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BLAST PARAMETERS FROM EXPLOSIONS IN MODEL EARTH COVERED MAGAZINES

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September 1976

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USA BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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

This report contains the results obtained from a series of high explosive tests designed to determine the blast parameters around a 1/50 scale model of an earth covered munition storage magazine. The tests were conducted using hemi-cylindrical pentolite charges of scaled weights to simulate the effects of an accidental explosion occurring in standard munition magazines when filled with 100,000, 300,000, and 500,000 pounds of explosives. The thickness of the earth cover was varied to determine the blast attenuation associated with double the standard earth cover thickness, the standard earth

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cover and one-half the standard earth cover thickness relative to no earth cover. Excellent correlation was obtained with limited data from one full-size storage magazine test.

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A. Background

This report covers a general study sponsored by the Department of Defense Explosive Safety Board (DDESB) to establish the effect of earth cover on the blast parameters generated from accidental explosions in munition storage magazines. This kind of study would be prohibitively expensive to do with full-size magazines and large amounts of explosive, but in theory, the relative effects could be documented using scaled models and high explosive charges.

The Ballistic Research Laboratory (BRL) proposed to conduct a series of model tests and relate the results to effects that might be expected from full-size magazines. This proposal was accepted and funded by DDESB.

B. Objectives

The primary objectives of the proposed tests were as follows:

1. Determine the blast parameters propagating along blast lines extending to the front, side, and rear of a 1/50 scale model magazine with a standard earth cover.

2. Determine the effect on blast parameters when the earth cover was varied from no cover, to one-half the standard cover, and to double the standard cover.

3. Determine the effect on blast parameters when the amount of explosive stored in the magazine was varied.

II. TEST PROCEDURE

The procedures used to meet the objectives were to, first design the model magazine, second design the high explosive charge weight and configuration, and third establish the instrumentation and blast lines.

A. Model Magazine Design

The standard munition storage magazine being modeled for this series tests is shown in Figure 1. The overall width is 90 feet (27.43 metres) with a length of 95 feet (28.96 metres). The total volume of the earth cover for this size magazine is 58812 feet^3 (1665 m^3), while the interior volume is approximately 17,500 feet^3 (496 m^3). The 1/50 scaled model designed for this project is presented in Figure 2. All linear dimensions have been scaled by a factor of 50. This makes the volume of the earth cover for the model 0.47 feet^3 (.0133 m^3) and the internal volume of the model is 0.14 feet^3 (.00396 m^3). A photograph of the interior portion of the model without the earth cover is shown in Figure 3. The model

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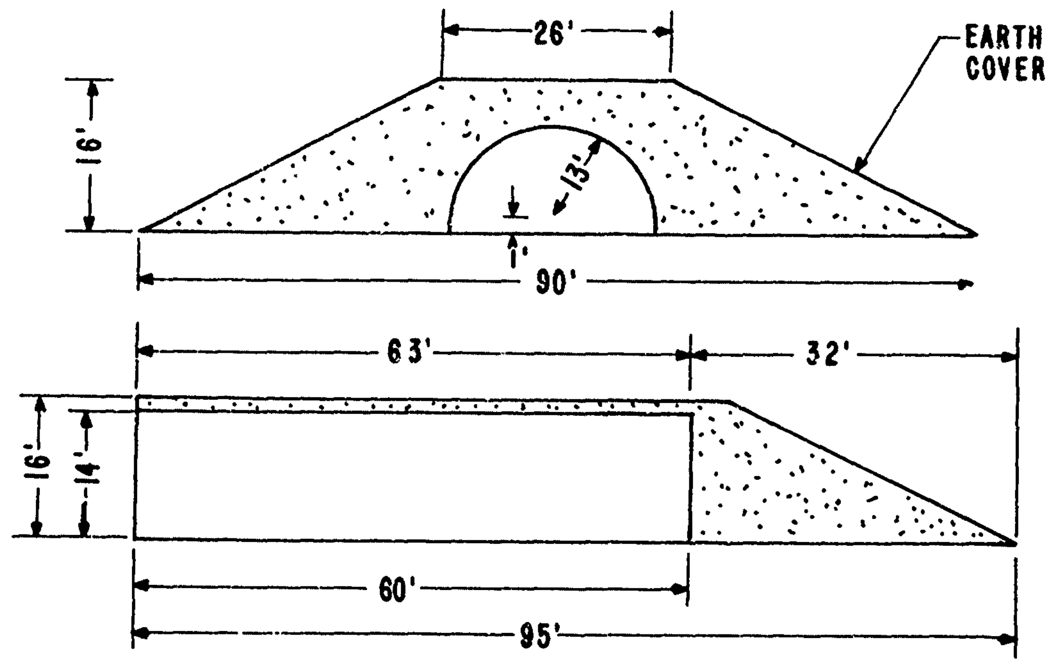


