01-12116

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories
Laboratoires de recherche minière

[redacted]

Canada

MRL 90-029 (OP,J)

THE TNT EQUIVALENT OF FIREWORKS REPORT SHELLS

E. CONTESTABILE, R.A. AUGSTEN,
D.E.G. JONES and T.R. CRAIG

CANADIAN EXPLOSIVES RESEARCH LABORATORY

MRL 90-029 (OPJ) April 1990

presentation at the International Pyrotechnics Seminar, July 9, 1990, and Publication in the Proceedings of IPS.

THE TNT EQUIVALENT OF FIREWORKS REPORT SHELLS

by

E. Contestabile, R.A. Augsten,
D.E.G. Jones, and T.R. Craig

Canadian Explosives Research Laboratory
Mining Research Laboratories, CANMET
Ottawa, Ontario
Canada

ABSTRACT

Concerns exist within the fireworks industry as to the safety of shells accidentally functioning in a mortar. The Canadian Explosives Research Laboratory (CERL) is presently studying this subject from the point of view of fragments generated. As part of this study CERL has undertaken a project to determine the TNT equivalent of report shells so that the hazard associated with a shell accidentally functioning in a mortar can be better quantified. The TNT equivalent data can be useful for determining the hazards associated with activities such as storage, transport and use, and should be considered when establishing safety distances.

Blast pressure profiles were recorded for single and multiple 50, 76, 102, and 127 mm diameter report shells. With the data measured at various distances, the overpressure and corresponding impulses are presented as a function of scaled distances. The results indicate that the TNT equivalent values determined for such shells have a certain dependency on the distance from the source.

Some overpressure data is also presented for shells bursting in mortars and on full cases of report shells functioning 'en masse'.

INTRODUCTION

The Canadian Explosives Research Laboratory (CERL) has the mandate to test fireworks for the Chief Inspector of Explosives for the purpose of having such items authorized in Canada. Due to some recent inquiries and incidents relating to fireworks mortars, CERL has initiated various projects to address these concerns. In support of this effort it was determined that the TNT equivalent of firework report shells would be a valuable figure to have available for evaluating data from other projects and to better appreciate the hazards associated with such items. Data presented in graphical form with pressure or impulse as a function of scaled distance can then be used to estimate such parameters for various distances from the source and for shells containing various masses of pyrotechnic composition.

Some data already exist on the TNT equivalent of pyrotechnic compositions (1,2). One must , however, be aware of the method used to generate such data. Most explosives normally have an energy output for a given initiator that has some dependency on confinement. The underlying assumption with some studies is that, unconfined or not, the explosive is detonating at or close to its ideal value. This may not be the case with pyrotechnic compositions.

As point sources, chemical explosives and to a lesser extent, pyrotechnics, are not comparable to nuclear explosives. That is, their energy is released over a finite volume and often, especially if not properly initiated, the source could behave as many point sources in motion. This behaviour gives rise to errors in both the mass of and the distance from the charge which are two parameters used to determine the TNT equivalent. As an example, a plastic bag containing 200 g of powdered TNT can be initiated with a high strength electric detonator and on detonation the blast pressure monitored. The measured pressures and impulses will not compare favourably with those normally quoted in the literature. They will be lower. A careful search of the area after the blast will reveal unreacted explosive. Thus, an uncertainty will exist in the mass of the reacted explosive and because of the dispersive action of the blast, in the distance. Similarly, the broad spectrum of pyrotechnics will give TNT equivalents that may not only be highly dependent on confinement, sample configuration, and mass but also on the distance from the charge.

The work presented in this report was performed from the practical consideration of functioning single or multiple report shells and the TNT equivalent is valid solely for such situations.

EXPERIMENTAL SET-UP

The data presented was collected either at CERL's facility or at a military base. In both cases, the tests were set-up in an open field where the only source of reflections would be the ground plane.

Report shells from two manufacturers were available in 50 and 76 mm sizes while the 102 and 127 mm sizes were only available from one. The report shells had their outside wrap, fuse and lift charge removed. Then an electric match was taped to the delay composition so that the item could be functioned from a remotely located bunker. String was used to suspend the shell one meter above the ground from a wire stretched taut between two steel bars. The bars were driven into the ground outside the area of and away from the blast gauges. When more than one shell was used, they were taped together side-by-side and hung in the same manner as a single shell. Initially only one shell was initiated with the assumption that it would communicate to the rest. However, once it was discovered that communication was not occurring, all the shells were ignited separately.

In the tests with the case loads of report shells, the centre of the case was set 1 m above the ground on styrofoam supports. Initially, the tests were performed as with the single shells with only a fraction of the shells wired with electric matches. However, since the shells were packaged in an egg-crate fashion, they did not function en masse. Therefore, with the smaller sizes, groups of six bare shells taped around a central, electrically initiated shell were prepared. The black powder lift charge and fuse were bundled and placed in the case.

Four, lollipop-style, blast gauges (3), were rigidly clamped 1 m above the ground to steel posts and located at 0.5 m intervals from the shells. The gauges were oriented with their sensing surface skyward and coplanar with the plane bisecting the report shell to measure the side-on pressure. A light film of silicone grease was applied to the sensing area of the gauge to reduce any thermal effects from the heat generated by the explosion. The transducer cables were taped to the posts and led along the ground for a distance of about 100 m to the conditioning amplifiers and digital storage oscilloscope. The recording equipment was triggered by the arrival of the blast wave at the closest gauge.

Pressure data were collected on single shells, two and four shells, and full cases. Some overpressure data are also presented for shells bursting in mortars.

DATA ANALYSIS

The data were stored on magnetic discs and were later analyzed to generate parameters of interest such as peak pressure, pulse duration and impulse.

The peak pressure was simply determined by measuring the voltage from the baseline (atmospheric pressure) to the peak of the pressure pulse. Then, via the transducer's sensitivity value, the peak pressure is reported in kPa.

The duration of the pressure pulse, reported in milliseconds, was measured from the point where the pressure just begins to rise to the point where it returns to the baseline. This is the duration of the positive phase of the blast wave.

To determine the positive impulse, which gives a measure of the damage-causing ability of a blast, it is first necessary to identify the limits for the integration. The first point is the one where the pressure just begins to rise, and the second is the one where the pressure curve intersects the baseline and where the negative cycle begins (the duration time). This "impulse" is reported in kN ms.

The TNT equivalent is determined from the pressure data and is the ratio of the mass of TNT to that of the pyrotechnic composition that will produce the same peak overpressure at a specified distance. A similar comparison can be made with the positive impulses if one wishes to estimate blast damage.

RESULTS

The results obtained from the measurements on single and multiple shells are listed in Tables 1, 2, 3, and 4. Table 5 shows the results for the case loads of shells. In Tables 1 and 2 the notation [A] and [B] indicate shells from the two different manufacturers. Table 6 lists the blast pressures obtained from causing both star and report shells to burst within mortars manufactured from various materials.

Table 1 - Blast pressure test results for 50 mm report shells.
- Manufacturer [A] and [B]

Test Type	No of Tests	Gauge Distance /m	P /kPa	P Range /kPa	Impulse /kN ms	Impulse Range /kN ms	Scaled Distance $/m/kg^{1/3}$
Single [A]	4	0.5	113.8	92.4-123.6	15.1	12.8-18.5	1.52
	6	1.0	42.7	37.2-49.0	10.3	9.2-11.2	3.04
	6	1.5	22.1	17.2-24.8	6.6	6.0- 7.6	4.56
	6	2.0	16.5	15.2-18.6	4.2	2.3- 4.7	6.08
	2	2.5	11.7	10.3-13.1	3.5	3.3- 3.7	7.61
Double [A]	2	1.0	62.7	61.4-64.1	15.1	13.5-16.7	2.41
	2	1.5	46.9	37.2-51.6	10.2	9.5-10.8	3.62
	2	2.0	20.7	19.3-21.4	7.0	6.6- 7.3	4.83
	1	2.5	15.9	15.9	6.1	5.4- 6.8	6.04
Quad [A]	2	1.0	67.6	62.1-73.1	17.2	16.3-18.0	1.92
	2	1.5	44.1	41.4-46.9	16.0	14.1-17.9	2.88
	2	2.0	33.1	30.3-36.5	9.8	9.0-10.7	3.83
	2	2.5	20.7	19.3-22.8	8.4	8.1- 8.7	5.11
Single [B]	1	1.5	23.3	23.3	3.9	3.9	
	2	2.0	14.2	13.9-14.6	5.2	5.1- 5.3	
	2	2.5	10.8	9.3-12.4	5.1	5.1	
	1	3.5	7.4	7.4	3.8	3.8	
Double [B]	2	1.5	38.8	36.1-41.6	12.5	12.5	
	2	2.0	20.2	18.7-21.6	8.0	7.4- 8.7	
	2	2.5	18.4	18.0-18.8	7.4	7.3- 7.4	
	2	3.5	10.2	9.4-11.1	5.6	5.3- 5.9	
Quad [B]	1	1.5	53.0	53.0	16.7	16.7	
	1	2.0	26.9	26.9	12.6	12.6	
	1	2.5	22.6	22.6	10.2	10.2	
	1	3.5	13.9	13.9	8.2	8.2	

