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BACKFACE SIGNATURES OF SOFT BODY ARMORS AND THE ASSOCIATED TRAUMA EFFECTS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The National Institute for Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration has established a program to support the development of an improved, lightweight armor for protection against handgun threats. A subtask of this program was to develop a simple, readily available backing material for use in characterizing both the penetration and deformation effects of ballistic impacts on soft body armor materials and relate this deformation to the injury potential of nonpenetrating ballistic impacts. Plastilina 1 was tested and may be used as backing material against handgun firings.

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PREFACE

The work described in this report was authorized and supported by Contract LEAA-J-IAA-005-4 awarded by the Law Enforcement Assistance Administration, US Department of Justice, under the Omnibus Crime Control and Safe Streets Act of 1968, as amended. The work was started in August 1975 and completed in October 1976. The experimental data are contained in notebooks MN-2549 and MN-2553.

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BACKFACE SIGNATURES OF SOFT BODY ARMORS AND THE ASSOCIATED TRAUMA EFFECTS

I. INTRODUCTION.

The National Institute for Law Enforcement and Criminal Justice (NILECJ) of the Law Enforcement Assistance Administration (LEAA) supports a research and development program to improve and strengthen law enforcement methods. To further this end, studies are being conducted to support the development of improved lightweight soft armors for protection against specific street threats; i.e., armors which will withstand perforation by handgun projectiles and which will also reduce to an acceptable level the trauma associated with the impact of these projectiles upon soft armor.

This report describes the tests performed to develop a simple, readily available means of defining both the penetration and deformation characteristics of soft armor materials and relating the "backface signature" or behind-the-armor deformation to the trauma effects.

II. BACKGROUND.

Backing materials used in the ballistic testing of soft body armor play an important role in quantifying the penetration resistance characteristics of the material. A bullet impacting soft body armor fabrics will deform not only the armor but also the substance used as a backing for the armor. Energy and momentum will be imparted to the backing before any penetration takes place.

The primary function of a backing material is to simulate the tissue response appropriately beneath the point of impact so that the ballistic data generated in laboratory tests can be correlated to the effects seen on the human body. The extremely complex structure of the human body is not readily characterized by a simple, homogeneous material; its response is nonlinear, rate sensitive, and exhibits considerable variation to impact not only from body area to body area but also from individual to individual.

One simple backing material has been used successfully in the study of ballistic impacts on soft body armor materials: 20% gelatin.* Gelatin, a highly elastic material, exhibits a penetration resistance similar to that of living tissue. However, gelatin also exhibits nearly total recovery to deformation, thereby necessitating the use of high-speed photographic techniques for analyzing soft body armor deformations.

III. EXPERIMENTAL METHODS AND PROCEDURES.

By utilizing deformation-time histories of tissue and performing penetration resistance tests on various materials, a second backing material has been found the response of which can be correlated to tissue response. This material is an oil-based modelling clay called Roma Plastilina 1**

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* Metker, LeRoy W., Prather, Russell N., and Johnson, Earl M. EB-TR-75029. A Method for Determining Backface Signatures of Soft Body Armors. May 1975.

** Available from: Sculpture House
38 E 30th Street
New York, New York
212-679-7474.

This clay is a highly plastic material which undergoes viscous flow when deformed and exhibits little recovery, thus providing a readily available cavity formed during impact from which measurements can be taken.

Recommendation of Plastilina 1 as a backing material is based upon the following tests:

1. Penetration Resistance Tests.

V_{50} ballistic limit tests were conducted on the various materials listed in table A-1 (appendix A). A V_{50} ballistic limit can be defined as the striking velocity at which 50% of the impacts are expected to result in complete penetrations of an armor target in a limited statistical test. It is a common measure of the penetration resistance of a material. The 0.22-caliber, 40-grain lead bullet was used against 7 plies of Kevlar 29 and 8 plies of Hi-Tenacity Nylon because these were the only armor - projectile combinations for which penetration data was available on tissue.

From table A-1 (appendix A) it is apparent that gelatin is a good simulator of the penetration resistance of tissue on the basis of both the V_{50} ballistic limit and the lowest complete penetration (L.C.). Plastilina 1 is a slightly more conservative model but this difference is not statistically significant.

2. Deformation Tests.

Deformation - time histories of blunt impacts on thoracic structures were obtained under the Army program from which the present blunt trauma model (figure B-1, appendix B) was formulated. In this model, the discriminant lines establish three zones: from left to right, a low-lethality zone, a mixed zone and a highly lethal zone. By use of the deformation-time data and performance of similar tests on various backing materials, it was found that Plastilina 1 exhibited approximately the same depth of deformation as the thorax but in a shorter time frame (figure B-2). None of the materials tested exhibited the same deformation-time history as the thorax. The projectile used in these tests was a 200-gram, 80-millimeter hemispherical missile impacting at approximately 55 meters per second. Table A-2 lists some of the backing materials tested and the displacements recorded. Table A-3 lists the diameters and depths of deformation recorded for ballistic impacts on Kevlar 29 using gelatin and clay as backings. Note that the deformation diameters for gelatin are approximately 1.5 times those for similar impacts on clay.

3. Correlation of Clay Cavities with Blunt Trauma Effects.

In the present blunt trauma model, figure B-1, the discriminant lines establish three zones such that, for the zone of low lethality,

$$\ell n \frac{MV^2}{W^{1/3}DT} < 9.2 \qquad (1)$$

where

M = projectile mass (grams)

V = projectile velocity (meters per second)

W = body weight (kilograms)

T = tissue thickness (centimeters)

D = projectile diameter (centimeters)

This model was formulated using experimental data sets obtained from tests on unarmored anesthetized animals for which the physical characteristics of the impacting projectile were known.* To apply this model to clay-backed armor tests, it is necessary to apply the methodology developed under the original backface signature program. By determining the "effective" mass and velocity of the missile-armor interaction, equation 1 can be solved for the minimum backface signature diameter for the low-lethality zone.

By employing the principle of conservation of linear momentum an effective velocity for the armor deformation can be derived:

$$M_p V_p = (M_A + M_p) V \qquad (2)$$

or

$$V = M_p V_p / (M_A + M_p) \qquad (3)$$

where

$M_p V_p$ = the initial mass (kg) and velocity (m/sec) of the impacting projectile

M_A = the armor deformation mass (kg) and

V = the "effective" armor velocity (m/sec).

The armor mass was assumed to be the mass derived by using the base of the deformation, i.e.

$$M_A = (A_B)(a_d) = \frac{\pi D^2}{4}(a_d) \qquad (4)$$

where

$\frac{\pi D^2}{4} = A_B$ = the base area of the deformation cavity, (cm^2)

a_d = the areal density of the armor material, (gm/cm^2)

*Clare, Victor R. Lewis, James H., Mickiewicz, Alexander P., and Sturdivan, Larry M. EB-TR-75016. Blunt Trauma Data Correlation. May 1975

Substituting equations 2, 3, and 4 into equation 1:

$$\ell n \frac{MV^2}{W^{1/3}DT} < 9.2 \Rightarrow \frac{\pi a_d(D^2/4) + M_p}{W^{1/3}DT} \cdot \frac{M_p{}^2 V_p{}^2}{\left(\frac{\pi D^2}{4}(a_d) + M_p\right)^2} = e^{9.2}$$

or

$$D^3 + \frac{4DM_p}{\pi a_d} - \frac{4M_p{}^2 V_p{}^2}{W^{1/3}\ T\ e^{9.2}\pi a_d} = 0 \qquad (5)$$

Assuming that for

W = 55 kg, T = 2.0 cm, or

W = 75 kg, T = 3.0 cm, or

W = 95 kg, T = 4.0 cm,

equation (5) can then be solved for diameter D as a function of the armor materials' areal density.

Figures B-3 through B-9, appendix B, illustrate the application of this technique for some of the more common test projectiles. The minimum diameter is plotted as a function of the areal density (weight per unit area) of the armor material.

The estimates of "effective" mass and velocity are conservative in that the model employs an energy term, MV^2, and the armor base mass is used to determine the "effective" velocity behind the armor. If the entire surface mass had been used a smaller "effective" velocity would have been derived and hence a smaller dose level predicted. This approach appears to have been successful in applying gelatin deformation diameters to the provisional blunt trauma model. However, no lethalities have yet been observed for nonpenetrating-bullet impacts on armor and these estimates must also be considered provisional until the blunt trauma effects of higher energy threats (9-mm, .357-mag, .45-mag) are investigated.

Attempts have been made using the original blunt impactor data to correlate deformation depth with the probability of lethality (figure B-10). A depth of deformation greater than 5.0 cm is associated with a probability of lethality of approximately 15%. However, the available data is limited and hence no solid conclusions can be drawn as yet regarding the effect of deformation depth.

The effectiveness of the correlation effort is contingent upon test programs currently underway, specifically the investigation of the higher energy threats which probably will produce the lethal armor deformation data necessary to check out the scaling of the model.

Tables A-4 through A-10 list the results of clay-backed ballistic tests conducted at Biophysics Division on numerous armor materials.

