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TNT EQUIVALENCY OF COMPOSITION C4 IN SHIPPING AND PROCESS CONTAINERS

F. L. McINTYRE

NASA NATIONAL SPACE TECHNOLOGY LABORATORIES
COMPUTER SCIENCES CORPORATION
TECHNICAL SERVICES LABORATORY
NSTL STATION, MS 39529

D. WESTOVER, PROJECT ENGINEER

P. PRICE, PROJECT LEADER

ARRADCOM

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F. L. McIntyre, Computer Sciences Corporation
D. Westover, Project Engineer, and
P. Price, Project Leader, ARRADCOM

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Extruded and bulk composition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Composition C4, bulk and extruded, was detonated in configurations representative of orthorhombic shipping boxes and a simulated in-plant dryer bed. Blast output parameters were measured and TNT equivalencies computed based on comparison with TNT hemispherical surface bursts. The results indicated that peak side on pressure and scaled positive impulse values were generally greater than 100%. TNT equivalencies varied due to the effect of geometry.

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SUMMARY

Composition C4, bulk and extruded, was detonated in configurations representative of shipping boxes, and a simulated in-plant dryer bed. Blast output parameters were measured and TNT equivalency was computed based on comparison with TNT hemispherical surface bursts. The results of these tests are present in the table below.

Within experimental error the TNT pressure equivalency was greater than 100% at all scaled distances tested for the two (2) shipping containers. Scaled impulse equivalency for the two shipping containers was 100% or greater, except at the Z≈3.57 m/kg$^{1/3}$ (9 ft/lb$^{1/3}$).

TNT equivalency for the simulated dryer bed varied at all scaled distance tested, as shown in table below.

	Percent TNT Equivalency Scaled Distance											
Configuration Mass	1.19m/kg$^{1/3}$ (3ft/lb$^{1/3}$)		1.58m/kg$^{1/3}$ (4ft/lb$^{1/3}$)		2.14m/kg$^{1/3}$ (5.4ft/lb$^{1/3}$)		3.57m/kg$^{1/3}$ (9ft/lb$^{1/3}$)		7.14m/kg$^{1/3}$ (18ft/lb$^{1/3}$)		15.9m/kg$^{1/3}$ (40ft/lb$^{1/3}$)	
	P*	I**	P*	I**	P*	I**	P*	I**	P*	I**	P*	I**
17-kg M112 demolition blocks	480	235	375	210	420	175	200	65	100	110	165	120
27.2-kg Bulk shipping container	300	120	310	120	280	160	165	75	110	110	140	100
63.5-kg Dryer bed	105	50	90	50	80	55	65	130	220	155	240	160

* Percent TNT Equivalency Based on Side-on Pressure
** Percent TNT Equivalency Based on Impulse

FIG. 1A L/D .75:1
FIG. 1B L/D .43:1
FIG. 1C L/D .08:1

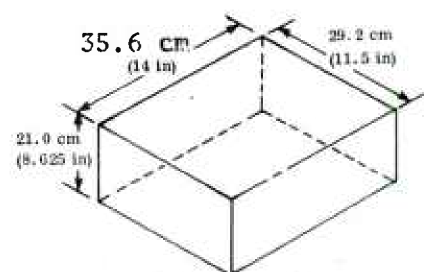


Fig. 1a. Shipping Box
Typical M112 Box 17 kg (37.5 lb)

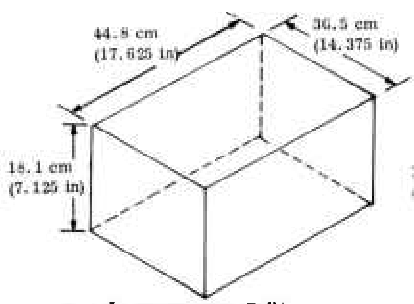


Fig. 1b. Shipping Box (Bulk)
Typical 27.2 kg (60 lb) Box

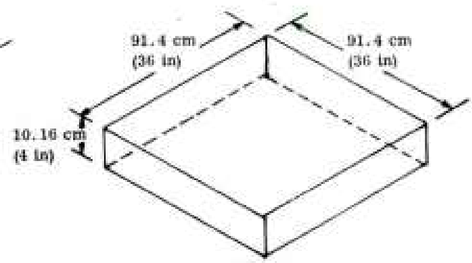
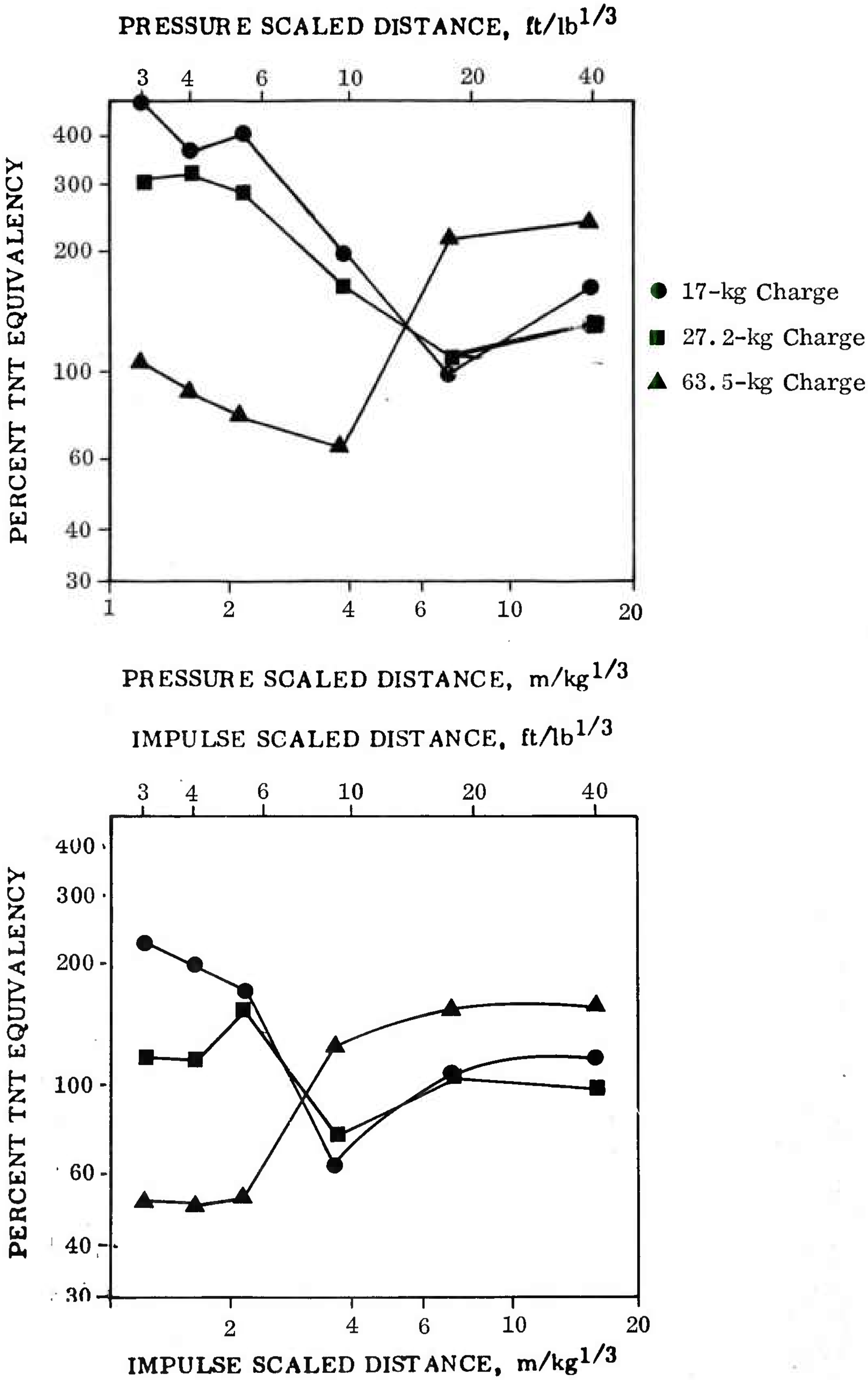


Fig. 1C.
Section of Dryer Bed



Pressure and Scaled Positive Impulse Equivalency Versus Scaled Distance

INTRODUCTION

BACKGROUND

Composition C4, Mil-C-45010, is manufactured in a batch process from the following raw materials: RDX class a&e, Vistanex (type L-120), dioctyl sebacate, or dioctyl adipate process oil, toluene, gelatin, water and dye (lead chromate/lamp black) as required.

Lacquer for composition C4 is prepared in an agitated lacquer pot. The lacquer consists of polyisobutylene, Vistanex (type L-120), dissolved in toluene with addition of dioctyl sebacate or dioctyl adipate and process oil. Specified amounts of class a&e RDX are washed through the charging hopper to the still with a measured amount of filtered water. A weighed amount of a dispersing agent (gelatin) is added to the still to control granulation of the material, and is followed by the addition of the prepared lacquer. The solvent is removed by atmospheric distillation, then the batch is cooled and transferred to nutsche containers where the material is dewatered and subsequently transferred to the drying building for drying and sampling. From the drying operation the material is transferred to the packaging area and packed in 27.2-kg (60-lb) boxes for storage and shipping.

A study has been completed on inprocess improvement in the manufacture of composition C4, including preparation, drying, bench scale work and preliminary engineering design for a continuous operating pilot line.

A follow on program (Project 5784499) will complete the design, and evaluate the pilot equipment using the improved (continuous) process for manufacturing of composition C4. The study will be continued until sufficient engineering data are obtained to formulate design criteria for new production facilities (Project 586B054) for the manufacture of composition C4.

Bulk composition C4 is manufactured per MIL-C-45010A class 3, and shipped in 27.2-kg (60-lb) quantities in a standard fiberboard container. Extruded C4 (M112) is shipped in a wirebound box, 30 blocks per box, with a total explosive weight per box of 17 kg (37.5 lb).

Safety engineering and cost effectiveness considerations require knowledge of hazardous material characteristics as an input to facility design requirement. In this instance, specific data are required on the explosive output characteristics of composition C4 in shipping containers and inprocess configuration (drying bed) found during manufacturing.

OBJECTIVE

The objective of this work is to determine the peak pressure and total positive impulse resulting from the detonation of both bulk and extruded composition C4 as compared to the same parameters produced by hemispherical surface detonations of TNT in order to determine the equivalency of composition C4 material relative to TNT.