Table 2 - Blast pressure test results for 76 mm report shells.
- Manufacturer [A] and [B]

Test Type	No of Tests	Gauge Distance /m	P /kPa	P Range /kPa	Impulse /kN ms	Impulse Range /kN ms	Scaled Distance $/m/kg^{1/3}$
Single [A]	4	1.0	40.0	37.0-43.3	9.2	8.3-10.9	2.86
	4	1.5	24.1	23.1-26.5	7.6	7.2- 8.0	4.30
	4	2.0	15.2	11.9-19.6	3.9	2.2- 5.0	5.73
	4	2.5	11.2	9.8-11.9	3.8	3.5- 4.5	7.16
Double [A]	2	1.0	44.0	43.3-44.7	11.9	10.1-13.7	2.27
	2	1.5	25.8	25.1-26.5	14.7	9.7-19.7	3.41
	1	2.0	16.8	16.8	6.2	6.2	4.55
	1	2.5	14.0	14.0	4.6	4.6	5.68
Quad [A]	2	1.0	39.8	38.4-41.2	9.2	8.9- 9.5	1.80
	2	1.5	27.2	27.2-30.0	8.8	7.6-10.0	2.71
	1	2.0	15.2	15.2	5.1	5.1	3.61
	1	2.5	9.8	9.8	3.7	3.7	4.51
Single [B]	2	1.5	55.6	54.3-57.0	19.0	17.8-20.2	
	2	2.0	29.3	29.0-29.6	10.4	9.8-10.9	
	2	2.5	23.6	23.4-23.7	11.0	10.5-11.5	
	2	3.5	12.8	11.7-13.9	7.9	7.8- 8.0	
Double [B]	2	1.5	80.5	77.4-83.6	25.2	22.7-27.6	
	2	2.0	43.4	42.5-44.4	17.2	16.9-17.5	
	2	2.5	27.0	21.9-32.1	16.7	16.7	
	2	3.5	20.9	20.7-21.1	15.3	12.8-17.8	
Quad [B]	1	1.5	115.1	115.1	32.9	32.9	
	1	2.0	61.2	61.2	23.3	23.3	
	1	2.5	45.4	45.4	18.4	18.4	
	1	3.5	24.5	24.5	17.8	17.8	

Table 3 - Blast pressure test results for 102 mm report shells.
- Manufacturer [A]

Test Type	No of Tests	Gauge Distance /m	P /kPa	P Range /kPa	Impulse /kN ms	Impulse Range /kN ms	Scaled Distance /m/kg$^{1/3}$
Single [A]	3	1.0	60.7	54.5-65.5	13.5	12.7-14.9	2.60
	4	1.5	34.5	33.8-35.2	11.5	10.5-12.9	3.90
	4	2.0	17.9	15.2-22.1	6.6	5.8- 7.5	5.20
	4	2.5	16.5	15.2-17.9	6.0	5.7- 6.3	6.50
Double [A]	2	1.0	88.3	85.5-91.7	24.5	23.9-25.1	2.06
	2	1.5	47.6	45.5-50.3	15.8	15.1-16.4	3.10
	2	2.0	34.5	33.1-35.9	11.6	10.4-12.7	4.13
	2	2.5	22.1	20.7-23.4	8.4	8.3- 8.6	5.16
Quad [A]	2	1.0	100.7	97.9-104.1	26.2	24.8-27.7	1.64
	2	1.5	60.7	41.4-80.7	27.4	27.1-27.6	2.46
	2	2.0	35.2	31.7-39.3	20.5	16.3-24.7	3.28
	2	2.5	22.4	21.0-23.4	15.4	14.8-16.1	4.10

Table 4 - Blast pressure test results for 127 mm report shells.
- Manufacturer [A]

Test Type	No of Tests	Gauge Distance /m	P /kPa	P Range /kPa	Impulse /kN ms	Impulse Range /kN ms	Scaled Distance /m/kg$^{1/3}$
Single [A]	4	1.0	95.7	81.7-122.2	16.4	14.3-18.6	2.16
	4	1.5	47.5	45.4-52.4	14.8	8.7-17.8	3.24
	3	2.0	31.4	27.9-36.3	9.2	8.2-10.2	4.32
	4	2.5	21.7	18.2-24.4	7.7	6.6- 9.3	5.40
Double [A]	1	1.0	127.8	127.8	28.5	28.5	1.71
	3	1.5	63.6	51.0-76.1	23.0	22.7-23.4	2.57
	3	2.0	32.8	29.3-37.7	17.4	11.8-26.3	3.43
	3	2.5	33.5	30.0-38.4	13.6	12.6-15.6	4.28
	2	3.5	16.8	14.7-18.9	15.0	14.5-15.5	6.00

Table 5 - Blast pressure test results for cases of report shells.
- Manufacturer [A]

Shell Size /mm	No of Tests/ Shells	Gauge Distance /m	P /kPa	P Range /kPa	Impulse /kN ms	Impulse Range /kN ms	Scaled Distance $/m/kg^{1/3}$
50	1/75	1.5	386.6	386.6	111.3	111.3	1.08
	1/75	2.0	197.3	197.3	93.2	93.2	1.44
	1/75	2.5	-----	-----	162.8	162.8	1.80
	1/75	3.0	14.6	14.6	128.4	128.4	2.17
76	1/40	1.5	160.2	160.2	126.3	126.3	1.26
	1/40	2.0	125.7	125.7	121.0	121.0	1.67
	1/40	2.5	106.4	106.4	91.6	91.6	2.09
	1/40	3.0	-----	-----	-----	-----	2.51
102	2/20	1.5	173.6	161.8-185.5	71.2	58.9-83.5	1.44
	2/20	2.0	103.8	94.7-113.0	86.0	83.1-88.9	1.92
	2/20	2.5	61.0	55.2- 66.7	72.5	56.5-88.5	2.40
	1/20	3.0	51.4	51.4	70.8	70.8	2.88
127	1/9	2.0	14.5	14.5	10.5	10.5	2.08
	1/7	2.0	14.1	14.1	11.6	11.6	2.26
	1/9	2.5	13.2	13.2	11.4	11.4	2.59
	1/7	2.5	18.5	18.5	13.2	13.2	2.82
	1/9	3.0	16.3	16.3	13.0	13.0	3.11
	1/7	3.0	15.3	15.3	11.9	11.9	3.39

Table 6 - Blast pressure test results for shells bursting in mortars.
- Report shells from manufacturer [A]
- Star shells from manufacturer [C]

Shell Size /mm	Gauge Distance /m	Shell Type	Mortar Material	No of Tests	P /kPa	P Range /kPa	Scaled Distance $/m/kg^{1/3}$
76	2	Report	Paper	4	16.1	12.6-19.4	5.73
76	2	Report	HDPE(m)	1	13.7	13.7	5.73
127	2	Report	Paper	4	27.2	24.0-29.5	4.32
102	2	Star	Paper	3	4.8	4.6- 5.4	
102	2	Star	HDPE(m)	1	8.1	8.1	
102	2	Star	HDPE	1	4.2	4.2	
127	2	Star	Paper	3	15.9	15.2-17.0	
127	2	Star	Aluminum	1	18.9	18.9	
155	2	Star	ABS	1	30.8	30.8	
155	2	Star	HDPE	1	24.6	24.6	
155	2	Star	FREP	1	24.1	24.1	

(m) - moulded high density polyethylene
FREP - Fiber Reinforced Epoxy Pultrusions

DISCUSSION

The fitted pressure and impulse data for the single and multiple shells, including the case shots have been plotted in Fig 1 to 14 as a function of distance so that one may readily appreciate the attenuative effect that distance has on such parameters.

In general, as expected, the pressure increases as the size of the shell (and the mass of the composition) increases. Within each shell size the same effect is noticed when multiple shells are tested. Also, note that the pressures and impulse for shells from manufacturer B are greater than those from manufacturer A.

A discrepancy exists with the set of pressure data for the 76 mm shells from manufacturer A as seen from Fig 3. There is very little difference in the pressures from functioning single and multiple shells. These results may be attributable to the construction of the shell and it is presently being investigated with the manufacturer. One of the questions to be resolved is whether the construction of this shell results in a degree of confinement that affects the energy output. There is also some interest in this phenomena from the point of view of classifying such items for transport. Some of this data with multiple shells was not included in the scaled distance graphs.