IV. CONCLUSIONS.

1. A readily available, easy-to-use backing material, Roma Plastilina 1, has been found which can be correlated to tissue response for use in characterizing both the penetration and deformation effects of ballistic impacts on soft body armor materials.

2. A technique has been demonstrated by which backface signature parameters can be related to the probability of lethality.

3. There is a lack of lethal armor deformation data necessary to validate the modelling effort and hence this effort should be considered provisional.

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APPENDIX A

TABLES

Table A-1. Penetration Resistance Tests

Target	LC	HP	V_{50}
	ft/sec*	ft/sec	ft/sec
1. 7 Ply Kevlar 29			
Abd**	1087	1115	1096
Thor	1091	1148	1115
Gel	1093	1122	1109
No. 1 (EA)	1062	1100	1079
No. 1 (LEAA)	1085	1087	1088
2. 8 Ply Hi-Tenacity Nylon			
Thor	821	850	830
Gel	815	857	836
No. 1 (EA)	819	841	831
No. 1 (LEAA)	798	794	788

* One foot = 0.3048 m; 1000 ft = 304.8 m; 800 ft = 243.84 m.

** Abd = abdomen; Thor = thorax; Gel = gelatin; EA = Edgewood Arsenal (now Chemical Systems Laboratory); LEAA = Law Enforcement Assistance Agency; LC = lowest complete penetration; HP = High partial penetration; V_{50} = striking velocity at which 50% of impacts are expected to result in complete penetrations of an armor target.

Table A-2. Maximum Deformation Depth, Blunt Impactor

Target	Depth
	cm
Gelatin	9.11
No. 1 Clay	8.53
Vaseline	8.22
Foam	7.31
No. 2 Clay	5.61
No. 1 + Rubber membrane	6.70

Table A-3. Other Deformation Data

Caliber	Velocity	Deformation depth		Deformation diameter	
		Clay	Gel	Clay	Gel
mag or mm	ft/sec*	cm		cm	
.22	1000	2.5	2.8	4.4	6.6
.38	800	4.5	4.7	6.0	8.6
.38	1000	4.8	5.5	8.0	10.9
.357 mag	1300	4.8	5.1	8.5	12.6
9	1200	4.0	4.0	7.0	9.9
.45	800	5.2	5.3	6.4	9.8

* One ft = 0.3048 m; 1000 ft = 304.8 m; 800 ft = 243.84 m.

Table A-4. Backface Deformation Studies, I.

0.22-Cal., 40-grain lead

V_{IS}	Construction	Results		Diameter	Depth	Date
ft/sec*				cm	cm	
886	7-ply Kevlar 29, 1000-d	PP		4.3 X 5.1	2.6	16 July 1976
885	Clark-Schwebel, plain weave, style 713	PP		4.5 X 4.7	2.3	
971		PP	V_{50} BL = 1084 ft/sec	4.3 X 4.5	2.8	
1020		PP	LC = 1063 ft/sec			
1061		PP				
1054		PP				
1011	7-ply Kevlar 2, 1000-d, Greenbrier Industry	PP		4.5 X 5.0	3.0	12 August 1976
1022	(For Secret Service)	PP		4.0 X 5.5	2.8	
1136	7-ply Kevlar 49, style 84, 1140 d, 29 X 29 (Analog to Kevlar 29,	PP		6.0 X 4.5	2.0	29 September 1976
1166	1000-d) No water repellency	PP		5.5 X 3.0	2.2	
1177		PP		5.0 X 5.0	2.6	
1212		PP		5.0 X 4.5	2.7	
1185		PP		5.5 X 5.0	2.4	
1186		PP	V_{50} BL = 1213 ft/sec	5.2 X 4.6	2.2	
1154		PP	LC = 1192 ft/sec	5.0 X 4.5	2.0	
1213		CP	HP <LC = 1186 ft/sec			
1235		CP				
1218		PP		5.0 X 5.5	2.5	
1222		PP		5.0 X 5.0	2.4	
1196		PP		4.5 X 4.5	2.3	
1192		CP				
1236		CP				
1219		CP				
950	12-ply Devlar 29, 1000-d, Baltimore City	PP		4.6 X 4.3	1.5	23 July 1976
1049	Police Department vest	PP		4.2 X 5.5	2.1	

* One ft = 0.3048 m; 1000 ft = 304.8 m; 1100 ft = 335.28 m; 1200 ft = 365.76 m.

Table A-5. Backface Deformation Studies, II.

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec*			cm	cm	
	A. 0.38-Cal., 158-grain LRN				
833	7-Ply Kevlar 29, 1000-d	PP	6.2 X 5.5	3.4	20 June 1976
787	7-Ply Kevlar 29, 1000-d, Greenbrier Industry	PP	6.0 X 6.0	4.6	12 August 1976
778	(For Secret Service)	PP	6.0 X 6.5	4.4	
819		PP	6.0 X 6.0	4.5	
885	7-Ply Kevlar 29, 1000-d, Clark-Schwebel style 713, CS 800 finish	PP	6.5 X 6.5	4.5	29 April 1976
808	Style 713, CS 800 finish	PP	6.0 X 6.5	4.6	
801		PP	6.0 X 6.5	4.5	
995		PP	7.0 X 6.5	4.8	
1023		CP			
831	7-Ply Kevlar 49, style 84, 1140-d, 29 X 29 (Analog to Kevlar 29,	PP	6.2 X 7.5	3.5	29 September 1976
828	1000-d). No water repellency	PP	6.5 X 7.5	4.0	
852		PP	7.5 X 7.0	4.5	
832		PP	7.0 X 7.0	3.8	
819		PP	6.0 X 7.5	3.7	
832		PP	6.5 X 6.8	4.1	
853	6-Ply Kevlar, 1500-d, 24 X 24, style 2082 (Fabric development)	PP			
814		PP	4.2 X 4.6	4.5	10 February 1976
	B. 0.38-Cal., 158-grain semi wadcutter				
1061	12-Ply Kevlar 29, 1000-d, Baltimore city Police Department vest	PP	6.3 X 8.5	3.6	23 July 1976
1050		PP	6.0 X 8.0	4.1	
1051		PP	6.5 X 6.8	4.2	
	C. 0.38-Cal., 130-grain MC, Super, Hi-Speed				
1201	20-Ply Kevlar 29, 1000-d (For DEA)	PP	7.5 X 4.0	4.0	9 April 1976

* 780 ft = 237.744 m; 800 ft = 243.84 m; 810 ft = 246.888 m; 820 ft = 249.936 m; 830 ft = 252.984 m; 850 ft = 259.08 m; 1020 ft = 310.896 m; 1050 ft = 320.04 m; 1060 ft = 323.088 m; 1200 ft = 365.76 m.

Table A-6. Backface Deformation Studies, III.

0.357 Magnum, 158-grain Lubaloy

V_{IE}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1342	Safariland M2A, Panel B, 880 grams (For Berkeley, California Police	PP	7.0 X 7.5	5.0	21 June 1976
1339	Department)	PP			
1321		PP	6.0 X 8.0	4.1	
1318		PP			
1415		PP	8.0 X 8.0	4.8	
1374	Armour of America Super Armor Hide	PP	6.5 X 7.5	5.9	21 June 1976
1374	Panel B, 850 grams (Berkeley Police Department)	PP	6.5 X 8.5	5.9	
1335		PP	7.0 X 7.0	5.5	
1369		PP	7.0 X 8.0	5.2	
1378		PP			
1246	23-ply Kevlar 29 vest from Greenbrier Industry (For Berkeley Police	PP	6.0 X 7.5	4.5	14 June 1976
1290	Department)	PP	6.0 X 7.0	4.5	
1323		PP	7.0 X 7.0	4.5	
1313		PP	7.5 X 8.0	4.4	
1317		PP			
1231	12-ply Kevlar 29, 1000-d, West Point Pepperel (Lot 23-5529-01)	CP			6 May 1976
1249		PP	7.0 X 7.0	5.0	
1041	15-ply Kevlar 29, 1000-d, style 713, CS 800 finish Clark-Schwebel	PP	7.0 X 7.0	3.3	29 April 1976
1212		PP	7.5 X 7.5	4.4	
1230		PP	8.0 X 8.0	4.6	
1292		PP	8.5 X 8.5	4.8	
1247	20-ply Kevlar 29, 1000-d (DEA)	PP	7.0 X 7.0	3.5	9 April 1976
1262	10-ply PACA Material, Kevlar 29, impregnated	PP	6.2 X 7.1	5.5	3 March 1976
1495			6.9 X 6.6	7.6	

