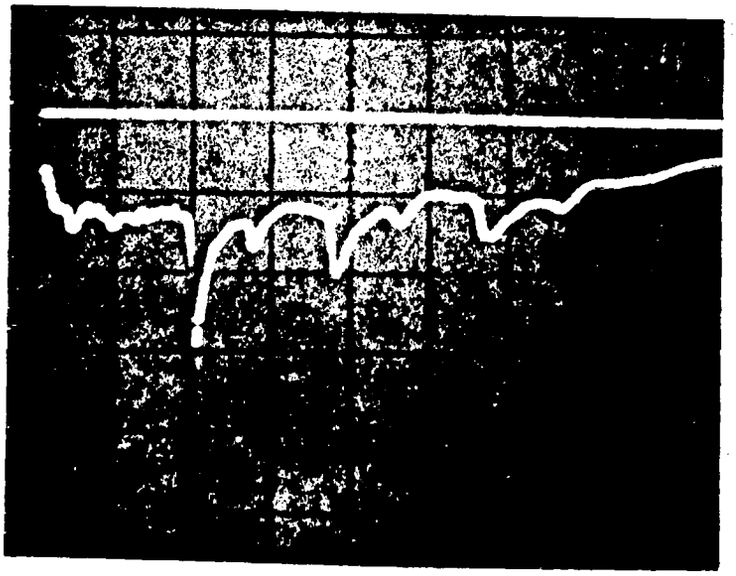
8-13-79 Multiple Projectile Test



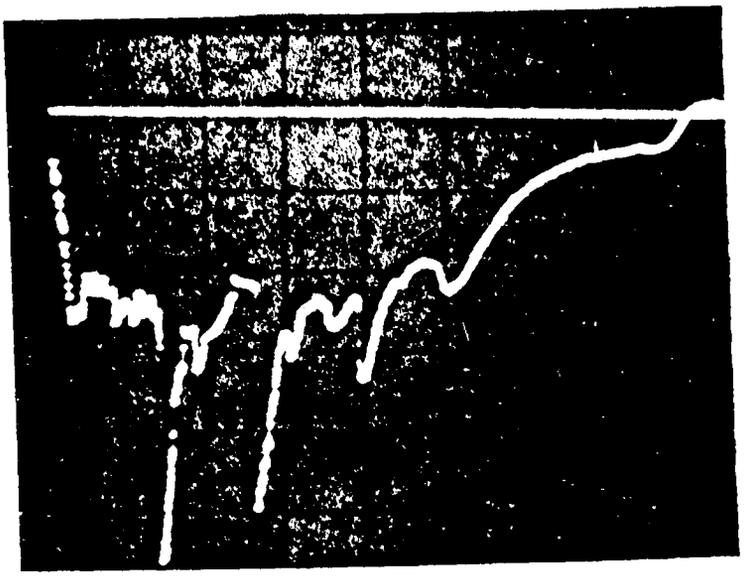
Shot No F-9 1(2x2)
Material Dyplast styrofoam
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 333.2 (μsec)
Velocity 500 (ft/sec)
Scale 54.6 (psi/cm)



Shot No F-10 2(2x2)
Material Dyplast Styrofoam
Mass 3700 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 330.6 (μsec)
Velocity 504 (ft/sec)
Scale 54.6 (psi/cm)



Shot No F-11 4(2x2)
Material Dyplast styrofoam
Mass 7400 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 340.3 (μsec)
Velocity 427 (ft/sec)
Scale 54.6 (psi/cm)



Shot No 5 4x(2"x2")

Material DYPLAST 5F

Mass 7400 (milligrams)

Temperature RT

Vert. Sens. .2 (Volts/cm)

Horiz. Sens. 200 (μsec/cm)

Time 258.1 (μsec)

Velocity 646 (ft/sec)

Scale 54.6 (psi/cm)

Shot No _____

Material _____

Mass _____(milligrams)

Temperature _____

Vert. Sens. _____(Volts/cm)

Horiz. Sens. _____(μsec/cm)

Time _____(μsec)

Velocity _____(ft/sec)

Scale _____(psi/cm)

Shot No _____

Material _____

Mass _____(milligrams)

Temperature _____

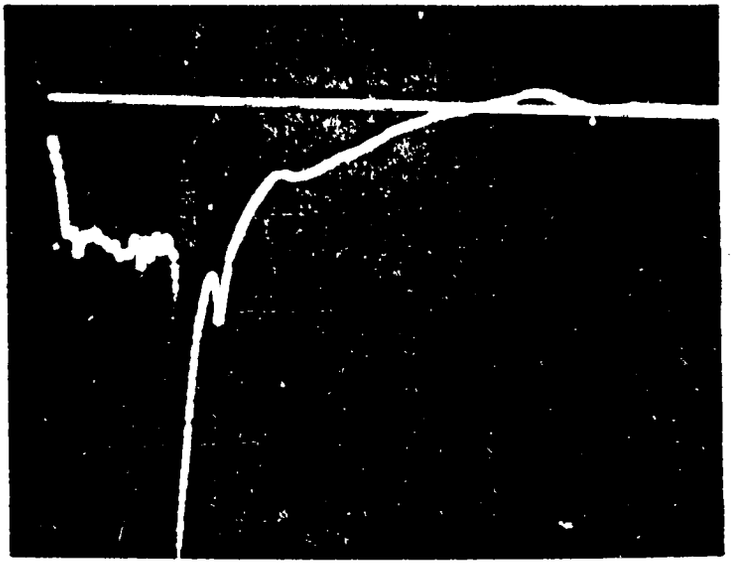
Vert. Sens. _____(Volts/cm)

Horiz. Sens. _____(μsec/cm)

Time _____(μsec)

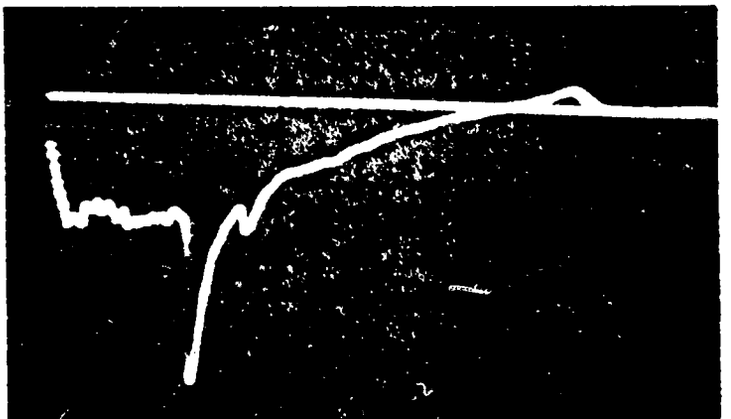
Velocity _____(ft/sec)

Scale _____(psi/cm)

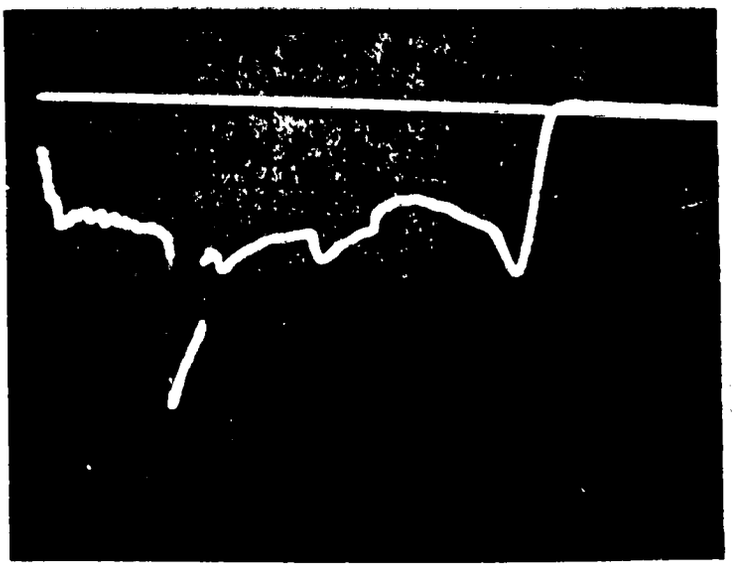


8 cm

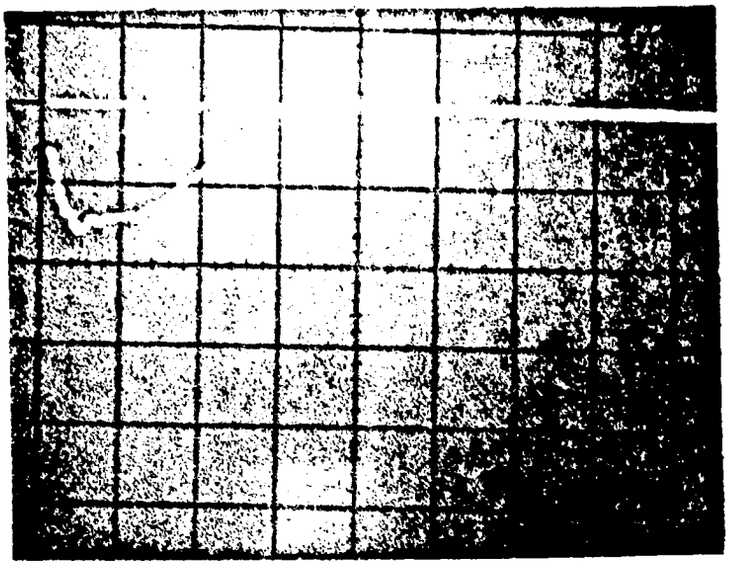
Shot No F-6 2×(2"×2")
Material DYPLAST SF
Mass 3700 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 314.6 (μsec)
Velocity 530 (ft/sec)
Scale 54.6 (psi/cm)



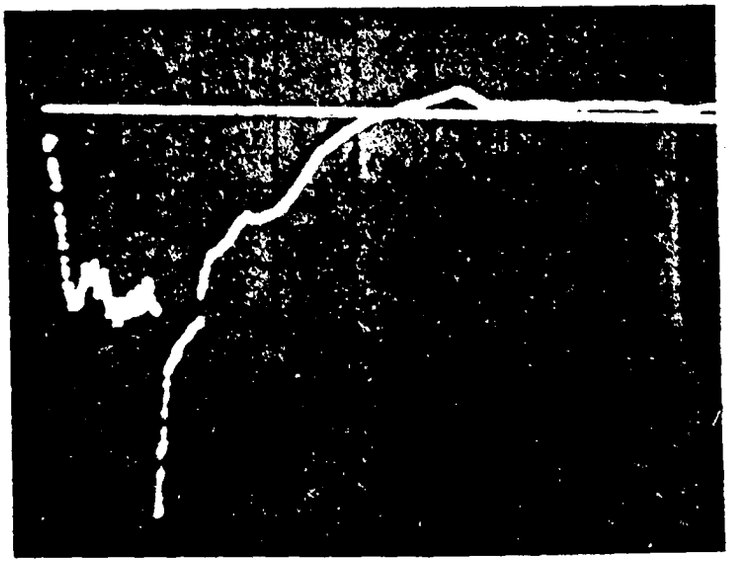
Shot No F-7 2×(2"×2")
Material DYPLAST SF
Mass 3700 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 354.3 (μsec)
Velocity 470 (ft/sec)
Scale 54.6 (psi/cm)



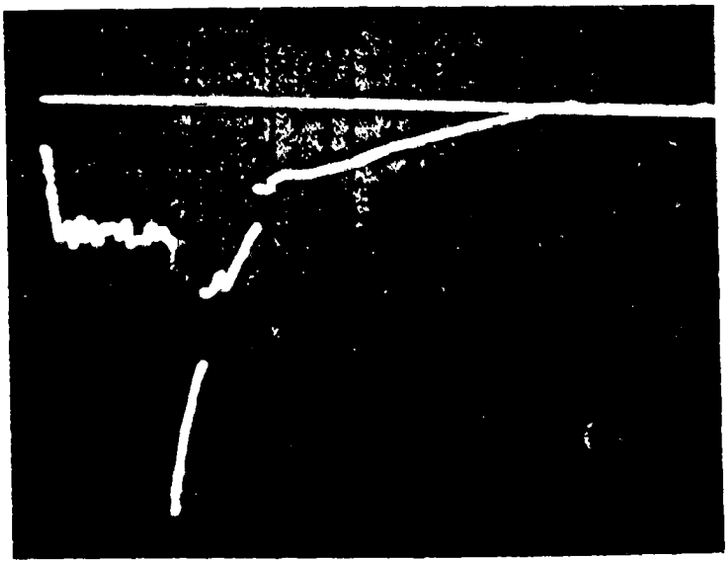
Shot No F-4 3×(2"×2")
Material DYPLAST SF
Mass 5550 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 343.8 (μsec)
Velocity 485 (ft/sec)
Scale 54.6 (psi/cm)



Shot No F-8 1 x (2" x 2")
Material DYPLAST SF
Mass 1850 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 337.3 (μsec)
Velocity 494 (ft/sec)
Scale 54.6 (psi/cm)