EXPERIMENTAL METHODS

MATERIALS

Composition C4 was received in bulk quantities and in M112 extruded demolition blocks. The bulk C4 was received in 27.2-kg (60-lb) quantities in fiberboard shipping containers, lot HOL 78E415-004. The M112 demolition blocks were received in wirebound boxes, 30 blocks per box with a total explosive weight per box of 17 kg (37.5 lb), lot LOP 5-7.

TEST PLAN

Airblast output was evaluated for masses and configuration in two shipping containers and scaled in-plant dryer bed configurations. Physical characteristics of the test items were as follows:

(1) Extruded M112 demolition blocks (figure 1a) in the original shipping container were placed on a 45.7 by 45.7 by 1.27-cm (18 by 18 by 1/2-in) steel witness plate and tested.

(2) Bulk composition (figure 1b) in its original fiberboard shipping container was placed on a 61 by 61 by 1.27-cm (24 by 24 by 1/2-in) steel witness plate and tested.

(3) An orthorombic fixture (figure 1c) was used to simulate a section of the dryer bed. The fixture was constructed from plywood with dimensions of 91.4 by 91.4 by 10.16-cm (36 by 36 by 4-in). Composition C4 with a charge weight of 63.5 kg (140 lb) was placed inside the dryer bed, spread evenly, and a lid was placed atop the fixture.

A J-2 special blasting cap was inserted in the center of a conically-shaped booster charge. The booster charge, with initiating device, was placed atop the test material at the center. The booster charges had a height to width (h/w) ratio of 1:2 for the 17-kg (37.51-lb) and 27.2-kg (60-lb) charge weights and h/w ratio 1:4 for the dryer bed tests, charge weight of 63.5-kg (140-lb).

INSTRUMENTATION

Twelve PCB Piezotronics side on pressure transducers were mounted flush to the surface in two arrays as shown in figure 2. Distances from the charge to the transducer corresponded to scaled distances from 1.19 to 15.87 m/kg$^{1/3}$ (3 to 40 ft/lb$^{1/3}$). The transducers were individually calibrated prior to the beginning of each test series with pressure pulses from a standard solenoid-actuated air pressure calibration fixture, adjusted to correspond to expected blast pressure based on an assumed TNT equivalency of 100%. Signal line continuity and channelization were checked prior to each test along with a daily electrical calibration of the recording system. Details of distances between charge and transducers, calibration pressure and expected peak blast pressure at each distance are shown in table 1.

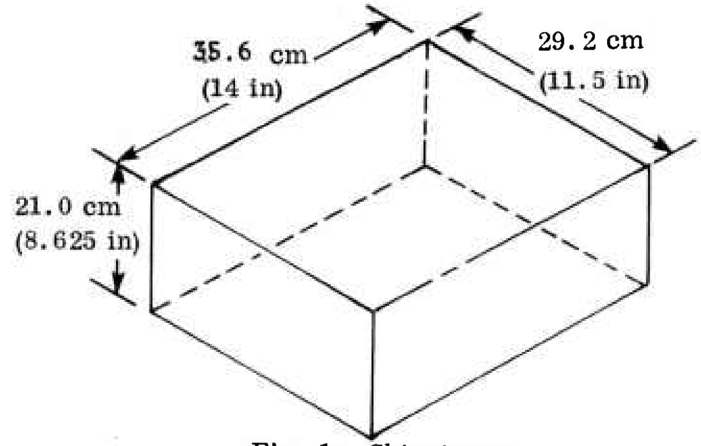


Fig. 1a. Shipping Box
Typical M112 Box 17 kg (37.5 lb)

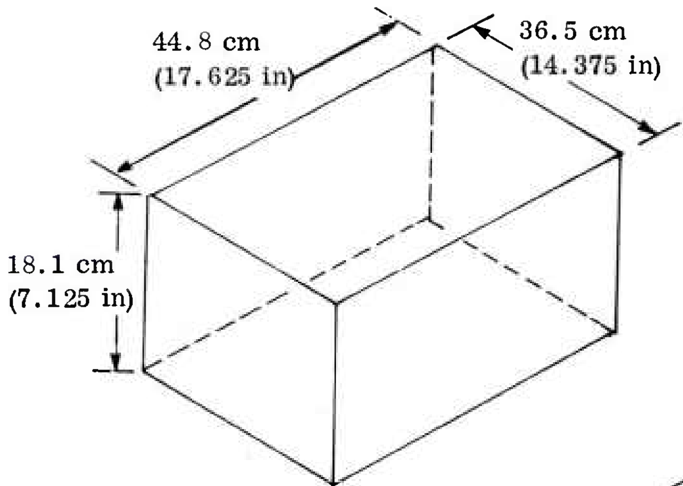


Fig. 1b. Shipping Box (Bulk)
Typical 27.2 kg (60 lb) Box

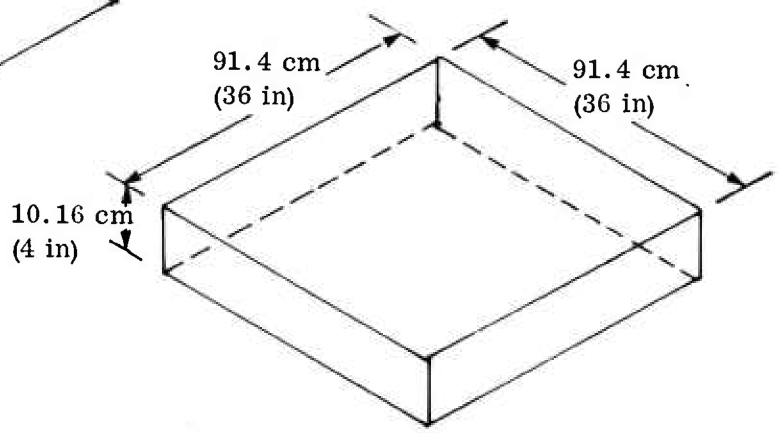


Fig. 1c.
Section of Dryer Bed
63.5 kg (140 lb)

Figure 1. Test Container Configuration

Each transducer with inherent charge amplifier was connected to an underground coaxial cable system which leads to the Test Control Center. All signals are amplified and conditioned by PCB Model 494A06 Power Supply Amplifier. The signals were recorded in digital form on 4 Biomation Model 8100 Transient Recorders and in analog form on a Honeywell Model 96 Tape Recorder.

Photographic coverage was restricted to one test of each configuration (figure 3). Motion picture coverage included a Mitchell camera Model H516-E4 operating at 500 frames per second (fps) and one Mitchell camera (same model) operating at 24 fps. Before and after color still photographs were taken of each test showing typical setup and results. Standard meteorological data were recorded for each test.

TABLE 1. TRANSDUCER CALIBRATION AND PLACEMENT

Channel number	Scaled distance m/kg 1/3 (ft/lb$^{1/3}$)	Calibration pressure kPa (psi)	Expected pressure kPa (psi)	R, distance in meters (ft) from charge		
				Charge weight 17 kg (37.5 lb)	Charge weight 27.2 kg (60 lb)	Charge weight 63.5 kg (140 lb)
1,2	1.19 (3.0)	1034 (150)	917 (133)	3.06 (10.04)	3.58 (11.74)	4.75 (15.58)
3,4	1.59 (4.0)	551.6 (80)	479.7 (69.58)	4.08 (13.39)	4.77 (15.66)	6.33 (20.77)
5,6	2.14 (5.4)	275.8 (40)	242.5 (35.17)	5.51 (18.07)	6.44 (21.14)	8.55 (28.04)
7,8	3.57 (9.0)	103.4 (15)	81.5 (11.82)	9.18 (30.12)	10.74 (35.23)	14.24 (46.73)
9,10	7.14 (18)	34.5 (5)	24.1 (3.49)	18.36 (60.25)	21.48 (70.47)	28.49 (93.46)
11,12	15.87 (40)	20.7 (3)	8.1 (1.18)	40.81 (133.89)	47.73 (156.59)	63.12 (207.1)