Table A-6. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	
ft/sec			cm	cm	
1257	12-ply West Point Pepperel (see above) + 4-ply fabric development,	PP	7.0 X 8.0	4.0	6 May 1976
1256	special weave	PP	7.5 X 8.5	4.0	
1259	12-ply West Point Pepperel (see above) + 4-ply Kevlar laminate	PP	8.0 X 9.0	3.7	6 May 1976
1240		PP	8.0 X 8.5	4.0	
1239	12-ply West Point Pepperel (see above) + 4-ply West Point Pepperel Lot No. 235235-01, 45 X 50	PP	8.0 X 9.0	3.9	6 May 1976
1302	12-ply PACA Crimpless Material, sytle 211-2	PP	6.0 X 7.5	4.8	14 July 1976
1313		PP	6.0 X 7.0	4.5	
1303		PP	7.0 X 7.0	4.5	
1367		PP	5.5 X 8.0	4.9	
1377		PP	7.0 X 9.0	5.5	
1264	12-ply J. P. Stevens Kevlar 29, 1000-d, backed by 4-ply dip-coated	PP	8.1 X 10.8	3.4	21 September 1976
1314	impregnated Kevlar	PP	10.5 X 8.8	4.2	
1273	(Lot No. 9944, Style 7307/45)	PP	10.2 X 8.2	3.7	
1321		CP			
1331	12-ply J. P. Stevens, as above, backed by 4-ply 8.5-oz/yd fabric development special weave (200-d X 1000-d)	PP	7.2 X 9.5	4.5	
1320	As above, special weave in front	PP	8.2 X 7.8	5.0	
1304	12-ply Kevlar 29, 1000-d + 2-ply impregnated Kevlar	PP	8.5 X 10.5	5.0	5 October 1976
1310		PP	9.0 X 11.0	4.3	
1307		PP	8.5 X 9.5	4.2	
1313		PP	8.0 X 10.0	4.8	
1295		CP			
1317		PP	8.5 X 10.0	4.5	

Table A-6. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1315	10-ply Kevlar 29, 1000-d + 4-ply impregnated Kevlar	PP	8.0 X 10.5	3.0	
1301		PP			
[illegible]	(JPS Lot No. 98627 713/55-1/2)	PP	8.3 X 9.0	3.5	
1300		PP	9.0 X 12.2	3.0	
1299		PP	10.0 X 10.5	3.8	
1300		PP	8.5 X 11.5	4.0	
11299	12-ply Kevlar 29, 1000-d + 4-ply M. Miller	PP	11.0 X 8.3	3.3	19 October 1976
1289	9-oz-impregnated Kevlar	PP	9.0 X 5.9	1.9	
1293		PP	10.5 X 7.3	2.7	
1314		PP	8.5 X 11.0	3.2	
1330		PP	11.0 X 8.6	2.8	
1326	12-Ply Kevlar 29, 1000-d + 4-ply	PP	9.5 X 7.7	2.7	
1346	SHT 470 impregnated	PP	9.5 X 8.0	3.3	
1351		*CP			
1323		PP	9.5 X 9.0	3.3	
1345	12-ply Kevlar 29, 1000-d + 4-ply	PP	12.0 X 7.2	3.4	
1339	8-oz TP1016 impregnated Kevlar	PP	12.5 X 6.5	3.5	
1352		PP	9.0 X 7.3	3.4	
1332		PP	7.7 X 8.0	3.1	

Table A-6. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1334	12-ply Kevlar 29, 1000-d + 4-ply TP 41016	PP	9.5 X 7.5	3.4	19 October 1976
1302	Impregnated Kevlar	*CP			
1342		PP	8.5 X 7.0	3.6	
1337		PP	10.0 X 5.9	3.3	
1341	12-Ply Kevlar 29, 1000-d + 4-ply DHT670	PP	10.3 X 7.8	2.5	
1335	Impregnated Kevlar	PP	10.0 X 7.2	2.7	
1330		PP	10.0 X 8.0	3.0	
1327		PP	11.0 X 7.2	2.5	
1305	12-ply Kevlar 29, 1000-d + 3-ply DHT670	PP	9.3 X 8.0	3.5	
1334	Impregnated Kevlar	PP	9.3 X 8.3	3.0	
1343		*CP			
1351	11-ply Kevlar 29, 1000-d,+ 4-ply DHT670 + 1-ply Kevlar 29, 1000-d	PP	10.0 X 7.0	3.4	
1346	1-ply Kevlar 29, 1000-d	PP	10.5 X 7.5	3.4	

* As missile deforms, dome-like cap becomes very thin. Base of missile at center of dome has not yet deformed. Reaches a point where base "punches" thru cap and proceeds to perforate few remaining layers of material.

Table A-7. Backface Deformation Studies, IV.

0.357 Magnum, 125-Grain

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1548	23-Ply Kevlar 29 vest from Greenbrier Industry (For Berkeley Police	PP	7.0 X 6.4	4.3	14 June 1976
1561	Department)	PP	6.5 X 8.0	4.4	
1653	Safariland M2A, 1090 gms	CP			21 June 1976
1607	(For Berkeley Police Department)	PP	7.0 X 7.5	3.5	
1539		PP	7.0 X 8.0	3.2	
1456		PP	8.5 X 7.6	2.3	
1518		PP	8.5 X 8.0	3.1	
1528	Armour of America Super Armour Hide	PP	7.8 X 7.4	3.8	21 June 1976
1544	Panel B2, 1320 gms (Berkeley Police Department)	PP	6.8 X 8.0	3.4	
1554		PP	6.0 X 7.5	3.6	
1542		PP	6.0 X 6.4	3.2	
1614		PP	7.5 X 7.0	3.4	

Table A-8. Backface Deformation Studies, V.

9-mm, 124-Grain FMJ

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1236	23-ply Kevlar 29 vest from Greenbrier Industry (Berkeley Police	PP	7.0 X 8.0	3.2	14 June 1976
1217	Department)	PP	5.3 X 7.0	2.9	
1221		PP	6.0 X 8.0	3.2	
1230		PP	6.0 X 8.0	3.5	
1250		PP	7.0 X 8.0	3.5	
1201	Armour of America Super Armor Hide	PP	6.5 X 7.5	2.6	
1221	Panel A2, 1120 grams	PP	6.5 X 7.4	2.5	22 June 1976
1199	(Berkeley Police Department)	PP	6.5 X 8.0	3.0	
1209		PP	7.0 X 7.2	2.8	
1268		PP	7.0 X 7.1	2.9	
1268	Safariland M2A, Panel A, 910 grams	PP	7.0 X 7.2	2.4	
1287	(Berkeley Police Department)	PP	7.0 X 7.5	2.3	
1245		PP	7.0 X 6.5	2.8	
1234		PP	7.0 X 7.0	2.0	
1259		PP	7.5 X 7.5	2.4	
1099	12-ply Kevlar 29, 1000-d	PP	6.5 X 5.6	4.0	6 May 1976
1238	14-ply Kevlar 29, 1000-d, JP Stevens	CP			9 September 1976
1280	Lot 9944, style 7307/45	PP	6.5 X 6.5	4.1	
1210		PP	6.0 X 6.5	4.4	
1242		CP			

Table A-8. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1204	16-ply Kevlar 29, 400/2-d	PP	5.9 X 6.5	4.5	23 May 1975
1194	16-ply Kevlar 29, 1000-d, Clark-Schwebel style 713	PP	7.2 X 6.5	4.8	3 September 1976
1260	16-ply Kevlar 29, 1000-d, JP Stevens Lot No. 9944, style 7307/45	PP	6.0 X 7.0	3.9	9 September 1976
1250	18-ply Kevlar 29, 1000-d	CP			27 May 1976
1234	20-ply Kevlar 29, 1000-d	PP	6.7 X 6.8	3.9	27 May 1975
1270	20-ply Kevlar 29, 1000-d (DEA)	PP	6.5 X 8.5	3.0	9 April 1976
1282		PP	6.5 X 7.5	4.0	
962	20-ply Kevlar 29, 1000-d, Clark-Schwebel, style 713	PP	6.5 X 6.5	3.0	29 April 1976
1303	20-ply Kevlar 29, 1000-d, JP Stevens	PP	6.5 X 7.5	4.5	
	Various Construction of Bob Coppage's Materials				
	L = Triple Laminate				
	K = Kevlar 29, 1000-d				
1147	1L, 5K, 1L	PP	5.5 X 7.0	4.5	12 December 1975
1129	1L, 3K, 1L	CP			
1119	1L, 7K, 1L	PP	7.0 X 7.5	3.5	
1137	1L, 9K, 1L	PP	6.5 X 8.0	4.0	

Table A-8. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1143	5K, 2L	PP	6.5 × 7.0	4.0	
1136	1L, 5K, 2L	PP	6.5 × 7.0	4.0	
1125	2L, 5K, 1L	PP	6.0 × 7.0	5.0	
1138	12 Sateen	PP	6.5 × 6.5	5.0	
1313	1L, 10K, 1L, 10K, 1L	PP - Canadian Round	7.5 × 7.5	3.5	
1318	10-ply impregnated Kevlar (PACA)	PP	5.9 × 5.9	6.8	3 March 1976
1161	12-ply JP Stevens Kevlar 29, 1000-d	PP	7.5 × 10.5	2.7	21 September 1976
1142	(Lot No. 9944) backed by 4-ply dip-coated impregnated Kevlar	PP	7.4 × 10.0	2.8	
1249		CP			
1217		PP	7.9 × 10.0	3.0	
1225		CP			
1194	12-ply JP Stevens Kevlar 29, 1000-d, as above backed by 4-ply	PP	8.0 × 8.8	4.0	
1222	top-coated impregnated Kevlar	CP			
1205		PP	8.5 × 8.5	4.0	
1252	12-ply JP Stevens Kevlar 29, 1000-d, as above, backed by	CP			
1236	2-ply mill-end impregnated Kevlar	PP	6.7 × 9.5	4.3	
1204	12-ply JP Stevens Kevlar 29, 1000-d, as above, backed by 4-ply green top coat impregnated Kevlar	PP	7.3 × 8.7	4.0	

Table A-9. Backface Deformation Studies, VI.