Figure 1. Standard Munition Storage Magazine

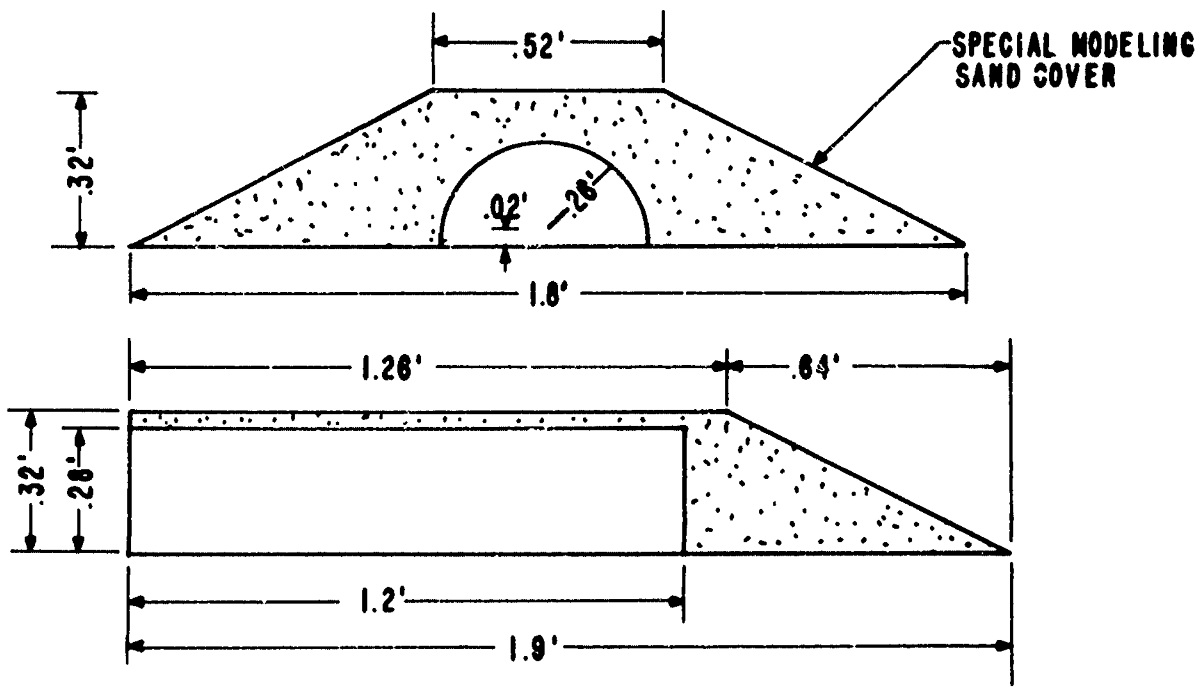


Figure 2. 1/50 Scaled Model Munition Storage Magazine

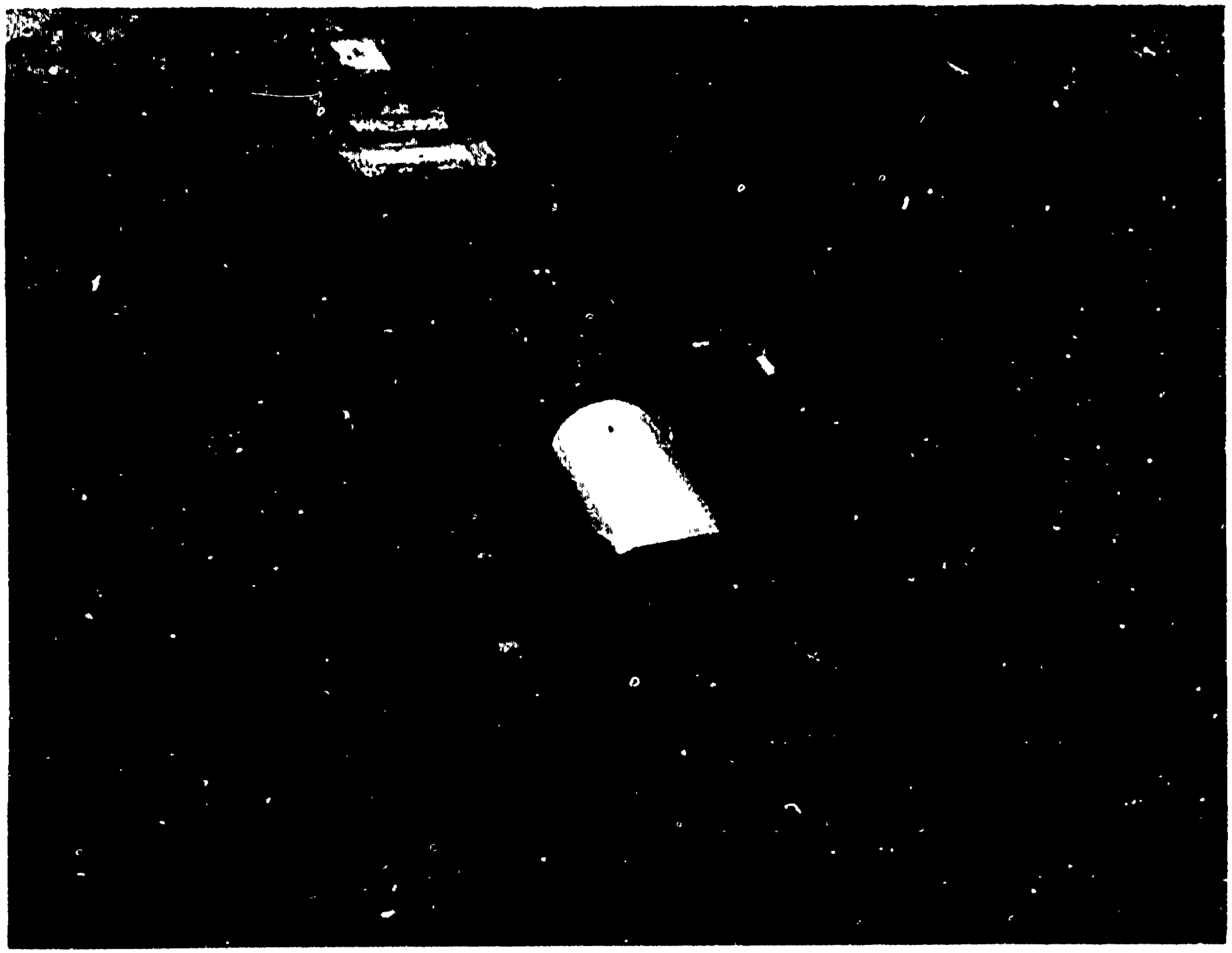


Figure 3. Internal Portion of the Model Magazine

magazine with earth cover is shown with the first two gage stations for each line in Figure 4.

B. Test Charges

The test charges were cast pentolite. The weight of the charges was based on the weight of the high explosive stored in a magazine of specified volume. The ratio of the charge weight to storage volume should be the same when scaling from the full size structure to a model structure.

$$\frac{W}{V} = \frac{W_M}{V_M} , \tag{1}$$

where

W = Weight of munition explosive,

V = Volume of Standard Magazine

W_M = Weight of model charge, and

V_M = Volume of Model Magazine.

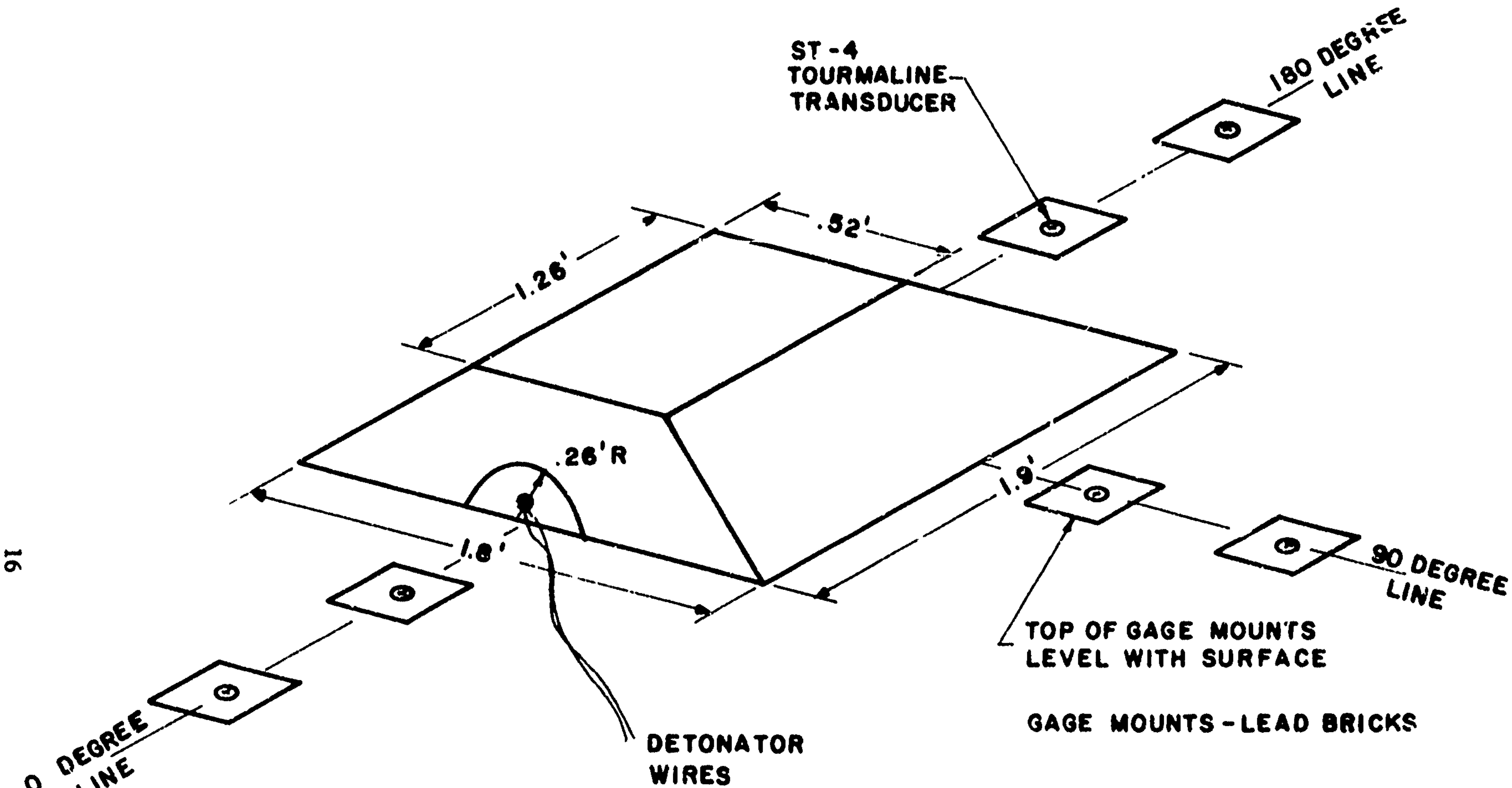
The program was designed to simulate the blast from the accidental explosion of 500,000 pounds (226,800 kg), 300,000 pounds (136,080 kg), and 100,000 pounds (45,360 kg) of munition stored in a magazine having a volume of 17,500 feet^3 (496 m^3). The model charge weights were determined as presented in Table I. The scaling factor for the model volume and the charge weights is 50^3 or 125,000.