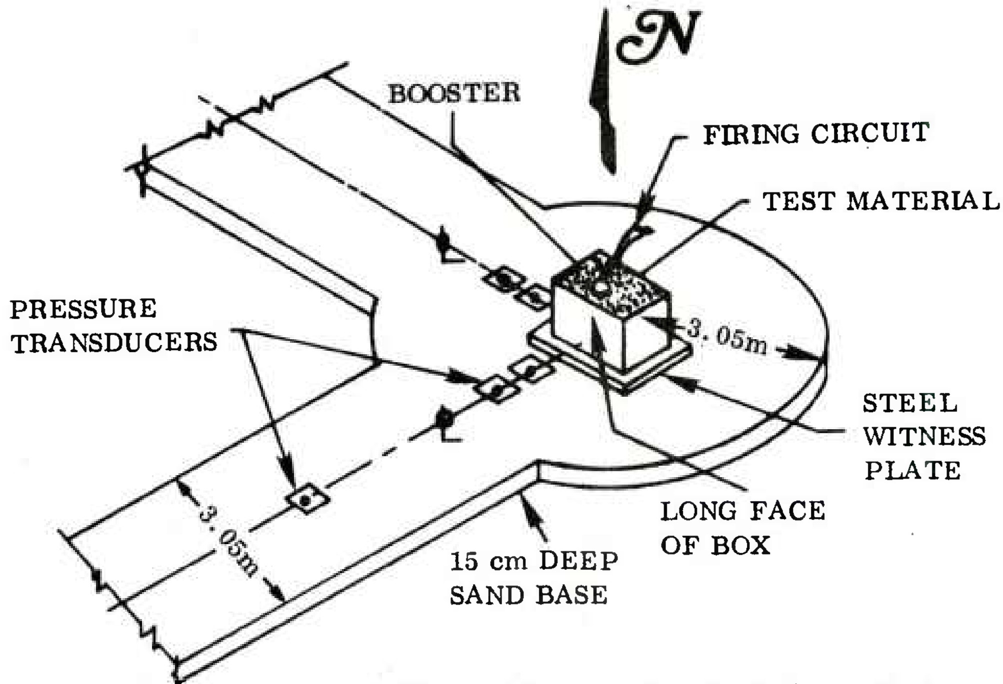


Figure 2. Typical Charge Placement for Equivalency Tests

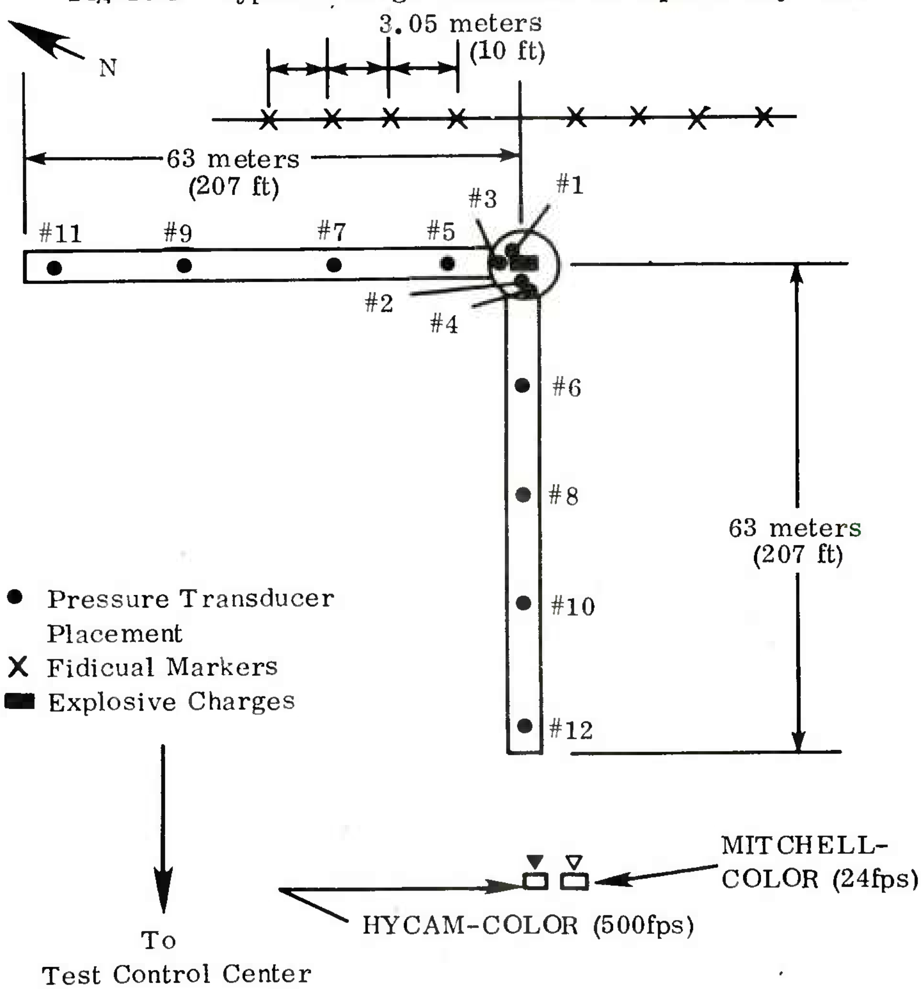


Figure 3. Test Area Showing Transducer and Camera Placement

RESULTS

DATA ANALYSIS

Peak blast overpressure and positive impulse information were obtained in digital form by the Tektronix 4051 Graphic System. After exclusion of inconsistent results that could be attributed to instrumentation or explosive malfunction, average values for pressure and impulse were used to calculate equivalencies based on comparison to data from TNT hemispheres[1] shown in figure 4. McKown[2] describes the program written for the Graphic System which utilizes an iterative process first reported by Swatosh and Cook[3] which factors out the contribution of the booster charge weight and calculates the pressure and impulse equivalencies. With the effect of the booster weight factored out, the calculated TNT equivalencies were tabularized and plotted as functions of sample scaled distance. The program is discussed and listed in Appendix C.

TEST RESULTS

Data sheets for all tests with pertinent measured parameters are contained in Appendix A. Selected pretest and posttest still photographs are contained in Appendix B. Test numbers shown are for local reference only and provide access to original range data files.

Average pressure, scaled positive impulse, and time of arrival data with standard deviations, are summarized by test configuration in tables 2-4 and figures 5-7. Percent TNT equivalencies for all charge weights and configurations are shown in figure 8 as functions of scaled distance. Deviation from cube-root scaling for pressure and impulse at each scaled distance versus charge weight for Composition C4 is shown in figure 9. Fireball duration and diameter as measured from the high speed motion pictures are given in table 5.

DISCUSSION

The plots of peak TNT pressure equivalency versus scaled distance for the extruded and bulk composition C4 tested in the shipping containers (tables 2 and 3 and figures 5 and 6) indicate that the near field equivalency values ($z \leq 2.14$ m/kg$^{1/3}$) were generally greater than 300%, while the far field values ($z \geq 7$ m/kg$^{1/3}$) approached 100%. Generally, both peak pressure and scaled impulse for the shipping containers were greater than 100% at all scaled distances tested. Differences in results is attributable to two factors: 1) Mckown and McIntyre[4], McIntyre[5,6], and Napadensky and Jablansky[7] have shown that geometry has an effect on TNT equivalency; 2) the type of confinement and/or the shipping container may have contributed something to the reaction. The Engineering Design Handbook, Explosive Series, Explosive Train [8] indicates that certain confining or packaging material will react with the explosive material, thus increasing the explosive materials' output. The M112 shipping container uses both a plastic and an aluminum wrap that could have contributed somewhat to the reaction. The increase in contribution from the shipping container material and the effects of geometry could explain tne increase in peak pressure and impulse values.

Peak pressure and scaled impulse values for the dryer bed tests are shown in table 4 and figure 7. Generally, the values were equal to or less than 100% at the near field values ($z \leq 3.57$ m/kg$^{1/3}$) and greater than 100% at the far field values ($z \geq 7$ m/kg$^{1/3}$). This is attributed to the effects of geometry (l/d) ratio which has been shown in the results.[6]

Fireball diameter and duration information were taken from the movies and these data are summarized in table 5. These data are reported as information only as there are no references to effectively gauge the significance.

TABLE 2. SUMMARY OF TEST RESULTS, 17-kg CHARGE (M112 STICK)

Radius meters (ft)	Scaled Distance $m/kg^{1/3}$ $(ft/lb^{1/3})$	Peak Pressure kPa (psi)	Scaled Positive Impulse $kPa \cdot ms/kg^{1/3}$ $(psi \cdot ms/lb^{1/3})$	Pressure TNT Equivalency %	Impulse TNT Equivalency %
3.06 (10.04)	1.19 (3.0)	2885 (418.5)	288 (32.12)	479	235
4.08 (13.39)	1.59 (4.0)	1273 (184.6)	218 (24.3)	373	207
5.51 (18.07)	2.14 (5.4)	715 (103.7)	152 (16.98)	417	175
9.18 (30.12)	3.57 (9.0)	119.1 (17.27)	52.6 (5.86)	196	63
18.36 (60.25)	7.14 (18.0)	23.6 (3.42)	36.9 (4.1)	98	110
40.81 (133.89)	15.87 (40.0)	10.48 (1.52)	19.7 (2.19)	163	120

TABLE 3. SUMMARY OF TEST RESULTS, 27.2-kg CHARGE (BULK)

Radius meters (ft)	Scaled Distance $m/kg^{1/3}$ $(ft/lb^{1/3})$	Peak Pressure kPa (psi)	Scaled Positive Impulse $kPa \cdot ms/kg^{1/3}$ $(psi \cdot ms/lb^{1/3})$	Pressure TNT Equivalency %	Impulse TNT Equivalency %
3.58 (11.74)	1.19 (3.0)	1930 (279.9)	193 (21.56)	301	120
4.77 (15.66)	1.59 (4.0)	1010 (146.5)	150 (16.74)	309	118
6.44 (21.14)	2.14 (5.4)	556 (70.6)	140 (15.6)	278	158
10.74 (35.23)	3.57 (9.0)	1048 (15.2)	51.6 (5.75)	164	76
21.48 (70.47)	7.14 (18.0)	26.3 (3.82)	43 (4.8)	108	107
47.73 (156.59)	15.87 (40.0)	9.03 (1.31)	17.5 (1.95)	141	100

TABLE 4. SUMMARY OF TEST RESULTS, 63.5-kg CHARGE (SECT DRYER BED)

Radius meters (ft)	Scaled Distance $m/kg^{1/3}$ ($ft/lb^{1/3}$)	Peak Pressure kPa (psi)	Scaled Positive Impulse $kPa \cdot ms/kg^{1/3}$ ($psi \cdot ms/lb^{1/3}$)	Pressure TNT Equivalency %	Impulse TNT Equivalency %
4.75 (15.58)	1.19 (3.0)	1023 (148.42)	118 (13.18)	105	52
6.33 (20.77)	1.59 (4.0)	466 (67.6)	93.2 (10.38)	88	51
8.55 (28.04)	2.14 (5.4)	198.8 (28.83)	73.4 (8.18)	77	53
14.24 (46.73)	3.57 (9.0)	57.3 (8.31)	80.9 (9.02)	65	127
28.49 (93.46)	7.14 (18.0)	35.9 (5.2)	49.4 (5.5)	217	153
63.12 (201.1)	15.87 (40.0)	12.13 (1.76)	23.2 (2.59)	237	160

TABLE 5. FIREBALL DURATION AND DIAMETER

Charge Weight kg (lb)	Maximum Fireball Diameter meters (ft)	Fireball Duration msec
17 (37.5)	14.02 (46)	194
27.2 (60)	16.76 (55)	172
63.5 (140)	17.68 (58)	172

