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RIGHT CIRCULAR CYLINDER FRAGMENTS IMPACTING COMPOSITE KEVLAR 49 PANELS

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

A test program to determine the perforation limits at normal incidence for a series of test panels is described. Steel-right-circular cylinders of four weights and with a length to diameter ratio (L/D) equal to one were fired against the test panels. Panels were of two general types. One type consisted of single KEVLAR 49 panels of varying resin type content and thickness. The other consisted of sandwich panels of KEVLAR 49 face sheets with various core materials. A total of fourteen different panels was tested. All of the data obtained are presented with tabulated summaries along with some general conclusions.

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I. INTRODUCTION

The mitigation of the effects of spall fragments on "soft" components (i.e. personnel, electronic equipment, wiring, etc) in armored vehicles is a major research problem. An often proposed method to resolve this problem is the installation of spall suppression panels to intercept or at least slow the fragments before they can reach any soft components. This technique was explored in the Ballistic Research Laboratory by conducting a series of test firings of fragments against a number of candidate light weight spall suppression materials. This report contains a description and preliminary analysis of the test results. This group did not attempt to determine the overall best candidate to use as a spall suppression shield, but various data trends were noted and a gross estimate was made to rate the various panel materials according to their ability to stop or slow the fragments.

II. THE TEST FACILITY AND PROCEDURE

The test facility and procedures used were the traditional ones usually applied in this kind of work. The fragments were propelled down the range with a 50 caliber smooth bore Mann barrel. The positions and speeds of the fragments were determined by the use of x-ray filming techniques using break screens, timing devices, and x-ray flash tubes. The orientation of the fragments just before impact on the front surface of the target panel was one of the important parameters which needed to be evaluated. This required a precise prediction of the velocity of the fragment before firing, so that an x-ray tube would be set to flash when the fragment reached the correct position, but predicting the velocity to the degree required was not possible. However, the problem was resolved by using a newly developed device[1]. This device provides a method to cause an x-ray tube to flash exactly when the fragment reached the front surface of the target panel regardless of the actual speed of the fragment.

Figure 1 presents a schematic drawing of the main features of the test range. The x-ray tube center sources were indexed on six inch fiducials and the x-ray heads were located 48 inches from the corresponding film planes. With two fragment images recorded on a single x-ray film, sufficient information was available to calculate the speed of the fragment corresponding to a particular position relative to the target. As shown in Figure 1, there were three break screens positioned in front of the target between the gun muzzle and the target. The first two screens were light break screens that provide a start and termination pulse when broken by the passing fragment which was transmitted to the X-ray Trigger Predictor. The distance between the target and the gun muzzle was 4.928 meters and the distances of the first and second light break screen and the gun muzzle were 3.848 meters and 3.658 meters, respectively. These distances made the space between the light screens equal

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[1] *Donald F. Merritt and Charles E.Anderson, "X-Ray Trigger Predictor Automatic Electronic Time Delay for Flash X-ray Systems," January 1981, ARBRL-TR-02284, US Army Armament Research and Development Command, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005 (AD B056362L)*

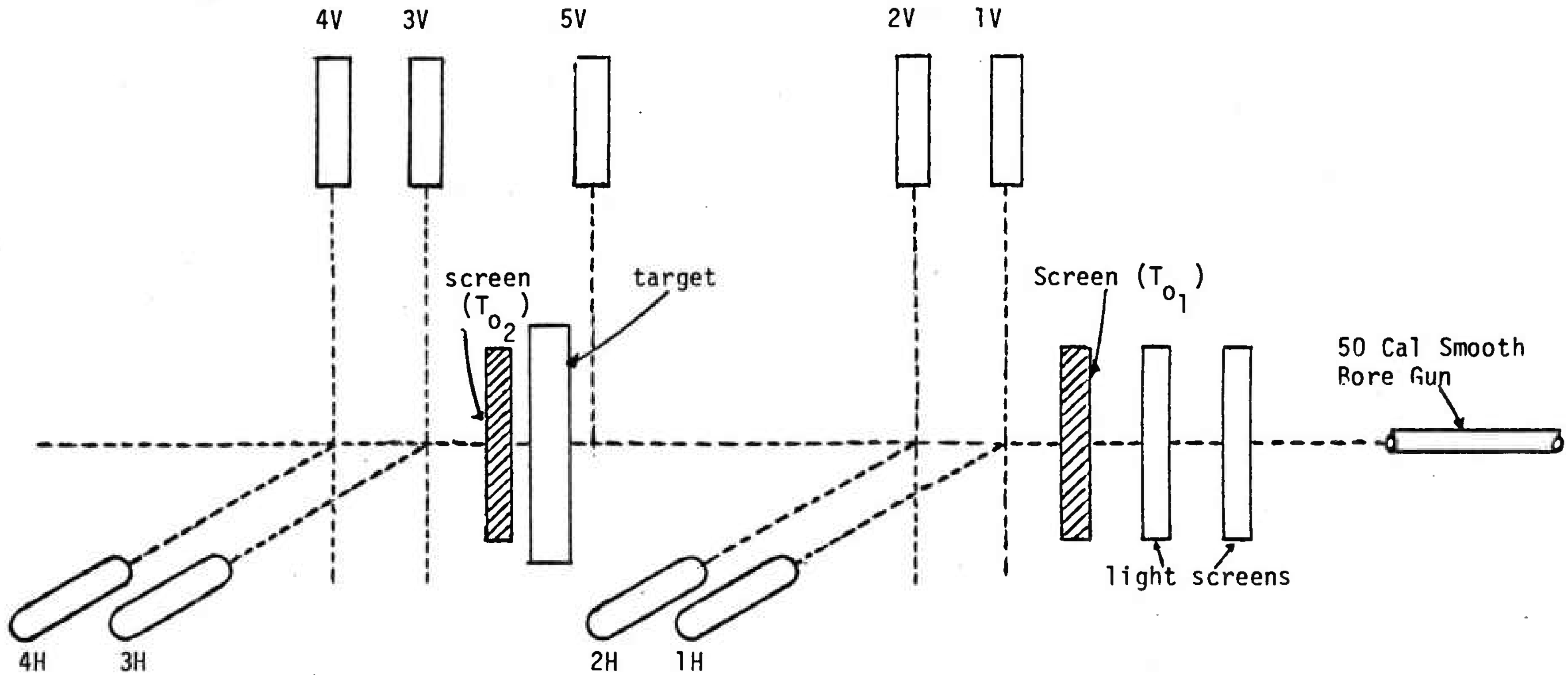

Figure 1 : The Range And X-ray Test Setup

to one-half the distance between the second light screen and the target. On the breaking of the first light break screen, the X-ray Trigger Predictor began a count at equal time intervals which continued until the second light break screen was broken. At that time the device doubled the count obtained and reversed the count with the built-in knowledge that once the count reached zero, the x-ray tube designated as 5V in Figure 1 would flash. Since the 5V x-ray tube was positioned to cover the point just in front of the target and once zero was reached in the count the fragment was located precisely at that point, then an image of the fragment was obtained on an x-ray film. This provided a reliable means to determine the orientation of the fragment just prior to impacting the target even though the exact speed of the fragment before firing is not known.

The striking speed of the fragment was obtained by using the third break screen and the four x-ray tubes shown in Figure 1 and designated as IV, 1H, 2V, and 2H. Two of these were located in a vertical position relative to the shot line of the fragment and the other two were horizontal. These tubes were initiated in a certain time sequence by a pulse generator triggered by the perforation of the paper break screen. After the screen was perforated and a preprogrammed time delay occurred with the use of the trigger delay generators of the flash x-ray system, the first set of orthogonal x-ray tubes flashed (IV and 1H); after another time delay, the second set. This procedure provided two images of the fragment on orthogonal x-ray films from which the striking speed was determined.

The residual velocity was obtained in the exact manner as that used for obtaining the striking speed. However, the break screen and the associated x-ray tubes were positioned behind the target as shown in Figure 1. Naturally, if the paper break screen behind the target was not perforated, then the fragment had failed to perforate the target and the x-ray tubes were not initiated by the trigger delay generator.

III. CHARACTERISTICS OF TEST MATERIALS

The fragments used in the test series were right-circular-steel cylinders with a length to diameter ratio (L/D) of one. The density of the fragments and the Rockwell hardness was 7.78 gm/cc, and C29 respectively. The nominal mass values of four different fragments used in the test series and their diameters are presented in Table 1. The actual mass values of each fragment fired are listed in the summary in the Appendix.

Table 1: The Weights and Diameters of the Right-Circular Cylinders

MASS (Grams)	MASS (Grains)	DIAMETER (cm)
0.3	4.94	0.376
1.0	14.97	0.542
2.0	30.09	0.683
4.0	60.02	0.860

The panels tested consisted of layers of various materials with the most prominent material being KEVLAR 49. All of the KEVLAR 49 layers contained concentrations of resin, phenolic-PVB, or epoxy. Table 2 contains a listing of these along with values of the number of layers of each and their thicknesses. These materials served as the outermost layers of the panels (facings) and, for convenience, have a "facing identification number".

Table 2: Characteristics of the Facing Layers of the Spall Suppression Panels

FACING ID.	MATERIALS	NUMBER OF LAYERS	THICKNESS (cm)
F1	KEVLAR 49 /22% Resin	8	0.203
F2	KEVLAR 49 /25.7% Resin	8	0.203
F3	KEVLAR 49 / 29.5% Resin	8	0.203
F4	KEVLAR 49 / 20% Resin	4	0.102
F5	KEVLAR 49 / 20% Resin	16	0.406
F6	KEVLAR 49 / Phenolic-PVB	8	0.203
F7	KEVLAR 49 / Epoxy	1	0.360

Table 3 provides a summary of data describing the 14 panels used in the tests. Panels A through E in the list are KEVLAR 49 facings only, without any core materials (interior materials). The KEVLAR material in these panels contained various concentrations of resin. Panels F and G had interior core material called Quadricore. Figure 2 gives the size of the cells of the Quadricore and an idea as to how these cells are arranged. Panel N consisted of the Quadricore material only without any outside facing material. On the other hand, Panel M consisted of a single layer panel made of KEVLAR 49 with a concentration of epoxy. In Panel G, the cells were filled with foam which had a density of 32 g/cc. There were three other types of core materials and a descriptive diagram of these materials are presented in Figures 3, 4, and 5. As can be seen, these panels are structured in a complicated manner and for that reason it was not possible to anticipate the level of penetration before testing.

Table 3: Characteristics of the Spall Suppression Panels

PANEL ID.	FACING ID.	CORE MATERIAL	DENSITY W/O FOAM kg/m^3	DENSITY OF FOAM Kg/m^3	TOTAL THICKNESS (cm)
A	F1	N/A	N/A	N/A	0.203
B	F2	N/A	N/A	N/A	0.203
C	F3	N/A	N/A	N/A	0.203
D	F4	N/A	N/A	N/A	0.102
E	F5	N/A	N/A	N/A	0.406
F	F6	QUADRICORE	*	0.0	5.400
G	F6	QUADRICORE	*	32.04	5.400
H	F6	WR II	60.88	0.0	5.400
I	F6	WR II	60.88	32.04	5.400
J	F6	HRH-10	144.20	*	5.400
K	F6	HRH-10	96.12	0.0	5.400
L	F6	5056 ALUMINUM H.C.	49.66	0.0	5.400
M	F7	N/A	N/A	N/A	0.360
N	*	QUADRICORE	*	0.0	0.240

*An asterisk indicates that no data is available. N/A - This symbol indicates "not applicable".