A similar trend exists for the impulse values. The tests with multiple shells for the larger sizes, however, do show a more dramatic difference.

The results from the case tests plotted in Fig 13 and 14 are not as well defined as those from individual and multiple shell tests. Aside from the limited number of trials, another possible reason for the discrepancy may have resulted from the test method. To obtain a scaled distance value of approximately one, it was necessary to locate one of the blast gauges as close as possible to the test sample. At a distance of 1.5 m from the centre of the case and considering the case size, the shells did not approximate a point charge very well. Also, as already explained, some of the larger shells were not functioning simultaneously and for this reason, the data from the 127 mm shells was omitted from the scaled distance graphs.

Table 6 lists some pressure data recorded from bursting shells in mortars made from various materials. This is only a fraction of the data from another project which is scheduled to be completed in the near future. The only comparison that can be made with the report shells functioned in the mortar and those functioned unconfined in this study is with the 76 and 127 mm sizes from manufacturer [A]. Comparing the data at 2 m from Table 2 and Table 4 to those in Table 6, the range of pressures for the 76 mm shells are almost identical (11.9-19.6 vs 12.6-19.6) whereas there is a slight difference with the 127 mm shells (27.9-36.3 vs 24.0-29.5). The difference could easily arise from the mode of fracture of the mortar. Oftentimes, the mortar plug simply blew out, releasing the pressure as a jet in a direction perpendicular to the blast gauge. This would result in lower blast pressure being registered. A comparison between the pressures developed by 127 mm star and report shells (15.2-18.9 vs 24.0-29.5) indicates that, on the average, the report shells are approximately 30% more energetic. Also, from the preliminary data in Table 6, the pressures from a 155 mm star shell seem equivalent to those from 127 mm report shells (24.1-30.8 vs 24.0-29.5).

Finally, Figures 15 and 16 show the average experimental data values and the corresponding fitted pressure and impulse data for report shells plotted as a function of scaled distance. (The scaled distance is the distance from the centre of a charge to the blast gauge divided by the cube root of the mass of the charge). The experimental pressure data of Fig 15 and impulse data of Fig 16 were fitted to the following equations.

$$\ln P = \ln B + C \ln Z$$

$$\ln I = \ln D + E \ln Z$$

where P is the overpressure in kPa,
with the constants ln B = 5.59, C = -1.585
I is the impulse in kN ms,
with the constants ln D = 4.72, E = -1.68
Z is the scaled distance in $m/kg^{1/3}$

Also plotted are the pressures and impulses per unit area for TNT at 15°C and 101.3 kPa derived from the following equations quoted in reference (5).

$$P/P_a=797[1+(Z/4.5)^2]/\{[1+(Z/0.048)^2]^{1/2}[1+(Z/0.32)^2]^{1/2}[1+(Z/1.35)^2]^{1/2}\}$$

$$I/A=\{0.056[1+(Z/0.23)^4]^{1/2}\}/\{Z^2[1+(Z/1.55)^3]\}$$

where P_a is atmospheric pressure and
A is the unit area

Entering Fig 15 with a pressure of 237 kPa (the highest available value from the fitted line), the corresponding scaled distances for the report shells and TNT are 1.08 $m/kg^{1/3}$ and 1.87 $m/kg^{1/3}$, respectively. Then, at the same distance, the TNT equivalent is determined to be 0.19 for the above range of scaled distances. Entering with pressures of 100 kPa and 30 kPa results in TNT equivalents of 0.32 and 0.54 respectively. At lower pressures, the TNT equivalent value becomes constant at 0.59. Thus the TNT equivalent is lower at the higher pressures. That is, as one nears the charge or increases the charge mass (small Z values), the reaction behaviour of TNT and the report shells must be very different. Although an almost constant TNT equivalent would be expected from most high explosives, this is not the case with the report shells. Using the same method as above, the third curve in Fig 15 was generated to indicate the trend of the TNT equivalent as a function of the average scaled distance values used in its determination. Initially, at small Z values, this curve is slightly skewed to the right due to the large difference in the scaled distances. However, this bias approaches zero as Z increases.

The data for the impulse seems to be more scattered than that for the overpressure. This is especially evident with the data from the case loads and some multiple shells since there can be an inherent time delay in their functioning. At a scaled distance of about 1.2 $m/kg^{1/3}$, the impulse values for TNT and those for the report shells are the same. As the scaled distance increases the two curves diverge and then begin to converge again.

Figures 15 and 16 can also be entered with a Z value to determine the expected blast pressures or impulses for report shells or TNT charges.

CONCLUSIONS

Blast overpressures and positive impulses were measured for report shells of various sizes and arrangements. Over the scaled distance range of approximately 1 $m/kg^{1/3}$ to 7.5 $m/kg^{1/3}$, the report shells are less energetic than TNT. Their TNT equivalent is not constant in this range and varies from about 0.19 to 0.59.

As mentioned earlier, the TNT equivalent of a particular material must be quantified within the context by which it was determined. Only within such constraints can such data be used to determine hazards that may be associated with the particular substance. Thus, the data presented in this report is pertinent only to complete, and unconfined fireworks report shells.

BIBLIOGRAPHY

1. McIntyre, F.L., A compilation of hazard and test data for pyrotechnic compositions, US Army Armament Research and Development Command, Dover, NJ, Report ARLCD-CR-80047, 1980.

2. de Yong, L.V., & G. Campanella, A study of blast characteristics of several primary explosives and pyrotechnic compositions, Journal of Hazardous Materials, V 21, 1989.

3. PCB Piezotronics, Inc., Depew, New York, USA.

4. Held, M., Blast waves in free air, Propellants, Explosives, Pyrotechnics, V 8, 1983.

5. Kinney, G.F., Explosive shocks in air, Springer-Verlag, New York, USA, 1985.

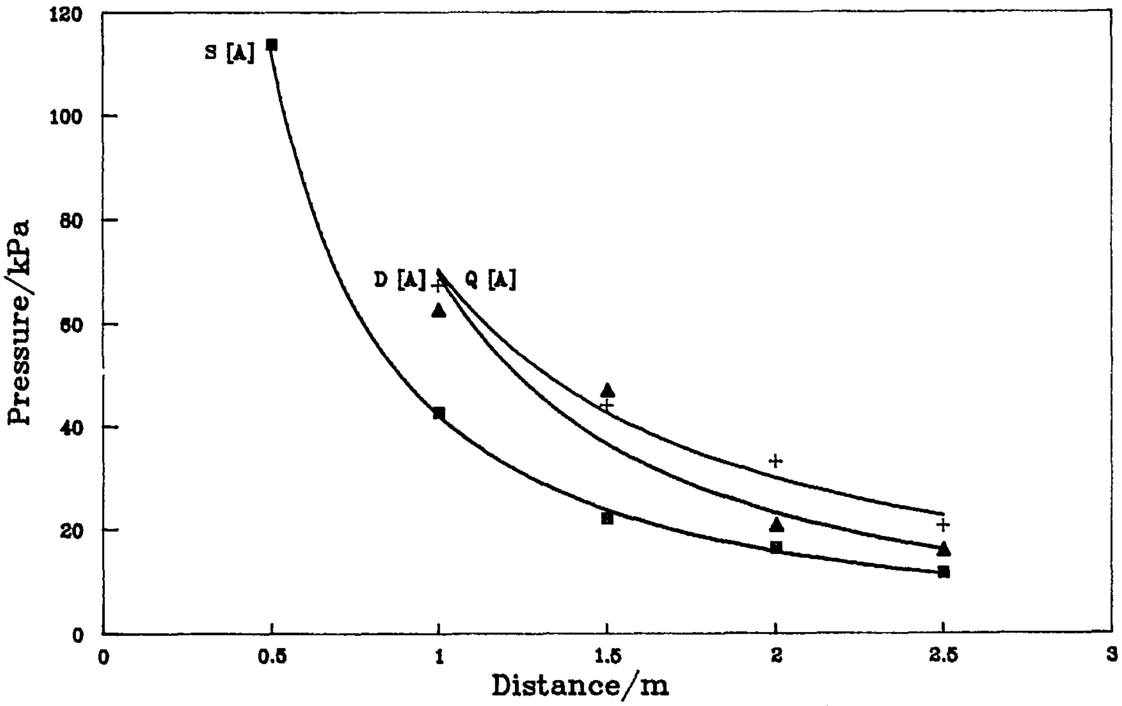

Fig. 1 - Peak pressure versus distance for 50 mm shells.
Manufacturer A.