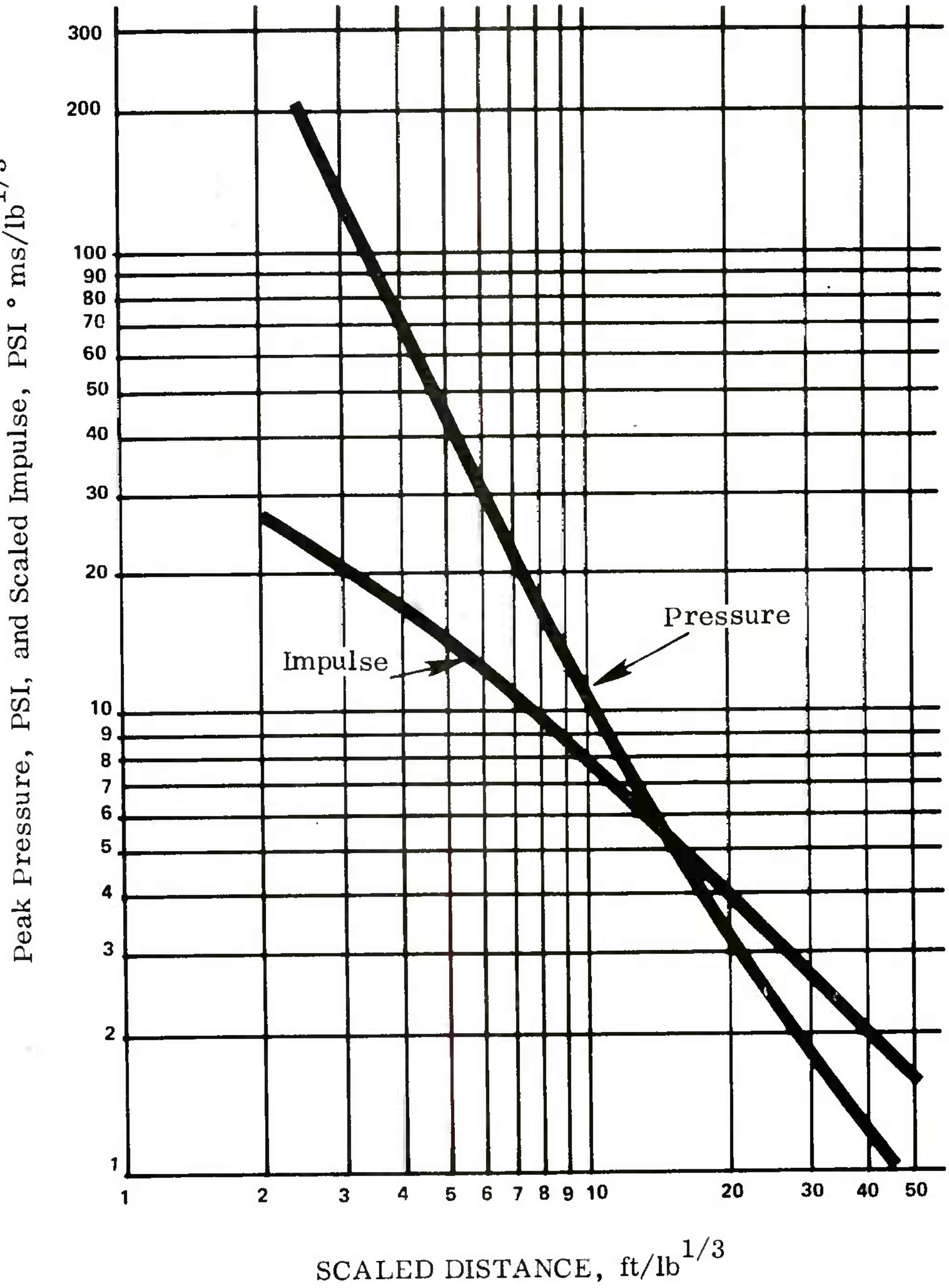


Figure 4. TNT Hemispherical Pressure and Impulse Curve

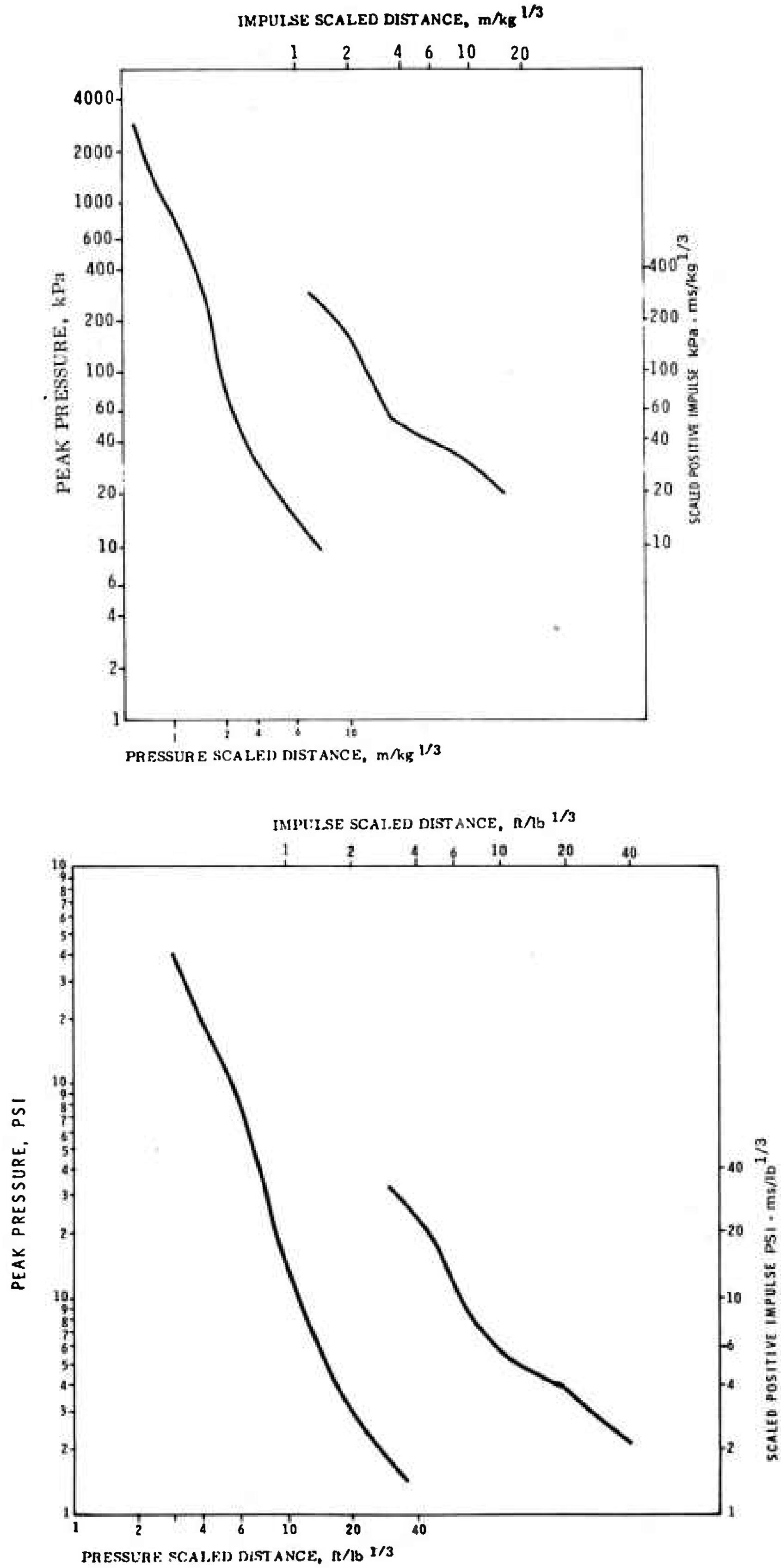


Figure 5. Pressure and Impulse Versus Scaled Distance 17-kg Charges (M112 STICK)

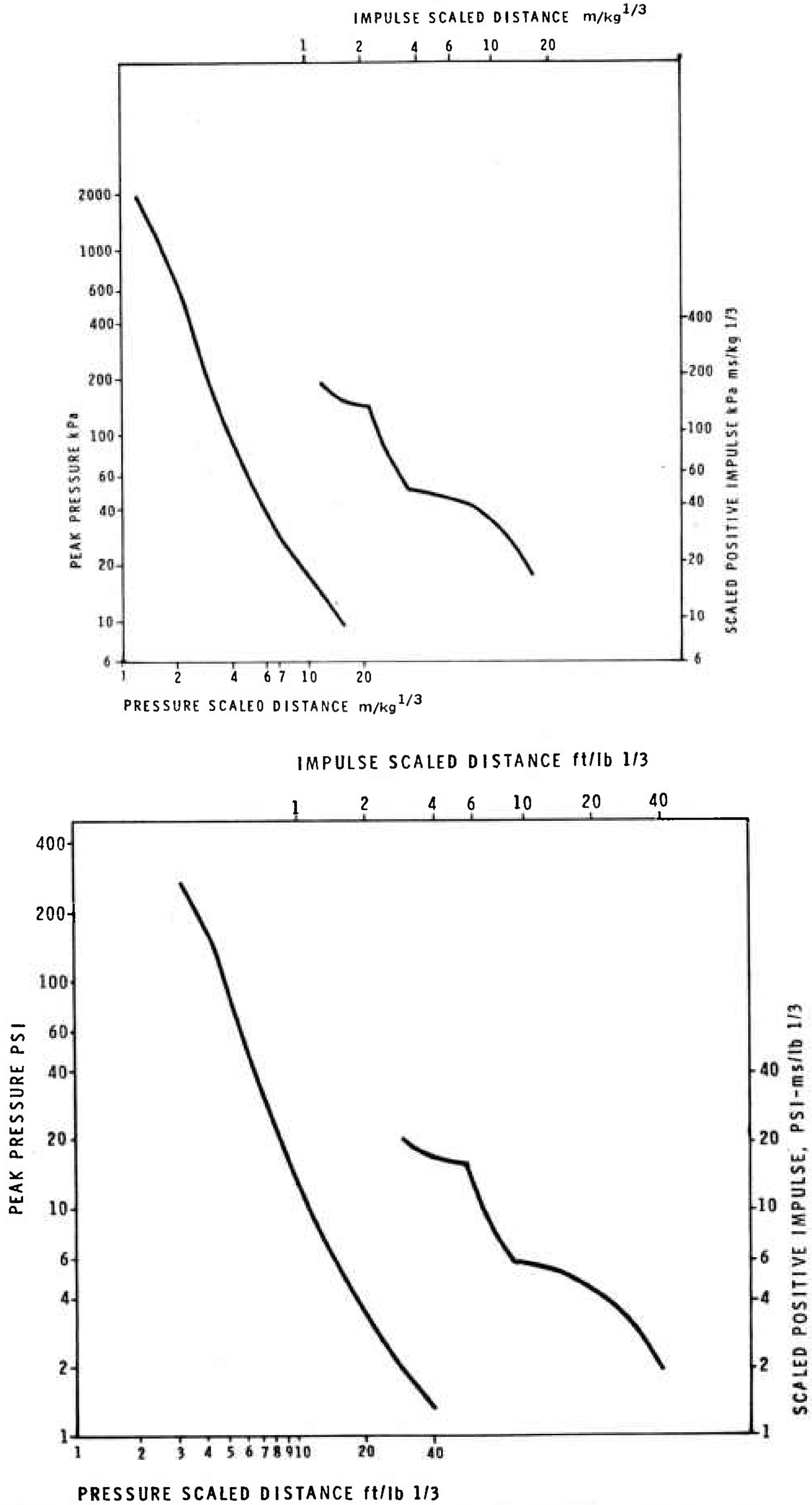


Figure 6. Pressure and Impulse Versus Scaled Distance 27.2-kg Charges (BULK)