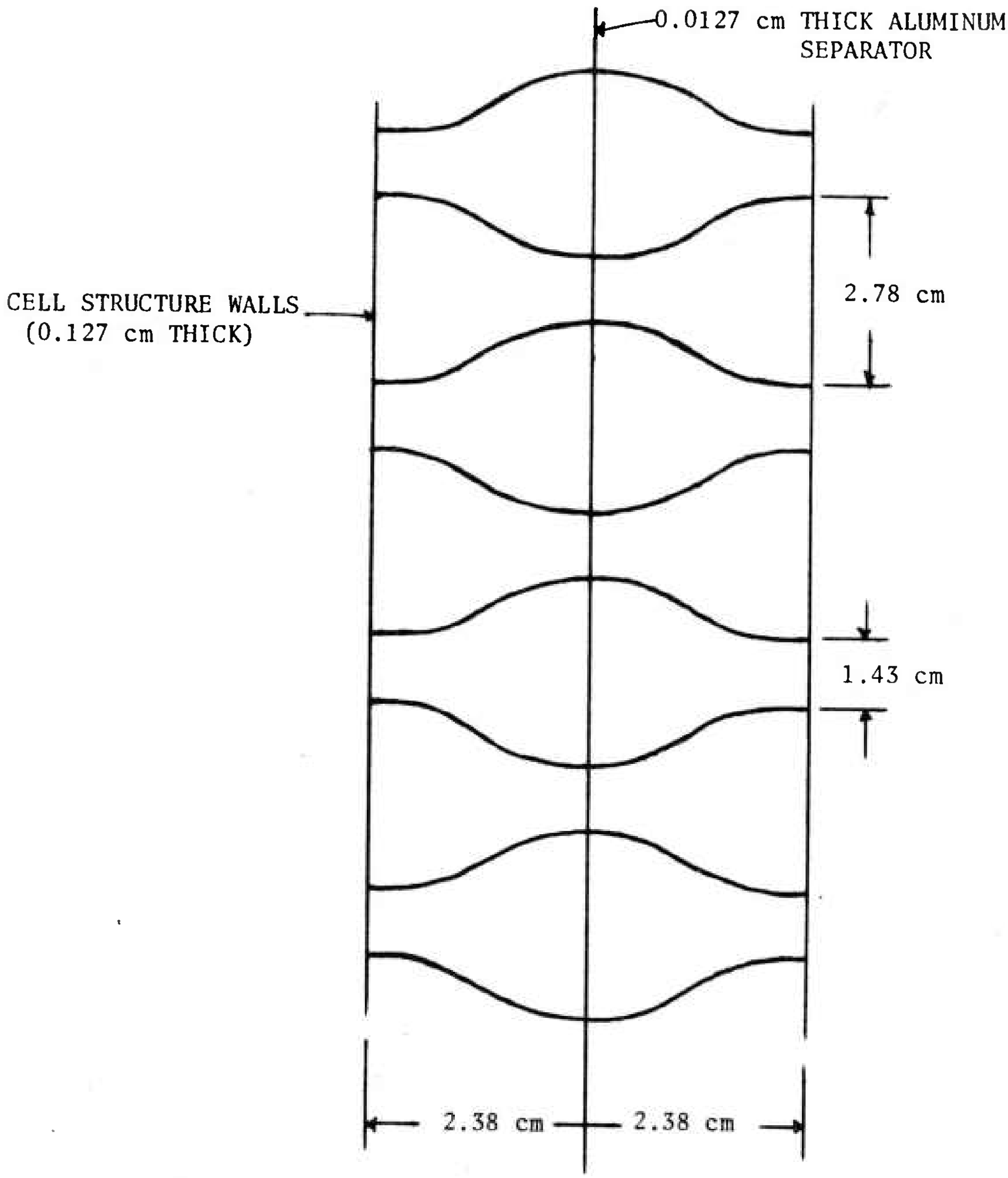

Figure 2. The Cell Structure for the Quadricore Core Material

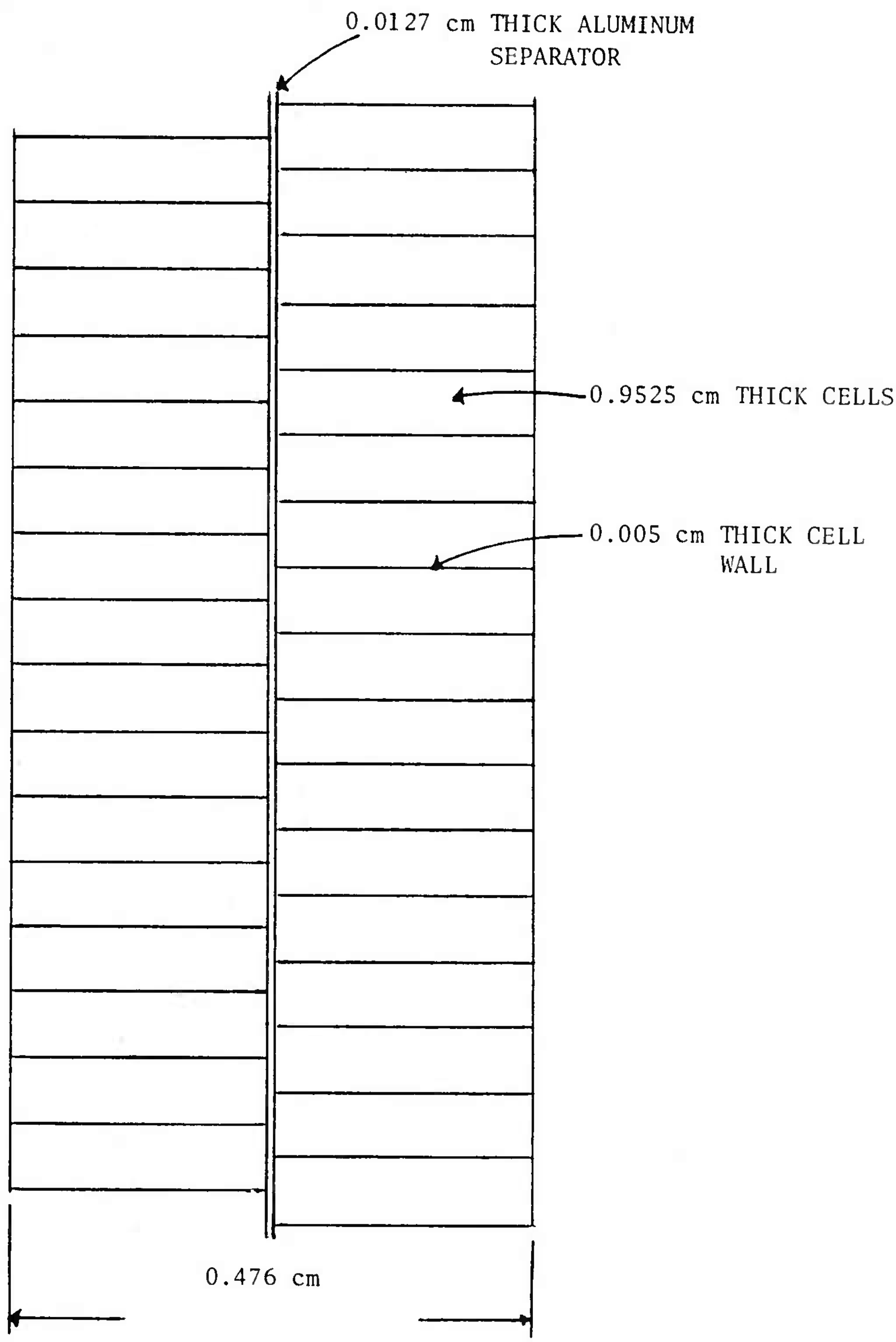

Figure 3. The Cell Structure for the WR II Core Material

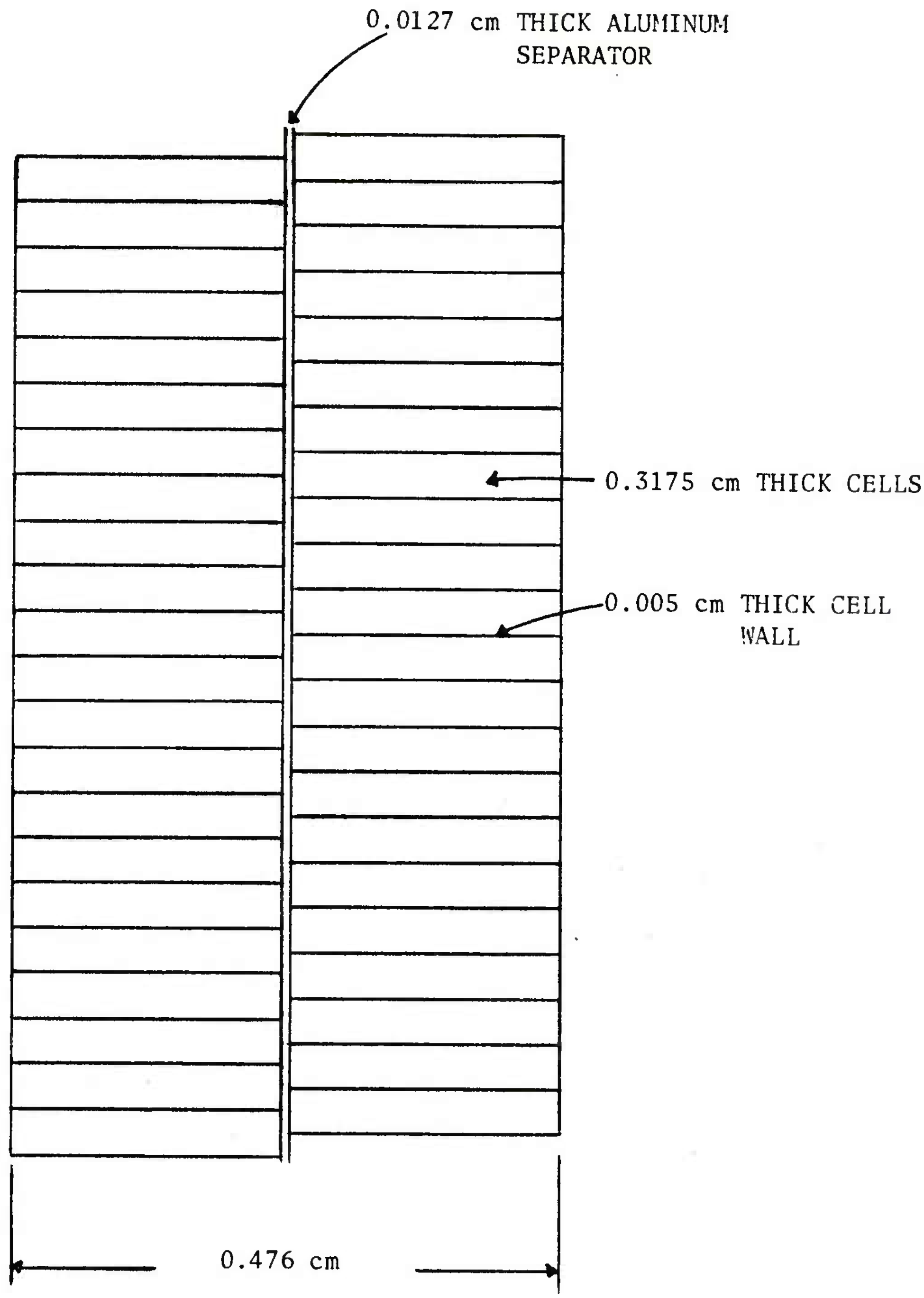

Figure 4. The Cell Structure for the HRH-10 Core Material

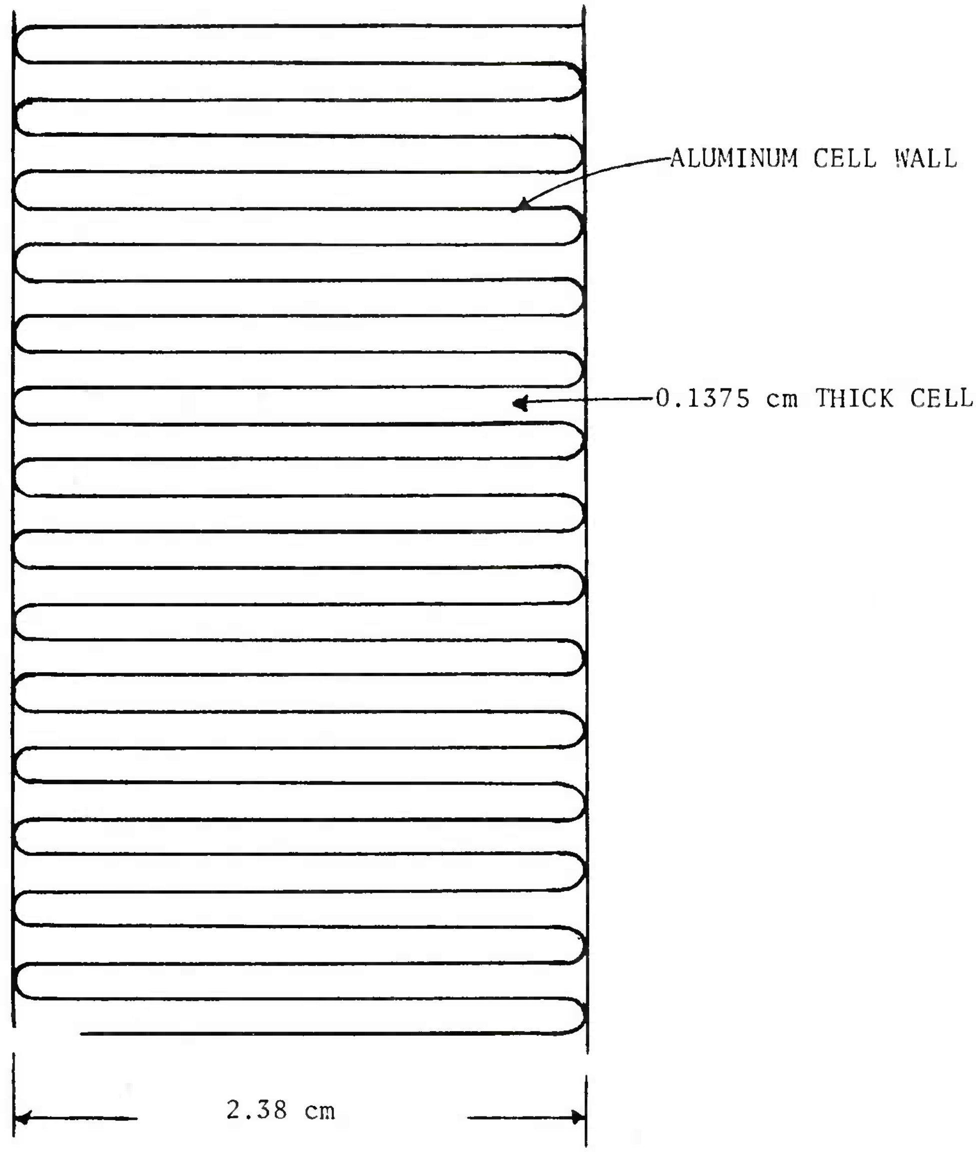

Figure 5. The Cell Structure for the 5056 Aluminum H.C. Core Material

IV. DISCUSSION OF THE TEST RESULTS

A summary of all of the data obtained in the test program is presented in the Appendix. Many of the standard data parameters recorded in fragment penetration work, such as hole size, are not included in the summary and were not obtained in the tests. A view of the panels after testing indicates that holes formed by the fragments in the KEVLAR 49 facings essentially closed following perforation. The pertinent data which were obtained consisted of the striking speeds, the residual speeds following perforations and the orientations of the right-circular cylinders just prior to impacting the target panel. The orientations of the fragments are expressed in terms of the yaw angle where a zero degree angle corresponds to that orientation where the end of the cylinder strikes the panel straight on. The data is presented in terms of ratios of the residual speeds and the striking speeds as functions of the striking speeds. The basis for comparing the shielding capabilities of the various panels is the limit velocity.

A substantial amount of scatter prevails in the data. The cause of the scatter can be attributed to several contributing factors. The most likely cause is the large inconsistency in the core materials over a projected area of the panels. The speed of a fragment would be reduced even if it passed cleanly through an empty cell, but if the fragment should hit the wall of a cell, its travel would be impeded a great deal more. However, there is large scatter even in data obtained from firings at panels of KEVLAR 49 without the core material, and these panels appeared to be homogeneous. An explanation could be the effect