9-mm, 115-Grain MC(FMJ)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1272	15-ply Kevlar 29, 1000-d	CP			18 October 1976
1253	16-ply JP Stevens Kevlar 29, 1000-d	PP	7.5 X 6.5	4.1	15 October 1976
1266		PP	7.0 X 6.5	4.4	
1264		CP			
1254		PP	6.5 X 7.0	4.3	
1253		PP	6.5 X 7.0	4.2	
1242	16-ply JP Stevens Kevlar 29, 1000-d	PP	8.2 X 7.5	3.8	10 October 1976
1272		PP	7.2 X 7.0	3.7	
1257	16-ply Kevlar 49, style 84, 1140-d 29 X 29	PP	7.0 X 7.3	4.2	15 October 1976
1273		PP	7.0 X 7.7	4.2	
1261		PP	7.5 X 7.5	4.2	
1278		PP			
1270		PP	8.2 X 7.8	4.3	
1285		CP			
1270	18-ply Kevlar 29, 1000-d	PP	7.2 X 7.1	3.8	18 October 1976
1284		PP	9.5 X 7.3	3.8	

Table A-9. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1272	12-ply Kevlar 29, 1000-d + 2-ply	CP			6 October 1976
1277	Impregnated Kevlar	CP			
1211		PP	8.0 X 9.0	4.0	
1253		PP	8.0 X 7.0	3.0	
1248		PP	7.0 X 8.2	3.5	
1259		PP	7.5 X 9.5	2.5	
1253	10-ply Kevlar 29, 1000-d (JPS Lot No. 98627/713/(55-1/2) + 4-ply	PP	7.5 X 11.0	2.5	
1244	impregnated Kevlar	PP	7.3 X 8.2	3.5	
1247		PP	7.5 X 8.9	3.3	
1260		PP	8.0 X 8.0	2.5	
1254		CP			
1260	4 – 3 ply fabric development laminate = 12-ply laminate	CP			15 October 1976
1247	6 – 3-ply fabric development laminate = 18-ply laminate	PP	6.8 X 5.2	3.5	
1266		PP	7.8 X 7.1	4.2	
1263	5 – 3-ply fabric development laminate = 15-ply laminate	CP			
1270		PP	7.7 X 5.5	6.7	

Table A-9. (Contd)

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1247	12-ply Kevlar 29, 1000-d + 4-ply M. Miller	PP	7.5 X 9.5	1.1	18 October 1976
1266	9-oz impregnated Kevlar	PP	7.5 X 10.0	2.0	
1250		PP	7.5 X 9.5	2.0	
1309		PP	8.0 X 11.5	2.5	
1263	12-ply Kevlar 29, 1000-d + 4-ply SHT 470 impregnated Kevlar	PP	7.0 X 10.0	2.5	
1280		PP	7.0 X 10.5	2.6	
1287		PP	7.0 X 9.0	2.1	
1279		PP	7.6 X 10.2	2.6	
1273	12-ply Kevlar 29, 1000-d + 4-ply 8-oz TP1016 impregnated Kevlar	PP	7.0 X 9.0	2.6	
1282		PP	9.5 X 6.0	2.5	
1271		PP	8.0 X 10.3	2.6	
1286		PP	6.5 X 10.5	3.0	
1266	12-ply Kevlar 29, 1000-d + 4-ply TP41016 impregnated Kevlar	PP	8.0 X 5.7	1.7	
1266		PP	9.0 X 6.2	2.7	
1294		PP	8.7 X 7.0	2.9	
1267		PP	10.0 X 7.0	2.5	
1284	12-ply Kevlar 29, 1000-d + 4-ply DHT 670 impregnated Kevlar	PP	10.0 X 7.9	2.9	
1277		PP	9.5 X 7.7	2.8	
1282		PP	9.0 X 7.3	2.2	
1269		PP	8.7 X 8.6	2.5	
124[illegible]		PP	9.5 X 7.1	2.5	
	9-mm. 115-Grain LAPUA Round				
1073	12-ply Kevlar 29, 1000-d + 8-ply TP1016	CP			
1068	4-Ply TP1016 + 12-ply Kevlar 29, 1000-d + 4-ply TP1016	CP			
1086	16-ply fabric development special weave + 8-ply TP1016	CP			
1075	12-ply Kevlar 29, 1000-d + 8-ply fabric development special weave	CP			

Table A-10. Backface Deformation Studies, VII.

0.44 Magnum, 240-Grain

V_{IS}	Construction	Results	Diameter	Depth	Date
ft/sec			cm	cm	
1423	Armour of America, Panel A, 705 grams (Berkeley Test)	CP			21 June 1976
1433		PP	7.0 X 14.5	7.0	
1454		CP			
1479		CP			
1178		PP	7.5 X 7.5	5.7	
1473	Safariland M2A, Panel A, 768 grams	PP	7.5 X 13.0	7.5	
1444		CP			
1438		CP			
1371		PP	9.0 X 9.5	6.6	
1337		PP	9.0 X 9.0	6.0	
1416		PP	9.0 X 10.5	6.5	
1414		PP	8.0 X 7.0	5.5	
1421		PP	10.0 X 10.5	5.5	
1437		PP	9.0 X 9.0	5.3	
1403	Armour of America (see above)	PP	8.0 X 10.5	7.0	
1421		CP			
1390		PP	8.5 X 9.5	4.6	
1467		PP	8.0 X 10.0	5.5	
1448		PP	7.5 X 9.0	4.6	
1473	23-ply Kevlar 29 vest from Greenbrier Industry	CP			
1558		CP			
1368		CP			
1450		PP	7.5 X 9.0	5.7	
1442		CP			
1406		PP	9.5 X 8.5	6.5	
1569	15-ply impregnated Kevlar Panel (PACA)	PP	7.8 X 9.9	9.7	3 March 1976
0.45-Cal, 234-Grain FMJ					
937	12-ply Kevlar 29, 1000-d vest (Baltimore County Police Department)	PP	8.0 X 7.9	4.2	