Shot No F-2 2 x (2" x 2")
Material DYPLAST SF
Mass 3700 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 259.4 (μsec)
Velocity 642.5 (ft/sec)
Scale 54.6 (psi/cm)

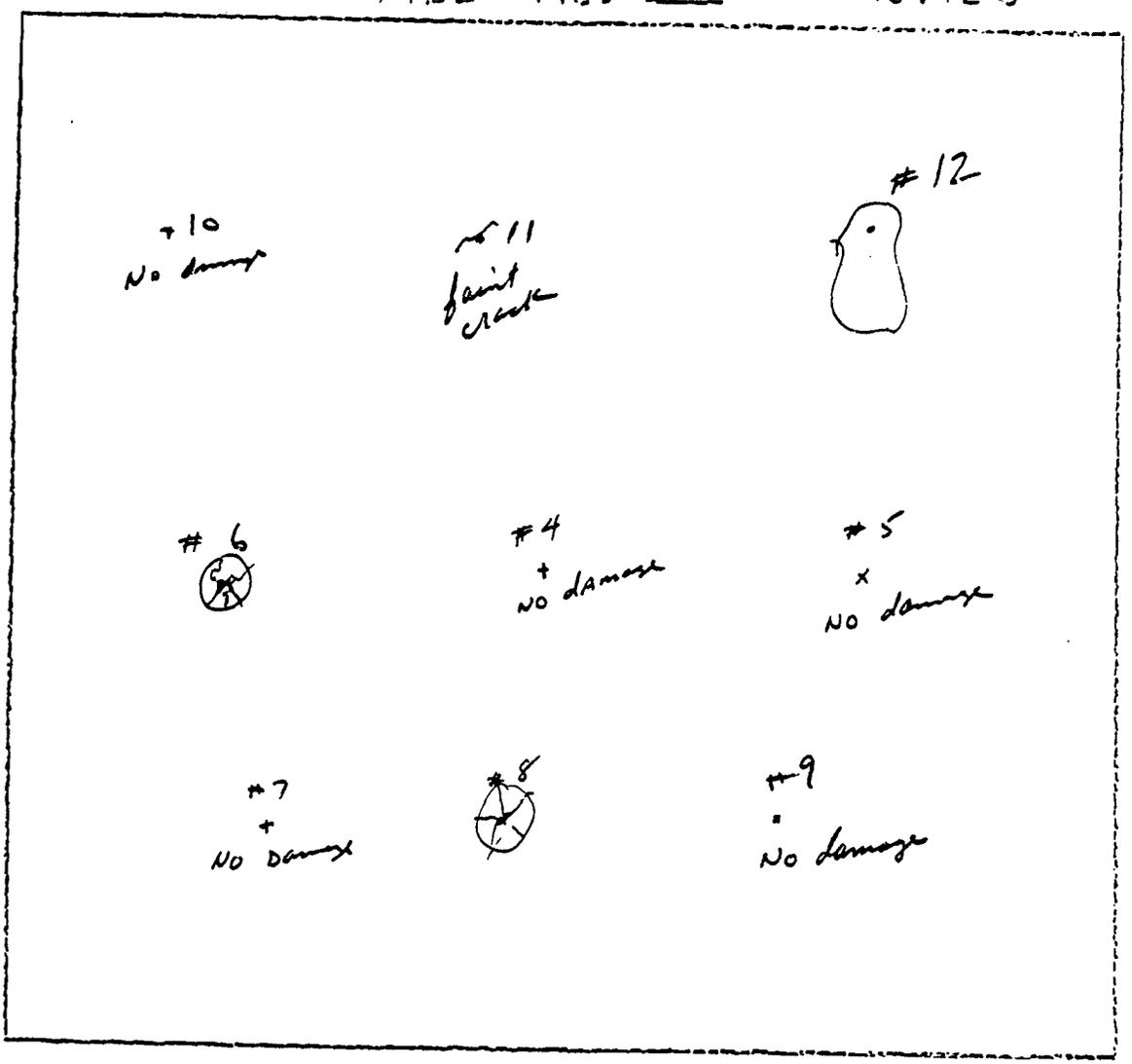


Shot No F33 2 x (2" x 2")
Material DYPLAST SF
Mass 3700 (milligrams)
Temperature RT
Vert. Sens. .2 (Volts/cm)
Horiz. Sens. 200 (μsec/cm)
Time 322.4 (μsec)
Velocity 517 (ft/sec)
Scale 54.6 (psi/cm)

Appendix G
HRSI Tile Impact

TILE NO. 12 - MOVIES

47



Test #1-
Projectile
Mass=
Counter=
Velocity=
Depth= -
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile Styrofoam $\frac{3}{8} \times 1''$
Mass= 31 milligrams
Counter= 746.4 usec
Velocity= 142.9 ft/sec
Depth=
Diameter=
Volume= No damage

All $\frac{3}{8} \times 1$

Test #5
Projectile Styrofoam
Mass= 31 milligrams
Counter= 307.4 usec
Velocity= 346.9 ft/sec
Depth=
Diameter=
Volume=

Test #6
Projectile Styrofoam
Mass= 27 milligrams
Counter= 135.3
Velocity= 788.4 ft/sec
Depth=
Diameter=
Volume=

Test#7
Projectile CPR
Mass=
Counter= none
Velocity= ≈ 200 ft/sec
Depth=
Diameter=
Volume=

Test #8
Projectile CPR
Mass= 70 milligrams
Counter= 188.9 usec
Velocity= 564.7 fps
Depth=
Diameter=
Volume=

Test #9
Projectile BX 250
Mass= 59 milligrams
Counter= 239.7 usec.
Velocity= 445 fps
Depth=
Diameter=
Volume=

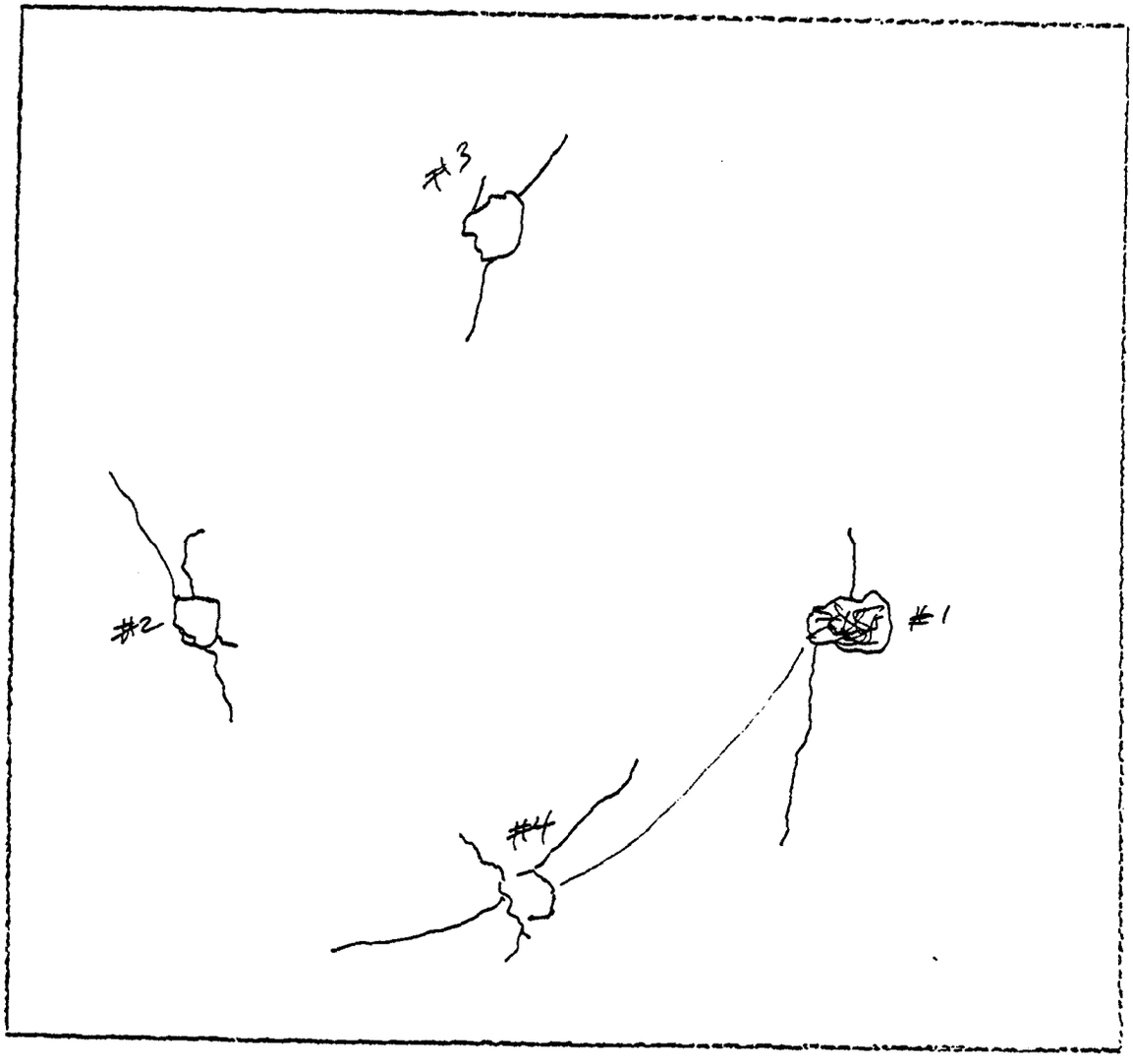
Test #10 Styrofoam
Projectile 27
Mass= 176.5 usec
Counter= 604.3 no damage
Velocity=
Depth=
Diameter=
Volume=

#11
Styrofoam
142.9
746.4 ft/sec
31 milligrams
faint crack
90°

all 90° except #12

#12 Styrofoam 29 milligrams
106 usec
1006 ft/sec
60° angle

TILE NO. 14



Test #1- THIN $\frac{3}{8}$x2
Projectile VITRON + STYROFOAM
Mass= 88 mg
Counter= 460.6
Velocity= 232
Depth= -
Diameter=
Volume=

Test #2 THIN
Projectile $\frac{3}{8}$x1
Mass= 66mg
Counter= 402.7
Velocity= 265
Depth=
Diameter=
Volume=

Test #3 THIN $\frac{3}{8}$x1
Projectile
Mass= 61
Counter= 316
Velocity= 340
Depth=
Diameter=
Volume=

Test #4 THIN $\frac{3}{8}$x1
Projectile
Mass= 64
Counter= 771.7
Velocity= 138 ft/sec
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

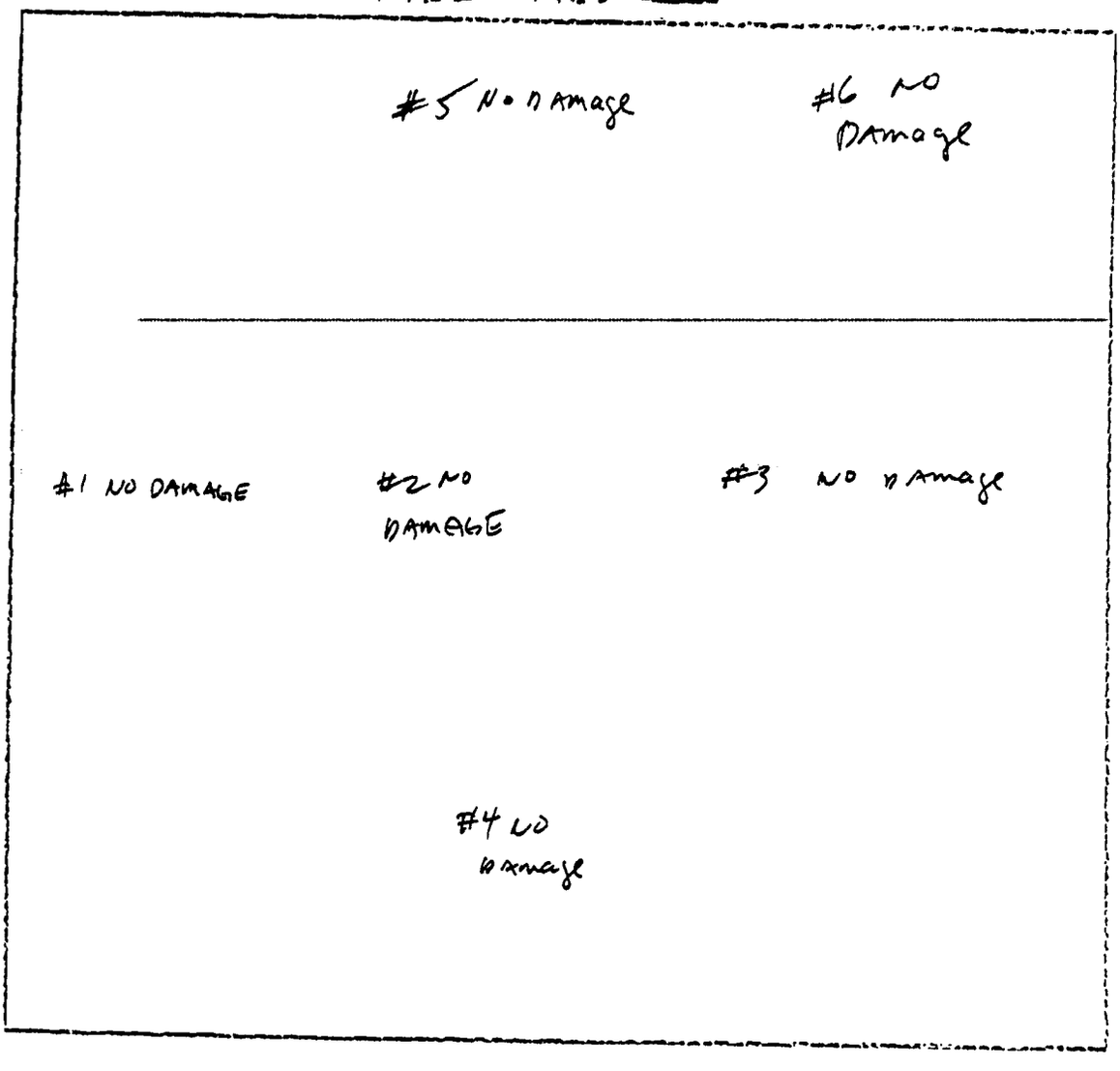
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. 15