of the yaw angle, but the data given in Appendix does not support that contention. One contributing factor for the scatter could be that the panel, made up of layers, is severely delaminated on perforation which could affect the penetration of a follow on firing if the hit occurred in a delaminated region. Finally, the actual weights of the fragments varied from the nominal value listed in Table 1 which could also have had a significant effect.

Regardless of the scatter, there are trends which can be identified by comparing the test results of selected panel groups where the panels in each group, are different in some particular way. For example, A, B, and C are of equal thicknesses of KEVLAR 49 with 22, 25.7, and 29.5 percent resin impregnation respectively. The .3 gram fragment data presented in Figure 6 has so much scatter that it was impossible to ascertain separate curves for data from each of the three panels. The data presented in Figures 7 and 8 for the 1 and the 2 gram fragment, respectively, indicate that the data for the C panel are separated significantly from the data of the other two panels. A study of all three figures will show that as the weight of the fragment increases, the general location of the data is shifted toward the origin. Also, the data shows that just above the perforation limit, the ratio of the speeds rapidly approaches 100 percent for small additional increases in the striking speed.

Another approach to comparing data was to consider composites (panels F, H, J, K, and L) to which no foam was added. This was accomplished in Figures 12, 13, and 14 for three of the fragment weights. With the scatter in the data, it is not possible to discern between the results from the different panels. However the amount of scatter becomes less as the weight of the fragment is increased. In addition the relative position of the data moves to lower

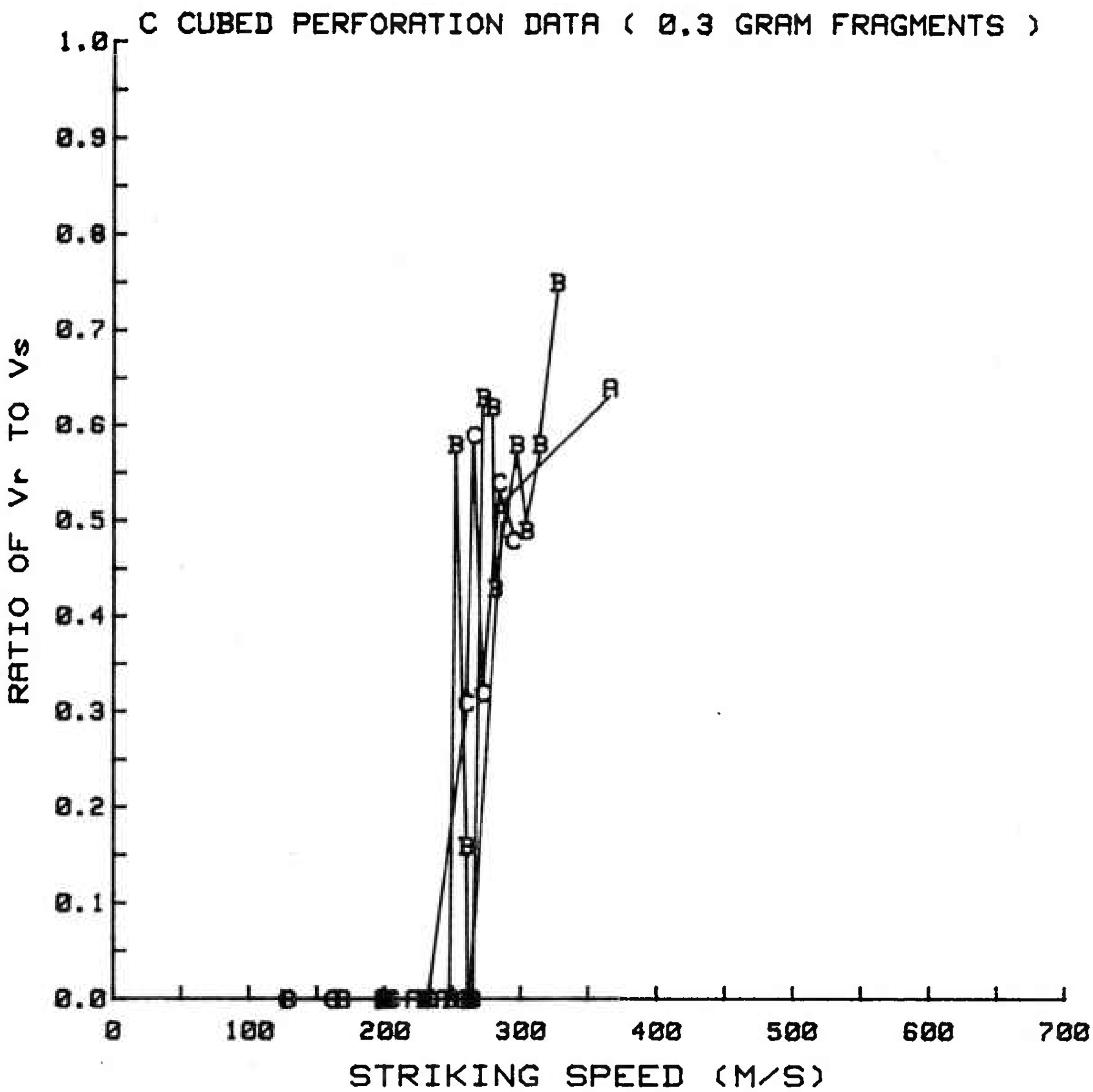

Figure 6. Comparison of Nominal .3 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A,B, and C) of Equal Thickness and Various Resin Percentage Levels