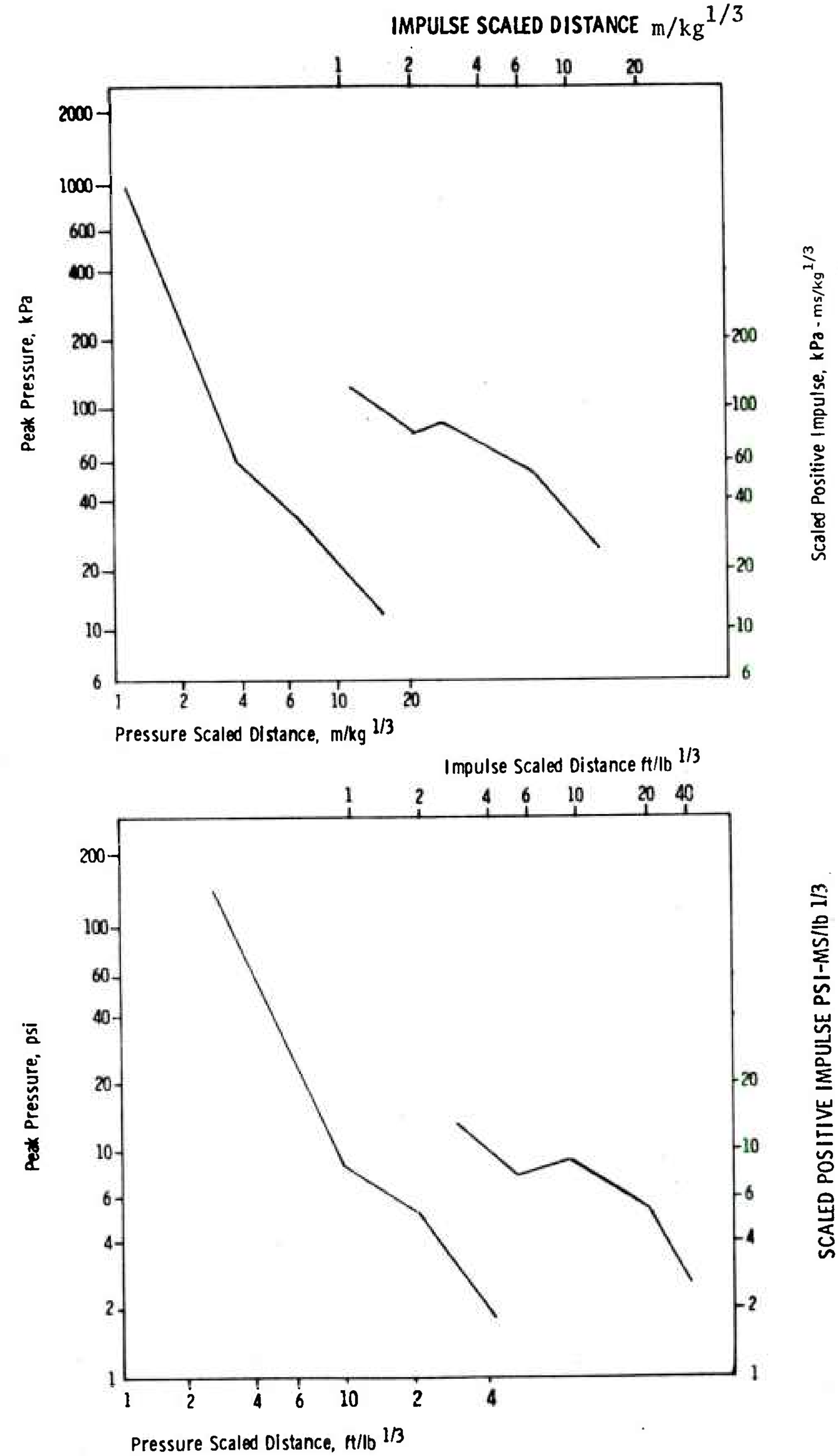


Figure 7. Pressure and Impulse Versus Scaled Distance 63.5-kg Charges Dryer Bed

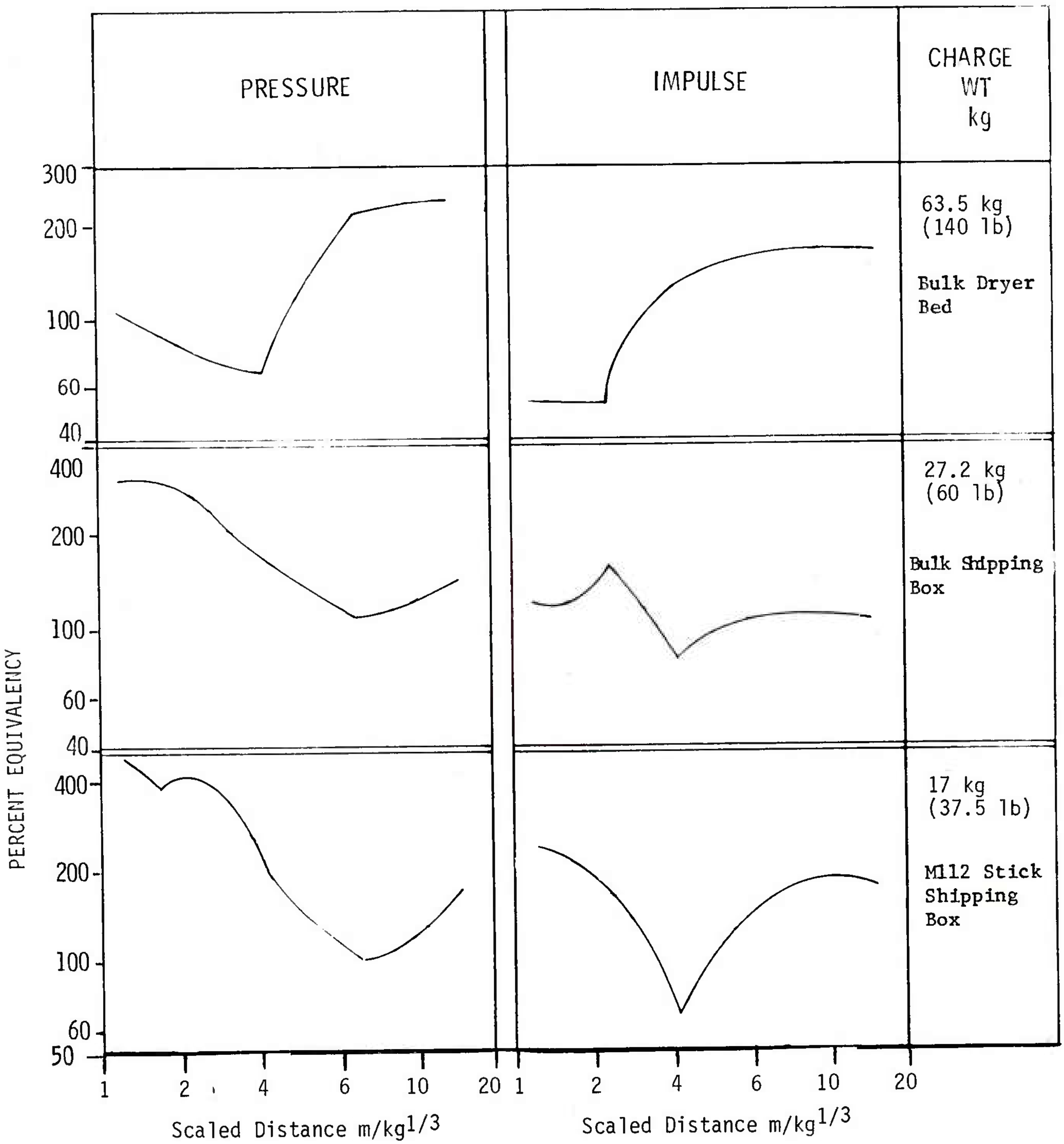
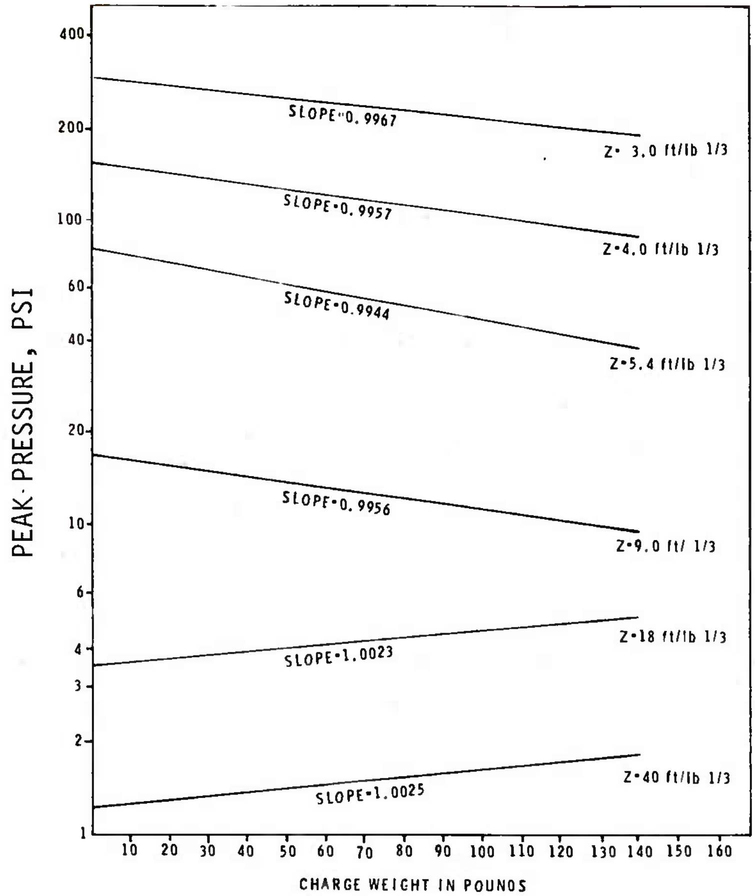