51



Test #1-
Projectile 3x1 SE
Mass= 31
Counter= 557.7
Velocity= 191.2
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 31
Counter= 425.1
Velocity= 251.0
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass= 31
Counter= 249.4
Velocity= 428.0
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 29
Counter= 235.5
Velocity= 453.0
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass= 27
Counter= 187.3
Velocity= 564.0
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass= 31
Counter= 349.5
Velocity= 306.0
Depth=
Diameter=
Volume=

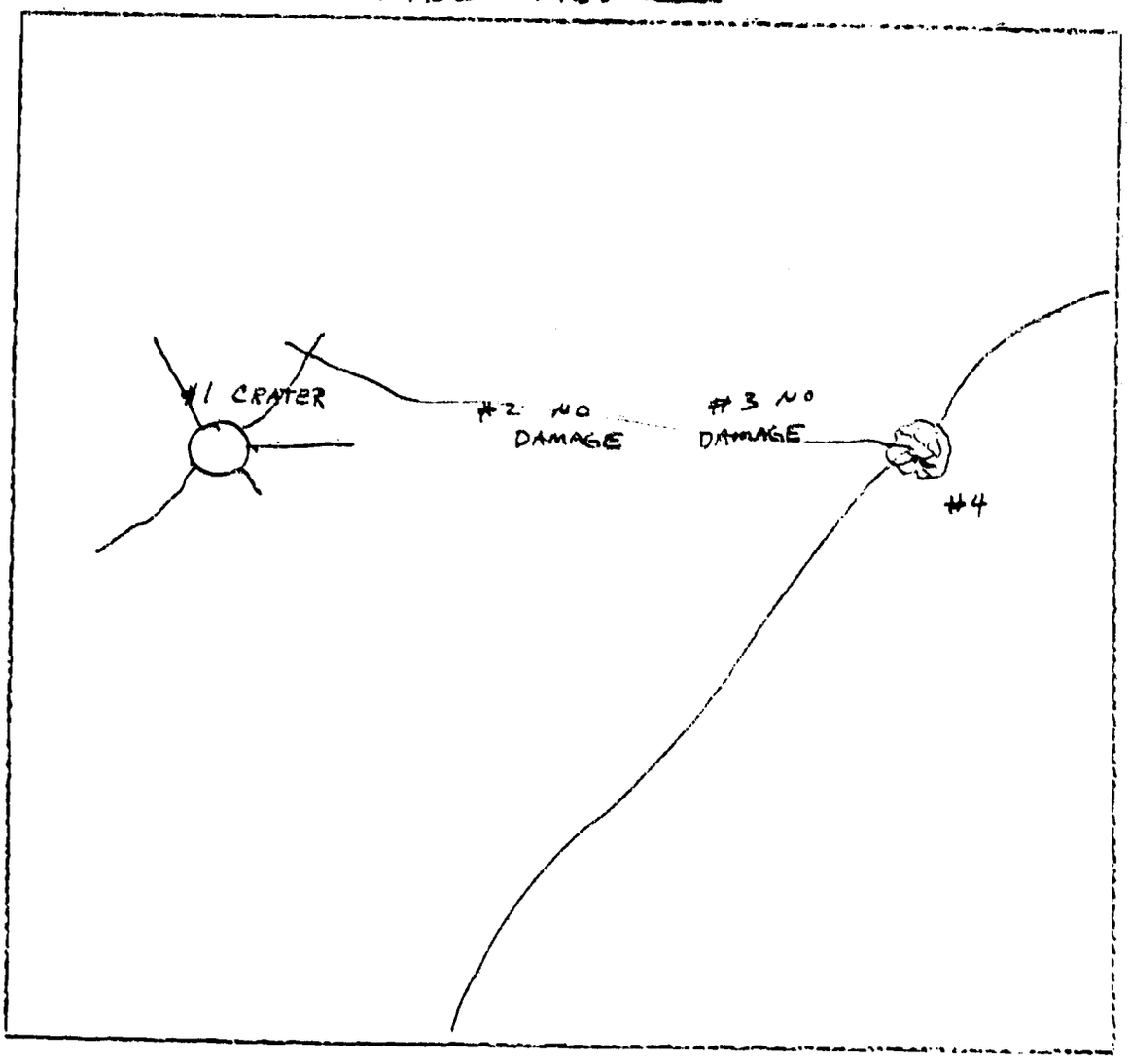
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. L²



Test #1-
Projectile THICK TIP $\frac{3}{8}$ x 2
Mass= 196 mg
Counter= 293.1
Velocity= 364.0 ft/sec
Depth= -
Diameter=
Volume=

Test #2
Projectile THIN TIP $\frac{3}{8}$x2
Mass= 85 mg
Counter= 948.8
Velocity= 112.0 ft/sec
Depth=
Diameter=
Volume=

test #3
Projectile THIN TIP $\frac{3}{8}$ x 2
Mass= 86 mg
Counter= 941.7
Velocity= 113.0 ft/sec
Depth=
Diameter=
Volume=

Test #4
Projectile THIN TIP $\frac{3}{8}$ x 2
Mass= 82
Counter= 629.1
Velocity= 170 ft/sec
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

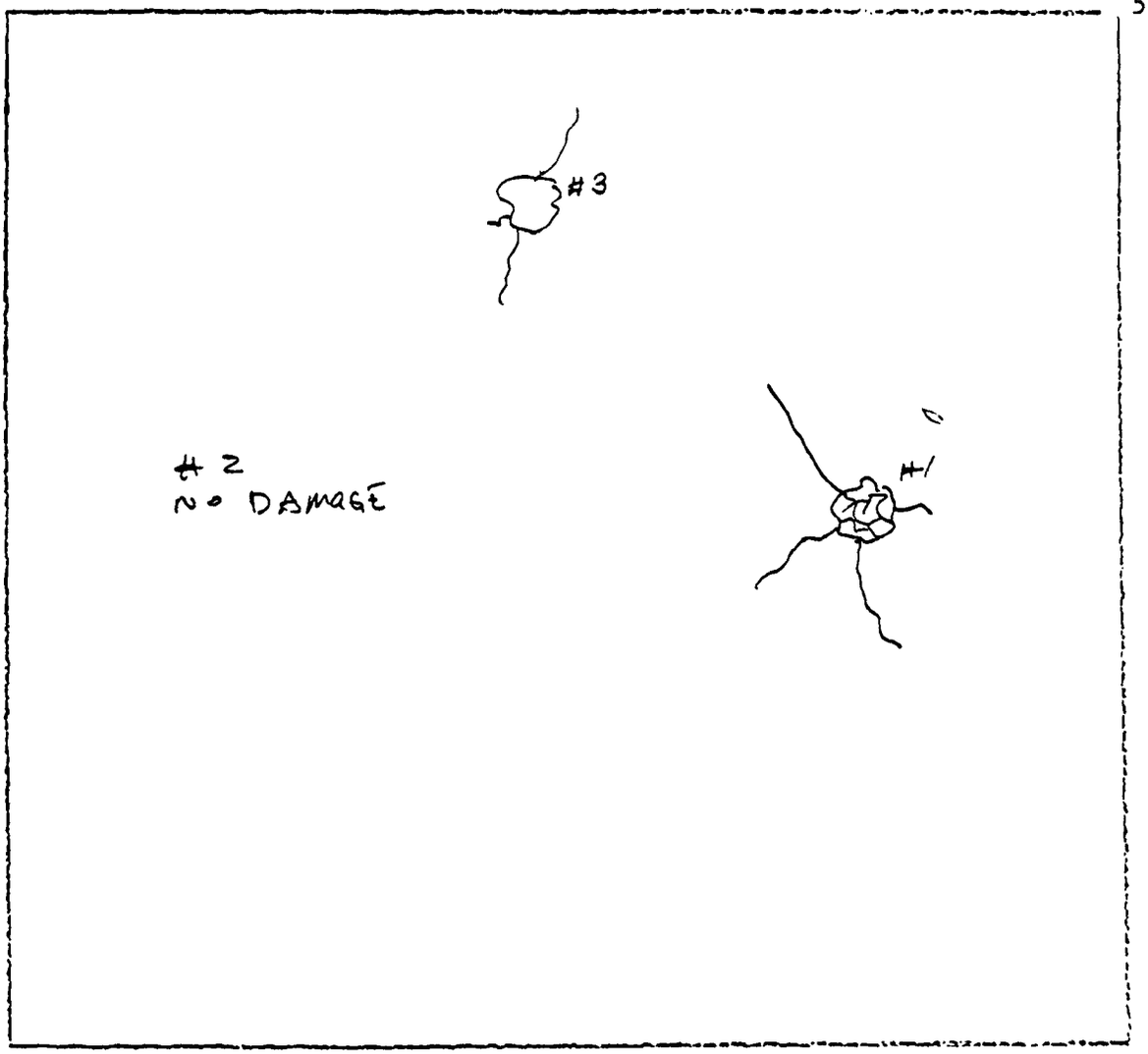
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. 15



Test #1- THIN TIP $\frac{3}{8} \times 1$
Projectile
Mass= 65
Counter= 602.5
Velocity= 177 ft/sec
Depth= -
Diameter=
Volume=

Test #3 THIN TIP w/Tape
Projectile
Mass= 61
Counter= 543.0
Velocity= 196
Depth=
Diameter=
Volume=

Test #2 THIN TIP w/ tape
Projectile
Mass= 61
Counter= 1005.7
Velocity= 106
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. A

57

#5 no damage

#1 no damage

#2 no damage

#3 no damage

#4 no damage

Test #1-
Projectile $\frac{3}{8}$x1 Styrofoam
Mass= 31
Counter= 244.1
Velocity= 437.0
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 27
Counter= 223.1
Velocity= 478.0
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass= 27
Counter= 191.4
Velocity= 557.0
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 26
Counter= 172.7
Velocity= 618.0
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass= 2f
Counter= 201.7
Velocity= 529.0
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