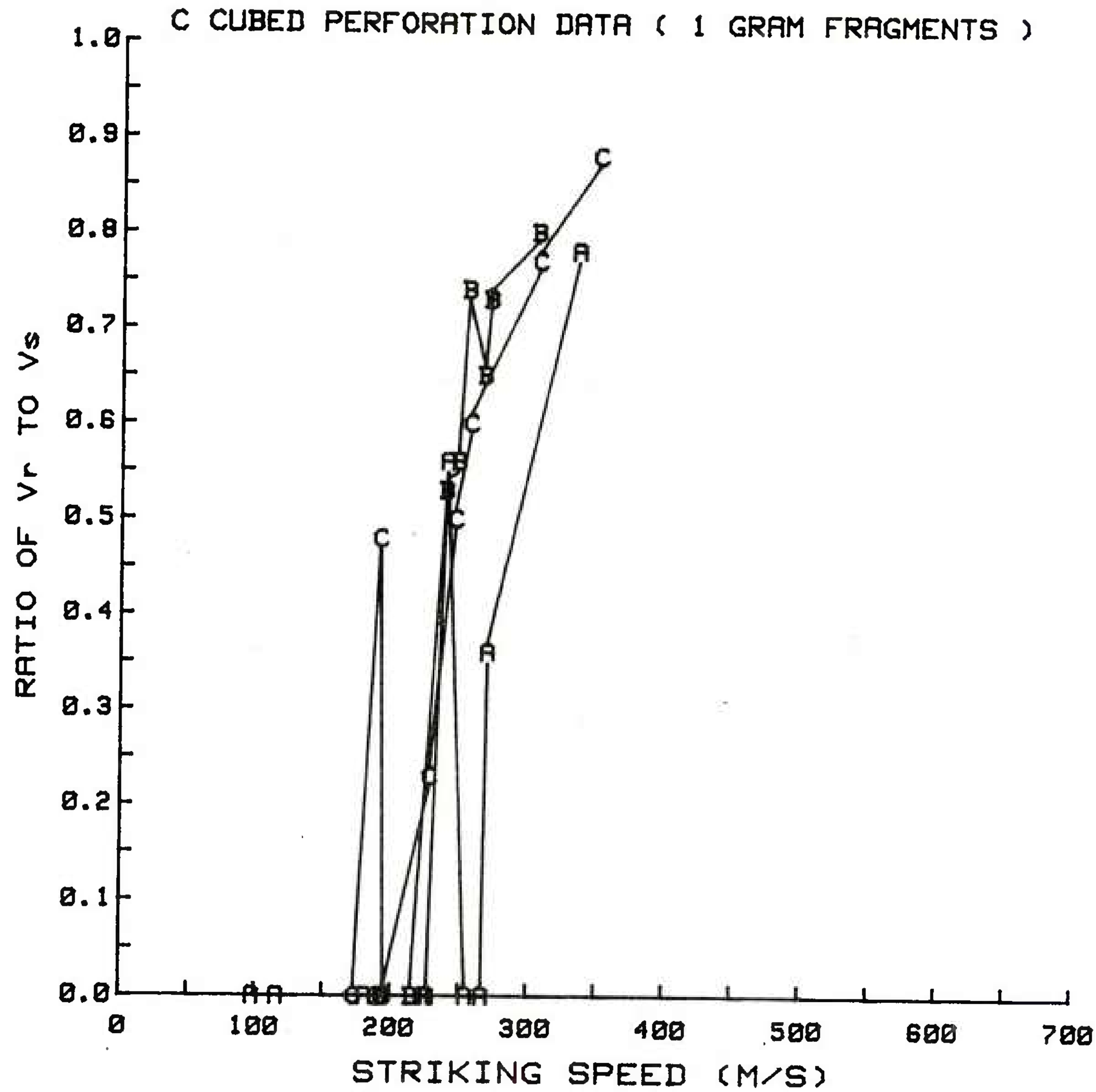

Figure 7. Comparison of Nominal 1 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A,B, and C) of Equal Thickness and Various Resin Percentage Levels

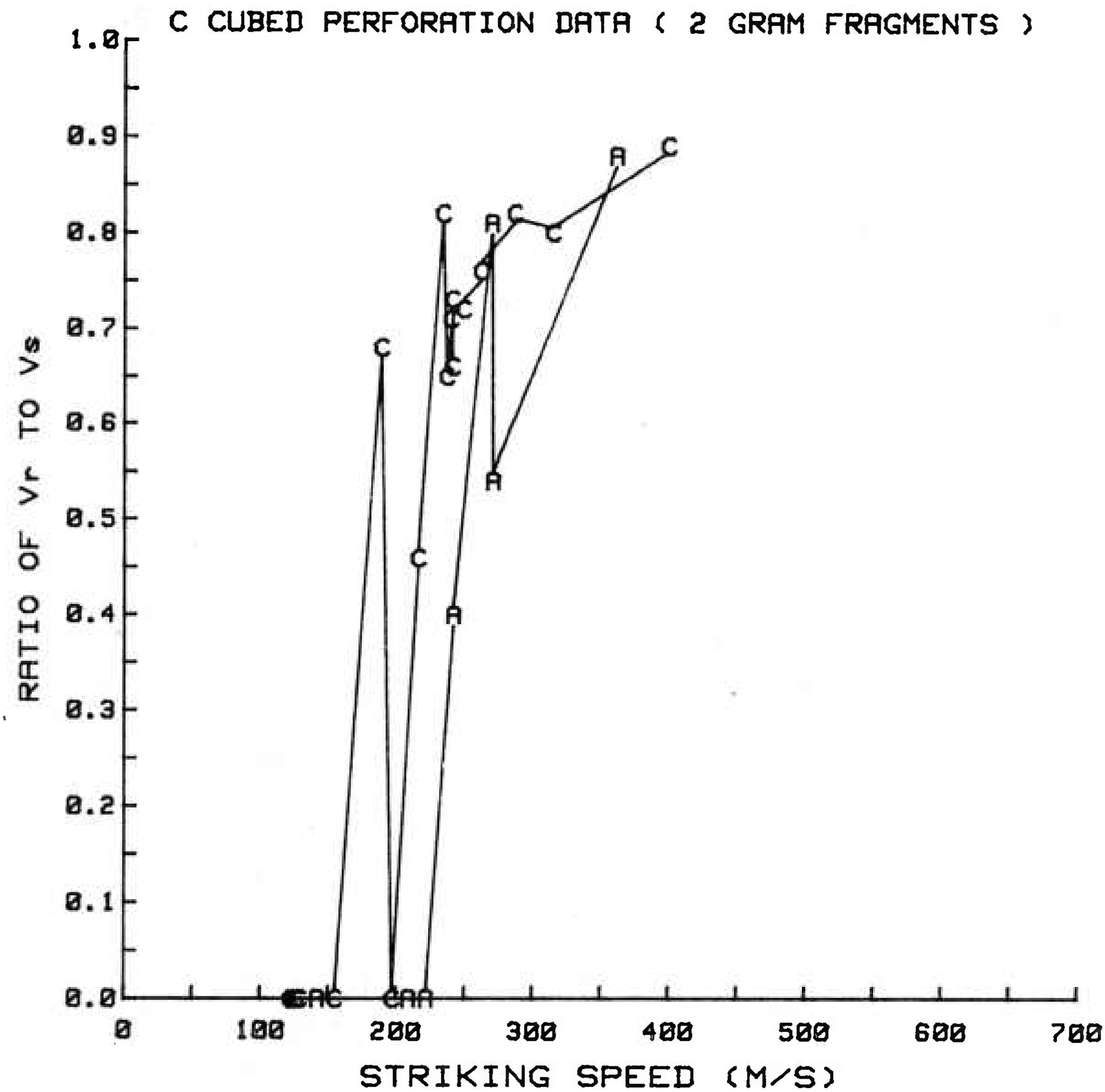

Figure 8. Comparison of Nominal 2 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A and C) of Equal Thickness and Various Resin Percentage Levels

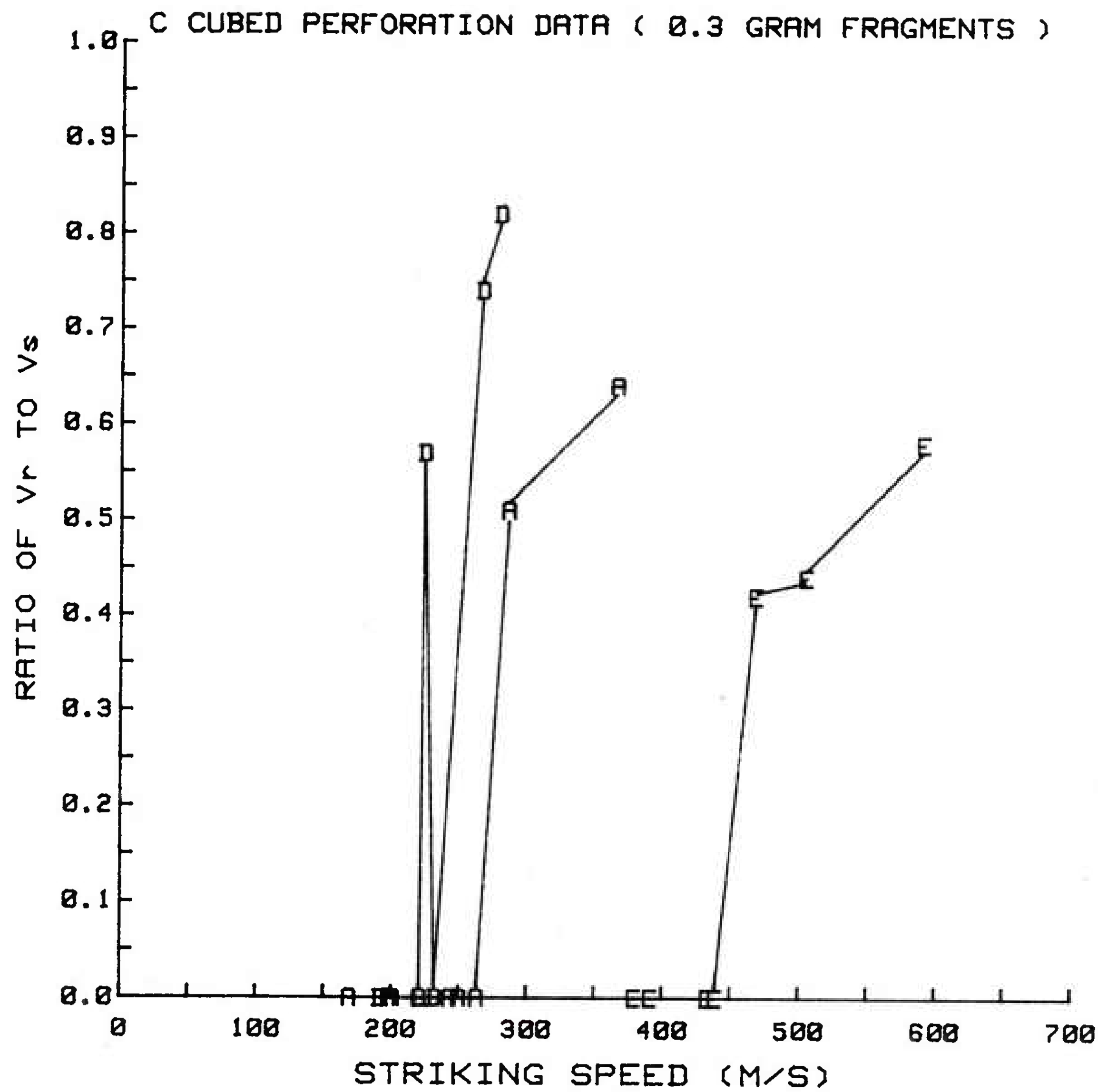

Figure 9. Comparison of Nominal .3 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A,D, and E) of Equal Resin Percentage Levels (20% Resin Concentration) and Various Thicknesses