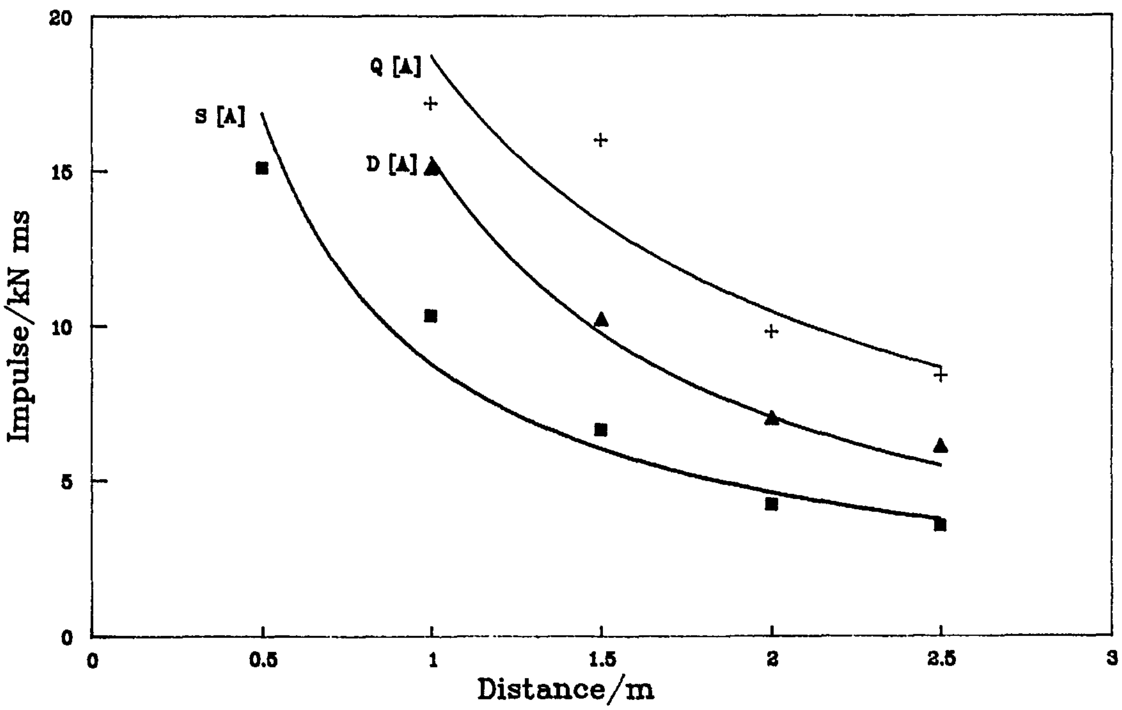

Fig. 2 - Impulse versus distance for 50 mm shells.
Manufacturer A.

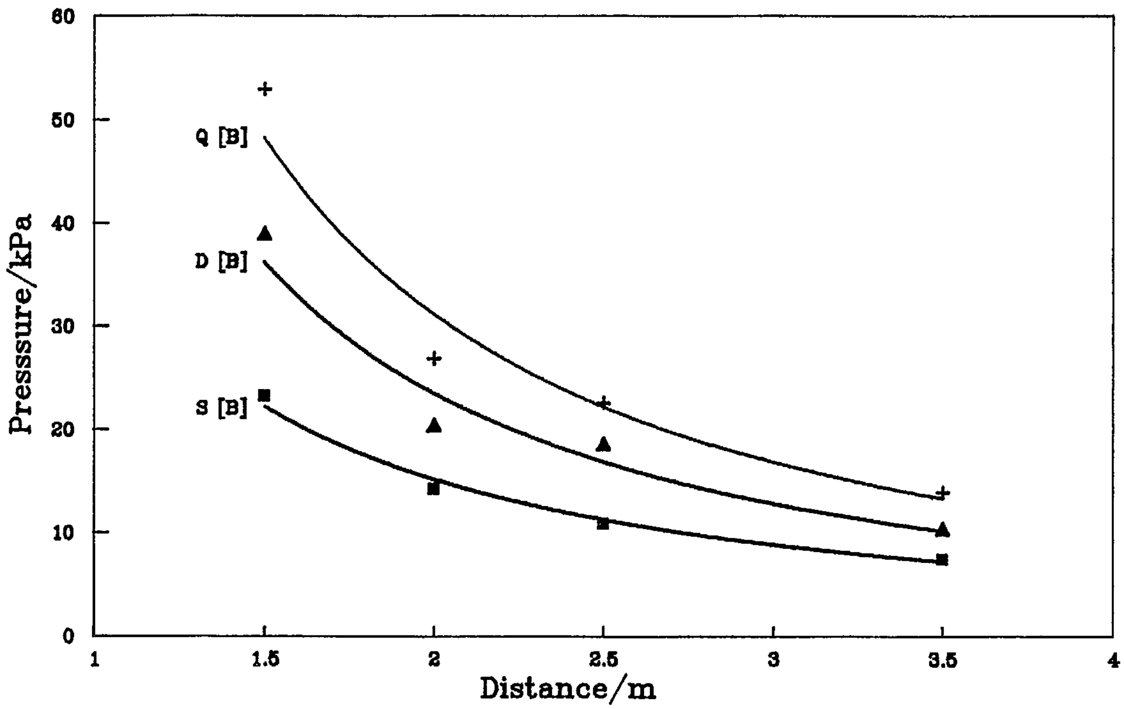

Fig. 3 - Peak pressure versus distance for 50 mm shells.
Manufacturer B.

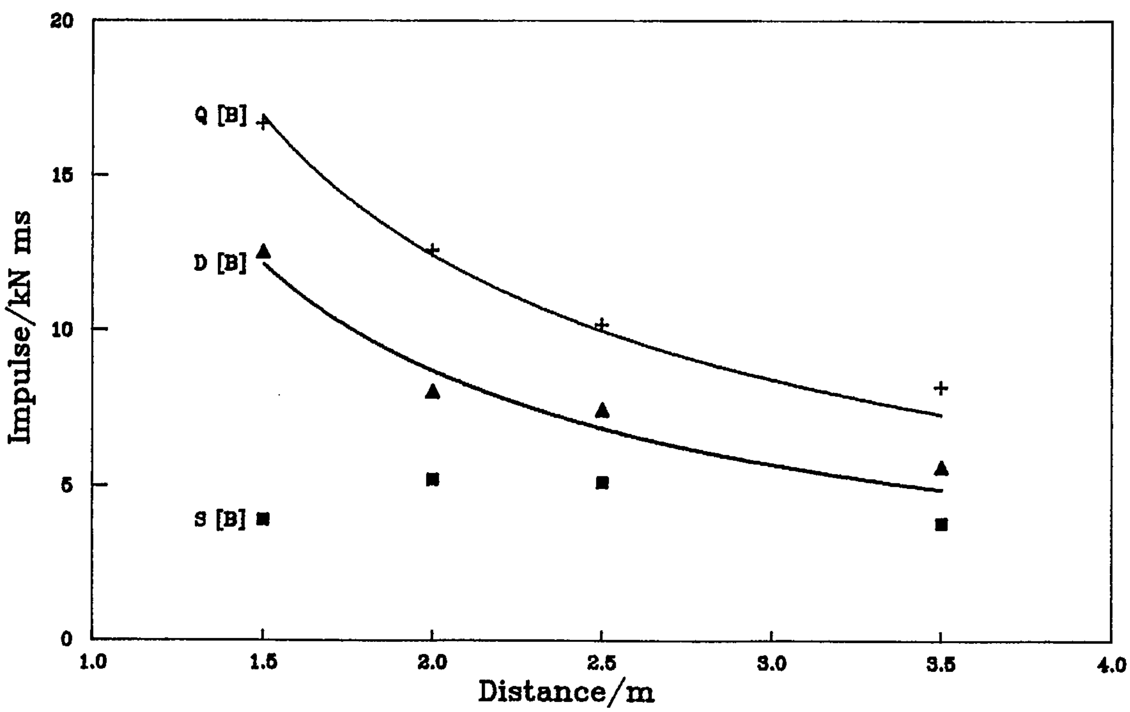

Fig. 4 - Impulse versus distance for 50 mm shells.
Manufacturer B.