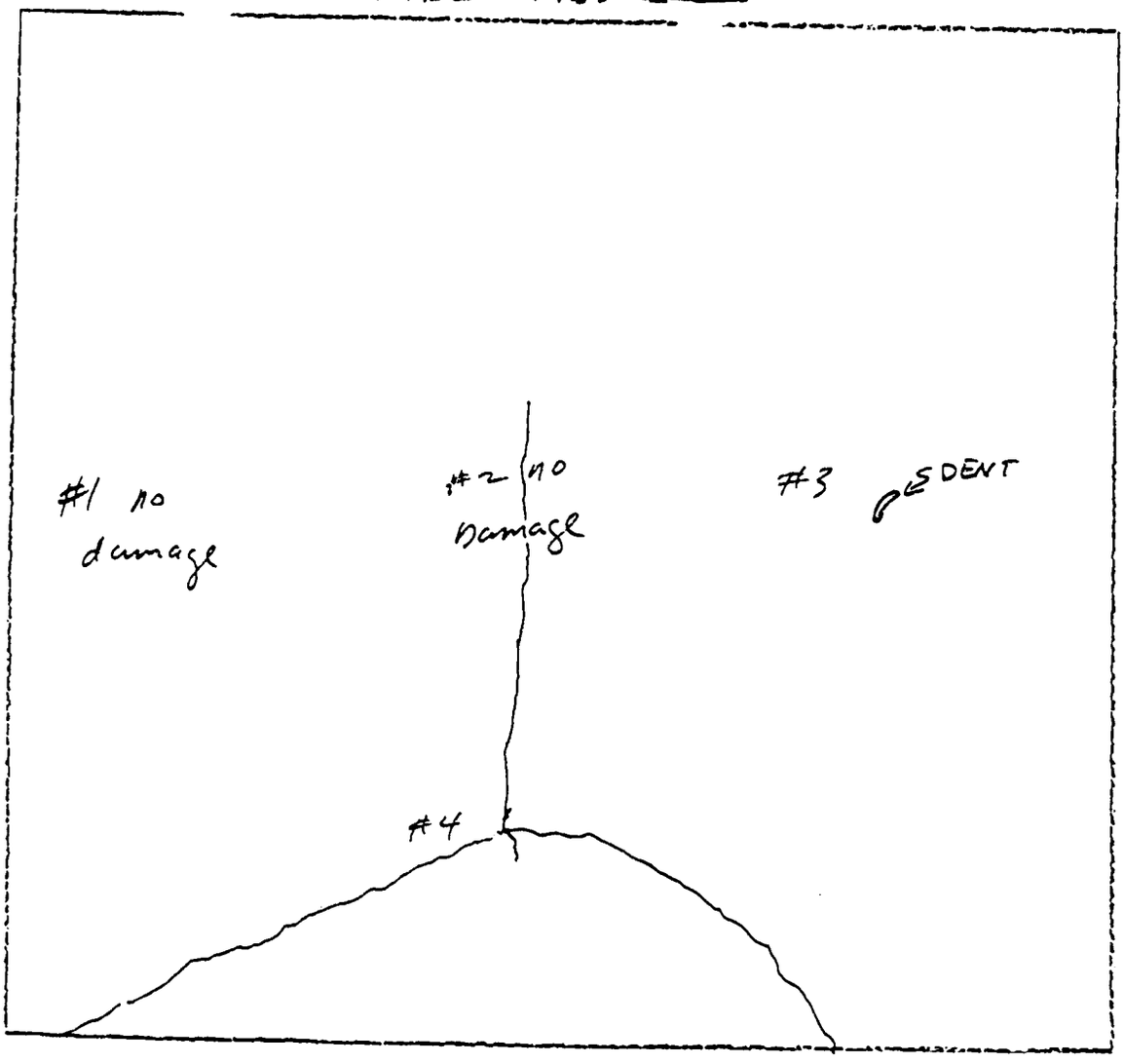
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. 15



Test #1-
Projectile 3/8x1 Styrofoam
Mass= 29
Counter= 241
Velocity= 409
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 26
Counter= 239.5
Velocity= 445
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass= 27
Counter= 150.3
Velocity= 710
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 30
Counter= 133.5
Velocity= 799
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

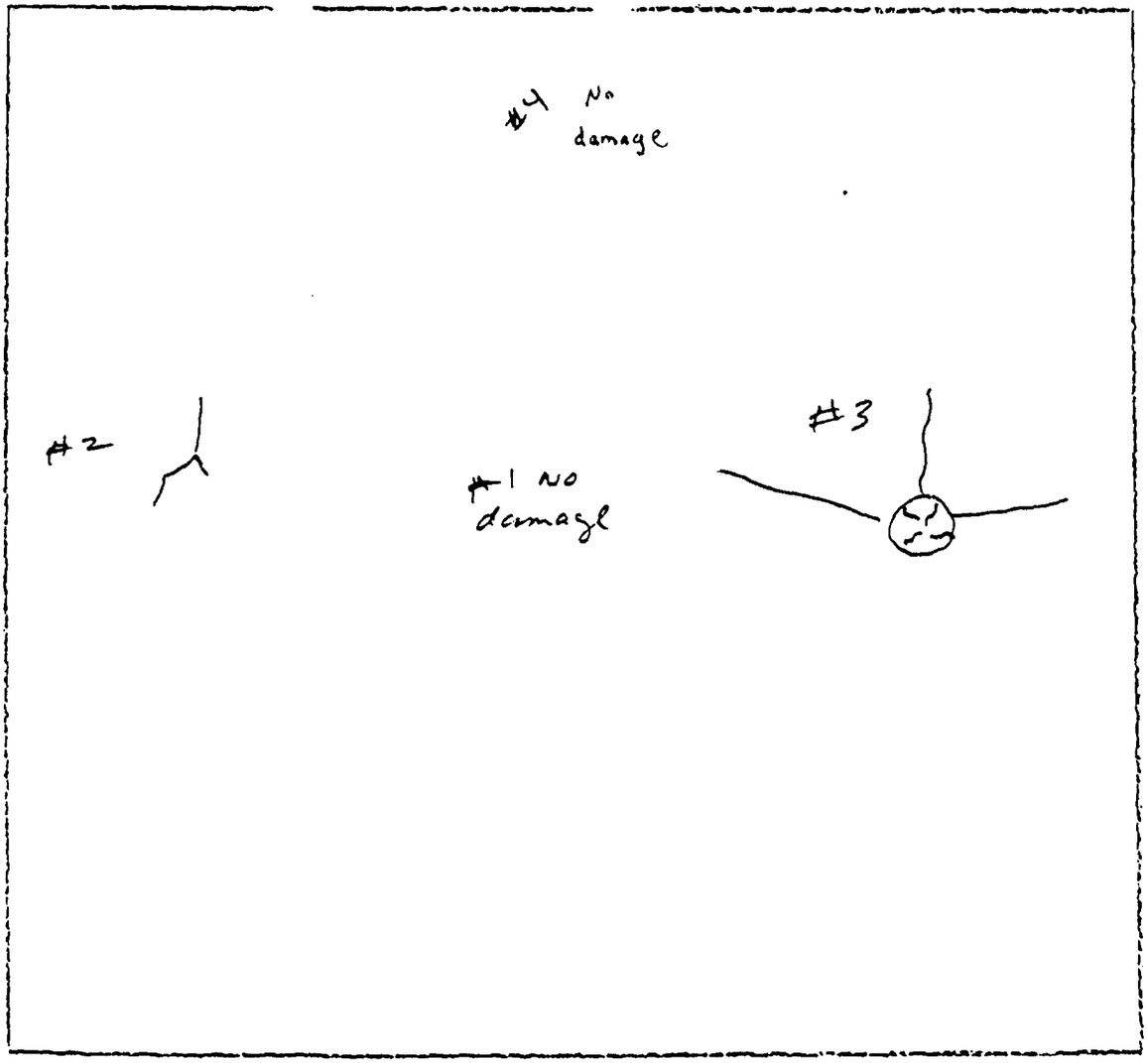
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO C



Test #1-
Projectile
Muss= 29 Ex/ St-jf-fm
Counter= 165.9
Velocity= 642.9
Depth= -
Diameter=
Volume=

Test #2
Projectile
Muss= 33
Counter= 140.7
Velocity= 758.1
Depth=
Diameter=
Volume=

Test #3
Projectile
Muss= 33
Counter= 137.7
Velocity= 774.6
Depth=
Diameter=
Volume=

Test #4
Projectile
Muss= 32
Counter= 156
Velocity= 683
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

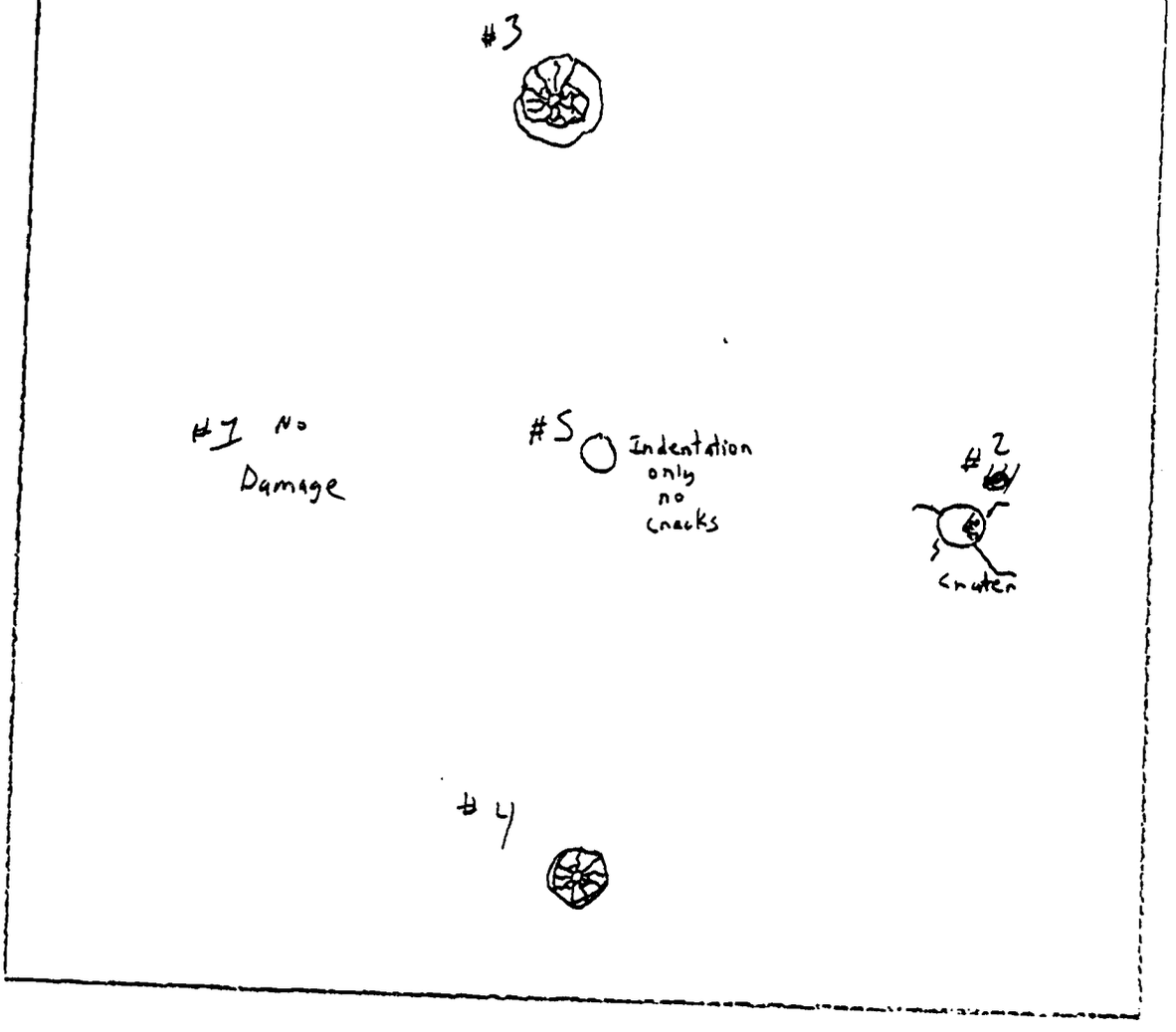
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Tile No. D – 60°

63



Test #1-
Projectile
Mass= 31 3x1 Styrofoam
Counter= 151.6
Velocity= 703.6
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 34
Counter= 110.6
Velocity= 964
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass= 34
Counter= 117.8
Velocity= 905.5
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 33
Counter= 125.8
Velocity= 847.9
Depth=
Diameter=
Volume=

Test #5
Mass= 35
Counter= 147.7
Velocity= 722

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

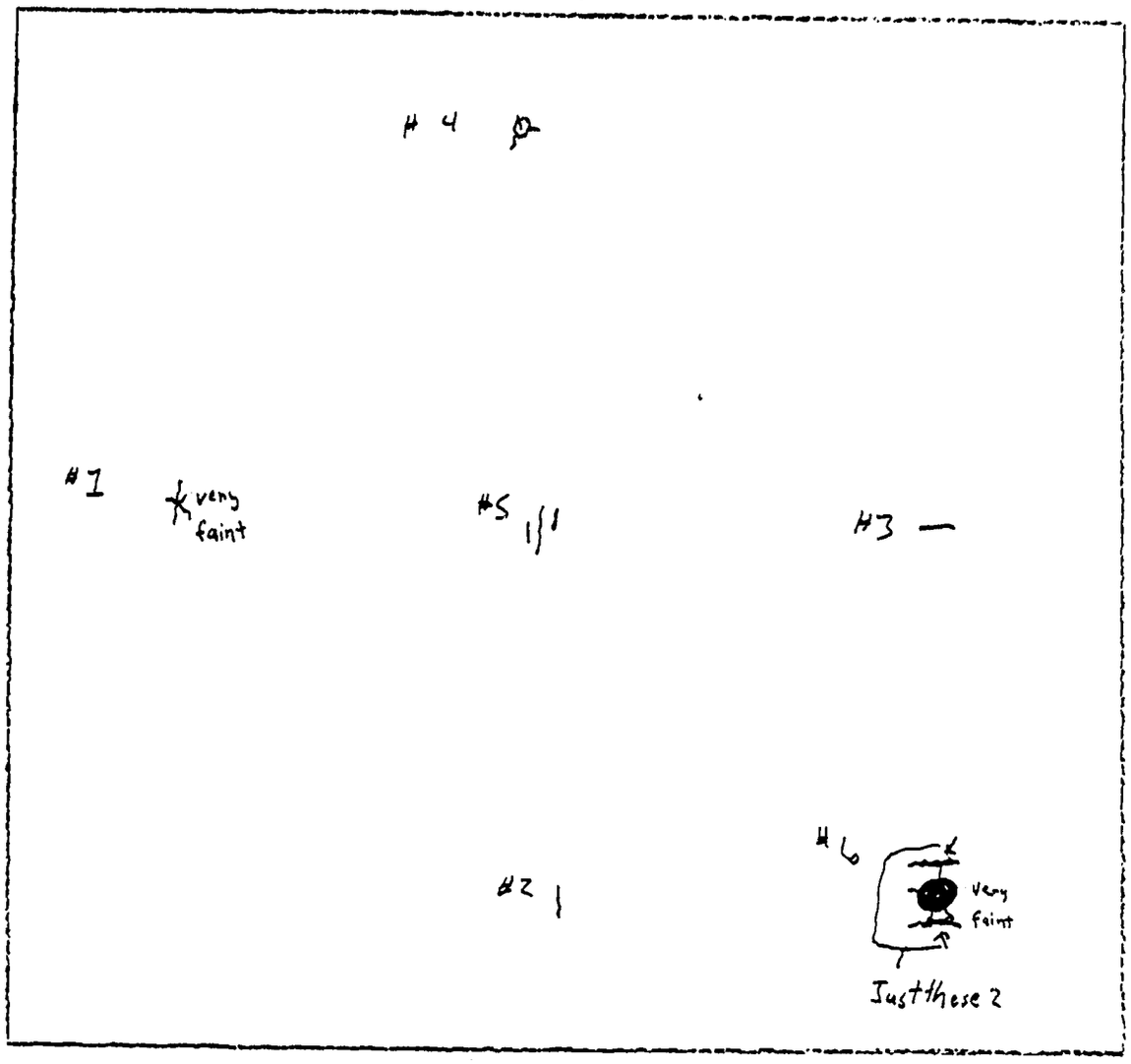
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. E 60