Table I. Charge Weights and Structure Volumes

W_M		V_M		W		V	
lb	kg	ft^3	m^3	lb	kg	ft^3	m^3
4.0	1.814	0.14	.00396	500000	226800	17500	496
2.4	1.088	0.14	.00396	300000	136080	17500	496
0.8	.363	0.14	.00396	100000	45360	17500	496

After the volume of the 1/50 scale model magazine was established, then the charge weights were determined and the configuration designed. There are data available on the airblast propagation from cylindrical charges (Reference 1) resting horizontally on the ground surface, with

[1] *R. Reisler, L. Giglio-Tos, and G. Teel, "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground," BRL MR-2471, April 1975. AD #B003883L.*



MODEL MAGAZINE $\frac{1}{50}$th SCALE

Figure 4. Model Magazine 1/50th Scale

length to diameter ratios of 3, 6, and 12. It was believed that a hemicylindrical charge would best represent the storage configuration in a model magazine and therefore the charges were designed with the end surface area the same as a cylindrical charge of L/D equal to 3.

Knowing the weight of the charge and assuming a density of pentolite of 103 lb/ft^3 (1.65 g/cm^3) the volume of the cylindrical charge can be calculated. When the volume of the charge (V_c) is known, then the other dimensions can be calculated.

$$V_c = \pi r_c^2 L \text{ for } L/D = 3 \qquad (2)$$
$$L = 6 r_c$$

Therefore the radius r_c for a cylindrical charge is

$$r_c = \left(\frac{V_c}{6\pi}\right)^{1/3}$$

and the end area of the cylindrical is

$$A_c = \pi r_c^2. \qquad (3)$$

When A_c, r_c, and L for the cylindrical charge have been determined, then the radius, r_h, for the hemicylinder can be calculated. The area A_h for the hemicylinder must equal A_c, the area of the cylinder, for the length L to be the same. Therefore,

$$r_h = \left(\frac{2A_c}{\pi}\right)^{1/2} . \qquad (4)$$

The dimensions of the model charge are listed in Table II.

Table II. Dimensions of the Model Charges

W_h		V_h		L_h		r_h		A_h	
lb	kg	ft^3	m^3	ft	m	ft	m	ft^2	m^2
4.0	1.814	.0388	.00110	.763	.229	.1798	.0548	.0508	.0046
2.4	1.088	.0233	.00066	.644	.196	.1518	.0463	.0362	.0034
0.8	0.363	.0078	.00022	.447	.136	.1052	.0321	.0174	.0016

When the charge was placed in the magazine the point of initiation was on the end toward the door and this was noted as the zero degree line for the blast measurements.

C. Test Instrumentation

The details of the complete instrumentation systems will be presented in this section. The system includes 1) the pressure transducer, 2) the amplifier, and 3) the recorder. Because of the small charges used and the requirement for close-in documentation; i.e., high overpressures, two instrumentation systems were utilized.

1. Oscilloscope Recorder System Three Tektronix 565 dual beam oscilloscopes were used to record the pressure versus time from six stations. Susquehanna Instruments Model ST-4 piezo gages with tourmaline sensors were the primary transducers used throughout the series of tests. The signal from the gage and source follower was fed directly into the oscilloscope where it was displayed on a video tube and photographed on a high contrast poloroid film. The analog display on the film was converted into a digital format using a film reader and punching IBM cards which were then processed through a computer. The digitized data was then tabulated and plotted. A block diagram of the oscilloscope recorder system is presented in Figure 5.

2. Tape Recorder System The tape recorder consisted of four basic units. The gages which have already been described, the power supply and voltage calibrator, the amplifier, and the FM recorder. The FM tape recorder used was a Honeywell 7600 having a frequency response of 80 kHz. Once the signal was recorded on the magnetic tape it was played back and recorded on a CEC-5-124 oscillograph for a quick look at the records. The analog signal on the magnetic tape was processed for an automatic digital conversion and was then programmed through the computer for a digital output which was tabulated and plotted. The tape recorder system and other field instruments are shown in Figure 5.

D. Test Layout

A requirement to meet the stated objectives is to measure the blast parameters at the current safe separation distances between storage magazines. Therefore, the blast lines, see Figure 6, were installed to measure overpressure and impulse in three principal directions in the near field. Stations to the front (0 degree line) should start at a scaled separation distance of 2 $ft/lb^{1/3}$ (.8 $m/kg^{1/3}$) and extend out to about 10 $ft/lb^{1/3}$ (4 $m/kg^{1/3}$). Stations to the rear (180 degree line) should start at and end at the same distances. The gage line extending from the side of the structure (90 degree line) should start at a scaled distance of 1.25 $ft/lb^{1/3}$ (.5 $m/kg^{1/3}$), and extend out to 50 $ft/lb^{1/3}$ (20 $m/kg^{1/3}$). The separation distance is measured from the internal wall of the steel arch for side to side separation distances and from the end walls for front and back separations rather than the center of the storage area. The gage station distances were measured from the geometric center of the flat side of the charge and therefore an adjusted distance of .26 feet (.079 m) was added to the separation distance on the 90 degree line