APPENDIX B

FIGURES

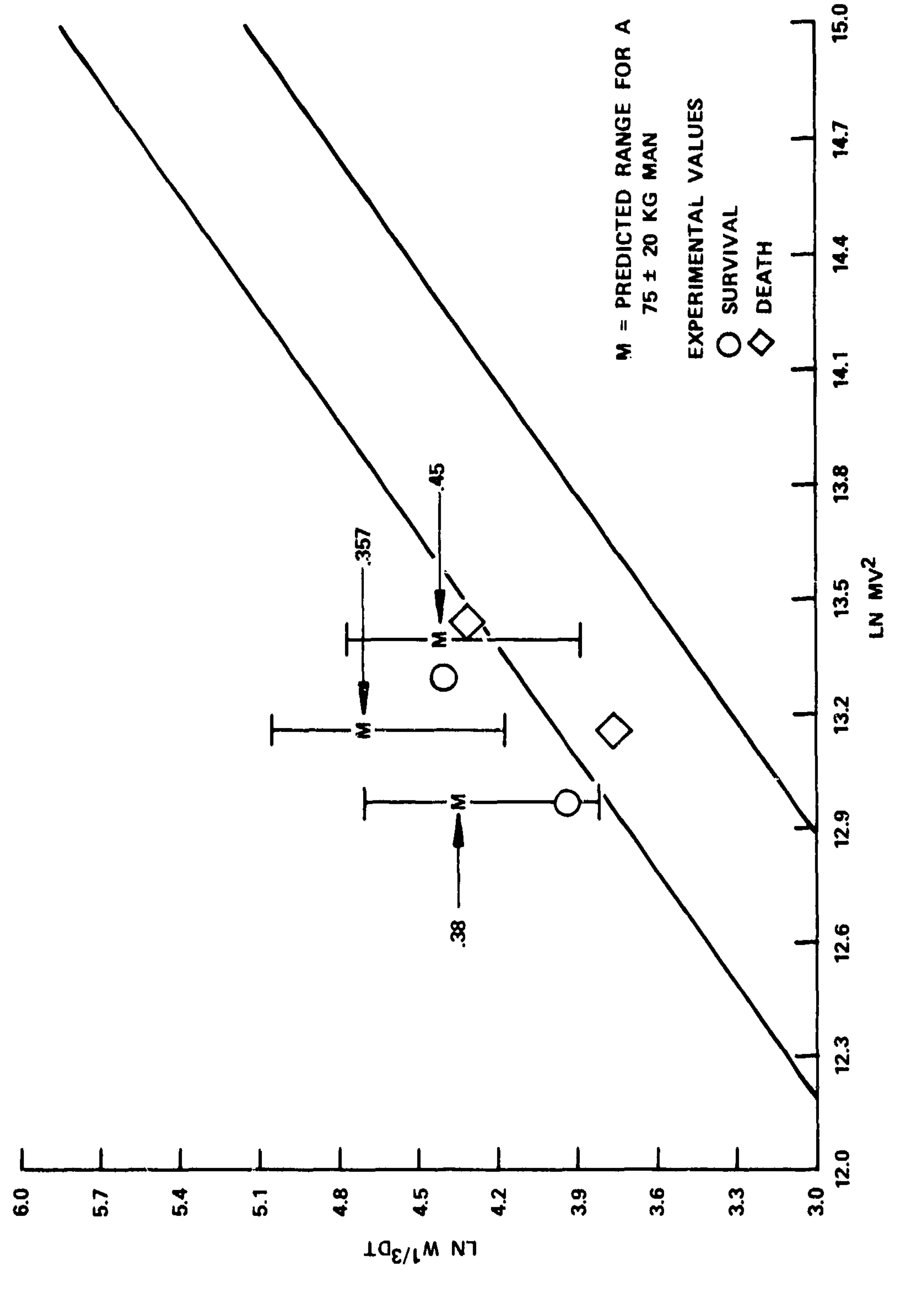

Figure B-1. Lethality from Blunt Impacts –Thorax

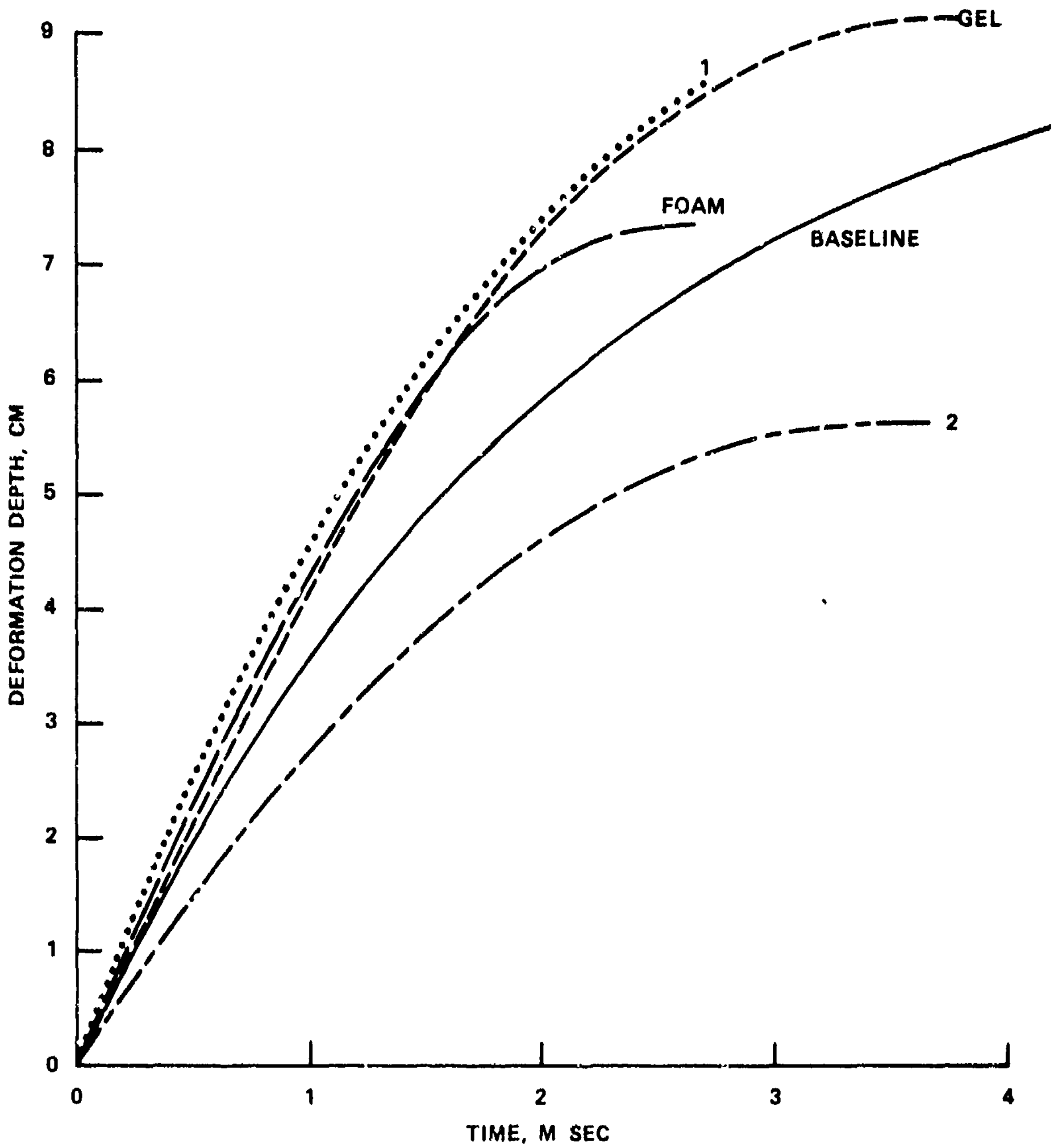

Figure B-2. Time–Deformation Data for Various Backing Materials

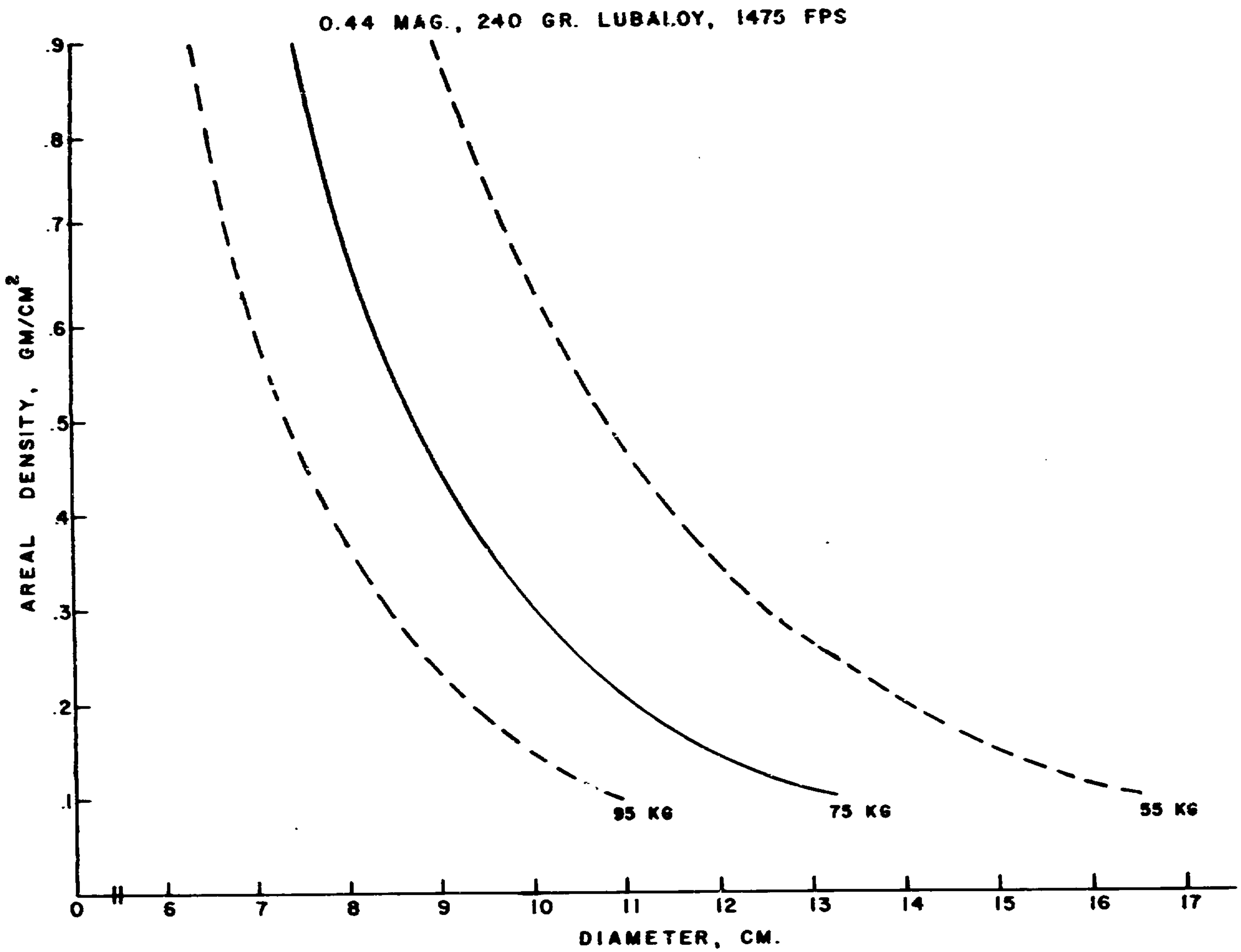

Figure B-3. Areal Density Versus Diameter of Projectile Deformation, for Lubaloy, I