Test #1-
Projectile 3 ex 1 Styrofoam
Mass= 34
Counter=133.3
Velocity=802.2
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 31
Counter= 148.4
Velocity=726.8
Depth=
Diameter=
Volume=

test #3
Projectile
Mass= 31
Counter= 153.8
Velocity= 693.5
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 33
Counter=144.8
Velocity=734.6
Depth=
Diameter=
Volume=

#5
Mass=31
Counter= 160.3
Vel = 665.4

#6
Mass=32
Counter= 148.8
Vel = 716.8

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

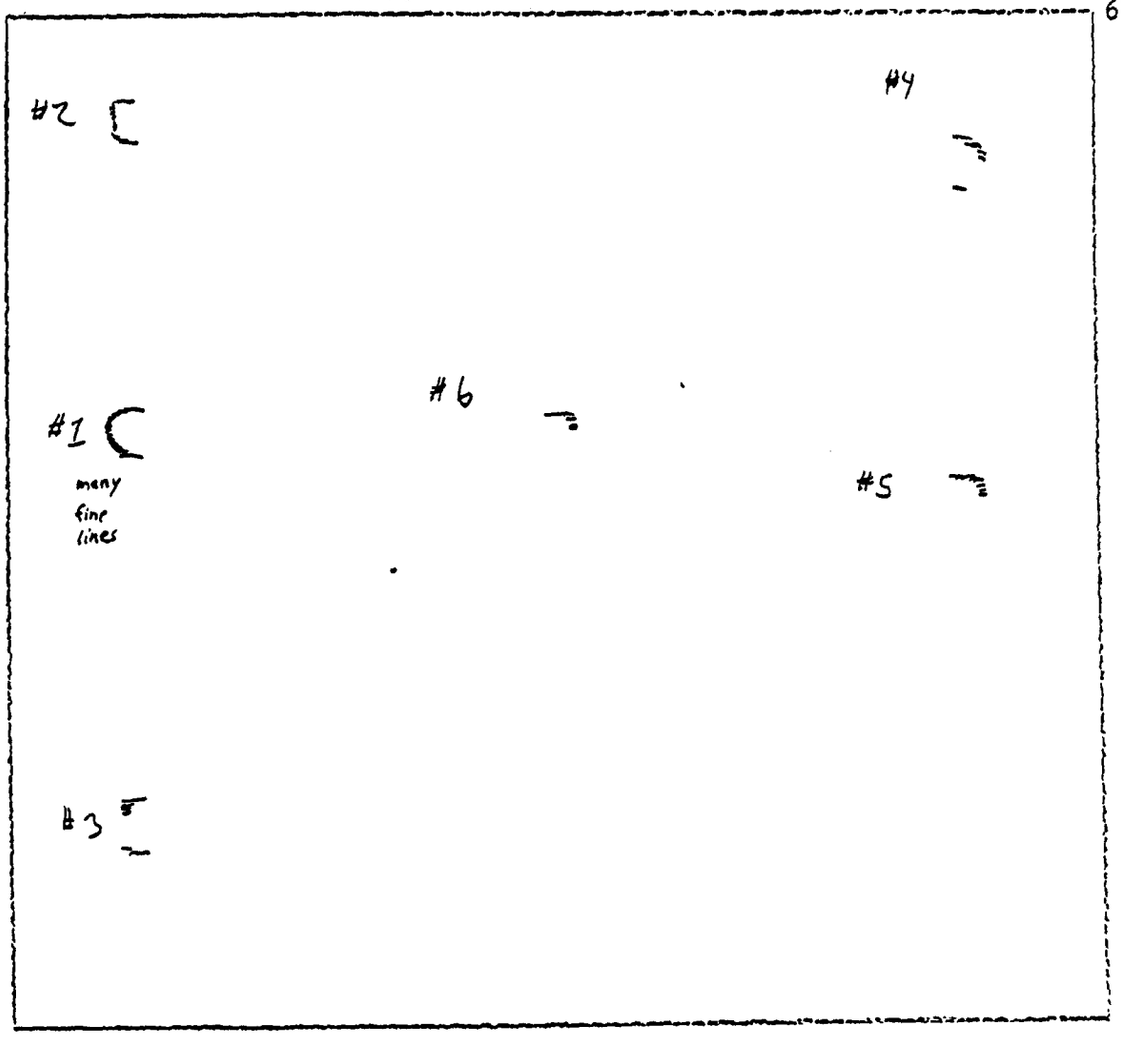
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. I 60

67



Test #1-
Projectile Ex1 Styrofoam
Mass= 34
Counter= 140.8
Velocity= 757.6
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass= 34
Counter= 169.4
Velocity= 629.7
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass= 34
Counter= 149.1
Velocity= 715.4
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass= 33
Counter= 185.8
Velocity= 574.1
Depth=
Diameter=
Volume=

#5
Mass= 33
counter= 173.5
Vel = 614.8

#6
Mass = 33
counter= 229.4
Vel= ~~464~~ 465.0

TILE NO. M

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

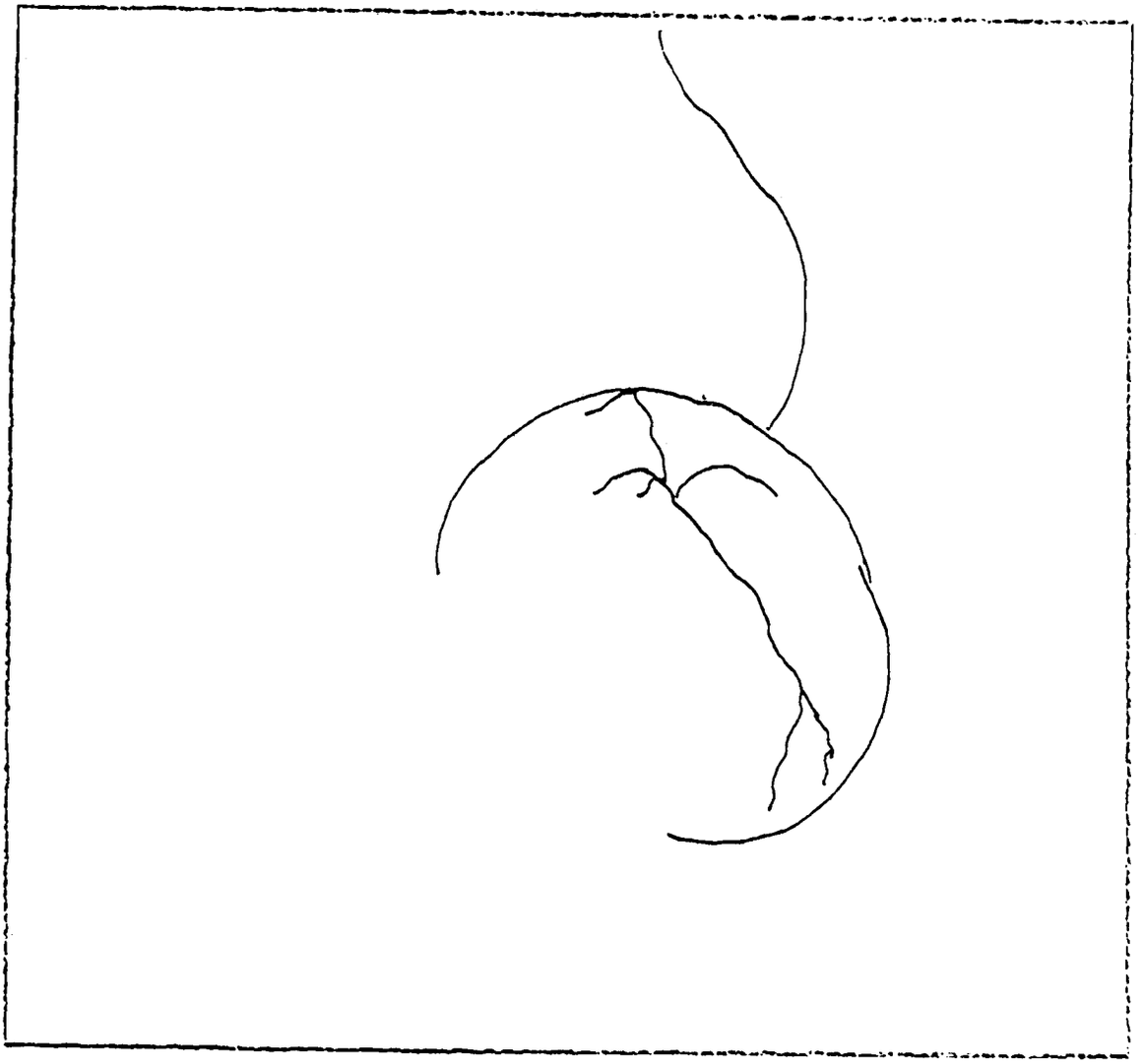
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. 9 -



Test #1-
Projectile 2" Styrofoam
Mass= 1.853 g
Counter= 313.5
Velocity= 532
Depth= -
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

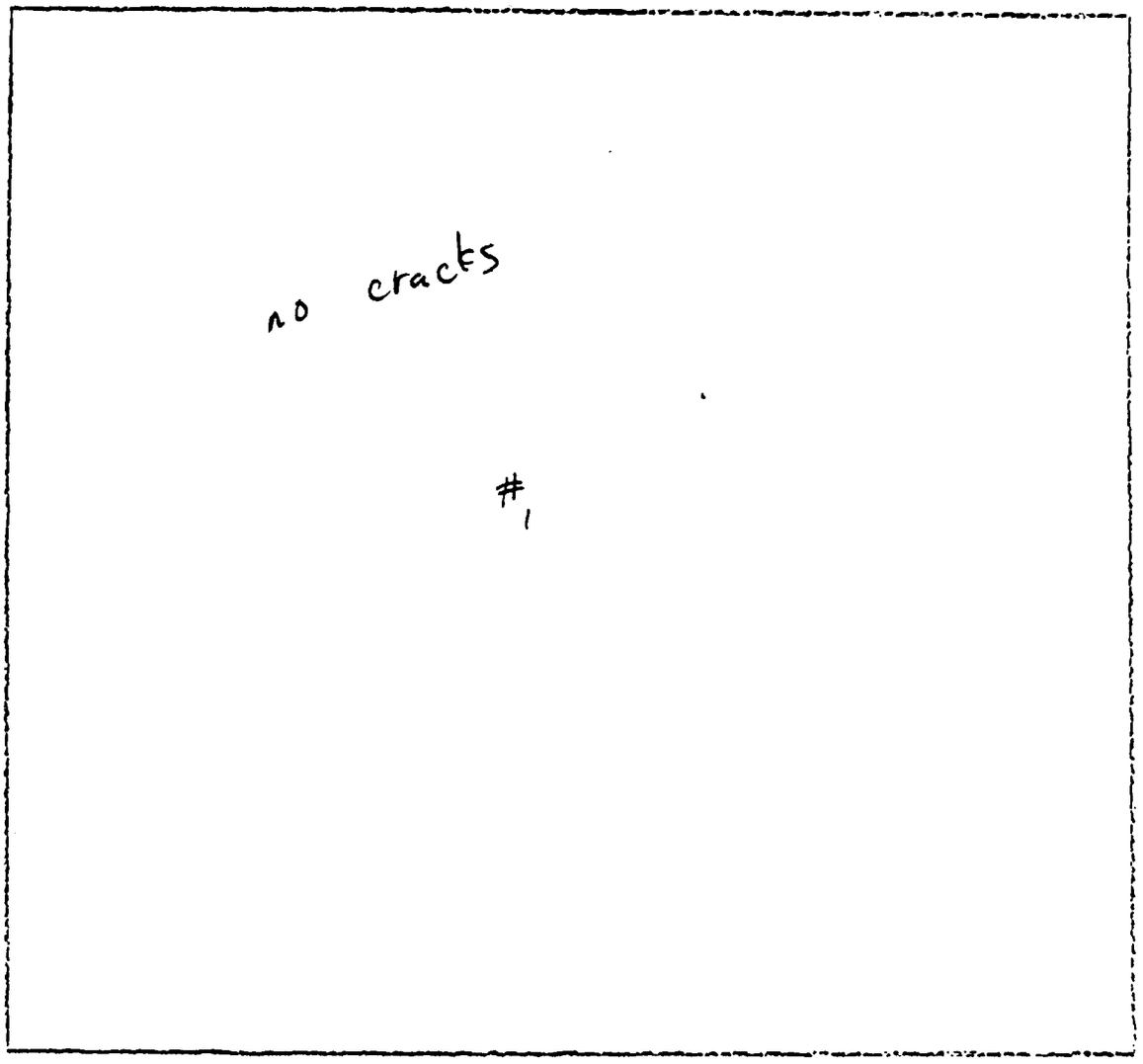
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. H-