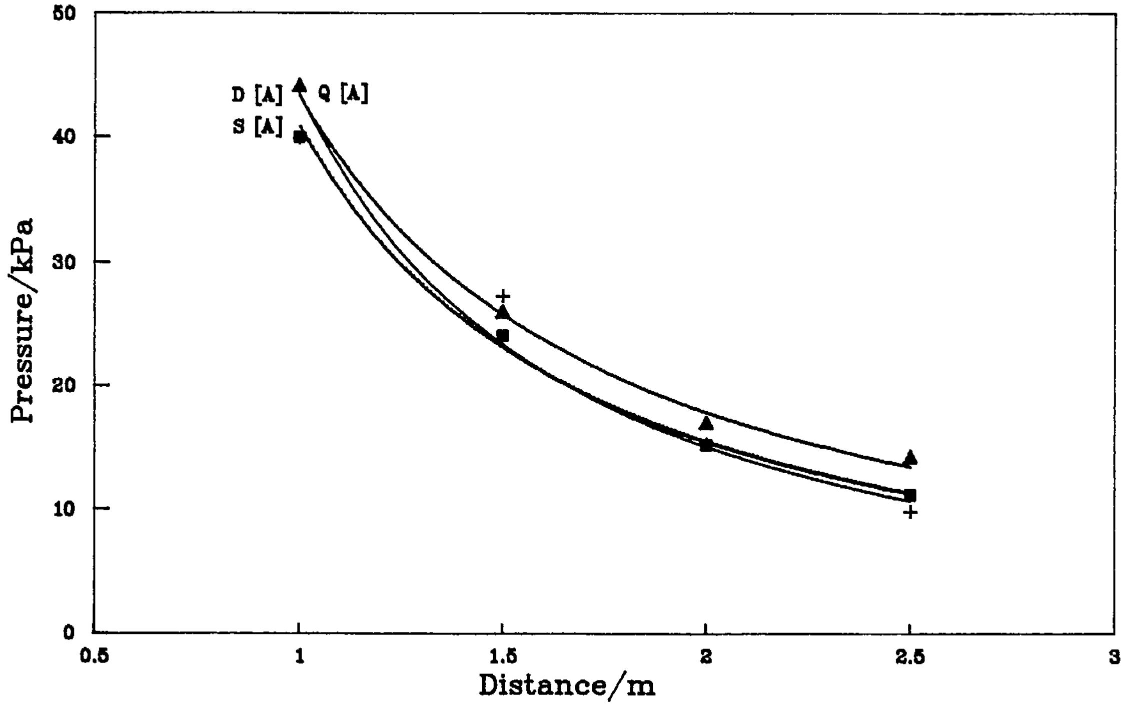

Fig. 5 - Peak pressure versus distance for 76 mm shells.
Manufacturer A.

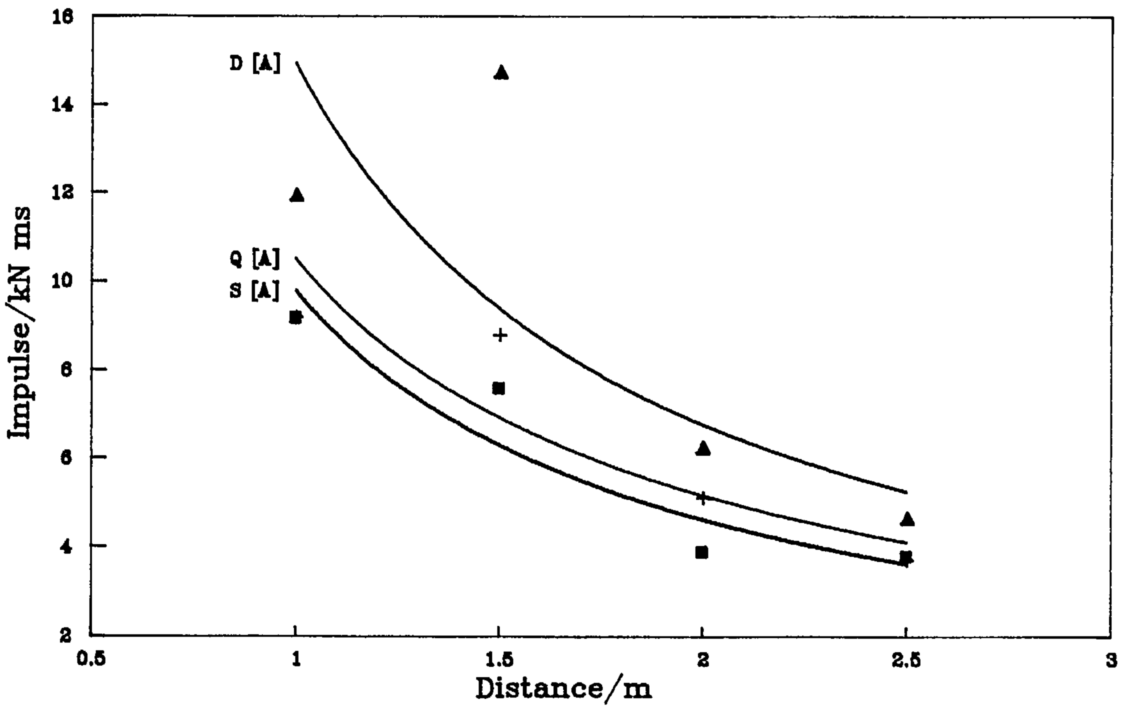

Fig. 6 - Impulse versus distance for 76 mm shells.
Manufacturer A.

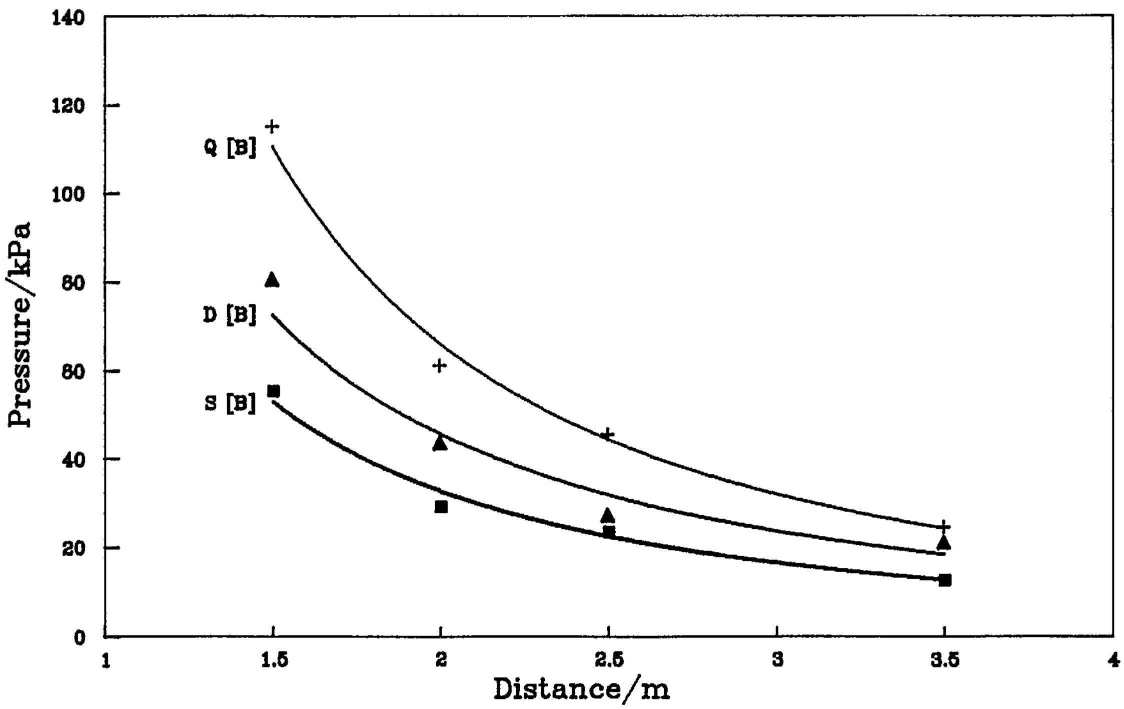

Fig. 7 - Peak pressure versus distance for 76 mm shells.
Manufacturer B.