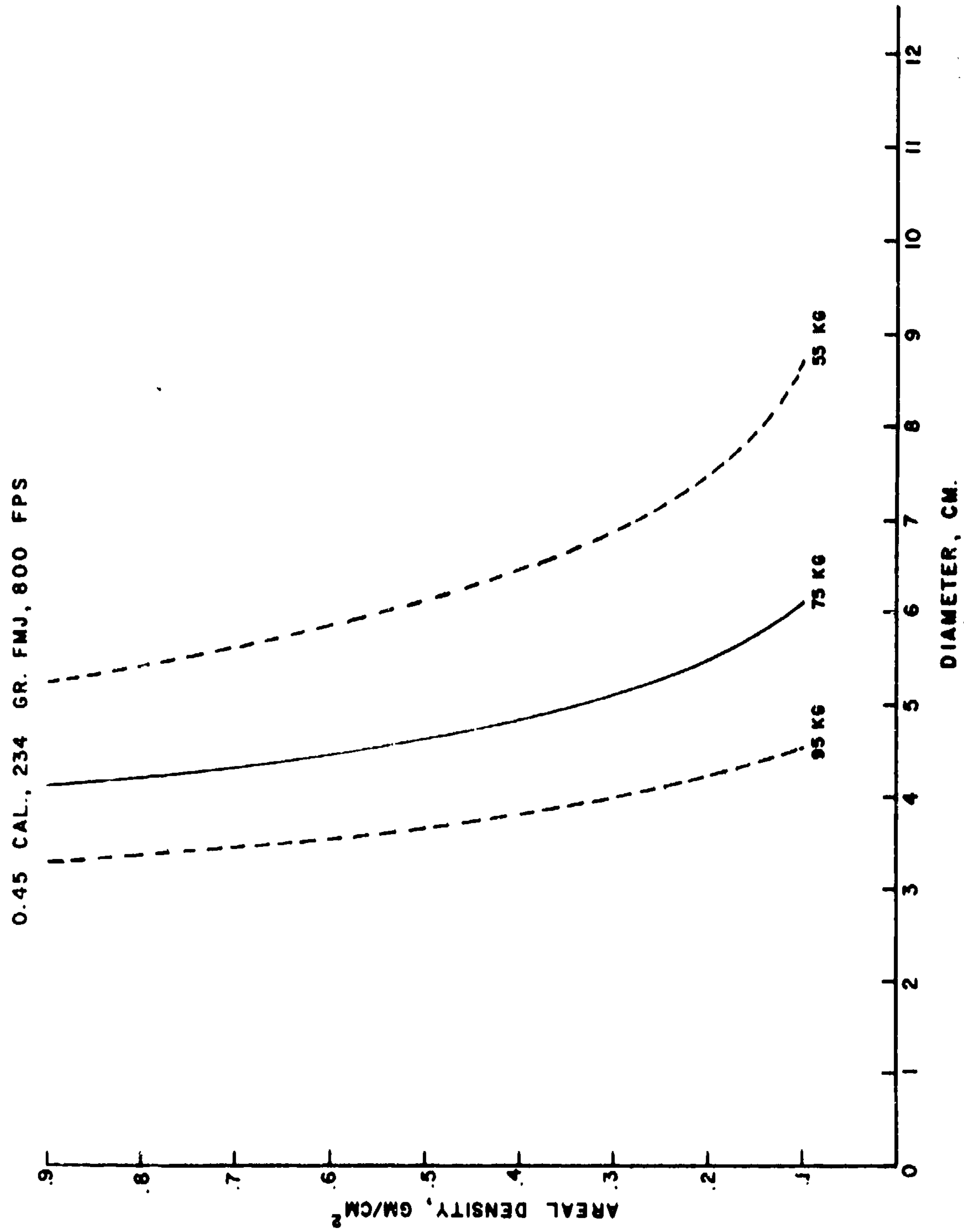

Figure B-4. Areal Density Versus Diameter of Projectile Deformation for FMJ

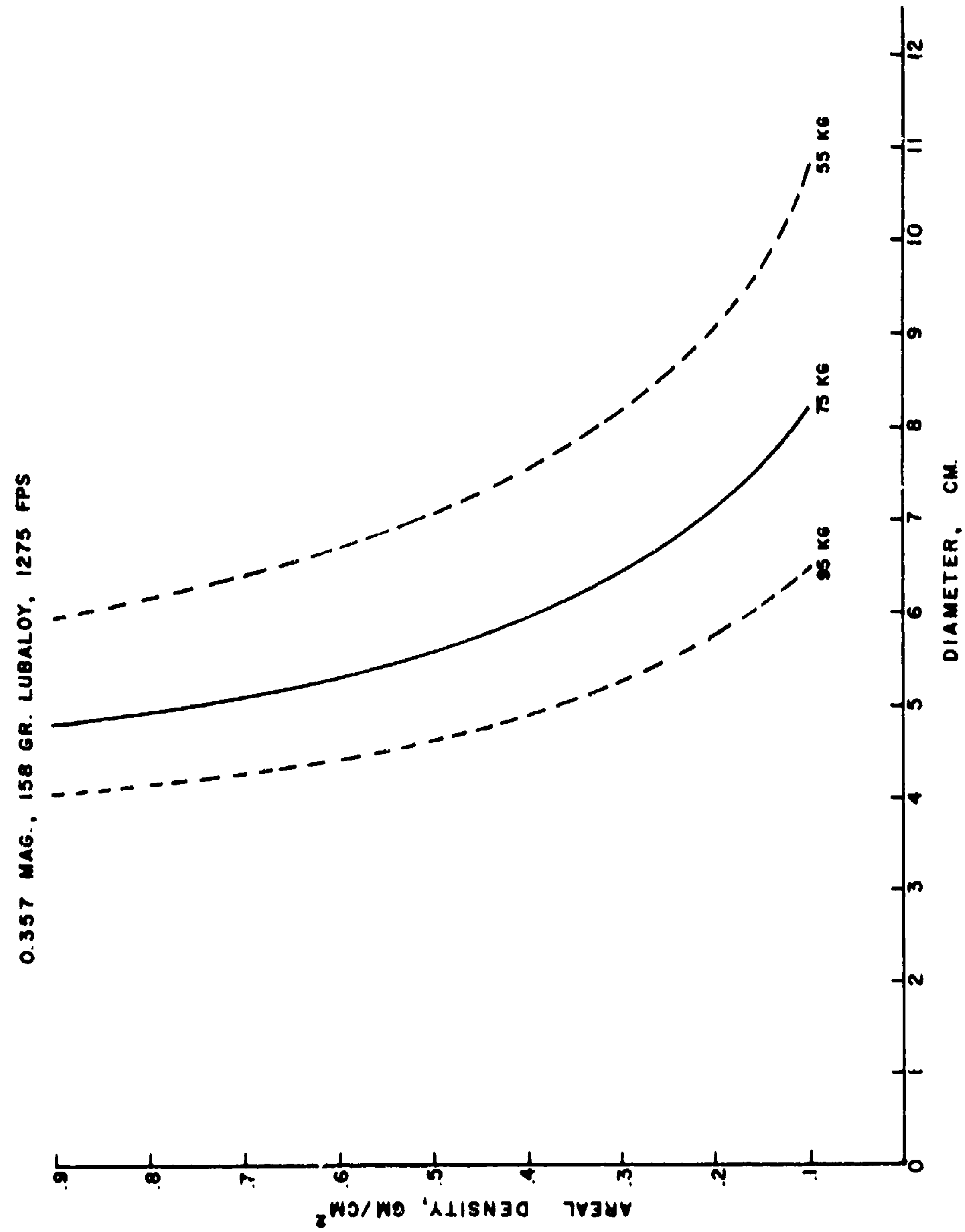

Figure B-5. Area Density Versus Deformation Diameter for Lubaloy, II

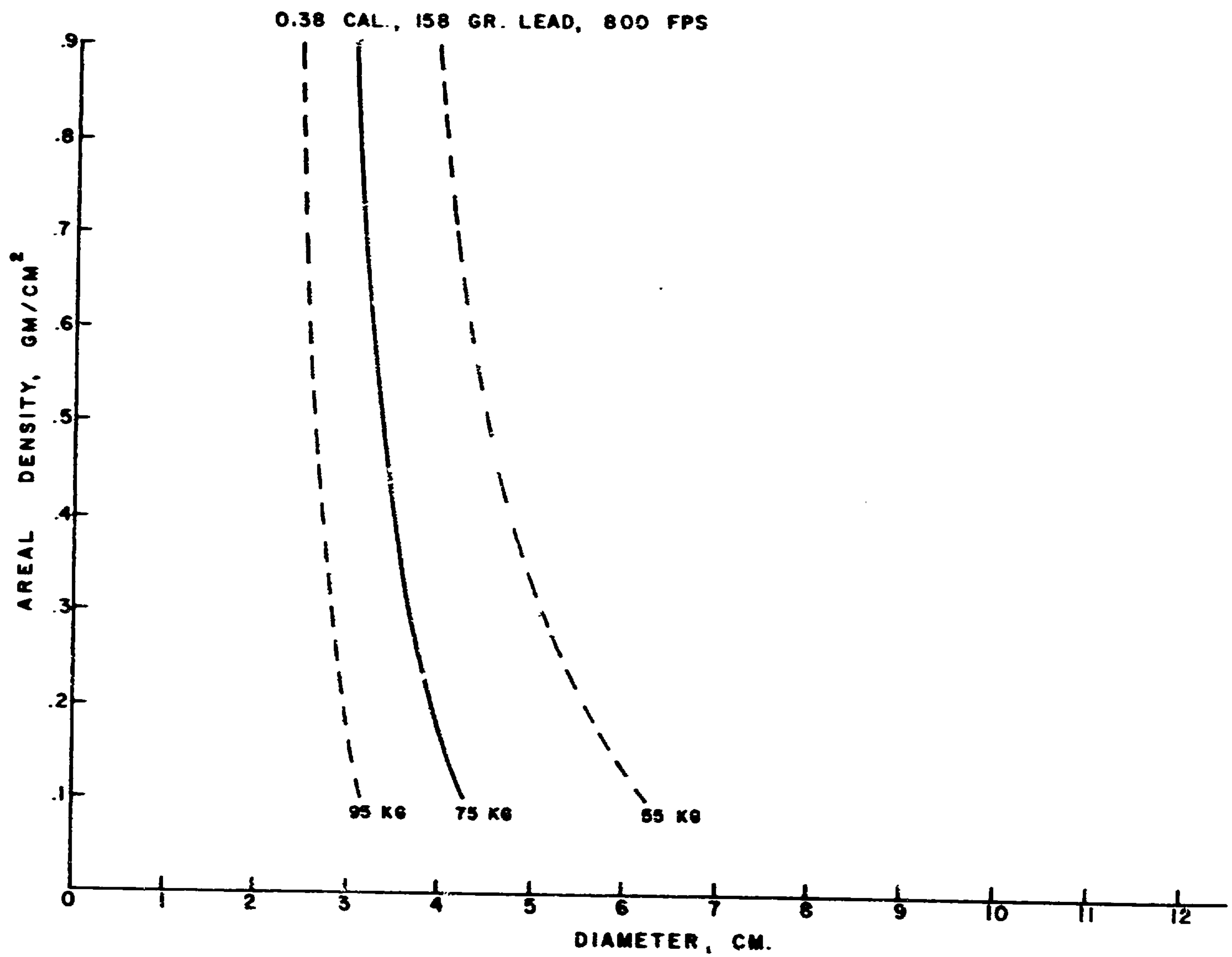