71



Test #1-
Projectile 2" - Styrofoam
Mass= 1.653
Counter= 511.4
Velocity= 326
Depth= -
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

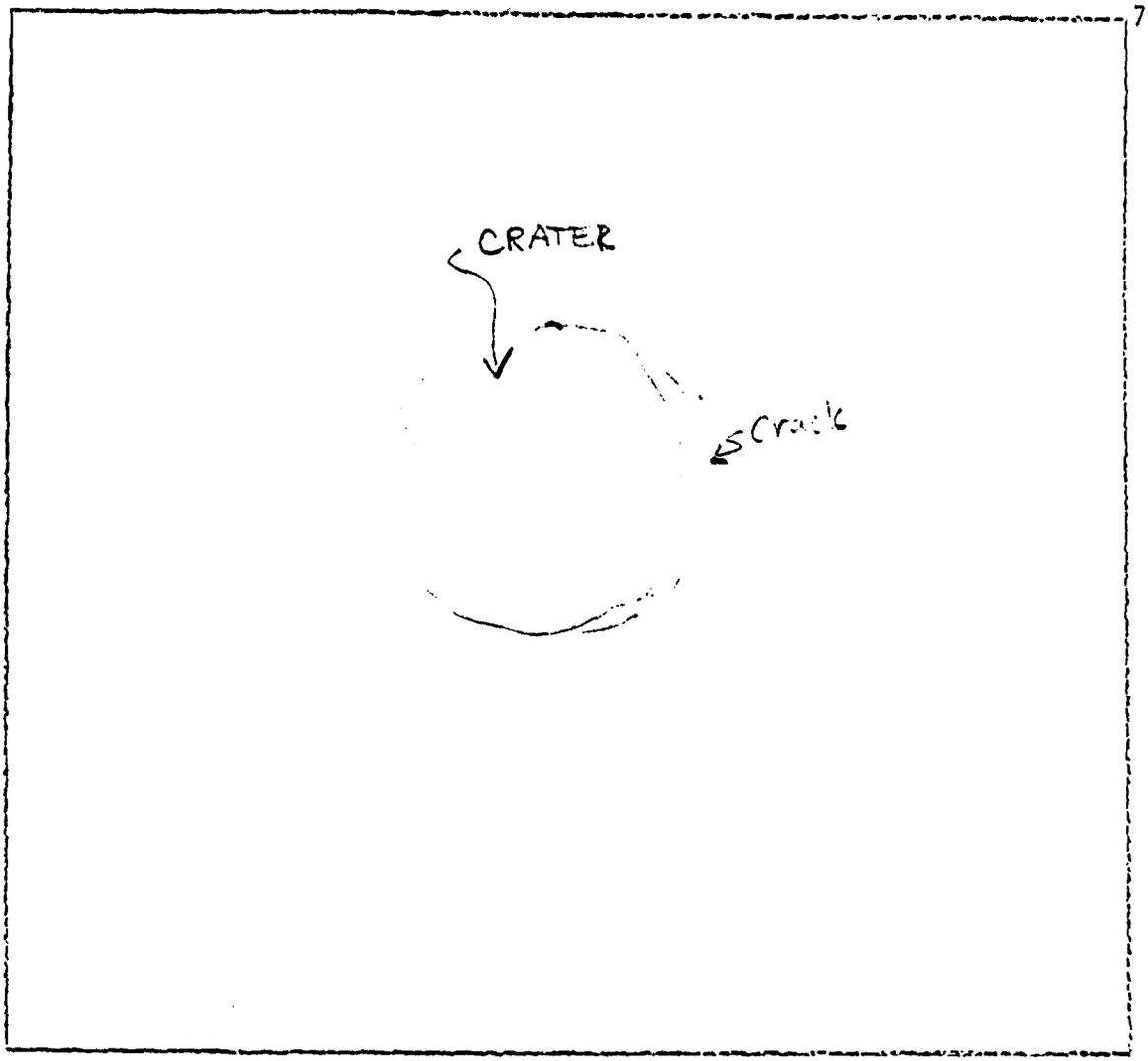
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. ±

73



Test #1-
Projectile 2" Styrofoam
Mass= 1.653
Counter= no co-t
Velocity= ≈ 700
Depth= - ~ 1/4"
Diameter= ~ 2"
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

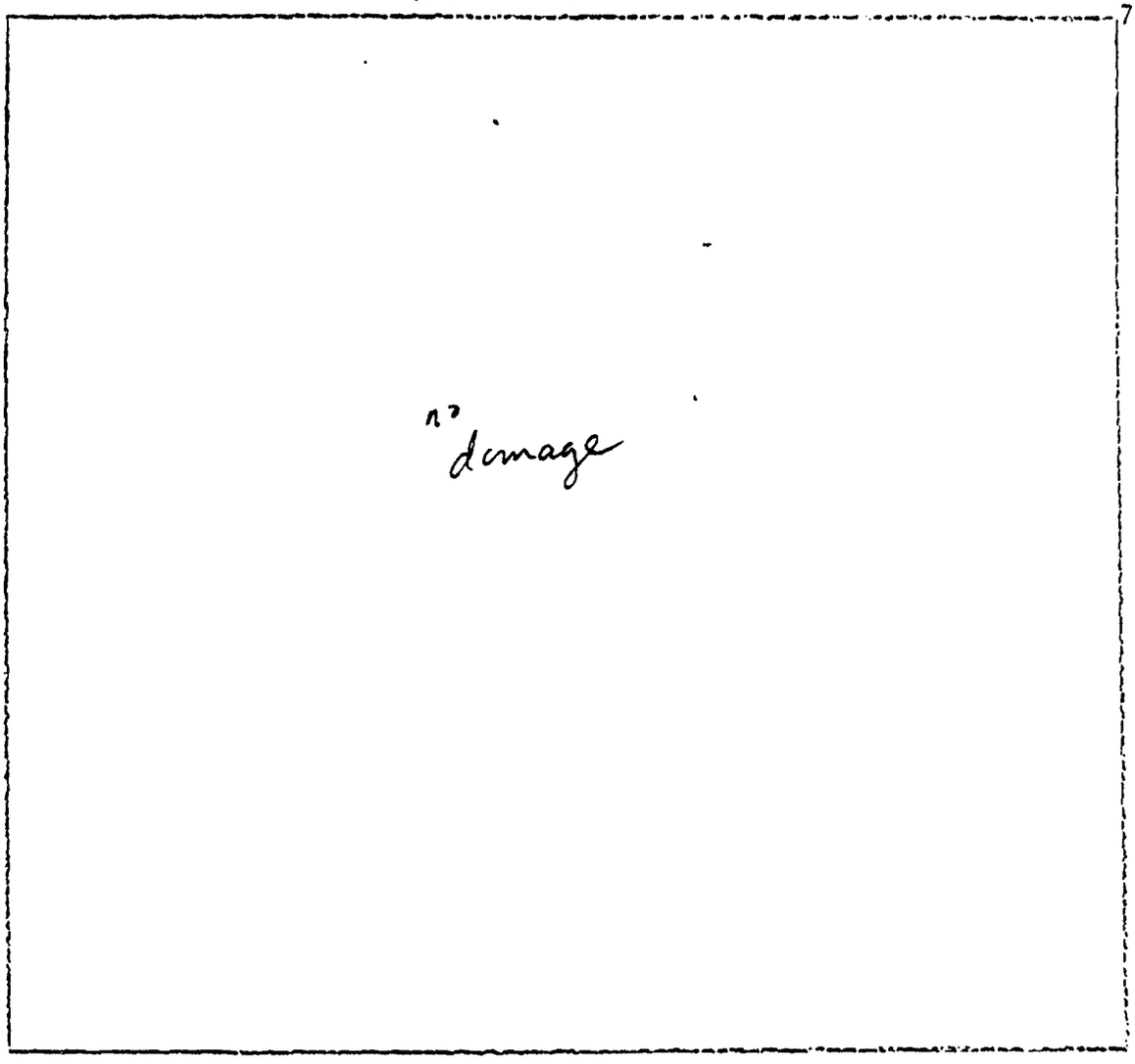
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. 2

75



Test #1-
Projectile 2" coated Styrofoam
Mass=
Counter= 1820.3
Velocity= 91.5
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

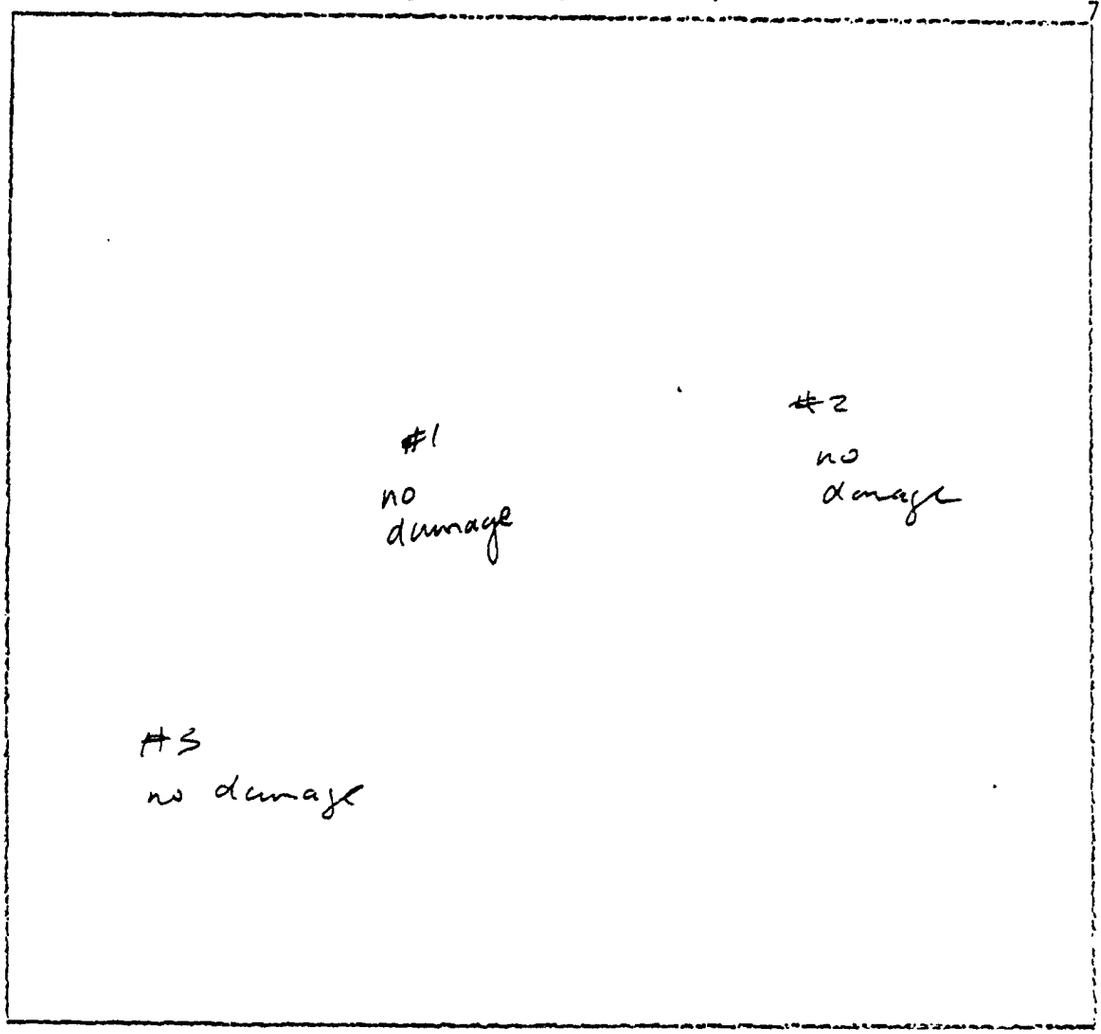
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