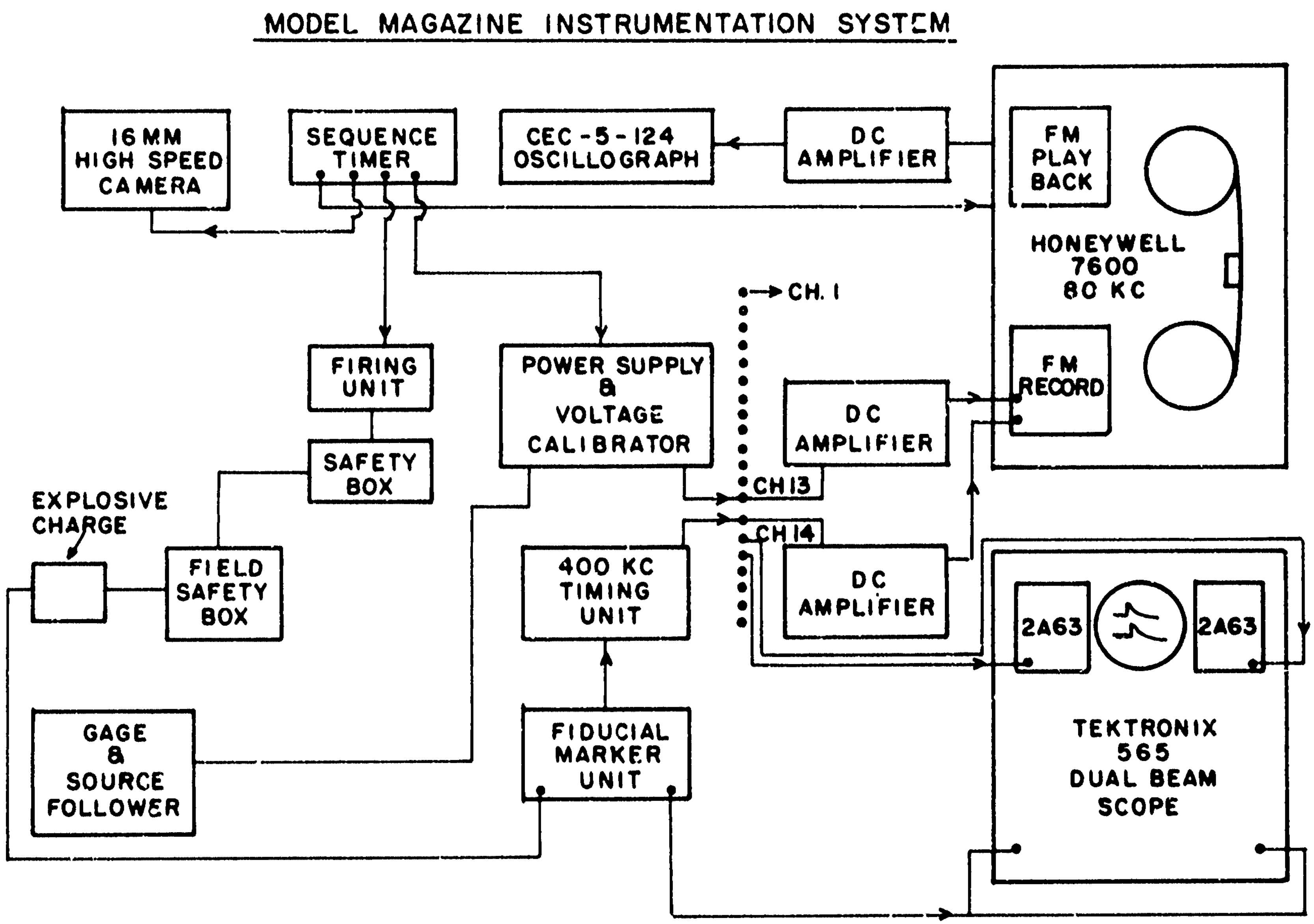


Figure 5. Model Magazine Instrumentation System

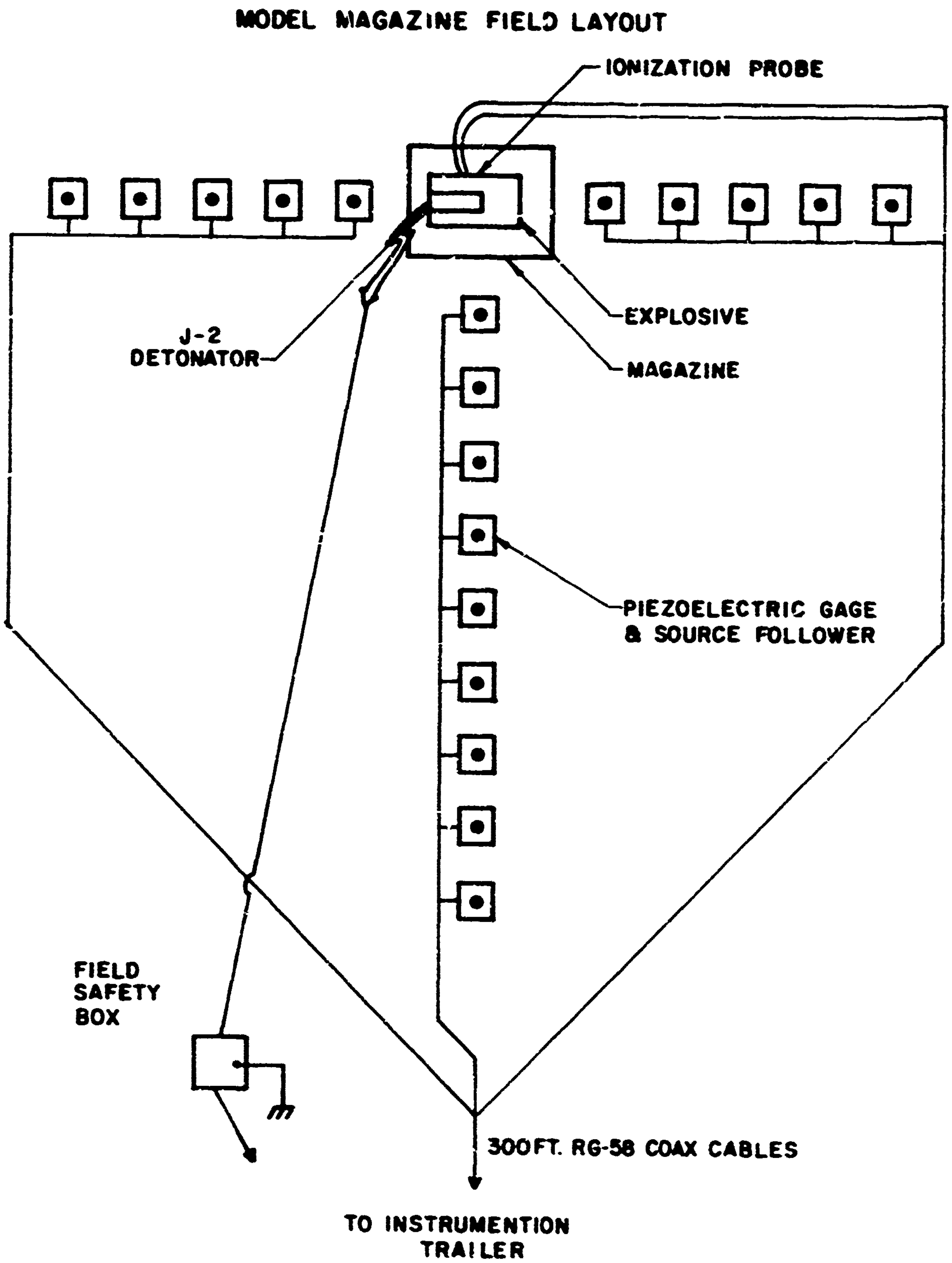


Figure 6. Model Magazine Field Layout

and .6 feet (.183 m) was added to the 180 and 0 degree lines. The station locations for the three charge weights are listed in Table III. Note that the distances remained the same for the uncovered tests and all earth covered tests.