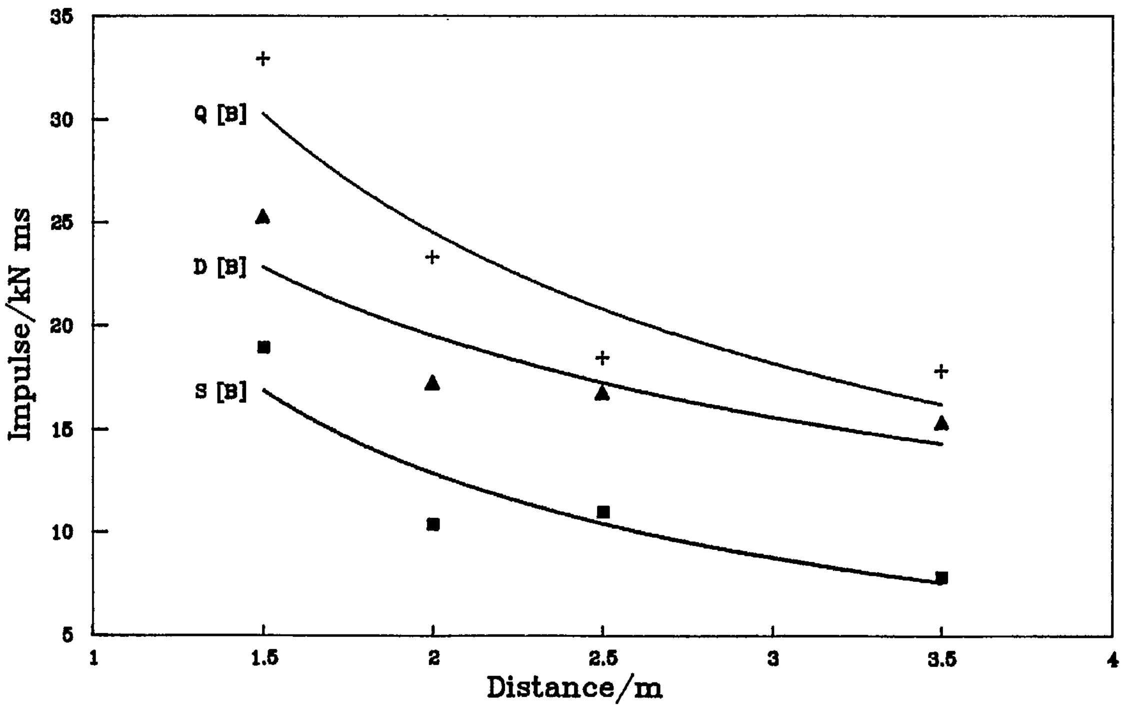

Fig. 8 - Impulse versus distance for 76 mm shells.
Manufacturer B.

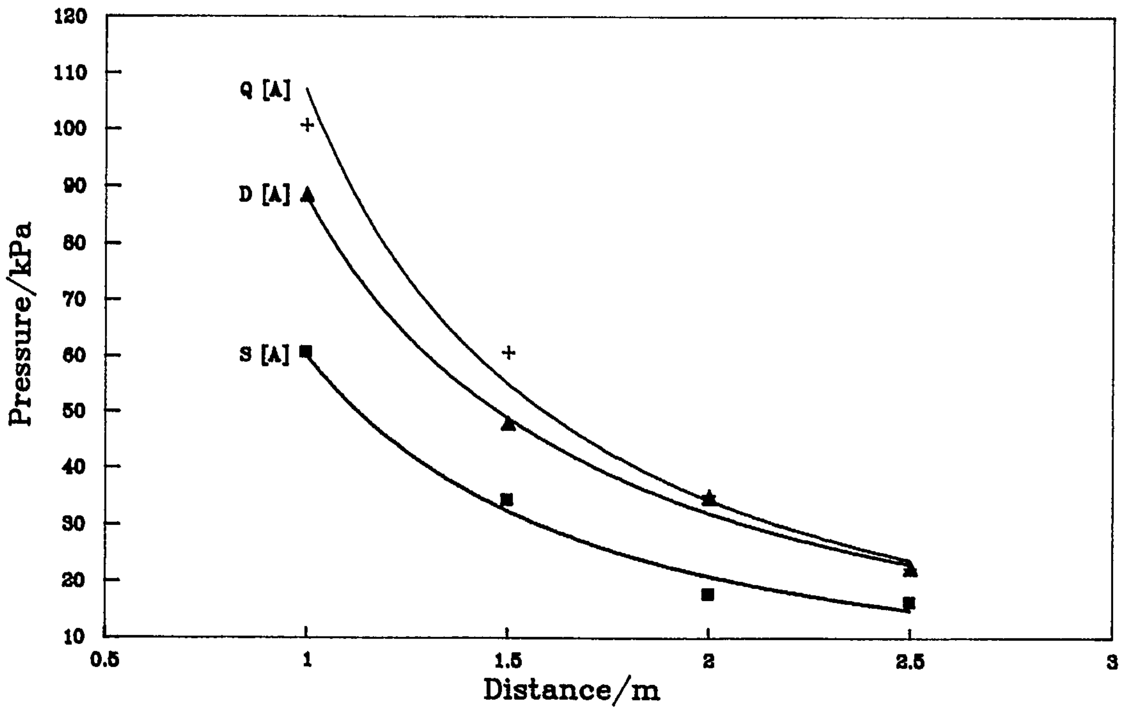

Fig. 9 - Peak pressure versus distance for 102 mm shells. Manufacturer A.

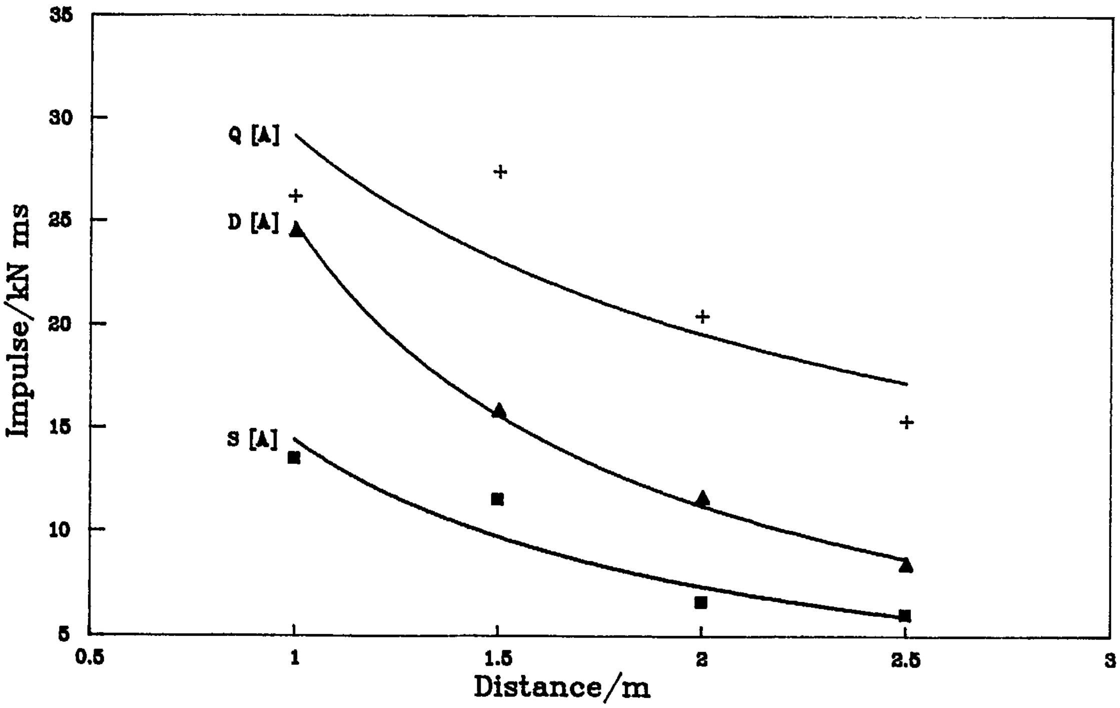

Fig. 10 - Impulse versus distance for 102 mm shells. Manufacturer A.