77



Test #1-
Projectile 2" coated Styrofoam
Mass=
Counter= 2717
Velocity= Glancing
Depth= -
Diameter=
Volume=

Test #3
Projectile 2" coated
Mass=
Counter= 2095.9
Velocity= 79.5
Depth=
Diameter=
Volume=

Test #2
Projectile 2" coated
Mass=
Counter= 1855.9
Velocity= 90 thru
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

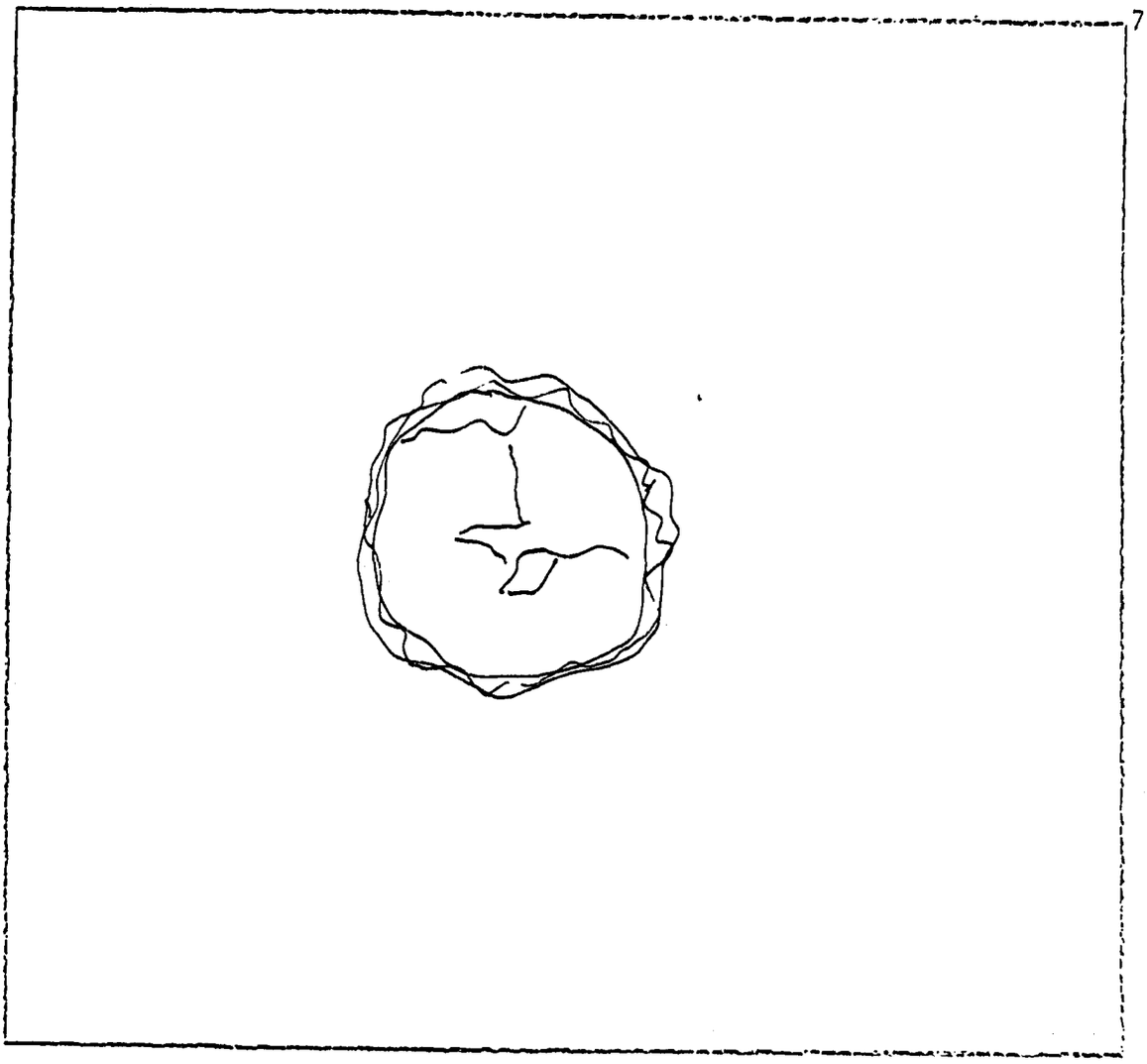
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. L

79



Test #1-
Projectile 2" coated Styrofoam
Mass=
Counter= 427
Velocity= 390
Depth= -
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

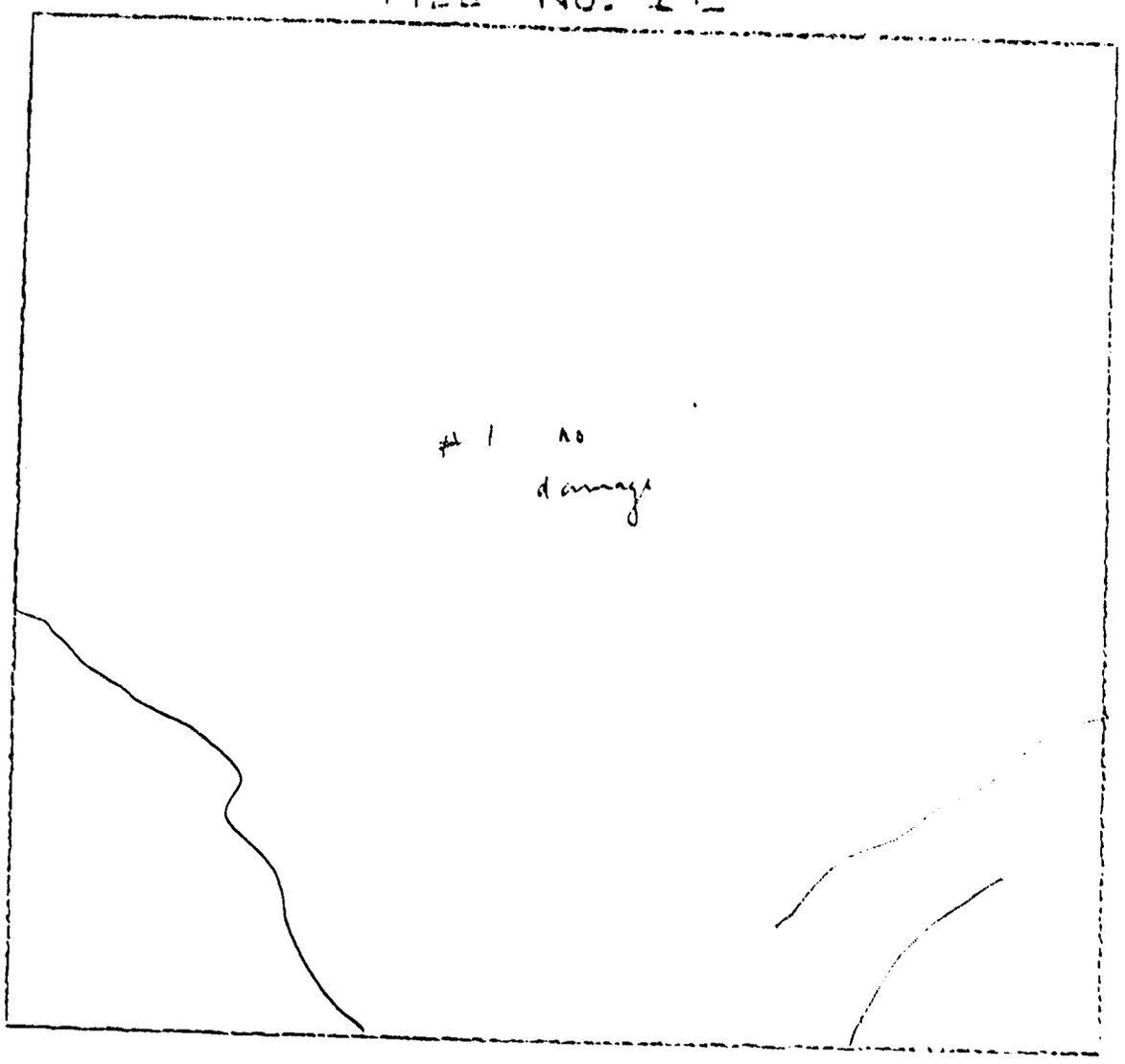
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. M_



Test #1-
Projectile 2"x2" coated Styrofoa...
Mass=
Counter= 445.2
Velocity= 176
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter
Velocity
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter
Velocity=
Depth
Diameter
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

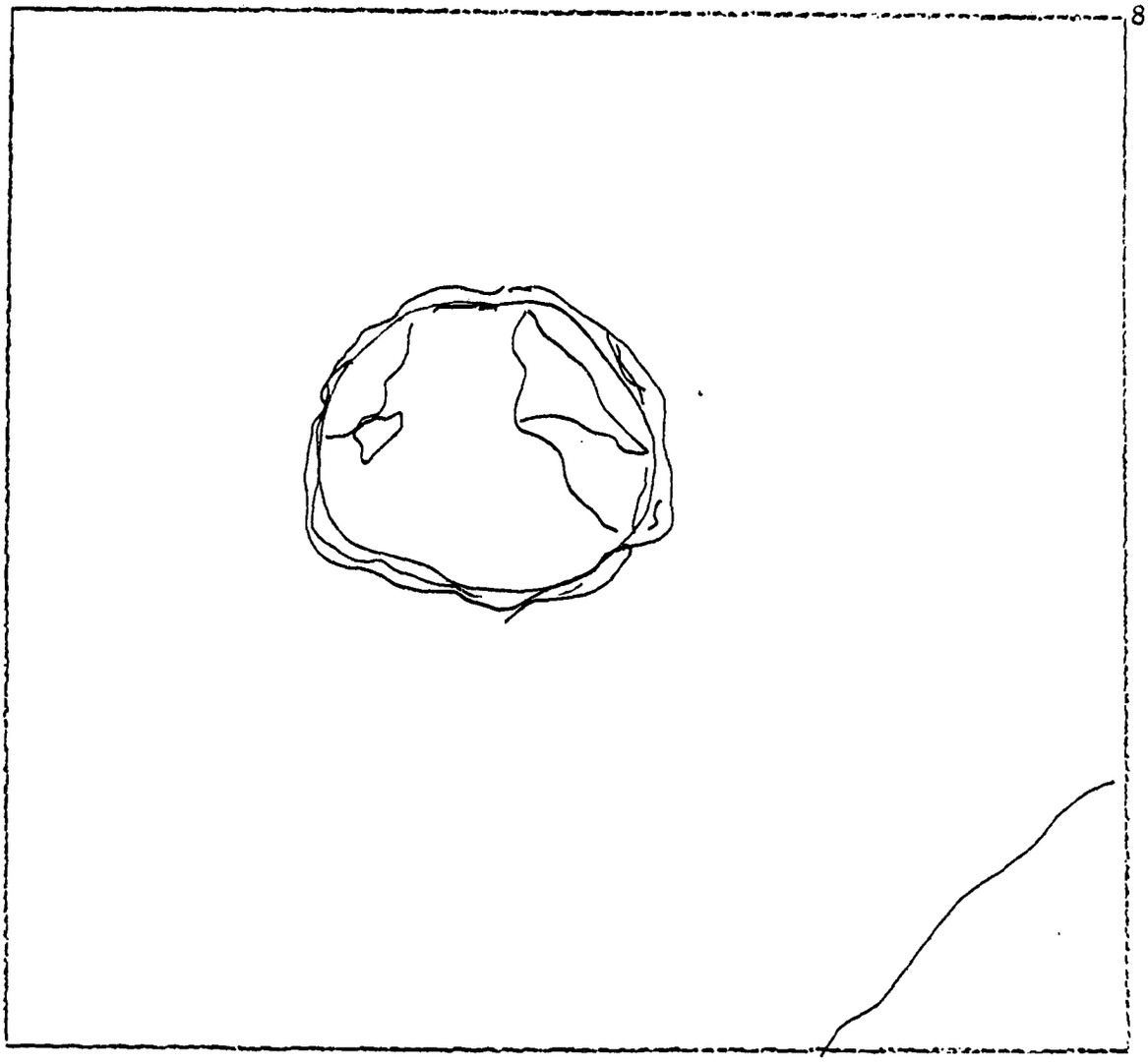
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. N



Test #1-
Projectile 2×2 coated Stypefoam
Mass=
Counter= 550.1
Velocity= 303
Depth= -
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