Table III. Gage Station Locations

	CHARGE WT.					
	.8 lb	.363 kg	2.4 lb	1.088 kg	4.0 lb	1.814 kg
Station	DISTANCE					
No.	ft	m	ft	m	ft	m
0-1	2.45	.750	3.28	1.00	3.77	1.15
0-2	3.77	1.15	4.41	1.34	4.41	1.34
0-3	4.41	1.34	5.88	1.79	5.88	1.79
0-4	5.88	1.79	8.16	2.49	8.16	2.49
0-5	8.16	2.49	12.0	3.66	12.0	3.66
*0-6	12.0	3.66	18.0	5.49	18.0	5.49
90-1	1.42	.433	1.93	.588	2.24	.683
90-2	2.46	.750	3.28	1.00	3.77	1.15
90-3	3.77	1.15	4.67	1.42	4.67	1.42
90-4	4.67	1.42	6.68	2.04	6.68	2.04
90-5	6.68	2.04	9.10	2.77	9.10	2.77
90-6	9.10	2.77	13.3	4.05	13.3	4.05
90-7	13.3	4.05	23.2	7.07	23.2	7.07
90-8	23.2	7.07	41.7	12.7	41.7	12.7
90-9	41.7	12.7	73.5	22.4	73.5	22.4
180-1	2.46	.750	3.28	1.00	3.77	1.15
180-2	3.77	1.15	4.41	1.34	4.41	1.34
180-3	4.41	1.34	5.88	1.79	5.88	1.79
180-4	5.88	1.79	8.16	2.49	8.16	2.49
180-5	8.16	2.49	12.0	3.66	21.0	3.66
*180-6	12.0	3.66	18.0	5.49	18.0	5.49

*Additional Station for the one-half of standard earth covered model tests.

E. Test Matrix

The test series was designed to meet the objectives with a minimum number of shots. Therefore, in establishing the base line for comparison only two charge weights were fired in the "no earth cover" environment. The data from the 0.8 pound (0.363 kg) and 4.0 pound (1.814 kg) charges were used to predict the blast parameters for the 2.4 pound (1.088 kg) charge. The study of the blast attenuation from the one-half covered model was added to the series after the completion of the standard and double cover. The use of the dual-beam oscilliscopes was dropped in favor of a second magnetic tape recorder. Therefore, a test shot was fired to repeat one of the conditions of the first series to check the change in instrumentation as well as a new lot of modeling sand used for simulating the earth cover. The repeat shot was with a standard earth cover model containing a 0.8 pound (0.363 kg) explosive charge. The number of shots fired, the charge weights, and the test conditions are listed in Table IV.

Table IV. Test Matrix

Charge Weight lb	Charge Weight kg	M_N No Cover	M_S Standard Cover	M_D Double Cover	M_H One-Half Cover
0.8	0.363	3	4	3	3
2.4	1.088		3		3
4.0	1.814	3	3	3	3

M_N - will be used to denote the test firings with a bare charge - no cover

M_S - will denote a model test with the standard earth cover - 0.04 feet (0.012 m) covering the apex of the arch

M_D - will denote a model test with double the standard earth cover, 0.08 feet (0.024 m) covering the apex of the arch

M_H - will denote a model test with one-half the standard earth cover 0.02 feet (0.006 m) covering the apex of the arch.

III. RESULTS

The results will be presented for the individual charge weights because each one represents a specific amount of explosive stored in a full size magazine. The volume of the model remains constant and therefore direct scaling from one charge weight to another should not be expected.

The complete overpressure versus time was recorded at each gage station. The data presented in this report will include the peak overpressure and impulse in tabular and graphic form. With the exception of the standard cover and smallest charge, three shots were fired for each configuration but average or mean values will be tabulated and plotted.

A. The 0.8 Pound (0.363 kg) Charge

This charge was modeled to represent 100,000 pounds (45,360 kg) of high explosive munition stored in a standard 60 foot magazine. The first series of shots was fired with the bare hemicylindrical charge placed with the flat side resting on the surface and the detonator end of the charge near the 0 degree blast line. The peak overpressure and impulse measured along the three blast lines are listed in Tables V and VI for the four conditions; i.e., uncovered, standard cover, double cover, and one-half cover.

1. Blast Parameters Along 0 Degree Line The average peak overpressure values versus distance measured along the 0 degree blast line for the four conditions are listed in Table V and plotted in Figure 7. The peak overpressure along the zero degree blast line was expected to be higher when the charge was covered because the mass of earth around the other three sides of the structure tend to focus more of the blast energy out the front of the structure. The pressure value at the second station for the double cover test is based on only one datum point which is probably lower than it should be. There appears to be little difference in the magnitude of the blast pressures along the 0 degree gage line between the standard and double covered magazine for this charge weight. The peak overpressures versus distance recorded for the half-covered model follow the same trend as the uncovered charge but with pressure enhancement of approximately 40 percent. There is a pressure enhancement of approximately 100 percent for the standard and double covered model over the uncovered charge.

The positive pressure impulse measured under the same conditions as described in the preceeding paragraph are listed in Table VI. The values listed are average values from three data points. The average values listed in the table are plotted in Figure 8. The same trend established for the peak overpressure is again shown in the impulse, in that the impulse is higher when the earth cover is over the charge. The accuracy of impulse measured at the first station is very questionable for the uncovered condition and the datum point has not been plotted in Figure 8. A dashed line indicates the possible trend. There is an enhancement of impulse recorded when the one-half standard earth cover model is placed over the charge. There is an increased impulse enhancement when the standard earth covered model is used. But when the double earth covered model configuration was used there appeared to be no further increase in the recorded impulse along the 0 degree line. The data from the standard and double models are represented with one curve in Figure 8. They show approximately the same enhancement (100 percent) as noted for the peak overpressure at the first three stations but the enhancement only about 30 percent at the last two stations. The one-half cover model data show approximately 40 percent enhancement at the first three stations and less than 10 percent at the last two stations.