Figure 8. Pressure and Impulse Equivalencies



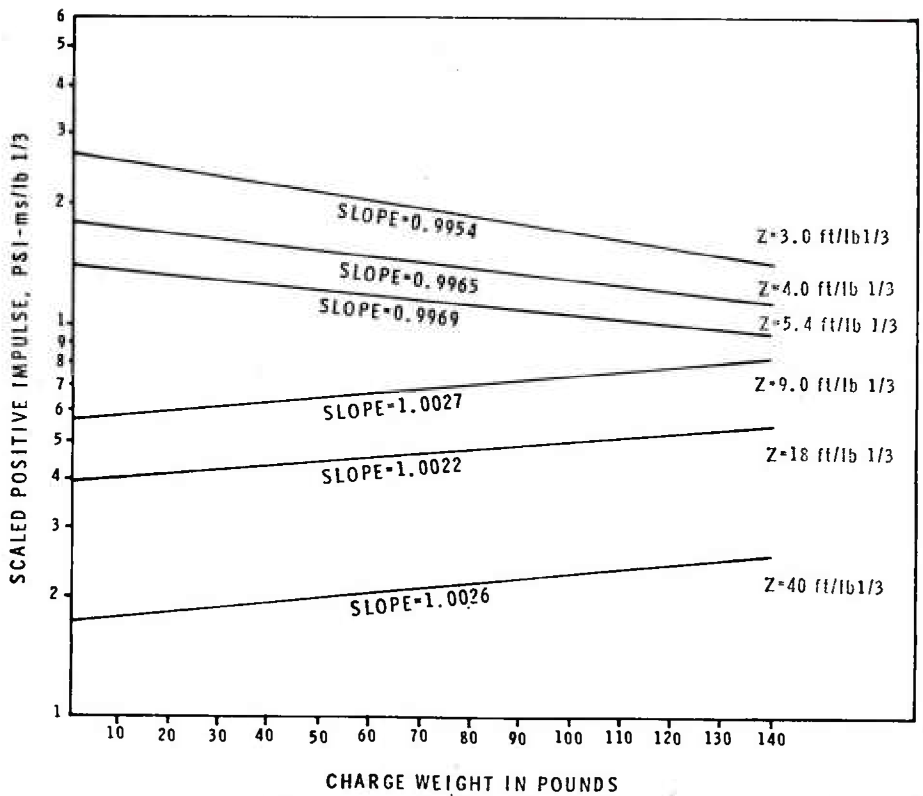


Figure 9. Deviation from Cube-Root Scaling of Pressure and Scaled Impulse Versus Charge Weight

CONCLUSIONS

In two different shipping containers, TNT equivalency values for Composition C4 were two to three times greater than the simulated dryer bed section. This may be attributable to geometry and the packing materials which might have enhanced the total reaction.

TNT equivalency values for the dryer bed configuration were generally equal to, or less than 100% at the near field values ($z \leq 3.57\ m/kg^{1/3}$), but greater than 100% at the far field values ($z \geq 7\ m/kg^{1/3}$).

In terms of peak pressure and positive impulse, TNT equivalency and blast output are dependent upon geometry.

RECOMMENDATION

The TNT equivalency value determined from this test series should be used in the structural design of protective facilities containing Composition C4.

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APPENDIX A

DATA SHEETS

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 29-8-04 B_1				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	2613.87 (379.11)	373.23 (41.59)	
2		2323.4 (336.98)	248.85 (27.73)	
3	4.08 (13.39)	1289.39 (187.01)	172.3 (19.2)	
4		1697.28 (246.17)	213.13 (23.75)	
5	5.51 (18.07)	737.6 (106.98)	143.4 (15.98)	
6		917.07 (133.01)	122.41 (13.64)	
7	9.18 (30.12)	125.35 (18.18)	50.61 (5.64)	
8		107.9 (15.65)	55.37 (6.17)	
9	18.36 (60.25)	27.3 (3.96)	31.5 (3.51)	
10		24.68 (3.58)	22.79 (2.54)	
11	40.81 (133.89)	9.65 (1.4)	16.15 (1.8)	
12		9.58 (1.39)	8.88 (0.99)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 29-8-05 B_2				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	2586.29 (375.11)	393.33 (43.83)	
2		2310.50 (335.11)	(---)	Bad Impulse Data
3	4.08 (13.39)	1197.69 (173.71)	162.61 (18.12)	
4		--- (---)	--- (---)	Loose Connection on Gauge
5	5.51 (18.07)	1039.8 (150.81)	119.17 (13.28)	
6		913.62 (132.51)	122.14 (13.61)	
7	9.18 (30.12)	110.52 (16.03)	19.2 (2.14)	
8		120.18 (17.43)	49.36 (5.5)	
9	18.36 (60.25)	27.72 (4.02)	38.32 (4.27)	
10		22.61 (3.28)	20.37 (2.27)	
11	40.81 (133.89)	10 (1.45)	14.81 (1.65)	
12		10.89 (1.58)	8.44 (0.94)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 30-8-01 B_3

Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	2999.01 (434.97)	428.15 (47.75)	
2		2772.66 (402.14)	(---)	Bad Impulse Data
3	4.08 (13.39)	1465.62 (212.57)	220.85 (24.61)	
4		1296.56 (188.05)	174.36 (19.43)	
5	5.51 (18.07)	804.69 (116.71)	146.55 (16.33)	
6		519.8 (75.39)	144.21 (16.07)	
7	9.18 (30.12)	123.35 (17.89)	42.45 (4.73)	
8		111.07 (16.11)	48.91 (5.45)	
9	18.36 (60.25)	25.37 (3.68)	33.29 (3.71)	
10		20.96 (3.04)	31.14 (3.47)	
11	40.81 (133.89)	4.69 (0.68)	2.69 (0.3)	
12		7.38 (1.07)	3.95 (0.44)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 51-8-01 B_4

Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	--- (---)	--- (---)	
2		--- (---)	--- (---)	
3	4.08 (13.39)	--- (---)	--- (---)	
4		--- (---)	--- (---)	
5	5.51 (18.07)	629.7 (91.33)	106.61 (11.88)	
6		742.29 (107.66)	205.5 (22.9)	
7	9.18 (30.12)	209.05 (30.32)	81.04 (9.03)	
8		166.78 (24.19)	(---)	Bad Impulse Data
9	18.36 (60.25)	20.62 (2.99)	12.2 (1.36)	
10		23.03 (3.34)	54.56 (6.08)	
11	40.81 (133.89)	9.65 (1.4)	24.05 (2.68)	
12		11.03 (1.6)	21 (2.34)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 51-8-02 B_5

Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	3104.71 (450.3)	263.3 (29.34)	
2		3463.93 (502.4)	261.05 (29.09)	
3	4.08 (13.39)	1175.76 (170.53)	263.84 (29.4)	
4		(---)	(---)	Bad Gauge
5	5.51 (18.07)	692.3 (100.41)	195.81 (21.82)	
6		717.47 (104.06)	181.01 (20.17)	
7	9.18 (30.12)	168.78 (24.48)	64.52 (7.19)	
8		(---)	(---)	Loose Connection
9	18.36 (60.25)	21.58 (3.13)	53.66 (5.98)	
10		23.06 (3.34)	47.02 (5.24)	
11	40.81 (133.89)	10.55 (1.53)	20.64 (2.3)	
12		9.72 (1.41)	21.54 (2.4)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 51-8-03 B_6				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	3136.08 (454.85)	264.82 (29.51)	
2		4156.71 (602.88)	275.59 (30.71)	
3	4.08 (13.39)	1220.1 (176.96)	284.21 (31.67)	
4		(---)	(---)	Loose Connection
5	5.51 (18.07)	725.26 (105.19)	215.65 (24.03)	
6		671.83 (97.44)	158.93 (17.71)	
7	9.18 (30.12)	128.52 (18.64)	57.97 (6.46)	
8		139.76 (20.27)	(---)	Bad Impulse Data
9	18.36 (60.25)	25.99 (3.77)	43.52 (4.85)	
10		23.06 (3.34)	43.7 (4.87)	
11	40.81 (133.89)	10.14 (1.47)	21.72 (2.42)	
12		11.03 (1.6)	21.27 (2.37)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 17 Kg (37.5 lb) 51-8-04 B_7				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.06 (10.04)	3543.77 (513.98)	230.63 (25.7)	
2		1039.18 (150.72)	330.78 (36.86)	
3	4.08 (13.39)	1264.5 (183.4)	218.34 (24.33)	
4		1626.06 (235.84)	288.16 (32.11)	
5	5.51 (18.07)	421.96 (61.2)	155.79 (17.36)	
6		545.79 (79.16)	166.74 (18.58)	
7	9.18 (30.12)	113.07 (16.4)	51.42 (5.73)	
8		111.21 (16.13)	(---)	Bad Impulse Data
9	18.36 (60.25)	22.55 (3.27)	43.97 (4.9)	
10		24.13 (3.5)	46.49 (5.18)	
11	40.81 (133.89)	11.58 (1.68)	20.37 (2.27)	
12		11.58 (1.68)	19.74 (2.2)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 27.2 Kg (60 lb) 31.8-01 C_1

Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.58 (11.74)	2556.78 (370.83)	189.53 (21.12)	
2		1860.83 (269.89)	(---)	Bad Impulse Data
3	4.77 (15.66)	852.05 (123.58)	119.62 (13.33)	
4		1194.17 (173.20)	159.2 (17.74)	
5	6.44 (21.14)	451.12 (65.43)	114.69 (12.78)	
6		550.27 (79.81)	121.78 (13.57)	
7	10.74 (35.23)	108.45 (15.73)	78.61 (8.76)	
8		119.69 (17.36)	43.61 (4.86)	
9	21.48 (70.47)	27.85 (4.04)	46.58 (5.19)	
10		19.1 (2.77)	21 (2.34)	
11	47.73 (156.26)	11.51 (1.67)	24.68 (2.75)	
12		6.93 (1.02)	17.23 (1.92)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 27.2 Kg (60 lb) 31-8-02 C_2				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.58 (11.74)	1786.57 (259.12)	113.34 (12.63)	
2		1674.74 (242.9)	(---)	Bad Impulse Data
3	4.77 (15.66)	1070.69 (155.29)	93.6 (10.43)	
4		1560.9 (226.39)	173.92 (19.38)	
5	6.44 (21.14)	530.34 (76.92)	172.48 (19.22)	
6		807.03 (117.05)	149.15 (16.62)	
7	10.74 (35.23)	125.35 (18.18)	48.82 (5.44)	
8		100.32 (14.55)	46.66 (5.2)	
9	21.48 (70.47)	11.93 (1.73)	43.34 (4.83)	
10		27.72 (4.02)	11.31 (1.26)	
11	47.73 (156.26)	11.17 (1.62)	41.55 (4.63)	
12		7.31 (1.06)	40.83 (4.55)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 27.2 Kg (60 lb) 31-8-03 C_3				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	3.58 (11.74)	2282.92 (331.11)	197.34 (21.99)	
2		2307.47 (334.67)	(---)	Bad Impulse Data
3	4.77 (15.66)	965.68 (140.06)	148.07 (16.5)	
4		1206.31 (174.96)	184.77 (20.59)	
5	6.44 (21.14)	506.28 (73.43)	157.05 (17.15)	
6		593.09 (86.02)	132.1 (14.72)	
7	10.74 (35.23)	103.63 (15.03)	61.83 (6.89)	
8		109.14 (15.83)	56.98 (6.35)	
9	21.48 (70.47)	23.86 (3.46)	41.55 (4.63)	
10		19.44 (2.82)	40.83 (4.55)	
11	47.73 (156.26)	11.51 (1.67)	23.69 (2.64)	
12		7.38 (1.07)	17.59 (1.96)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 63.5 Kg (140 lb) 31-8-04 D_1				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	4.75 (15.58)	739.26 (107.22)	88.57 (9.87)	
2		3275.08 (475.01)	112.53 (12.54)	
3	6.33 (20.77)	499.25 (72.41)	99.79 (11.12)	
4		582.26 (84.45)	86.96 (9.69)	
5	8.55 (28.04)	241.11 (34.97)	96.2 (10.72)	
6		187.26 (27.16)	69.28 (7.72)	
7	14.24 (46.73)	69.09 (10.02)	97.55 (10.87)	
8		55.64 (8.07)	71.25 (7.94)	
9	28.49 (93.46)	40.68 (5.9)	37.51 (4.18)	
10		38.13 (5.53)	44.24 (4.93)	
11	63.12 (207.1)	13.1 (1.9)	25.58 (2.85)	
12		10.62 (1.54)	22.44 (2.5)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 63.5 Kg (140 lb) 31-8-05 D_2				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	4.75 (15.58)	901.56 (130.76)	109.21 (12.17)	
2		1153.08 (167.24)	112.53 (12.54)	
3	6.33 (20.77)	450.88 (65.39)	91.8 (10.23)	
4		458.36 (66.48)	(---)	Bad Impulse Data
5	8.55 (28.04)	200.36 (29.06)	110.29 (12.29)	
6		148.31 (21.51)	65.78 (7.33)	
7	14.24 (46.73)	69.09 (10.02)	101.5 (11.31)	
8		52.19 (7.57)	46.75 (5.21)	
9	28.49 (93.46)	41.37 (6)	46.31 (5.16)	
10		41.16 (5.97)	49.54 (5.52)	
11	63.12 (207.1)	13.65 (1.98)	25.48 (2.84)	
12		10.96 (1.59)	20.82 (2.32)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 63.5 Kg (140 lb) 31-8-06 D_3				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	4.75 (15.58)	1079.44 (153.56)	106.88 (11.91)	
2		(---)	(---)	Bad Gauge
3	6.33 (20.77)	474.29 (68.79)	88.75 (9.89)	
4		619.42 (89.84)	(---)	Bad Impulse Data
5	8.55 (28.04)	218.01 (31.62)	78.88 (8.79)	
6		247.66 (35.92)	82.38 (9.18)	
7	14.24 (46.73)	73.84 (10.71)	89.02 (9.92)	
8		62.6 (9.08)	78.79 (8.78)	
9	28.49 (93.46)	36.61 (5.31)	38.23 (4.26)	
10		37.3 (5.41)	44.78 (4.99)	
11	63.12 (207.1)	14.2 (2.06)	25.85 (2.88)	
12		11.1 (1.61)	20.1 (2.24)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 63.5 Kg (140 lb) 34-8-02 D_4

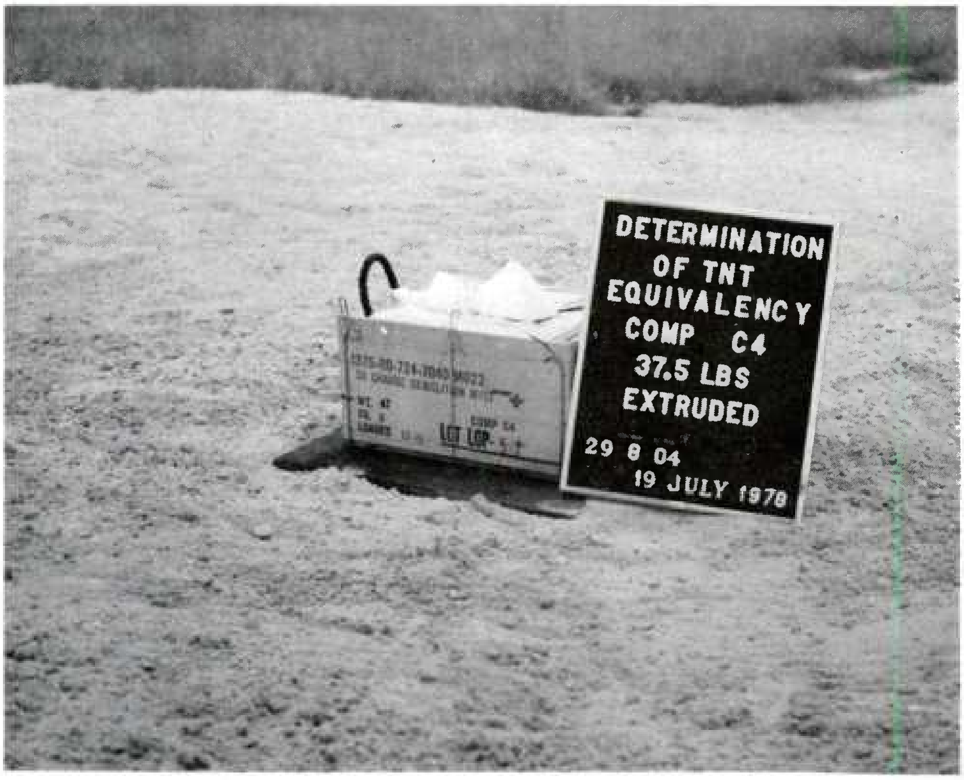
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	4.75 (15.58)	1102.61 (159.92)	114.87 (12.8)	
2		1142.12 (165.65)	115.76 (12.9)	
3	6.33 (20.77)	284.82 (41.31)	86.15 (9.6)	
4		432.16 (62.68)	87.95 (9.8)	
5	8.55 (28.04)	155.13 (22.5)	60.4 (6.73)	
6		173.75 (25.12)	56 (6.24)	
7	14.24 (46.73)	55.09 (7.99)	74.21 (8.27)	
8		56.12 (8.14)	71.7 (7.99)	
9	28.49 (93.46)	39.78 (5.77)	47.38 (5.28)	
10		28.87 (4.18)	38.59 (4.3)	
11	63.12 (207.1)	13.03 (1.89)	24.23 (2.7)	
12		10.69 (1.55)	19.47 (2.17)	

EXPERIMENTAL RESULTS

TNT EQUIVALENCY TEST: 63.5 Kg (140 lb) 34-8-03 D_5				
Channel Number	Distance Meters (Ft)	Peak Pressure kPa (psi)	Scaled Impulse kPa msec $kg^{-1/3}$ (psi msec $lb^{-1/3}$)	Remarks
1	4.75 (15.58)	910.11 (132)	115.85 (12.91)	
2		1169.14 (169.57)	128.51 (14.32)	
3	6.33 (20.77)	226.08 (32.79)	80.59 (8.98)	
4		363.91 (52.78)	88.03 (9.81)	
5	8.55 (28.04)	- (-)	- (-)	Loose Connection on Gauge
6		168.58 (24.45)	64.16 (7.15)	
7	14.24 (46.73)	48.61 (7.05)	32.76 (3.65)	
8		53.02 (7.69)	73.5 (8.19)	
9	28.49 (93.46)	37.58 (5.45)	50.61 (5.64)	
10		31.58 (4.58)	44.69 (4.98)	
11	63.12 (207.1)	13.72 (1.99)	23.24 (2.59)	
12		11.45 (1.66)	21.9 (2.44)	

APPENDIX B

SELECTED PHOTOGRAPHS

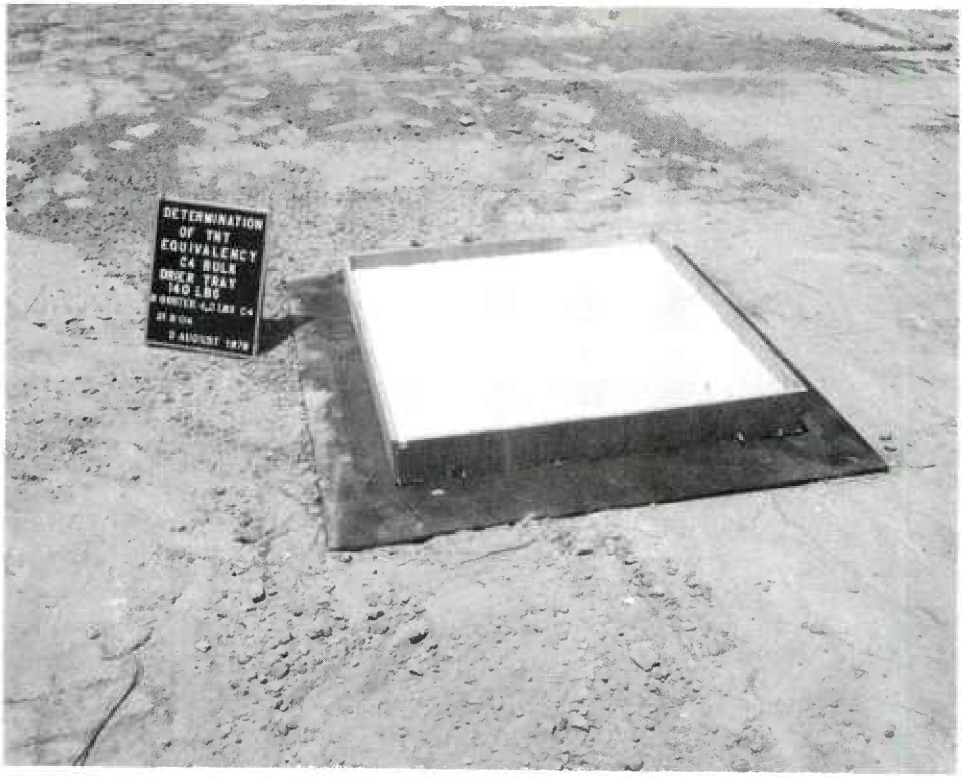


Pretest Configuration 17-kg Charge

Posttest Crater 17-kg Charge

Pretest Configuration 27.2-kg Charge

Posttest 27.2-kg Charge



Pretest Configuration 63.5-kg Charge

Posttest 63.5-kg Charge

APPENDIX C

TNT EQUIVALENCY PROGRAM

This program calculates the pressure and impulse TNT equivalency by an iterative process which factors out the contributions from C4 booster charges*. For each set of input data, the parameters are calculated according to the following procedure:

1. Assume zero contribution from the booster charge. Then W1 = W2 = W, where W1 and W2 are the pressure- and impulse-related sample weights, respectively, and W is the sample charge weight.