Figure B-6. Areal Density Versus Deformation Diameter, Lead, I

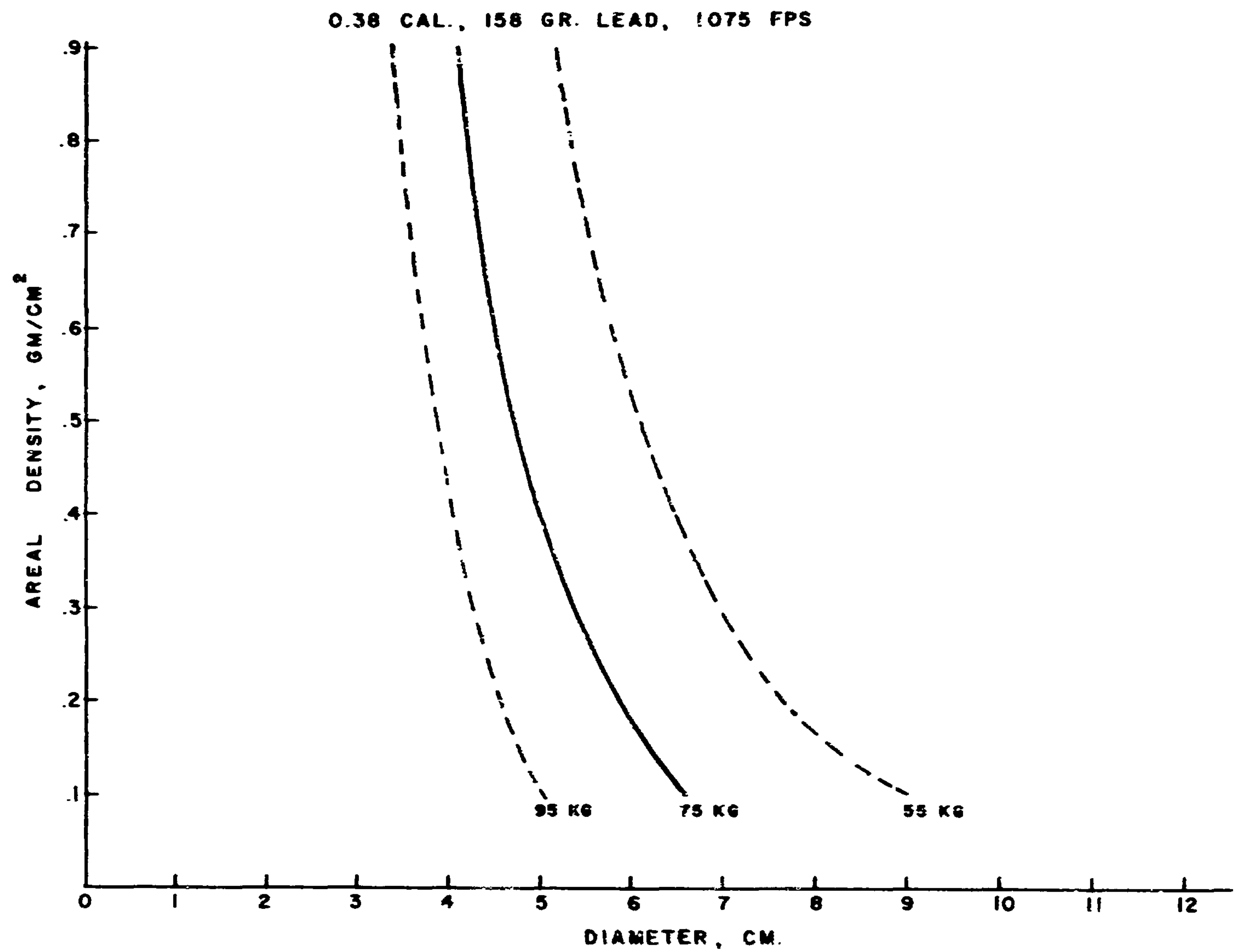

Figure B-7. Areal Density Versus Diameter of Deformation, Lead, II

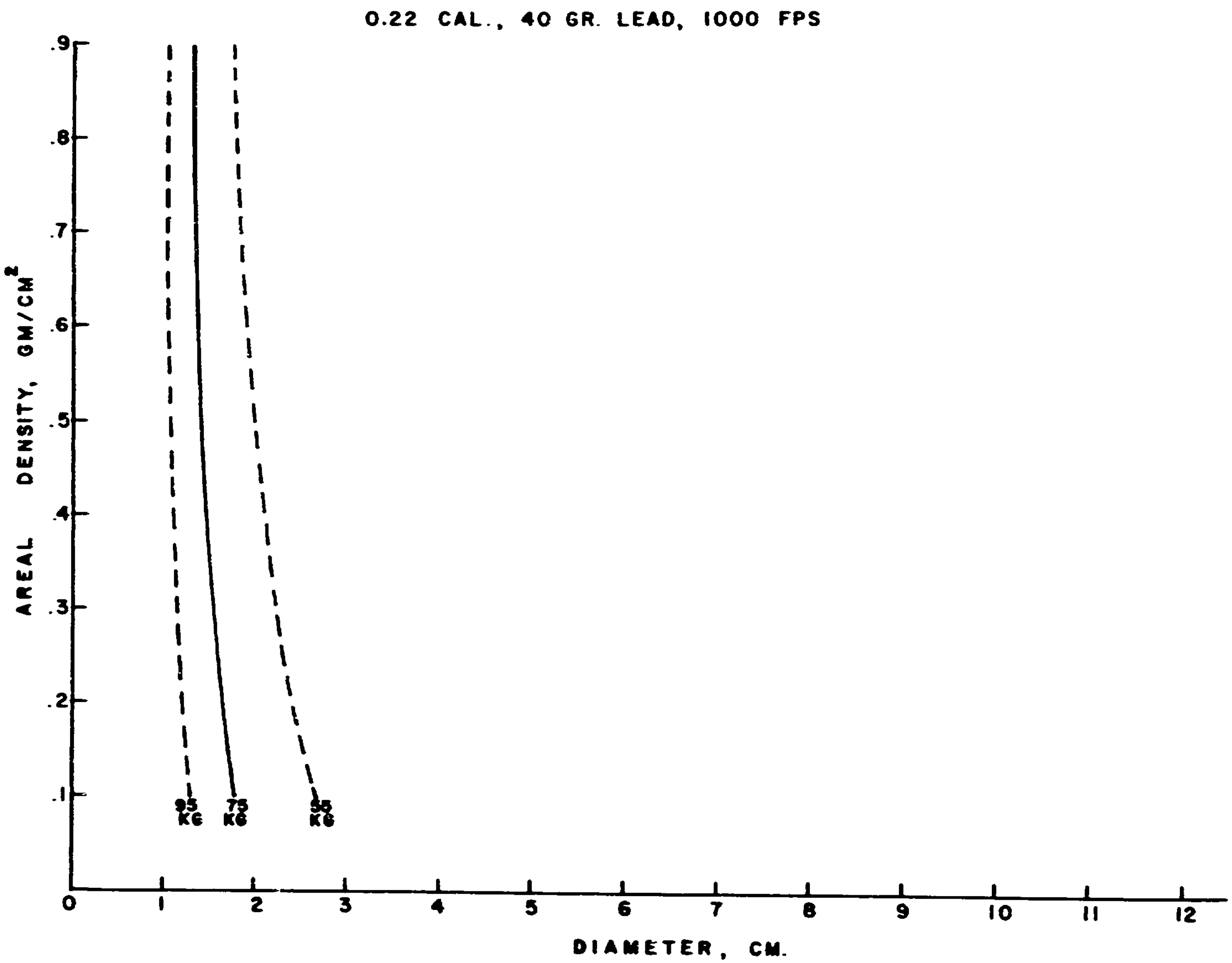

Figure B-8. Areal Density Versus Deformation Diameter, Lead, III