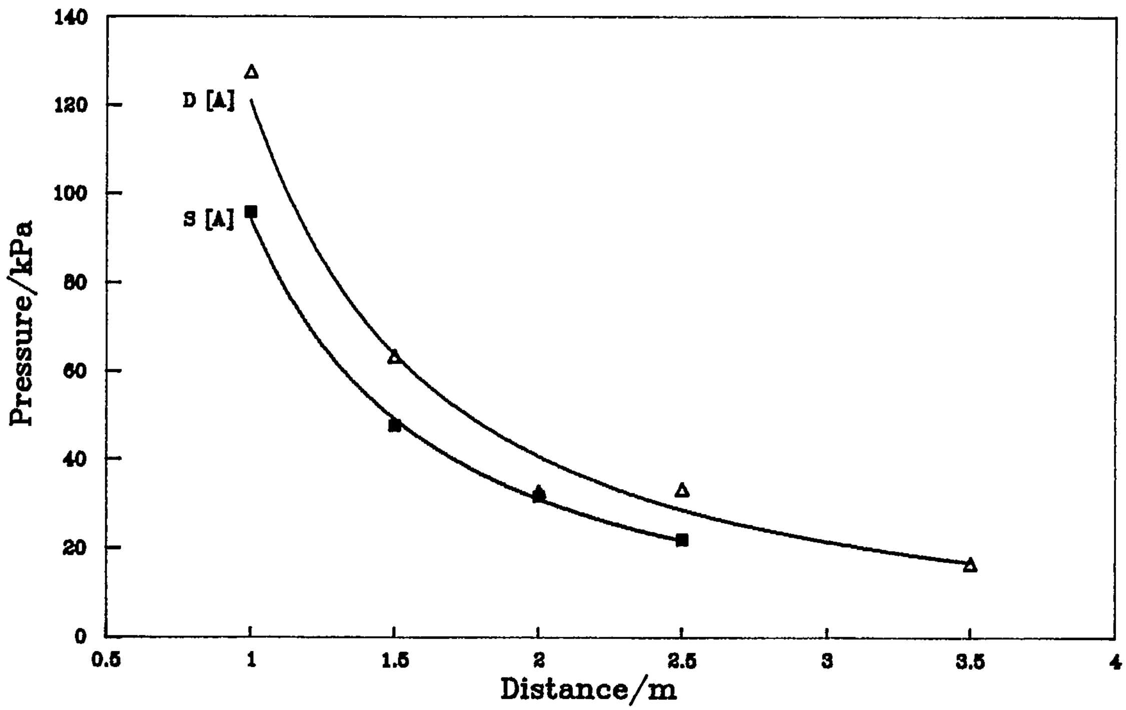

Fig. 11 - Peak pressure versus distance for 127 mm shells. Manufacturer A.

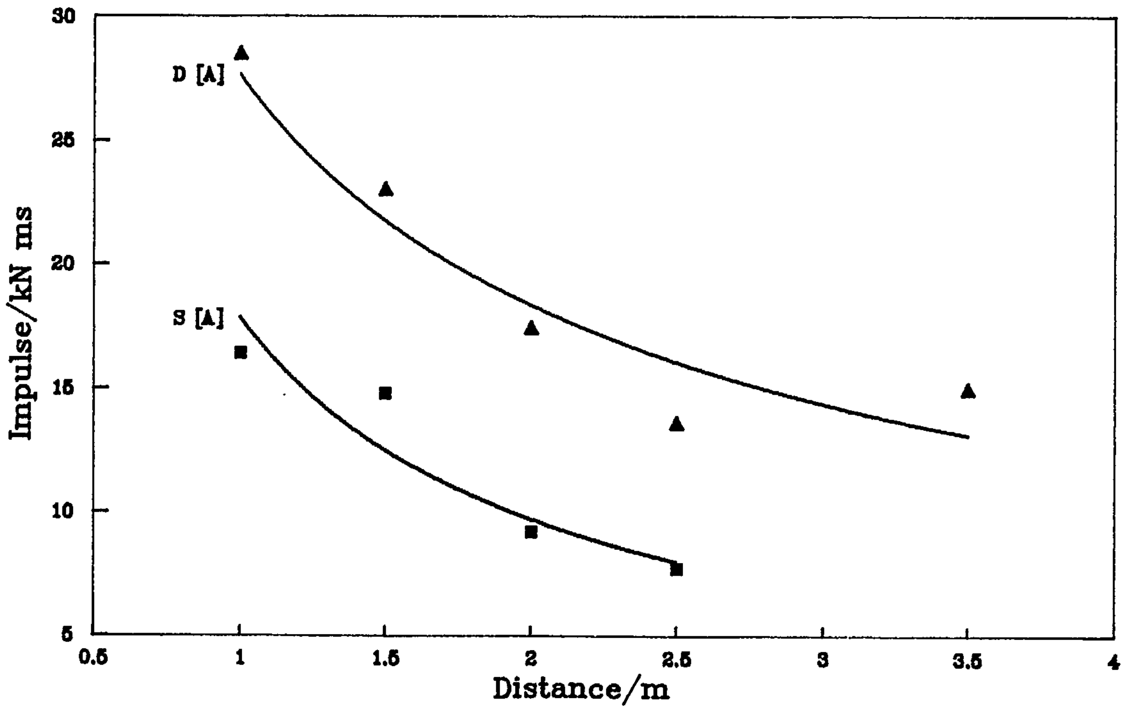

Fig. 12 - Impulse versus distance for 127 mm shells. Manufacturer A.

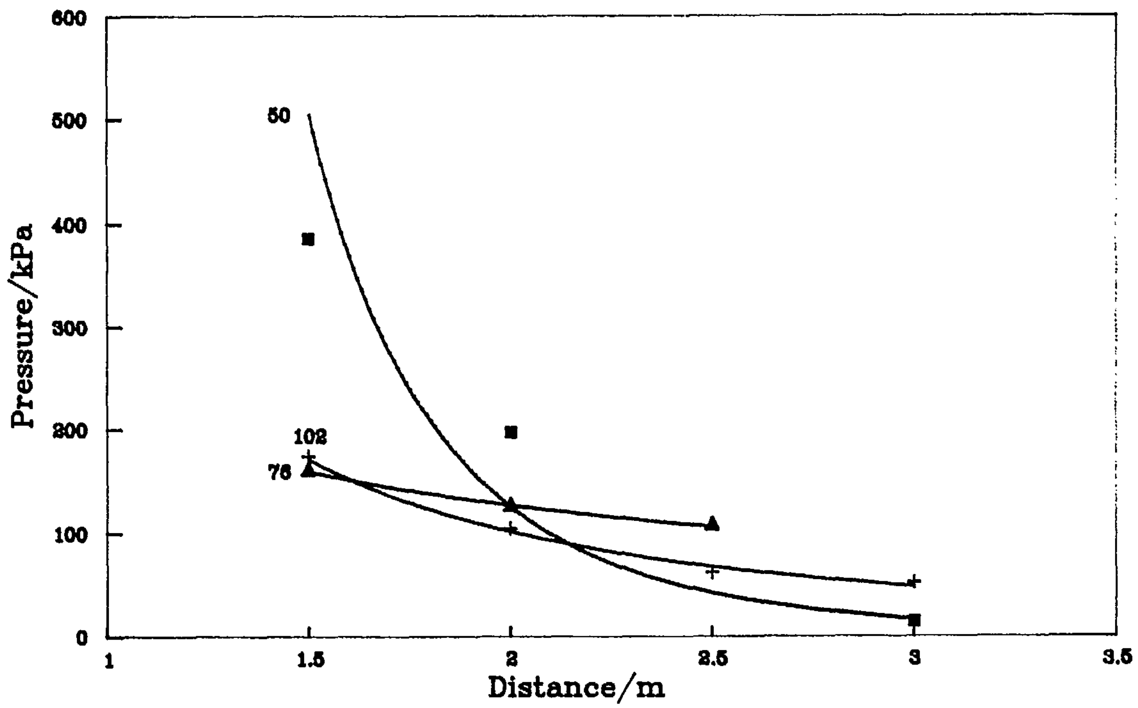

Fig. 13 - Peak pressure versus distance for cases of shells. Manufacturer A.

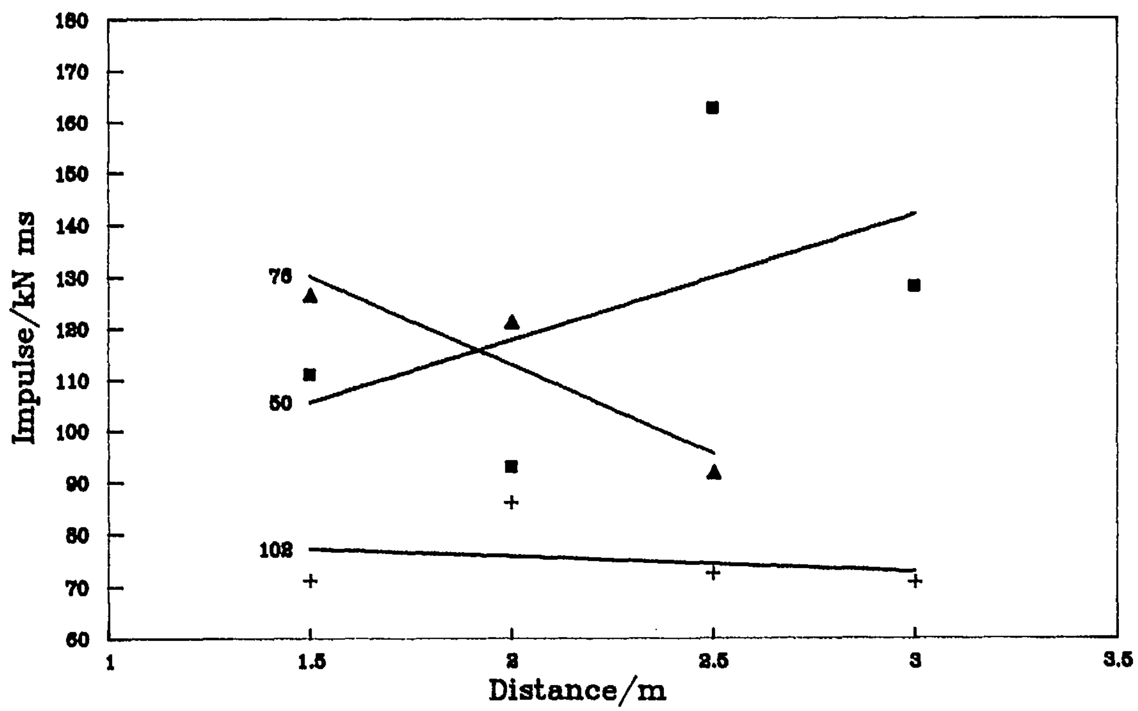

Fig. 14 - Impulse versus distance for cases of shells. Manufacturer A.