2. Calculate approximate sample scaled distances from

$$Z1 = R\ /(W1)^{1/3} \qquad \text{(pressure)}$$

$$Z2 = R\ /(W2)^{1/3} \qquad \text{(impulse)}$$

3. Calculate an approximate TNT (equivalent) scaled distance, Z5, from the estimated sample TNT impulse equivalency, E5:

$$Z5 = Z2/(.01E5)^{1/3}$$

4. Calculate the TNT pressure and impulse scaled distances, Z3 and Z4 respectively, from curve-fits of reference data, see figure A1. Use separate straight line (log-log) segments depending on the value of Z5:

(a) If $Z5 \leq 9$,

$$Z3 = 27.133\ P^{-0.4513}$$

$$Z4 = 47.247\ I^{-(1/1.8215)}$$

(b) If $9 < Z5 \leq 18$,

$$Z3 = 36.016\ P^{-0.5672}$$

$$Z4 = 55.874\ I^{-(1/1.5672)}$$

(c) If $Z5 > 18$,

$$Z3 = 45.555\ P^{-0.7557}$$

$$Z4 = 67.37\ I^{-(1/1.9626)}$$

* Swatosh, J. J., and J. Cook, "TNT Equivalency of M1 Propellant (Bulk)," Technical Report 4885, Picatinny Arsenal, December 1975.

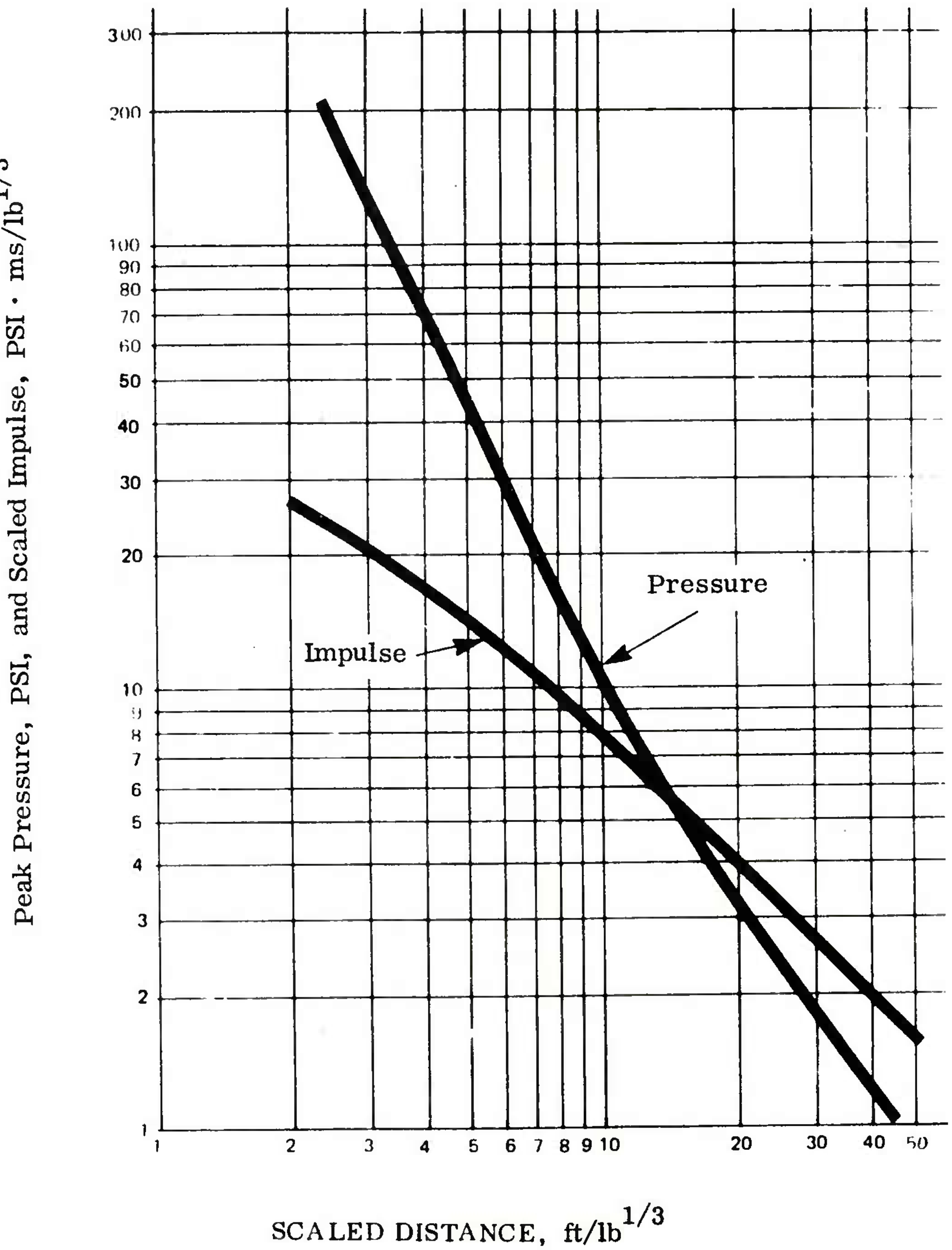


Figure C1. TNT Hemisphere Reference Data (Source: D. Westover, ARRADCOM DRDAR-LCM-SP, Private Communication)

5. Calculate the approximate TNT pressure and impulse equivalencies, E1 and E2, from:

$$E1 = (Z1)^3/(Z3)^3$$

$$E2 = (Z2)^3/(Z4)^3$$

6. Using the equivalencies obtained in step 5, recalculate the pressure- and impulse-related sample weights, and the estimated TNT impulse equivalency:

$$W1 = W + (W3)(1.25/E1)$$

$$W2 = W + (W3)(1.25/E2)$$

$$E5 = (100)(E2)$$

where W3 is the booster charge weight.

7. Using the values obtained in step 6, work through from step 2 again to obtain new, improved values for E1, E2, W1, W2, and E5. Each iteration improves both the curve-fits in step 4 and the minimization of booster contributions in step 6. Continue the iteration until changes in E1 and E2 are insignificant.

8. Begin calculation for a new set of data at step 1.

The entire program with 10 sets of input data requires less than 4 Kbytes of memory. Therefore it can be used in small, portable microcomputer systems and desktop programmable calculators. The mean accuracy of the calculations over the range of scaled distances from 2.5 to 60 is about 1%. The maximum errors occur at scaled distances of 9 and 18, i.e., the inflection points of the straight-line TNT data curve fits, and amount to less than 5% of the calculated equivalencies.

TNT EQUIVALENCY PROGRAM

```
100 REM        INPUT DATA REQUIRED IS:
110 REM        (1)  MATERIAL, CONFIGURATION, APPX. EQUIVALENCY
120 REM        (2)  SAMPLE WT, BOOSTER WT, DISTANCE, PRESSURE,
130 REM             IMPULSE UP TO10 CALCULATIONS CAN BE MADE IN
140 REM             ONE PASS.
150 INIT
160 DIM W(10), W3(10), R(10), Z(10), P(10), I1(10), I2(10)
170 DIM E1(10), E2(10)
180 PRINT "MATERIAL?"
190 INPUT M$
200 PRINT "CONFIGURATION?"
210 INPUT C$
220 PRINT "APPROXIMATE % EQUIVALENCY?"
230 INPUT E5
240 I=0
250 I=I+1
260 N1=I
270 PRINT "INPUT W(LB), BOOSTER(LB), R(FT), P(PSI), I(PSI*MSEC)"
280 INPUT W(I), W3(I), R(I), P(I), I1(I)
290 Z(I)=R(I)/W(I)↑0.333
300 I1(I)=I1(I)/W(I)↑0.333
310 PRINT "ANY MORE DATA?"
320 INPUT L$
330 IFL$= > "Y" THEN 250
340 FOR I=1 TO N1
350 W1=W(I)
360 W2-W(I)
370 Z1=R(I)/W1↑0.333
380 Z2=R(I)/W2↑0.333
390 Z5=Z2/(0.01*E5)↑0.333
400 IF Z5>18 THEN 520
410 IF Z5>9 THEN 470
420 A1=27.133
430 B1=0.4513
440 A2=47.247
450 B2=0.8215
460 GO TO 560
470 A1=36.016
480 B1=0.5672
490 A2=55.874
500 B2=0.8979
510 GO TO 560
```

```
520  A1=45.555
530  B1=0.7557
540  A2=67.37
550  B2=0.9626
560  B=1/(1+B2)
570  Z3=A1/P(I)↑B1
580  Z4=(A2*Z2/I1(I))↑B
590  E1(I)=Z1↑3/Z3↑3
600  E2(I)=Z2↑3/Z4↑3
610  W1=W(I)+W3(I)*1.25/E1(I)
620  W2=W(I)+W3(I)*1.25/E2(I)
630  E5=100*E2(I)
640  PRINT USING 650:"E(P)=",E1(I),"E(I)=",E2(I)
650  IMAGE 8X,5A,2X,4D,2D,10X,5A,2X,4D,2D
660  PRINT "ITERATE AGAIN???"
670  INPUT T$
680  IF T$=>"Y" THEN 370
690  E1(I)=100*E1(I)
700  E2(I)=100*E2(I)
710  NEXT I
720  PAGE
730  PRINT USING 740:"TNT EQUIVALENCY OF",M$
740  IMAGE 18X,19A,3X,20A/
750  PRINT USING 760:"CONFIGURATION:",C$
760  IMAGE 14X,15A,3X,30A//
770  PRINT USING 780:"W","R","Z","P","I","E(P)","E(I) "
780  IMAGE 4X,1A,9X,1A,9X,1A,9X,1A,9X,1A,8X,4A,6X,4A
790  PRINT USING 800:"LB","FT","SCALED","PSI","SCALED","(%)","(%)"
800  IMAGE 4X,2A,8X,2A,6X,6A,5X,3A,6X,6A,5X,3A,7X,3A/
810  FOR I=1 TO N1
820  PRINT USING 830:W(I),R(I),Z(I),P(I),I1(I),E1(I),E2(I)
830  IMAGE 1X,3D.3D,2X,4D.3D,2X,4D.3D,2X,4D.3D,2X,4D.3D,3X,4D,3X,4D/
840  NEXT I
850  END
```

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