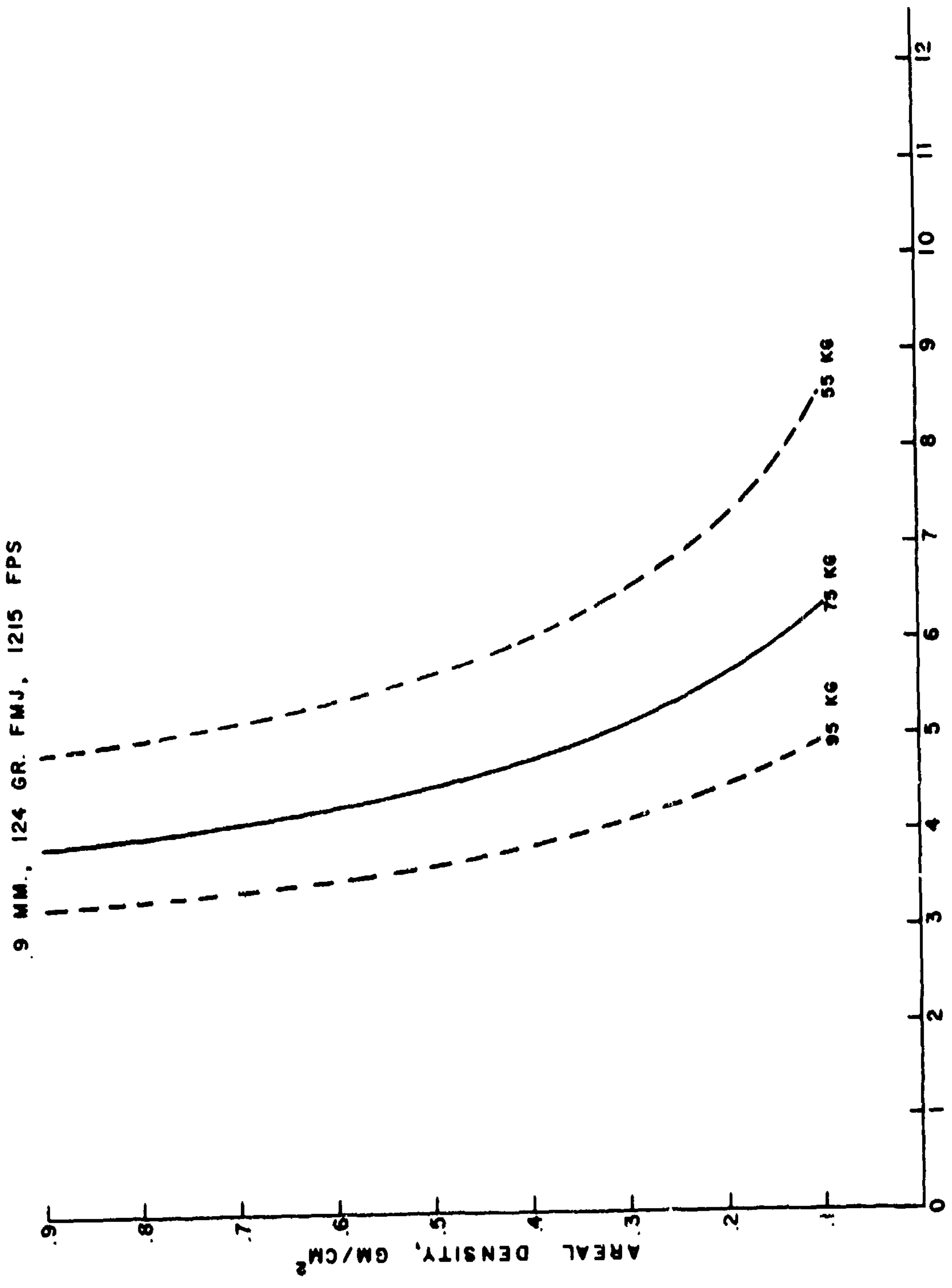

Figure B-9. Areal Density Versus Diameter of Deformation, FMJ, II

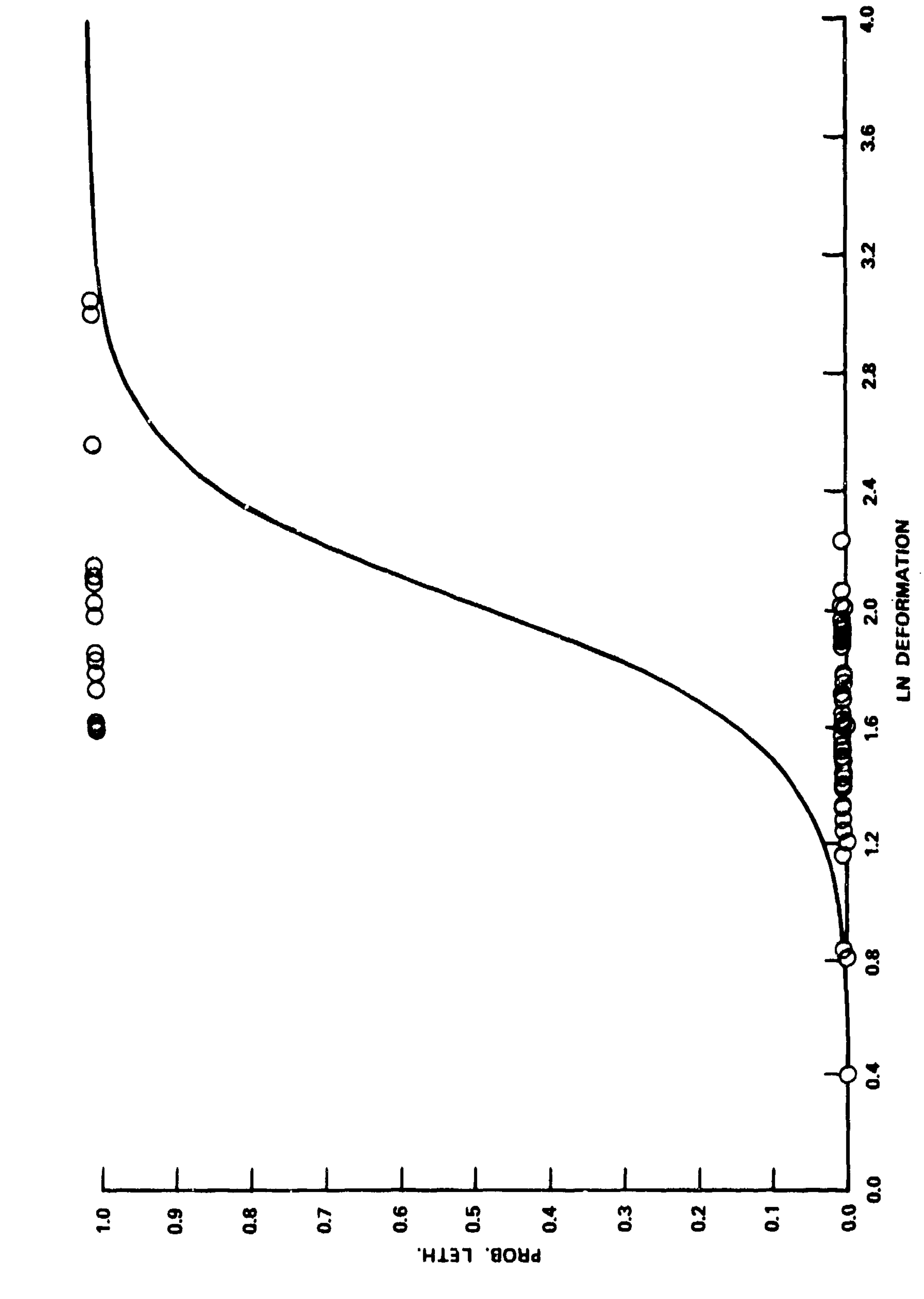

Figure B-10. Correlation of Probability of Lethality with Deformation Depth

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