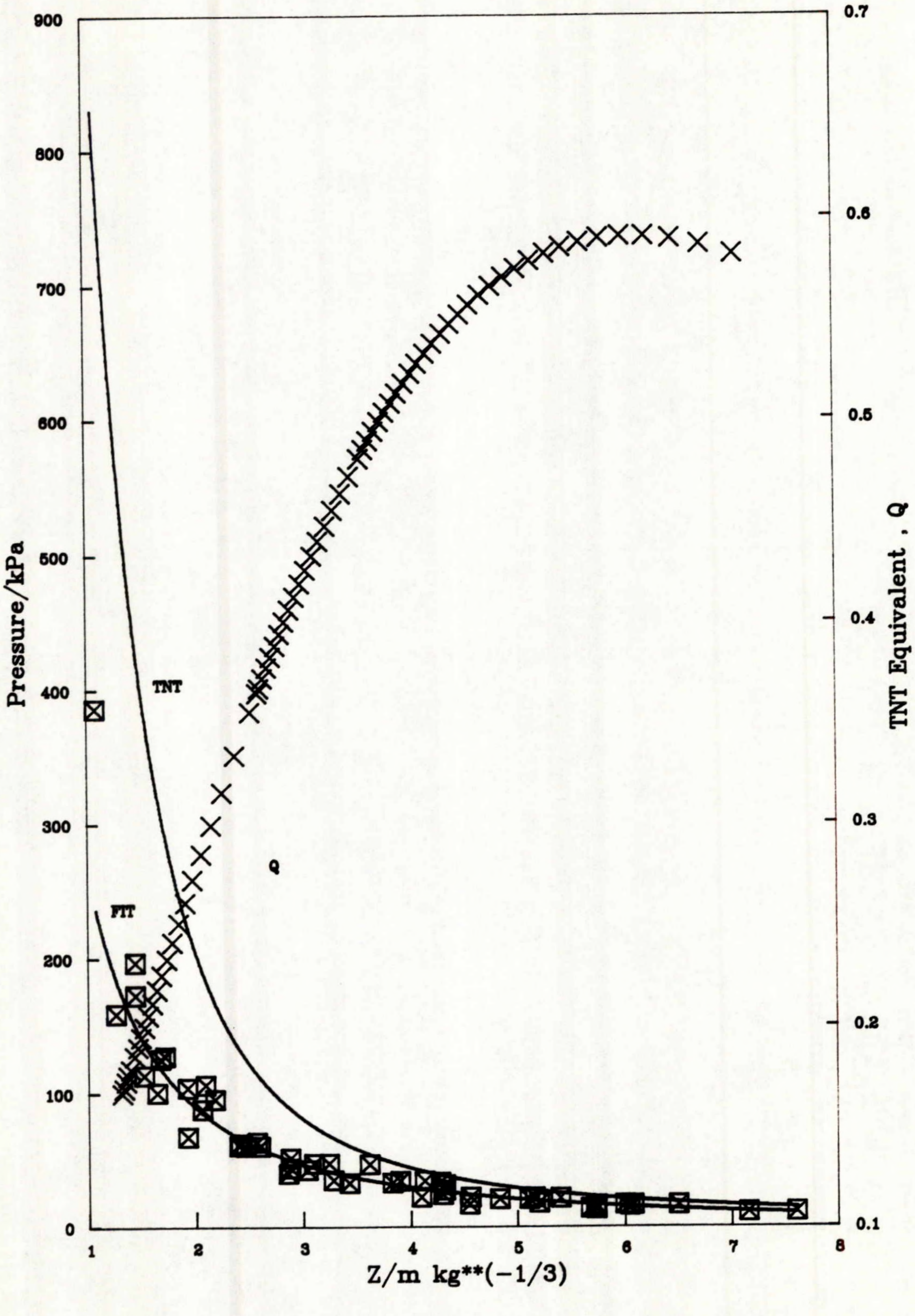

Fig. 15 - Peak pressure and TNT equivalent versus scaled distance.

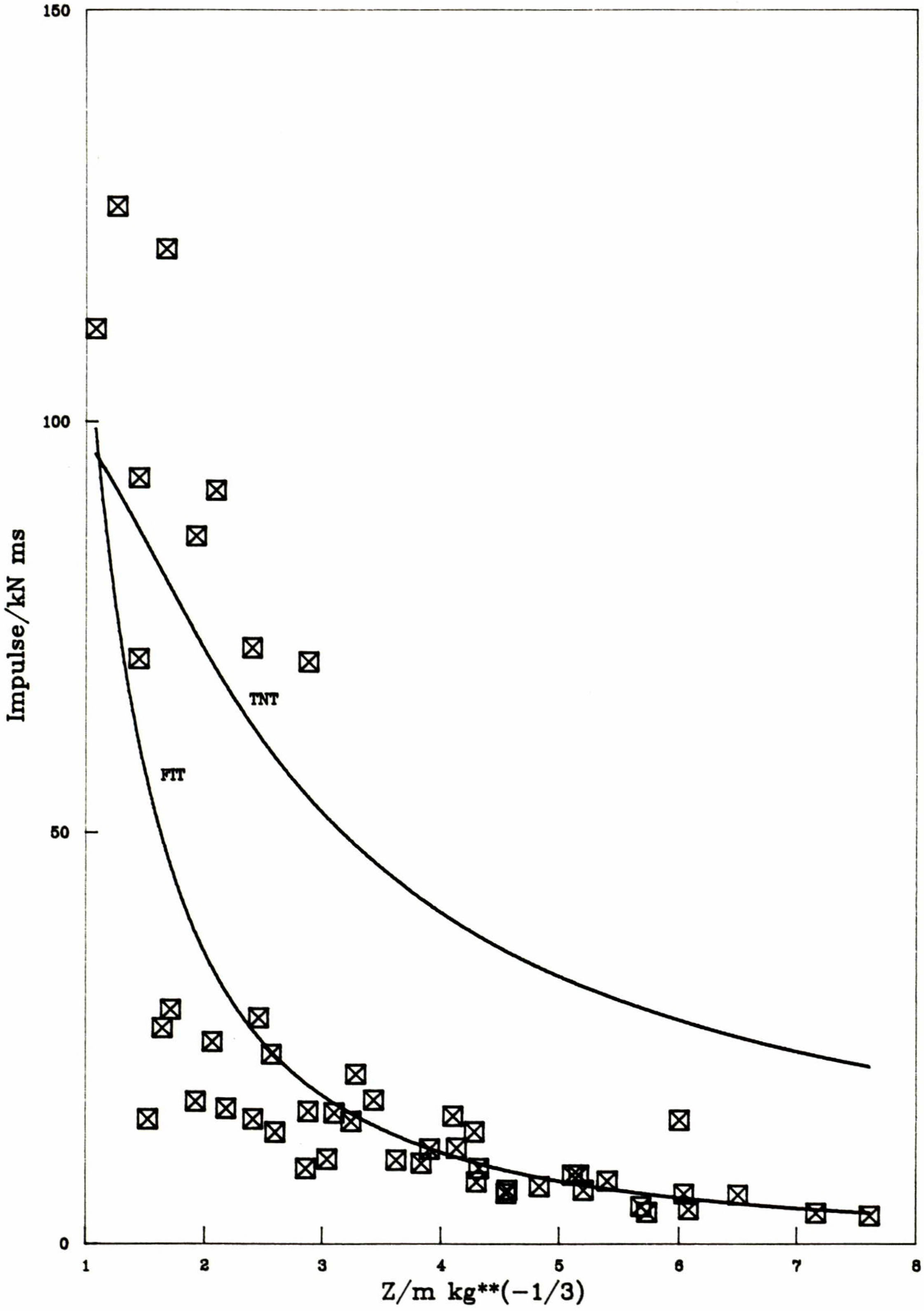

Fig. 16 - Impulse versus scaled distance.