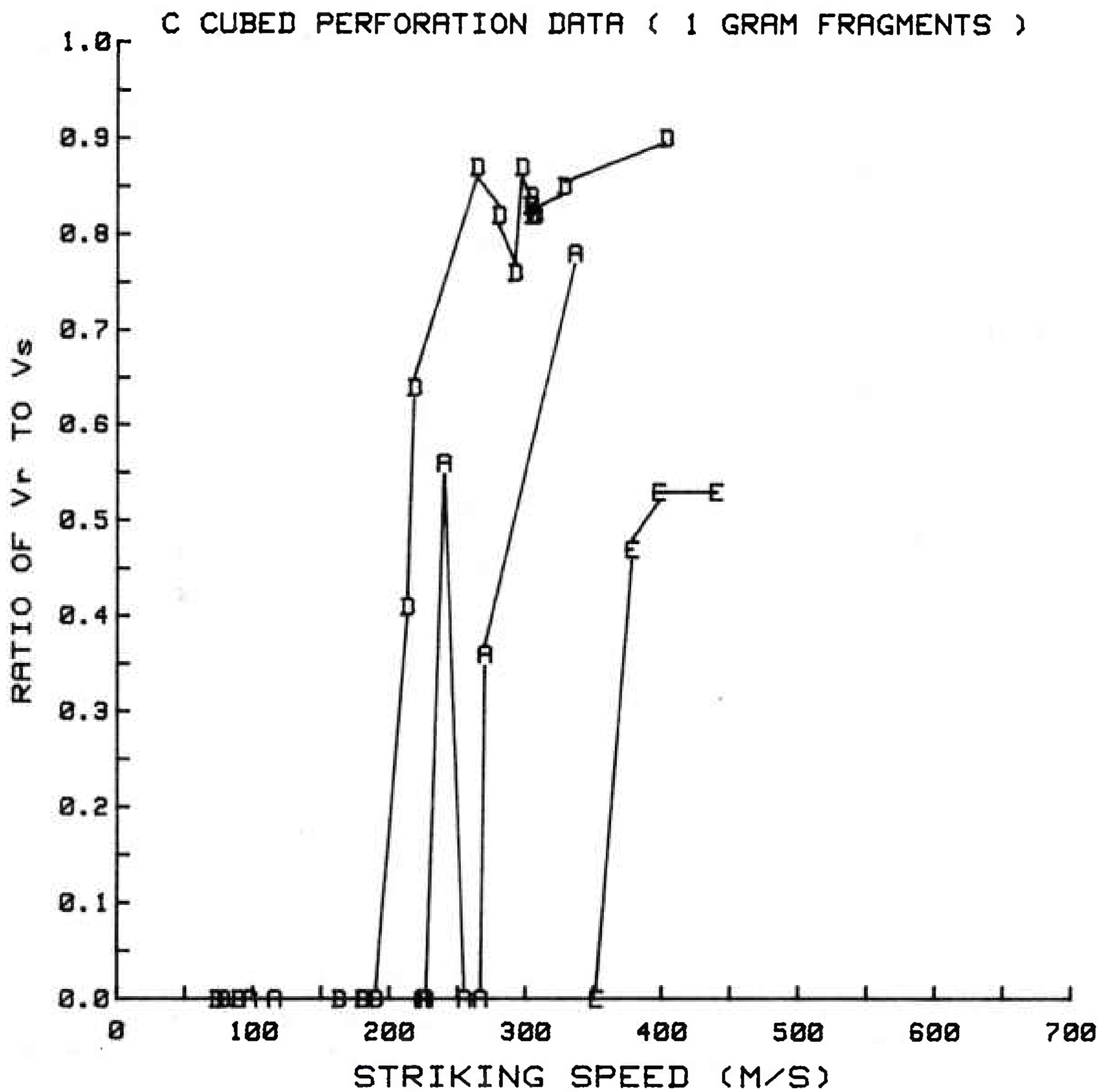

Figure 10. Comparison of Nominal 1 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A,D, and E) Resin Percentage Levels (20% Resin Concentration) and Various Thicknesses

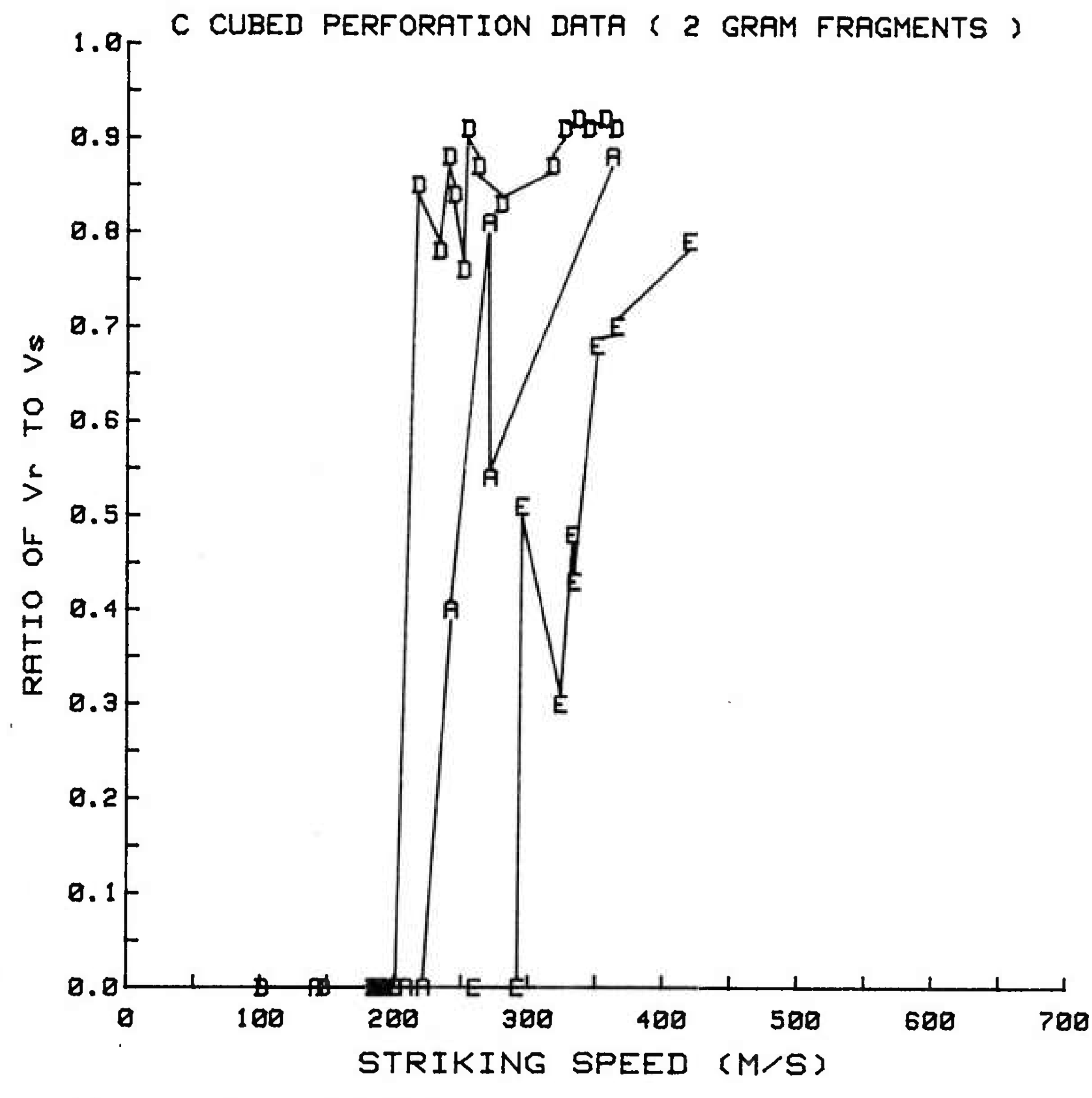

Figure 11. Comparison of Nominal 2 Gram Fragment Perforation Data for KEVLAR 49 Facing Panels (panels A,D, and E) of Equal Resin Percentage Levels (20% Resin Concentration) and Various Thicknesses.

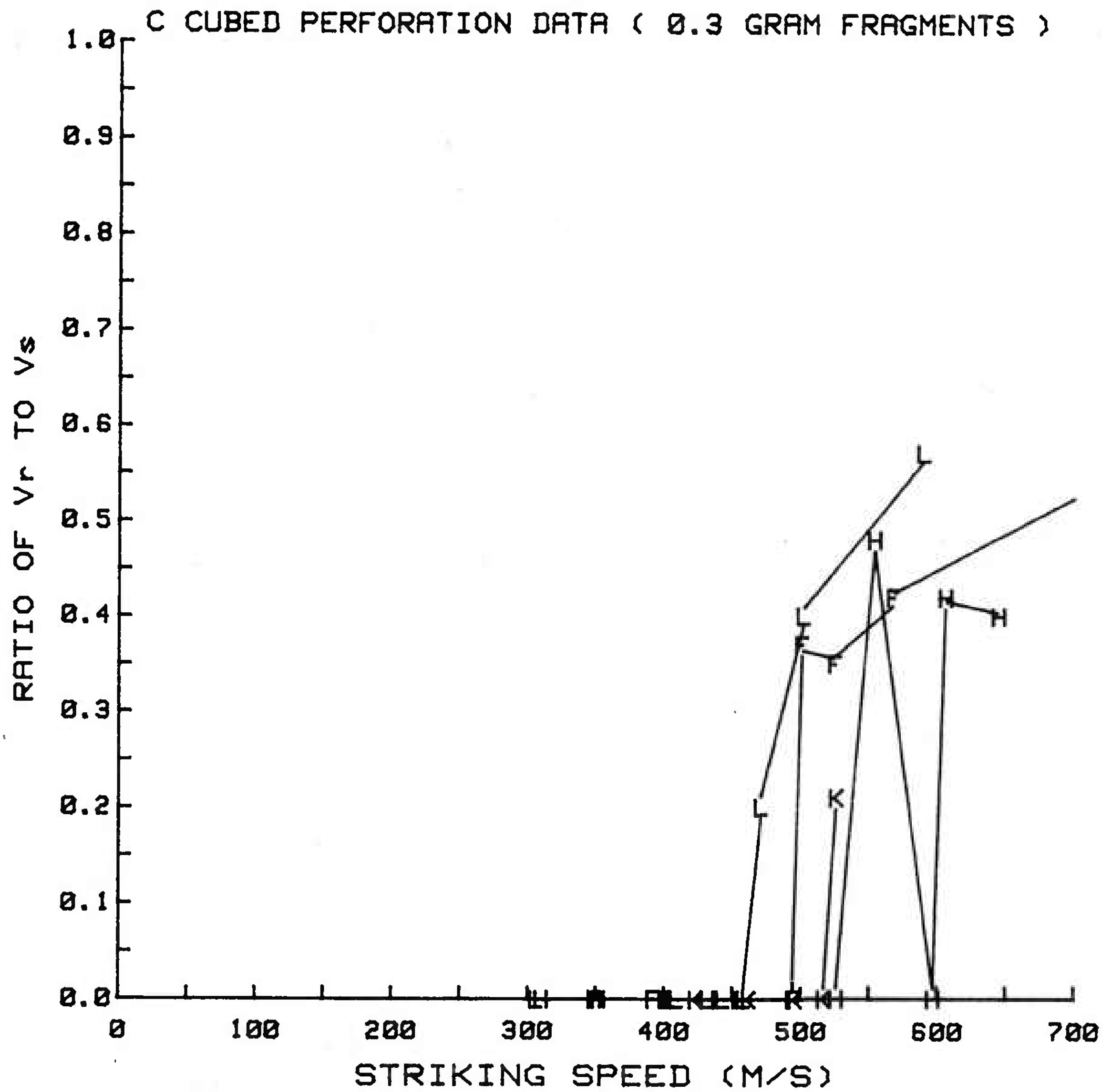

Figure 12. Comparison of Nominal .3 Gram Fragment Perforation Data for Panels (panels F, H,K and L) Containing Core Material But With No Foam Added