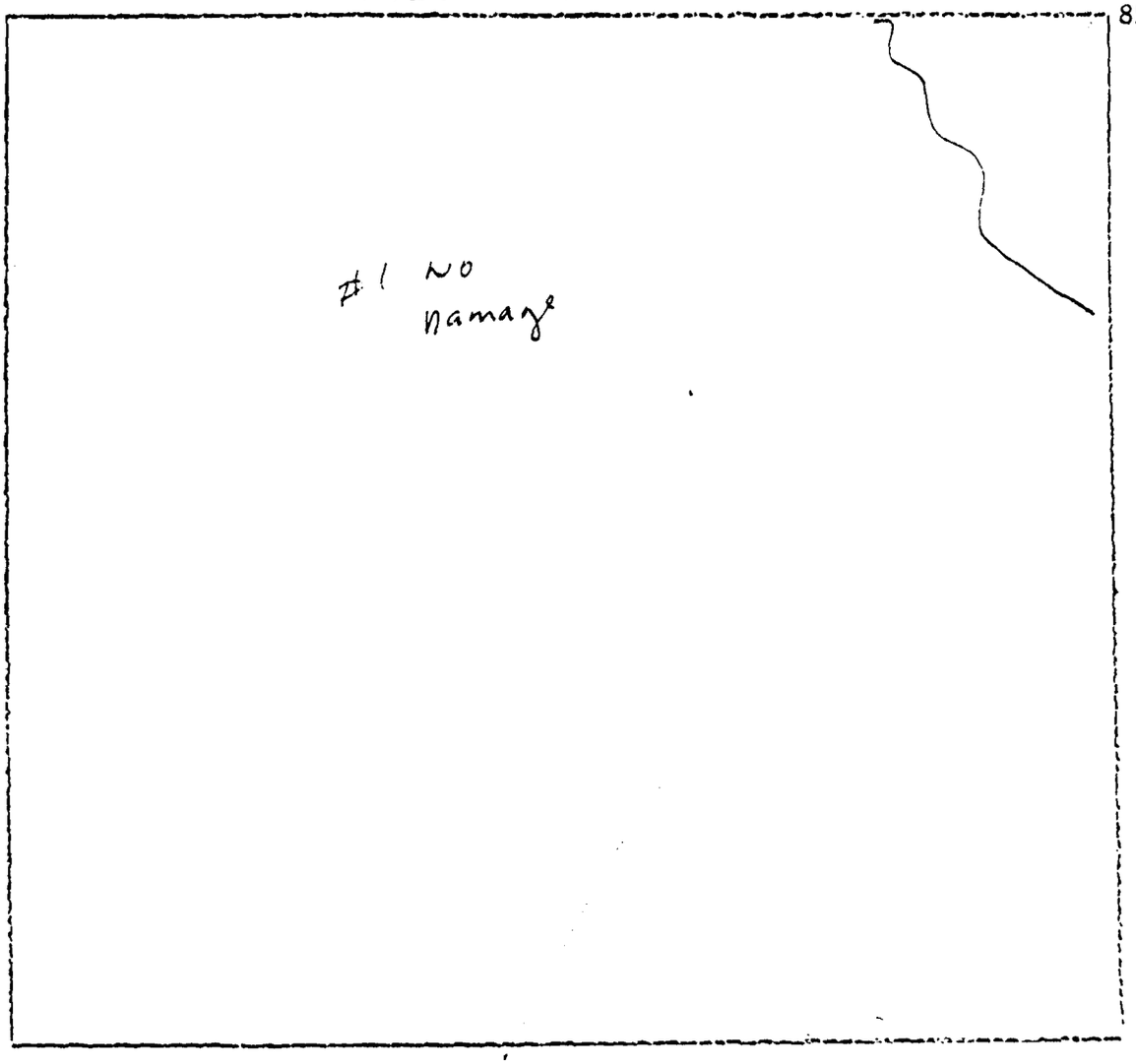
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. C2

85



Test #1-
Projectile 2" coated Styrofoam
Muss=
Counter= 759.4
Velocity= 220
Depth= -
Diameter=
Volume=

Test #3
Projectile
Muss=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Muss=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Muss=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

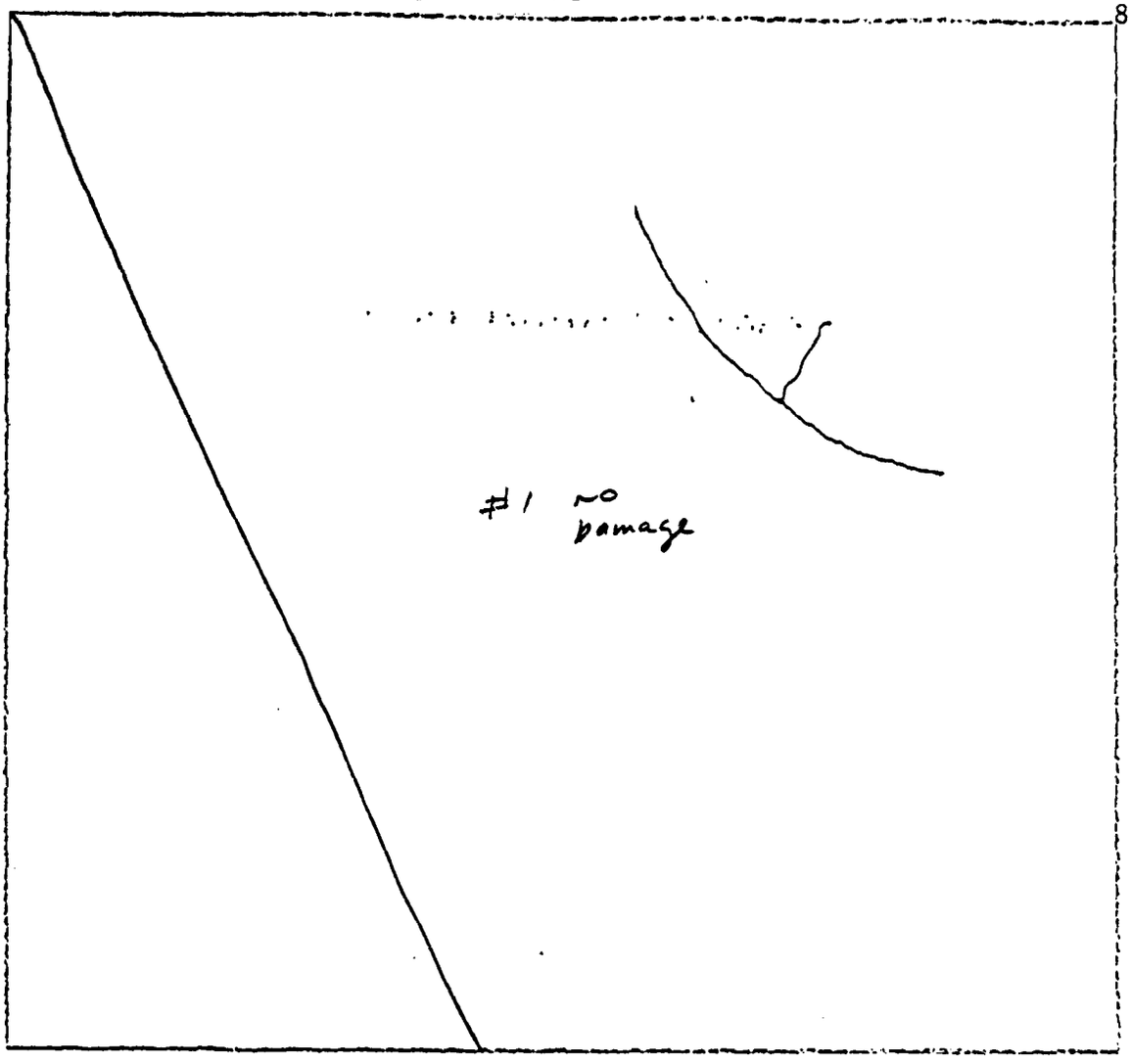
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. P



Test #1- no coat
Projectile $1\frac{1}{2} \times 2''$ S.F.
Mass=
Counter= 517.4
Velocity= 322
Depth= -
Diameter=
Volume=

Test #2 no coat
Projectile $1\frac{1}{2} \times 2''$ S.F.
Mass=
Counter= 357
Velocity= 475
Depth=
Diameter=
Volume=

test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

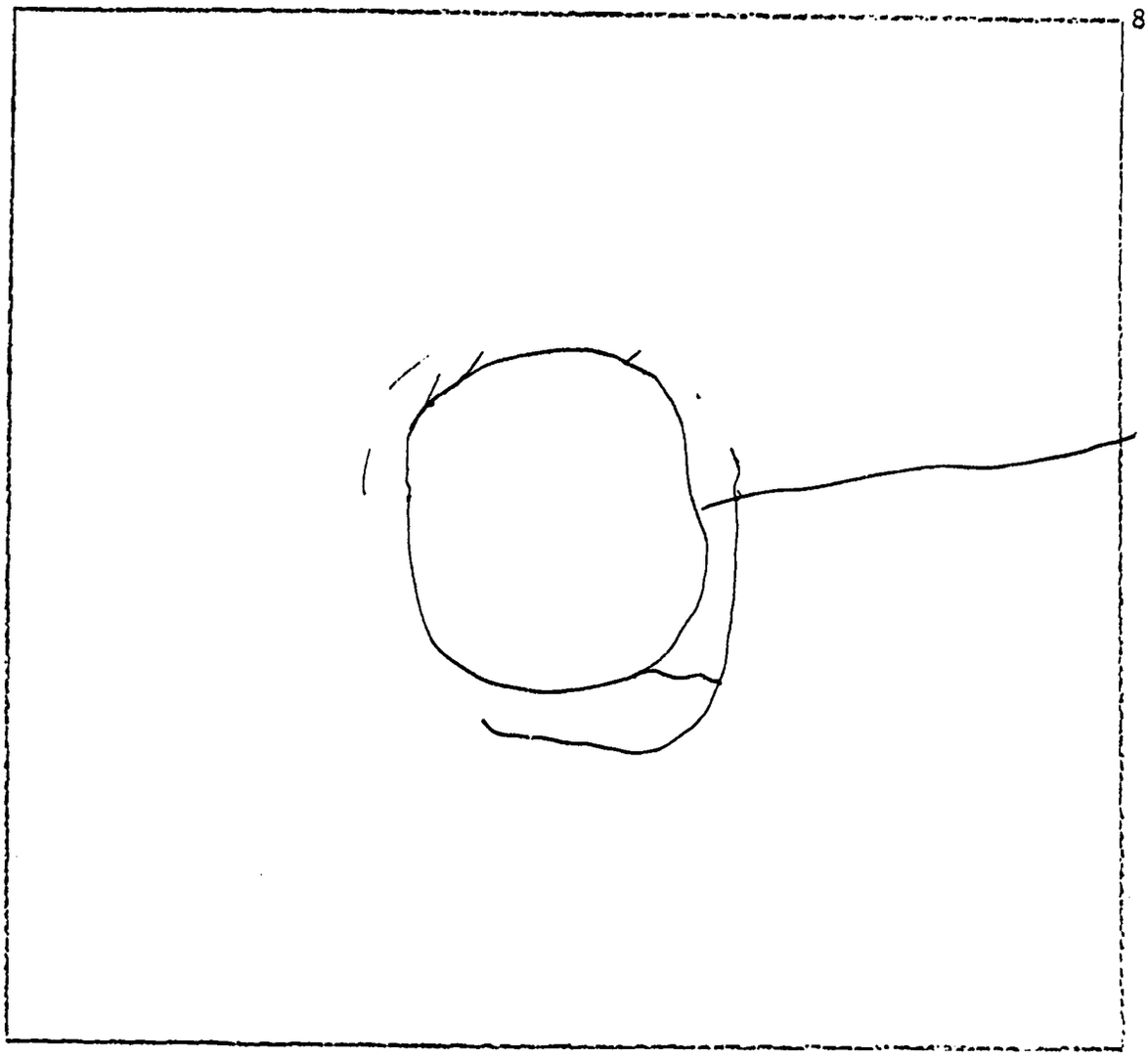
Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE NO. 7

89



Test #1-
Projectile 2" coated Styrofoam
Mass=
Counter= 545.1
Velocity= 306 ft/sec
Depth= -
Diameter=
Volume=

Test #3
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #2
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

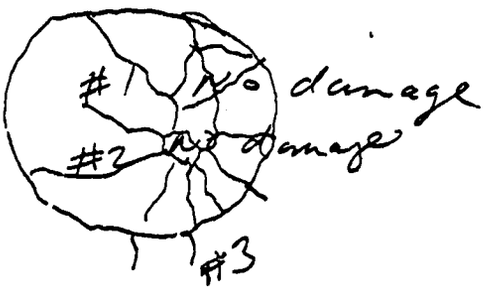
Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

TILE No. 15



Test #1- No coat
Projectile 1½ x 2 S.F
Mass=
Counter= 351
Velocity= 488
Depth= -
Diameter=
Volume=

Test #2 No coat
Projectile 1½ x 2
Mass=
Counter= 486.5
Velocity= 392
Depth=
Diameter=
Volume=

test #3 No coat
Projectile 1½ x 2
Mass=
Counter= 330.6
Velocity= 504
Depth=
Diameter=
Volume=

Test #4
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #5
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #6
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test#7
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #8
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #9
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=

Test #10
Projectile
Mass=
Counter=
Velocity=
Depth=
Diameter=
Volume=