Table V. Peak Overpressure from a 0.8 Pound (0.363 kg) Charge

Station	Distance from Ground Zero		Uncovered Peak Overpressure		Std. Cover Peak Overpressure		Double Cover Peak Overpressure		One-Half Cover Peak Overpressure	
	feet	metres	psi	bar	psi	bar	psi	bar	psi	bar
0-1	2.46	.750	83.7	5.84	179.	12.3	181.	12.5	150.	10.3
0-2	3.77	1.15	74.9	3.30	84.4	5.82	60.5	4.17	64.4	4.44
0-3	4.41	1.34	29.3	2.02	59.0	4.07	49.8	3.43	42.3	2.92
0-4	5.88	1.79	20.4	1.41	34.5	2.38	37.2	2.56	24.8	1.71
0-5	8.16	2.49	9.88	.681	18.5	1.28	20.6	1.42	13.0	.896
0-6	12.0	3.66	-	-	5.70	.393	-	-	7.34	.506
90-1	1.42	.433	832.	57.4	45.2	3.12	31.5	2.17	53.9	3.72
90-2	2.45	.750	334.	23.0	29.6	2.04	20.6	1.42	40.3	2.78
90-3	3.77	1.15	101.	6.96	17.6	1.21	12.8	.882	24.6	1.70
90-4	4.67	1.42	47.4	3.27	14.0	.965	8.34	.575	18.9	1.30
90-5	6.68	2.04		-	10.4	.717	7.50	.517	12.2	.841
90-6	9.10	2.77	10.6	.731	7.01	.483	5.52	.381	7.30	.503
90-7	13.3	4.05	5.16	.356	4.23	.292	3.76	.259	4.58	.316
90-8	23.2	7.07	1.94	.134	1.73	.119	1.53	.105	1.88	.130
90-9	41.7	12.7	0.79	.054	0.78	.054	0.74	.051	0.76	.052
180-1	2.45	.750	639.	44.1	22.2	1.53	17.6	1.21	38.0	2.62
180-2	3.77	1.15	312.	21.5	13.6	.938	12.3	.848	18.2	1.25
180-3	4.41	1.34	158.	10.9	12.0	.827	10.1	.696	14.8	1.02
180-4	5.88	1.79	38.4	2.65	8.72	.601	8.61	.594	10.6	.731
180-5	8.16	2.49	10.0	.689	5.93	.409	5.27	.363	6.46	.445
180-6	12.0	3.66	-	-	3.24	.223	-	-	3.62	.249

Table VI. Impulse from the 0.8 Pound (0.363 kg) Charge

Station	Distance from Ground Zero		Uncovered Impulse		Std. Cover Impulse		Double Cover Impulse		One-Half Cover Impulse	
	feet	metres	psi-msec	bar-msec	psi-msec	bar-msec	psi-msec	bar-msec	psi-msec	bar-msec
0-1	2.46	.750	25.8	1.78	23.6	1.63	24.7	1.70	19.9	1.37
0-2	3.77	1.15	10.5	.724	19.8	1.36	19.1	1.32	15.5	1.07
0-3	4.41	1.34	8.2	.565	15.1	1.04	13.0	.896	11.9	.820
0 4	5.88	1.79	8.9	.614	10.8	.745	11.8	.814	9.66	.666
0-5	8.16	2.49	6.9	.476	7.4	.510	8.1	.558	7.40	.510
0-6	12.0	3.66	-	-	5.2	.358	-	-	4.31	.297
90-1	1.42	.433	34.2	2.36	10.4	.717	8.5	.586	12.0	.827
90-2	2.46	.750	13.5	.930	8.1	.558	7.4	.510	10.1	.696
90-3	3.77	1.15	11.1	.765	7.6	.524	6.9	.476	8.63	.595
90-4	4.67	1.42	8.9	.614	6.0	.414	5.2	.358	7.74	.534
90-5	6.68	2.04	-	-	6.1	.421	5.9	.407	6.50	.448
90-6	9.10	2.77	6.2	.427	4.9	.338	4.9	.338	5.01	.345
90-7	13.3	4.05	4.3	.296	3.6	.248	3.5	.241	3.73	.257
90-8	23.2	7.07	2.6	.179	2.3	.159	2.1	.145	2.27	.156
90-9	41.7	12.7	1.6	.110	1.4	.096	1.2	.083	1.32	.091
180-1	2.46	.750	27.1	1.87	5.4	.372	5.4	.372	6.04	.416
180-2	3.77	1.15	-	-	5.3	.365	5.0	.345	5.75	.396
180-3	4.41	1.34	20.5	1.41	4.9	.338	5.0	.345	5.41	.373
180-4	5.88	1.79	10.1	.697	4.3	2.96	4.4	.303	4.46	.307
180-5	8.16	2.49	6.0	.414	3.5	.241	3.6	.248	3.77	.260
180-6	12.0	3.66	-	-	2.7	.186	-	-	2.81	.194