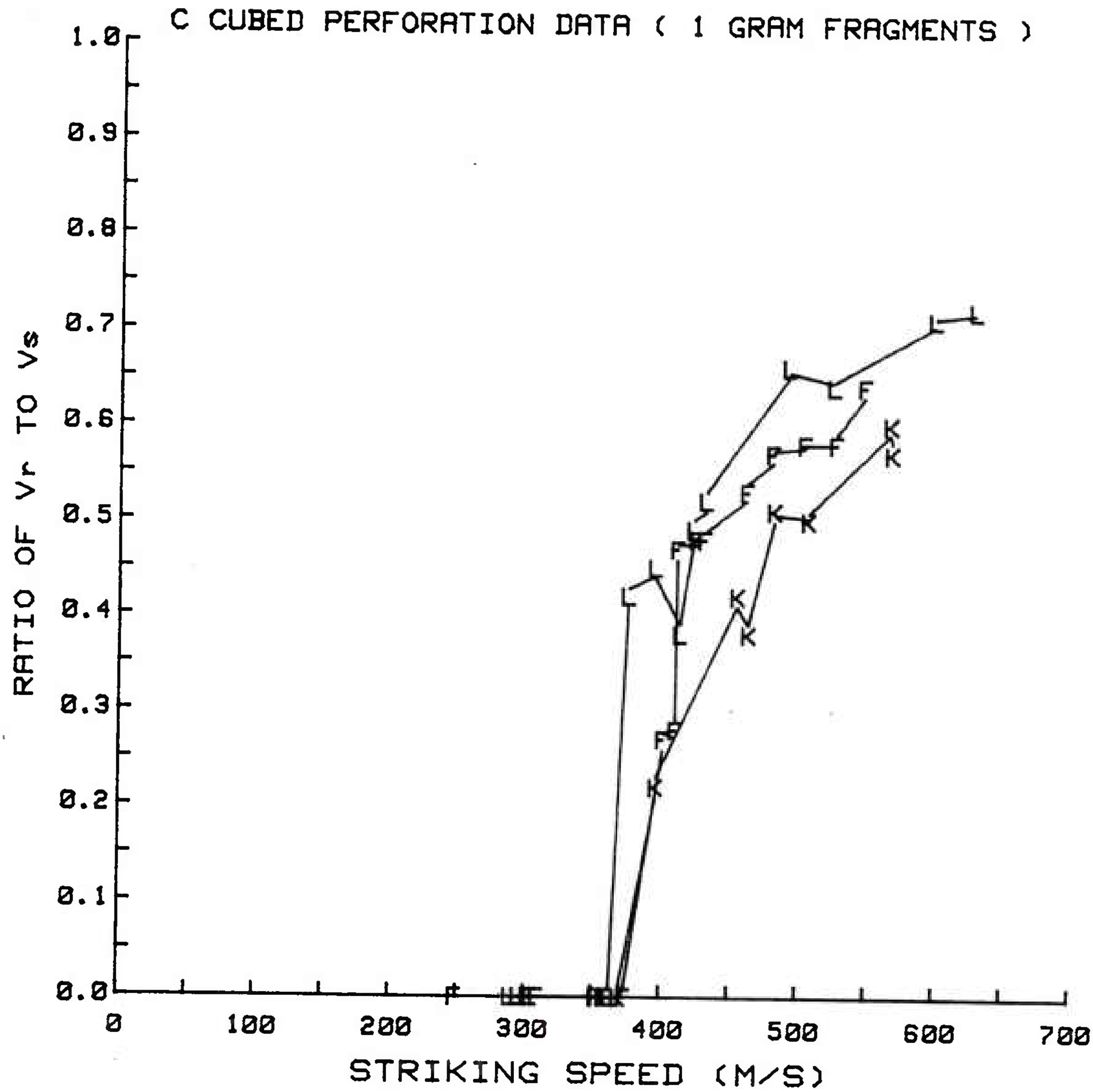

Figure 13. Comparison of Nominal 1 Gram Fragment Perforation Data for Panels (panels F,K, and L) Containing Core Material But With No Foam Added

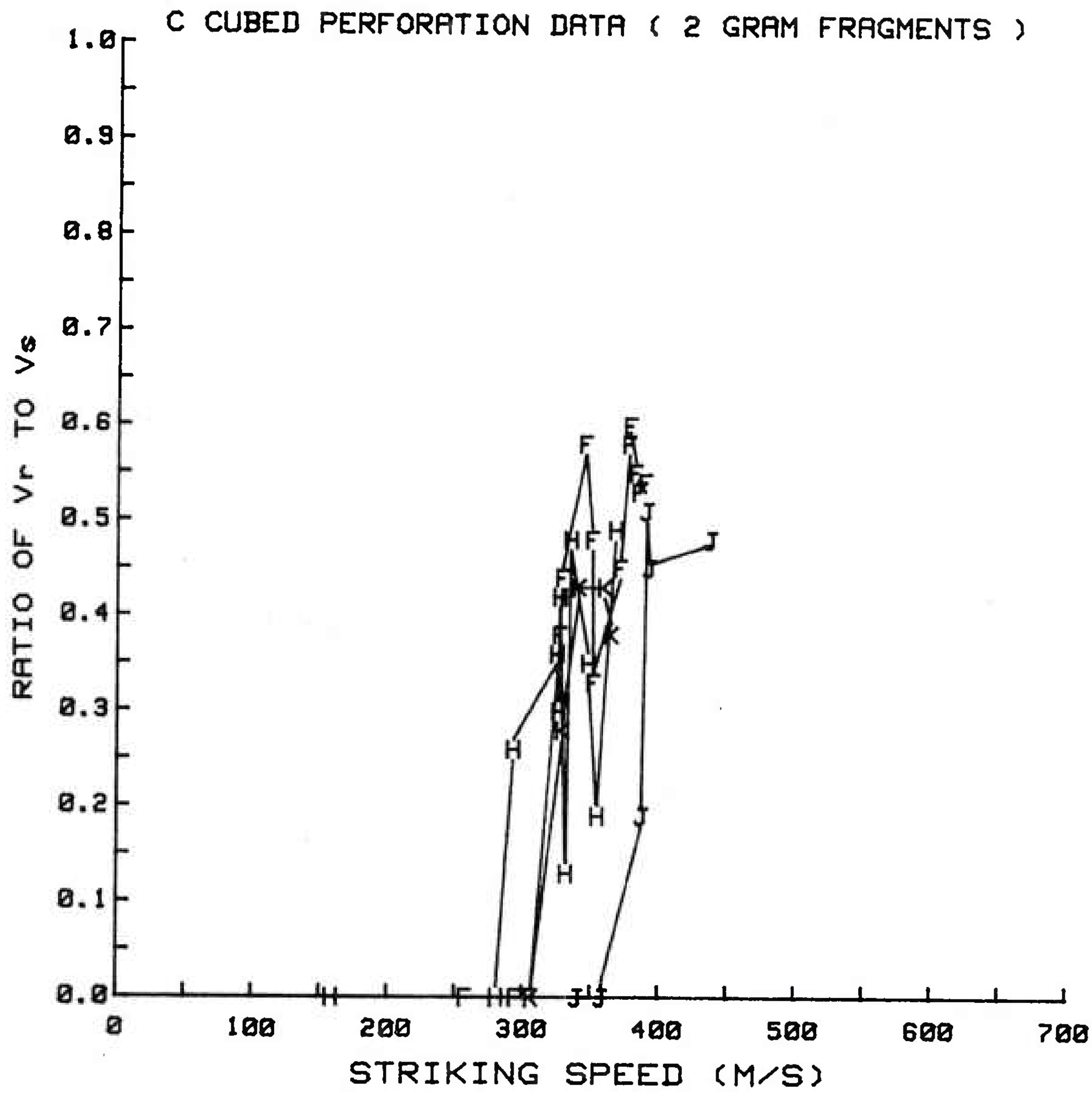

Figure 14. Comparison of Nominal 2 Gram Fragment Perforation Data for Panels (panels F, H,J, and K) Containing Core Material But With No Foam Added.

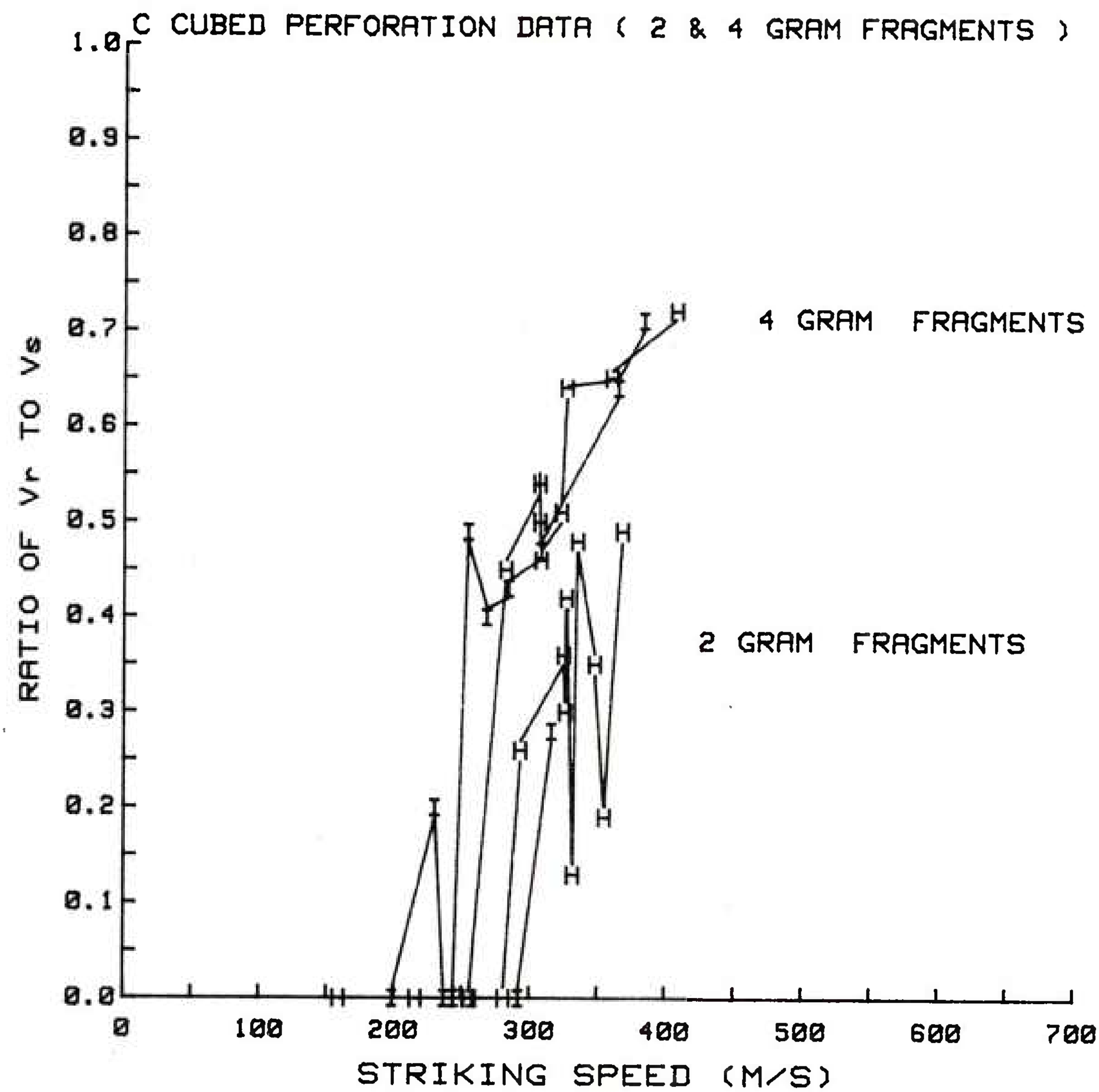

Figure 15. Comparison of Nominal 2 Gram and 4 Gram Fragment Perforation Data for Panels (Panels H and I) Containing Core Material and With Foam Added

striking speed as the fragment weight increases.

Figure 15 presents a comparison between two of the composite panels (panels H and I) which were filled with foam. Again, there is no discernible method for separating the data according to each of these types of panels and again the relative position of the data shifts left along the striking speed axis as the fragment weight increases. That is, the 4 gram fragment curves are to the left of the 2 gram fragment curves in Figure 15.

An attempt to ascertain values for the perforation limit for the data presented in the Appendix was made and these values are listed in Table 4. With all of the scatter in the data, these values should be viewed as very approximate, but they can be used to make at least a preliminary judgment on the comparative ability of each of the panels to shield against the various size fragments. The panels are listed in Table 4 according to increasing values of the perforation limit determined on the basis of the 1 gram fragment data. The 1 gram fragment data was used since only in that category was there a complete set of values for all of the panels. There are some inconsistencies in the table when the values for the .3 gram fragment are reviewed. However, this is probably the only feasible method to compare the panels in view of the large scatter in the test results. According to this comparison, Panel J is the best shield.

Table 4: Perforation Limits for the Panels for Four Fragment Weights

ORDER	PANEL ID	.3 (Gram)	1 (Gram)	2 (Gram)	4 (Gram)
1	D	220	190	200	*
2	C	235	195	145	130
3	B	250	212	*	*
4	A	260	225	212	*
5	M	300	275	210	200
6	H	525	280	260	*
7	E	440	350	290	240
8	L	457	365	*	195
9	K	515	370	310	320
10	I	445	375	300	245
11	F	495	375	310	260
12	G	540	420	305	*
13	N	520	420	340	*
14	J	*	435	360	*

* - An asterisk indicates that no data is available.

It is recommended that the data presented in this report be used to reduce the number of candidate panel materials and then repeat the test program. Any new program should be arranged so that a much larger number of tests per set of conditions be performed then that done in this study so that the data base will be statistically more accurate for predicting the shielding capabilities of the panels.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mr. Edward O. Baicy, Chief of the Target Effects Branch of TBD, for providing necessary administrative guidance and technical advice; Mr. John Zook and Mr. William Wright of TBD and Mr. William Kokinakis of VLD for reviewing the report for technical accuracy; and Mr. John Rakaczky for providing technical assistance.

APPENDIX A

SUMMARIES OF FRAGMENT TEST DATA FOR FIRINGS AGAINST COMPOSITE PANELS

This appendix contains summary tables of the data from the fragment tests conducted in this series. An asterisk in the tables indicates that the corresponding value is not available.

Table A1

Summary of Fragment Test Data for Firings Against Panel A

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
19	0.306	169	0	0	9
16	0.301	198	0	0	0
17	0.300	201	0	0	30
15	0.305	221	0	0	6
20	0.303	221	0	0	76
21	0.308	243	0	0	7
22	0.299	250	0	0	87
18	0.302	263	0	0	7
24	0.300	286	146	50	2
23	0.301	366	235	64	16
160	0.929	98	0	0	3
159	0.916	116	0	0	63
163	0.918	181	0	0	4
162	0.920	224	0	0	6
167	0.902	225	0	0	0
165	0.908	227	0	0	14
166	0.915	240	135	56	12
164	0.911	255	0	0	0
168	0.907	267	0	0	0
161	0.909	270	96	36	7
169	0.925	336	262	78	8
313	1.865	142	0	0	65
315	1.849	209	0	0	10
316	1.868	222	0	0	0
314	1.864	242	96	40	4
312	1.846	270	220	81	0
317	1.842	271	145	54	0
318	1.874	362	318	88	2

Table A2
Summary of Fragment Test Data for Firings Against Panel B

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
53	0.315	129	0	0	2.0
38	0.319	169	0	0	20.0
56	0.308	199	0	0	7.0
57	0.308	199	0	0	7.5
34	0.308	201	0	0	0
33	0.311	229	0	0	12.0
51	0.310	248	0	0	19.0
50	0.315	252	146	58	32.0
54	0.311	260	42	16	20.0
35	0.314	261	0	0	9.0
49	0.309	265	0	0	12.5
37	0.311	272	170	63	30.0
35	0.314	279	172	62	22.0
39	0.312	279	180	65	12.0
52	0.325	281	122	43	20.0
30	0.315	297	173	58	0
36	0.315	304	148	49	4.0
31	0.313	314	181	58	5.0
29	0.314	327	245	75	17.0
174	0.908	129	0	0	11.0
185	0.938	194	0	0	6.0
188	0.918	215	0	0	7.5
245	0.926	224	*	*	7.0
173	0.903	239	126	53	0
244	0.923	248	140	56	4.0
171	0.906	255	188	74	58.0
170	0.918	267	174	65	8.0
186	0.929	271	197	73	2.0
187	0.929	271	197	73	20.0
189	0.917	306	246	80	0
172	0.906	*	*	*	0

Table A3
Summary of Fragment Test Data for Firings Against Panel C

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
9	0.304	128	0	0	15.0
48	0.310	161	0	0	3.0
12	0.304	205	0	0	5.0
8	0.300	233	0	0	66.0
7	0.304	260	80	31	0
11	0.303	265	157	59	18
14	0.295	272	87	32	*
10	0.301	284	153	54	24.0
100	0.312	294	140	48	90.0
270	0.919	173	0	0	0.5
268	0.927	191	91	48	38.0
158	0.897	195	0	0	0
153	0.911	195	0	0	9.0
152	0.918	211	*	*	44.0
154	0.906	228	53	23	0
156	0.914	246	122	50	1.0
150	0.892	256	198	77	31.0
157	0.920	257	154	60	0
271	0.925	307	237	77	4.0
269	0.917	351	309	88	*
308	1.847	122	0	0	20.0
311	1.853	126	0	0	46.0
300	1.861	129	0	0	2.0
377	1.919	155	0	0	1.0
303	1.873	189	128	68	21.0
378	1.917	197	0	0	1.0
306	1.867	216	100	46	5.0
304	1.850	234	192	82	64.0
310	1.842	237	153	65	3.0
301	1.861	240	171	71	5.0
307	1.860	241	158	66	9.0
302	1.849	241	177	73	66.0
379	1.937	249	180	72	0.5
305	1.859	262	198	76	3.0
312	1.925	287	234	82	0.5
309	1.838	315	252	80	1.0
481	1.919	400	354	89	2.0

Table A3
(Continued)

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
646	3.848	131	0	0	5.0
617	3.752	158	111	70	35.0
616	3.750	159	124	78	47.0
647	3.834	162	123	76	39.0
619	3.760	191	151	79	9.0
622	3.629	200	162	81	8.0
648	3.850	224	147	66	4.0
624	3.712	240	206	86	28.0
618	3.741	347	317	91	9.0

Table A4
Summary of Fragment Test Data for Firings Against Panel D

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
45	0.316	191	0	0	2.0
47	0.314	221	0	0	3.0
43	0.315	224	128	57	45.0
41	0.314	232	0	0	78.0
44	0.311	266	197	74	4.0
42	0.315	279	229	82	34.0
195	0.919	73	0	0	0
193	0.917	78	0	0	0
199	0.917	89	0	0	90.0
249	0.922	163	0	0	8.0
255	0.921	180	0	0	0.5
250	0.920	190	0	0	0
252	0.921	213	88	41	2.0
254	0.931	218	140	64	14.0
256	0.916	264	230	87	47.0
248	0.919	280	230	82	2.0
198	0.920	292	222	76	4.0
192	0.921	297	260	87	37.0
197	0.933	303	251	83	90.0
253	0.925	304	249	82	0
246	0.929	304	254	84	*
194	0.921	307	251	82	1.0
191	0.924	328	280	85	2.0
247	0.929	403	361	90	*

Table A4
(Continued)

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
328	1.920	101	0	0	8.0
390	1.921	147	0	0	28.0
337	1.928	184	0	0	4.0
331	1.916	187	0	0	0
332	1.916	189	0	0	4.0
346	1.930	192	0	0	9.0
340	1.918	201	0	0	2.0
333	1.922	217	185	85	6.0
334	1.926	233	181	78	3.5
338	1.917	240	210	88	24.0
339	1.919	244	204	84	81.0
389	1.932	251	190	76	17.0
351	1.916	254	231	91	41.0
330	1.917	262	227	87	17.0
336	1.923	279	231	83	2.0
353	1.923	317	276	87	3.0
350	1.923	326	296	91	7.5
352	1.910	336	310	92	16.0
335	1.917	344	313	91	0
329	1.918	356	328	92	10.0
355	1.911	364	332	91	2.0

Table A5
Summary of Fragment Test Data for Firings Against Panel E

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
27	0.318	379	0	0	0
32	0.316	391	0	0	9.0
30	0.314	433	0	0	14.0
28	0.319	439	0	0	1.0
33	0.315	468	197	42	17.0
29	0.321	505	223	44	22.0
34	0.315	591	343	58	4.0
308	0.937	352	0	0	4.0
309	0.931	378	178	47	3.0
306	0.952	398	210	53	29.0
307	0.955	440	232	53	10.0
462	1.919	260	0	0	1.0
464	1.925	292	0	0	5.0
463	1.917	295	150	51	15.0
461	1.911	324	96	30	8.0
459	1.924	333	159	48	55.0
458	1.921	334	142	43	13.0
460	1.937	351	237	68	0
457	1.925	366	256	70	3.0
456	1.936	420	332	79	3.0
749	3.855	256	0	0	0
748	3.882	266	0	0	12.0
752	3.870	270	0	0	6.0
753	3.880	283	101	36	5.0
754	3.874	295	114	39	5.0
751	3.887	316	179	57	3.0
750	3.887	333	225	68	2.0