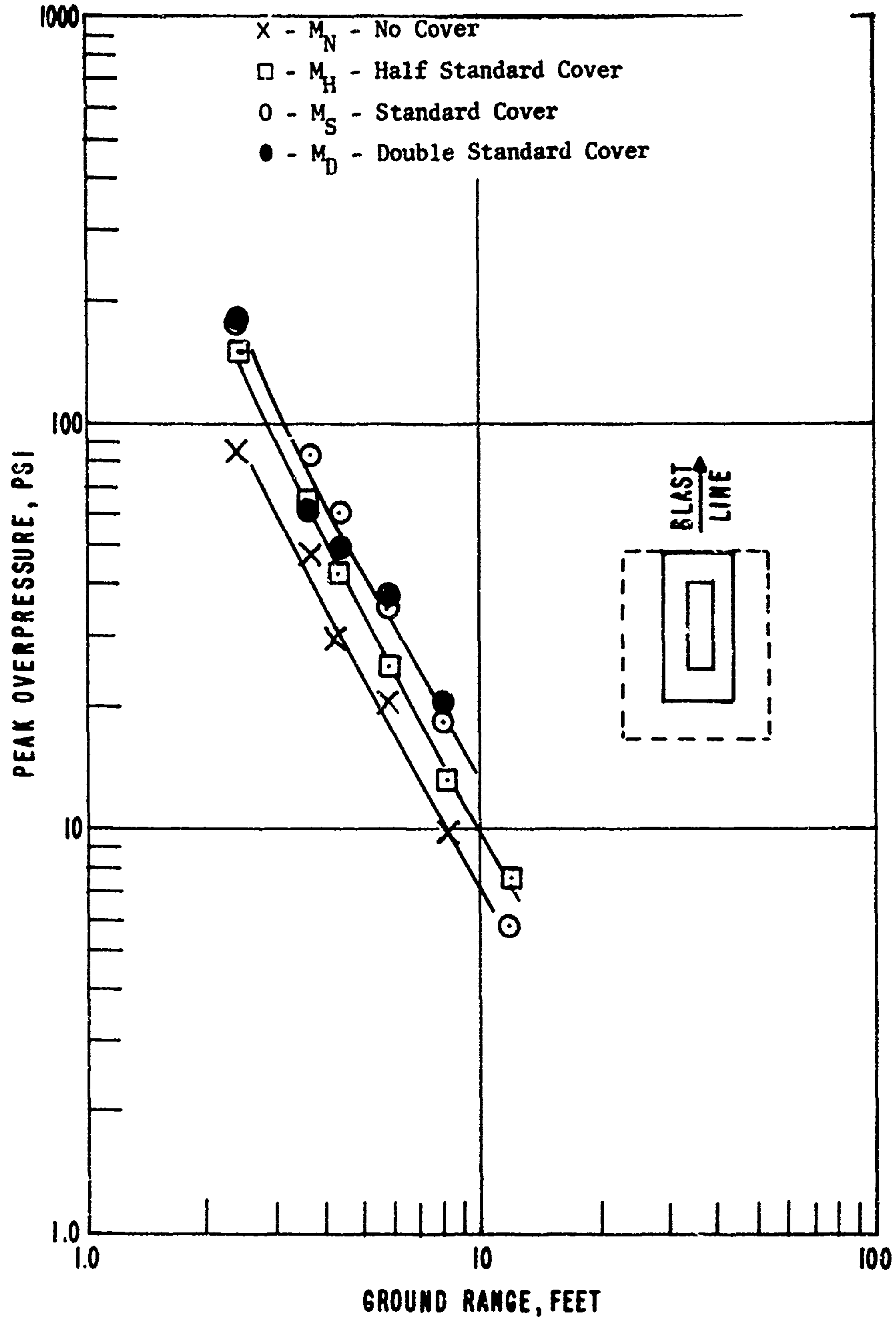


Figure 7. Pressure versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

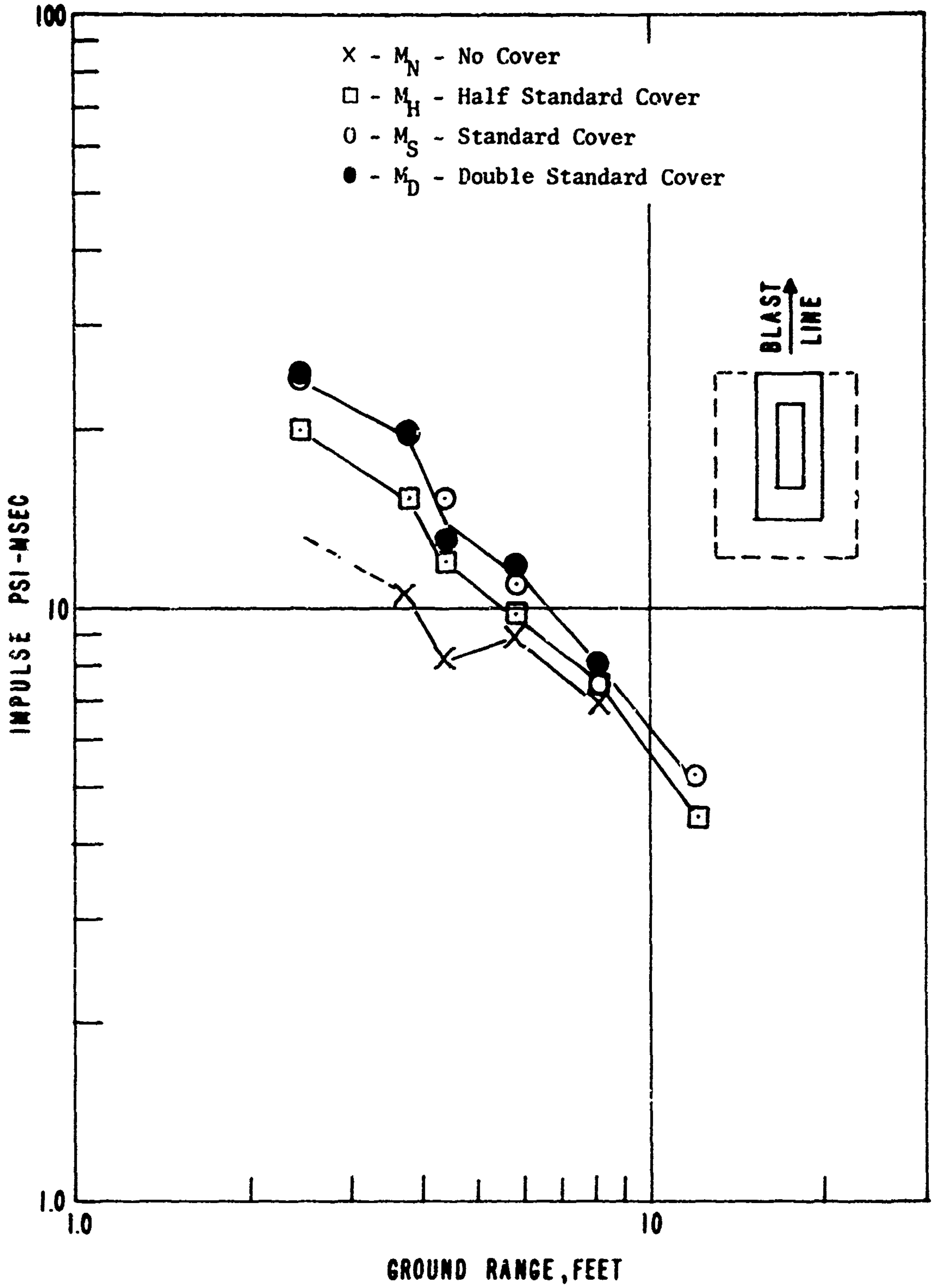


Figure 8. Impulse versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

2. <u>Blast Parameters Along the 90 Degree Line</u> Measured peak overpressure and impulse along the 90 degree blast line for the four test conditions are listed in Tables V and VI. A total of nine stations were instrumented starting at a scaled separation distance of 1.25 ft/lb$^{1/3}$ (.5 m/kg$^{1/3}$). The peak overpressure results listed in Table V for the 90 degree blast line are presented graphically in Figure 9. As the earth cover is increased, the blast attenuation is increased. It should also be noted that as the distance increases the peak overpressure attenuation decreases. The difference in the four average values of pressure measured at the last station is ±3 percent.

The impulse versus distance measured along the 90 degree line for the four test configurations are listed in Table VI and plotted in Figure 10. Here the impulse measurements show a trend similar to the one established for the peak overpressure with the exception of the decrease in attenuation with distance. From the fifth station to the last station the percentage of attenuation remains approximately constant. The half-cover and standard covered models show approximately a 15 percent attenuation while the double earth covered model gives a 20 percent attenuation.

3. <u>Blast Parameters Along the 180 Degree Line</u> The 180 degree line was established to the rear of the structure. The peak overpressure measured along this line is listed in Table V. The values from Table V are plotted in Figure 11. There is a dramatic drop in the peak overpressure at the close-in positions when one-half standard earth cover model was tested and the results compared with an uncovered charge. The peak overpressures measured from the standard cover and double cover models show further reductions. Approximately a 10 percent pressure reduction is noted when going from the standard to the double cover magazine.

The impulse measurements along the 180 degree line are listed in Table VI and plotted in Figure 12. There is no measurable difference in the recorded impulse from the 0.8 pound (0.363 kg) charge detonated in the standard and double earth covered models. There is only a 10 percent greater value noted at the first three stations from the same charge weight detonated in a one-half standard earth cover model.

B. <u>The 2.4 Pound (1.088 kg) Charge</u>

There were six 2.4 pound (1.088 kg) charges fired. Three were detonated in the standard earth covered model magazine and three were detonated with one half of the standard earth cover in place. To establish a basis for comparing the effect of the earth covers versus no cover the results from the 0.8 pound (0.363 kg) and 4 pound (1.814 kg) charges fired without cover were scaled to a 2.4 pound (1.088 kg) equivalent. There were no tests conducted for the 2.4 pound (1.088 kg) charge detonated in a model magazine with double the standard earth cover. It was assumed that results from the 0.8 pound (0.363 kg) and 4 pound (1.814 kg) charges could be used to interpolate effects for the mid-range