Table A6
Summary of Fragment Test Data for Firings Against Panel F

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
124	0.308	392	0	0	9.0
123	0.317	494	0	0	32.0
126	0.311	501	183	37	9.5
127	0.317	525	185	35	1.0
122	0.318	568	236	42	47
125	0.315	756	433	57	14.5
286	0.938	249	0	0	5.0
290	0.946	303	0	0	32.0
284	0.936	304	0	0	23.0
220	0.926	305	0	0	27.0
285	0.939	310	0	0	41.0
214	0.920	353	0	0	8.0
283	0.944	354	0	0	1.0
219	0.943	359	0	0	23.0
216	0.925	360	0	0	0
291	0.919	374	0	0	3.0
224	0.929	401	108	27	12.0
218	0.928	410	116	28	49.0
221	0.926	411	194	47	0
289	0.946	425	203	48	35.0
288	0.947	431	208	48	12.0
223	0.922	462	244	53	5.0
222	0.926	481	272	57	12.0
217	0.932	504	294	58	1.0
213	0.930	527	305	58	0
215	0.916	548	349	64	24.0
411	1.913	258	0	0	6.0
410	1.923	295	0	0	25.0
420	1.920	307	0	0	10.0
405	1.928	327	123	38	17.0
408	1.920	329	145	44	20.0
409	1.926	346	201	58	16.0
417	1.918	351	167	48	4.0
406	1.929	352	117	33	9.0
415	1.911	372	167	45	18.5
413	1.920	378	218	58	0

Table A6
(Continued)

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
419	1.910	379	228	60	4.0
418	1.923	383	209	55	23.0
414	1.914	385	204	53	1.5
412	1.914	390	209	54	4.0
716	3.867	241	0	0	17.5
715	3.859	243	0	0	19.0
714	3.846	265	0	0	6.0
712	3.866	268	120	45	31.0
711	3.866	410	279	68	0.5
710	3.859	434	320	74	1.0

Table A7
Summary of Fragment Test Data for Firings Against Panel G

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
117	0.314	386	0	0	34.0
118	0.314	426	0	0	6.0
37	0.317	469	0	0	30.5
39	0.312	481	0	0	10.0
116	0.314	496	0	0	27.5
113	0.320	497	0	0	5.5
119	0.316	503	0	0	3.5
41	0.315	536	0	0	3.5
120	0.316	552	119	22	0
114	0.315	558	198	35	1.5
40	0.315	561	38	7	3.0
38	0.315	585	247	42	4.0
115	0.311	603	195	32	4.0
121	0.310	615	184	30	8.0
209	0.922	219	0	0	0
203	0.919	324	0	0	0
208	0.922	327	0	0	83.0
204	0.925	362	0	0	20.0
211	0.918	381	0	0	1.0
206	0.930	420	0	0	2.0
205	0.925	429	204	48	5.0
210	0.933	441	162	37	10.0
212	0.928	520	300	58	1.0
399	1.920	187	0	0	47.0
398	1.926	264	0	0	9.5
420	1.920	279	0	0	27.0
400	1.915	281	0	0	16.0
396	1.928	293	0	0	3.0
404	1.911	309	71	23	3.0
395	1.926	322	113	35	2.0
403	1.920	325	96	30	7.0
394	1.916	331	135	41	58.0
393	1.923	393	188	48	7.0
391	1.921	399	234	59	1.0

Table A8
Summary of Fragment Test Data for Firings Against Panel H

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
130	0.313	310	0	0	6.0
131	0.313	349	0	0	33.0
132	0.310	352	0	0	40.0
134	0.314	432	0	0	14.5
62	0.310	526	0	0	0
63	0.317	554	268	48	8.0
129	0.317	597	0	0	4.0
65	0.312	606	254	42	79.0
133	0.311	647	259	40	8.0
466	1.900	159	0	0	2.0
426	1.921	281	0	0	6.5
467	1.902	293	77	26	83.0
428	1.920	325	117	36	10.0
465	1.923	326	98	30	79.0
425	1.924	327	137	42	3.0
423	1.914	332	42	13	28.0
421	1.920	335	160	48	32.0
427	1.930	348	123	35	79.0
424	1.923	355	68	19	*
422	1.926	368	182	49	8.0
724	3.847	216	0	0	57.0
721	3.837	255	0	0	32.0
726	3.850	256	0	0	1.0
727	3.874	282	127	45	2.0
720	3.856	307	165	54	0
722	3.858	307	152	50	1.0
725	3.835	308	143	46	8.0
723	3.852	323	165	51	25.0
719	3.860	327	208	64	49.0
717	3.852	360	234	65	26.0
718	3.842	408	293	72	13.0

Table A9
Summary of Fragment Test Data for Firings Against Panel I

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
43	0.320	347	0	0	12.0
77	0.315	416	0	0	6.0
81	0.314	423	0	0	6.0
44	0.310	432	0	0	40.0
82	0.315	434	0	0	1.5
78	0.312	435	0	0	7.0
83	0.315	435	31	31	27.5
46	0.312	445	0	0	45.0
76	0.312	471	170	170	55.0
45	0.311	482	0	0	90.0
80	0.316	489	*	*	10.0
75	0.312	531	240	240	42.0
42	0.311	543	190	190	19.0
74	0.313	686	357	357	0.5
73	0.316	724	270	270	12.0
284	0.938	348	0	0	8.0
310	0.928	374	0	0	18.0
311	0.935	402	100	100	8.0
283	0.950	476	290	290	54.0
281	0.932	533	325	325	44.0
282	0.933	612	413	413	4.0
437	1.917	258	0	0	16.0
438	1.925	292	0	0	10.0
439	1.941	316	87	87	7.0
730	3.869	199	0	0	45.0
734	3.896	230	46	46	15.0
736	3.870	237	0	0	1.0
737	3.878	244	0	0	6.0
731	3.881	254	125	125	34.0
733	3.902	268	108	108	2.0
732	3.887	274	*	*	86.0
735	3.870	284	121	121	0
680	3.870	308	144	144	11.0
728	3.870	365	235	235	3.0
679	3.836	384	271	271	40.0

Table A10
Summary of Fragment Test Data for Firings Against Panel J

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
238	0.922	343	0	0	5.0
242	0.917	436	0	0	10.0
241	0.920	443	200	45	12.0
280	0.947	444	158	36	20.0
240	0.928	476	130	27	1.0
239	0.929	513	205	40	0
434	1.924	340	0	0	0
436	1.934	358	0	0	0
435	1.937	388	73	19	0
431	1.910	391	201	51	36.0
433	1.924	393	177	45	0
432	1.938	438	209	48	2.0

Table A11
Summary of Fragment Test Data for Firings Against Panel K

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
84	0.315	423	0	0	12.0
88	0.318	462	0	0	25.0
85	0.314	496	0	0	20.0
89	0.313	517	0	0	45.0
86	0.311	526	108	21	2.0
293	0.951	370	0	0	90.0
291	0.934	396	86	22	30.0
290	0.959	455	192	42	8.0
292	0.946	463	178	38	6.0
289	0.953	482	246	51	22.0
287	0.943	507	256	50	10.0
286	0.940	567	338	60	56.0
285	0.940	568	324	57	35.0
445	1.917	307	0	0	1.0
444	1.924	329	93	28	56.0
440	1.929	341	147	43	49.0
443	1.926	360	153	43	1.0
441	1.932	365	139	38	6.0
738	3.892	218	0	0	10.0
737	3.845	235	16	7	21.0
736	3.900	281	115	41	75.0
733	3.900	305	179	59	9.0
732	3.873	313	157	50	18.0
735	3.892	323	170	53	22.0
731	3.866	327	167	51	8.0
734	3.882	366	214	58	3.0

Table A12
Summary of Fragment Test Data for Firings Against Panel L

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
96	0.309	306	0	0	30.0
95	0.309	401	0	0	28.0
91	0.317	404	0	0	13.0
93	0.319	407	0	0	4.0
90	0.320	409	0	0	0
99	0.323	432	0	0	4.0
98	0.317	443	0	0	40.0
100	0.314	455	0	0	7.0
97	0.317	458	0	0	31.0
101	0.313	471	96	20	53.0
92	0.314	502	201	40	0
94	0.318	590	334	57	4.0
297	0.951	290	0	0	2.0
300	0.950	296	0	0	5.0
304	0.943	305	0	0	3.0
305	0.943	363	0	0	8.0
294	0.947	375	159	42	34.0
299	0.951	395	177	45	37.0
303	0.935	413	158	38	2.0
301	0.935	423	207	49	1.0
302	0.945	432	223	52	0
298	0.939	492	324	66	1.0
296	0.944	525	336	64	1.0
295	0.945	599	428	71	5.0
294	0.947	629	456	72	20.0
742	3.880	191	0	0	19.0
745	3.884	197	0	0	1.0
746	3.871	206	42	20	4.0
739	3.843	243	102	42	23.0
744	3.893	288	206	72	8.0
740	3.892	338	206	61	7.0
743	3.893	380	210	55	48.0

Table A13
Summary of Fragment Test Data for Firings Against Panel M

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
98	0.310	258	0	0	10.0
99	0.311	301	0	0	0
97	0.312	302	167	55	14.0
96	0.313	329	160	49	6.0
95	0.309	454	272	60	0
272	0.919	241	0	0	0
273	0.916	275	0	0	0
275	0.924	295	50	17	0
274	0.920	310	107	35	0
276	0.925	331	174	53	1.0
277	0.925	362	284	78	38.0
278	0.930	422	338	80	6.0
384	1.919	207	0	0	14.0
382	1.932	212	0	0	15.5
381	1.917	234	158	68	9.0
382	1.920	276	63	23	7.0
385	1.922	309	169	55	6.0
386	1.923	327	218	67	5.0
645	3.870	111	0	0	25.0
643	3.854	205	0	0	2.0
642	3.840	214	168	79	4.0
640	3.842	223	0	0	8.0
639	3.840	268	103	38	2.0
638	3.874	278	237	85	68.0
641	3.834	331	283	85	7.0
644	3.856	336	286	85	47.0

Table A14
Summary of Fragment Test Data for Firings Against Panel N

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
107	0.312	404	0	0	0
109	0.320	435	0	0	11.0
108	0.314	481	0	0	5.0
102	0.314	503	0	0	0
110	0.313	531	93	18	13.0
105	0.311	531	0	0	5.0
104	0.313	568	70	12	43.0
112	0.312	579	144	25	1.0
101	0.313	585	180	31	7.5
103	0.315	639	301	47	15.5
106	0.316	682	268	39	7.5
259	0.922	378	0	0	*
177	0.923	402	0	0	5.0
258	0.931	403	0	0	4.5
262	0.911	413	0	0	0.5
184	0.927	415	99	24	0
183	0.927	424	0	0	11.0
257	0.922	427	0	0	3.5
179	0.920	429	68	16	1.0
260	0.926	462	208	45	5.0
263	0.919	470	180	38	85.0
180	0.926	470	158	34	10.0
182	0.924	485	155	32	4.0
261	0.923	491	211	43	0
181	0.932	506	241	48	0
178	0.917	540	214	40	1.5
264	0.929	590	339	57	1.5
265	0.919	658	427	65	26.0
267	0.921	703	*	*	50.0
266	0.929	711	449	63	6.0

Table A14
(Continued)

TEST NO.	FRAGMENT WEIGHT (Grams)	STRIKING VELOCITY V_s (m/s)	RESIDUAL VELOCITY V_r (m/s)	PERCENT RESIDUAL V_r/V_s	YAW HORIZONTAL (Degrees)
364	1.922	264	0	0	2.5
371	1.923	279	0	0	70.0
366	1.924	289	0	0	5.0
363	1.927	313	0	0	26.5
365	1.926	340	0	0	0.5
368	1.925	364	136	37	90.0
367	1.913	371	*	*	2.5
370	1.924	400	*	*	2.0
374	1.921	405	202	50	37.0
369	1.920	418	198	47	0
372	1.915	451	258	57	22.5
373	1.918	463	287	62	2.0
375	1.922	556	335	64	19.0
376	1.924	673	*	*	12

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