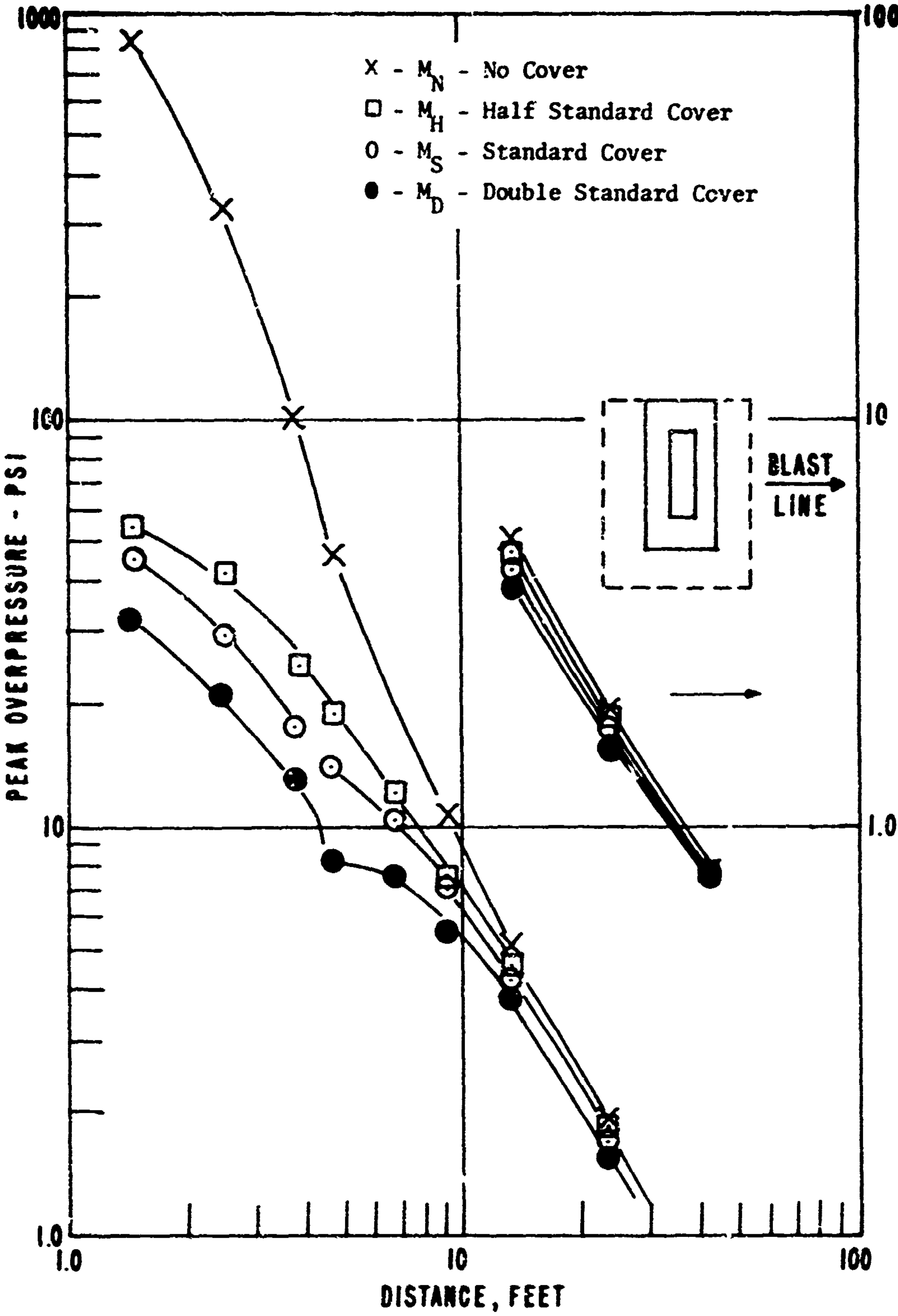


Figure 9. Pressure versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

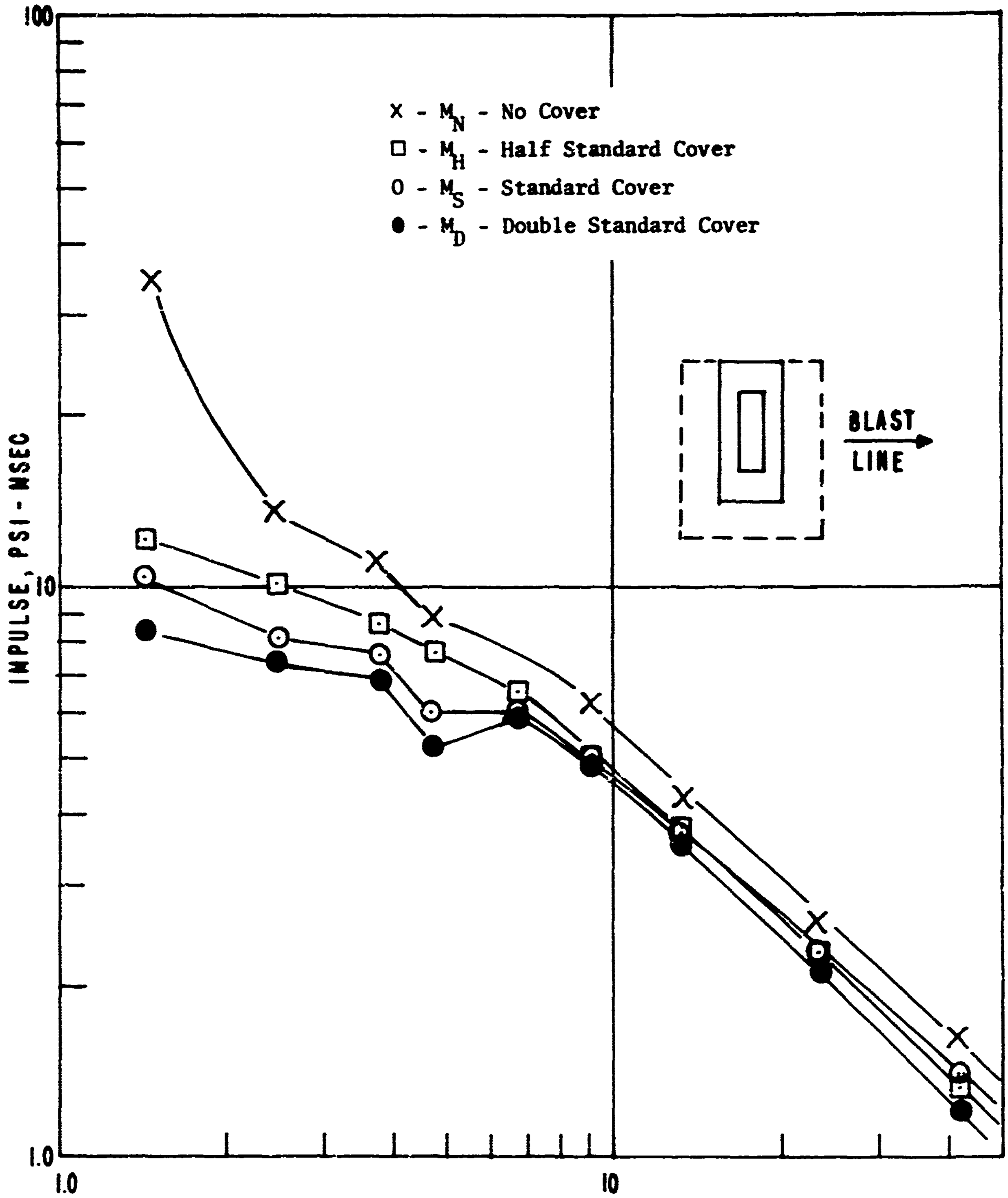


Figure 10. Impulse versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

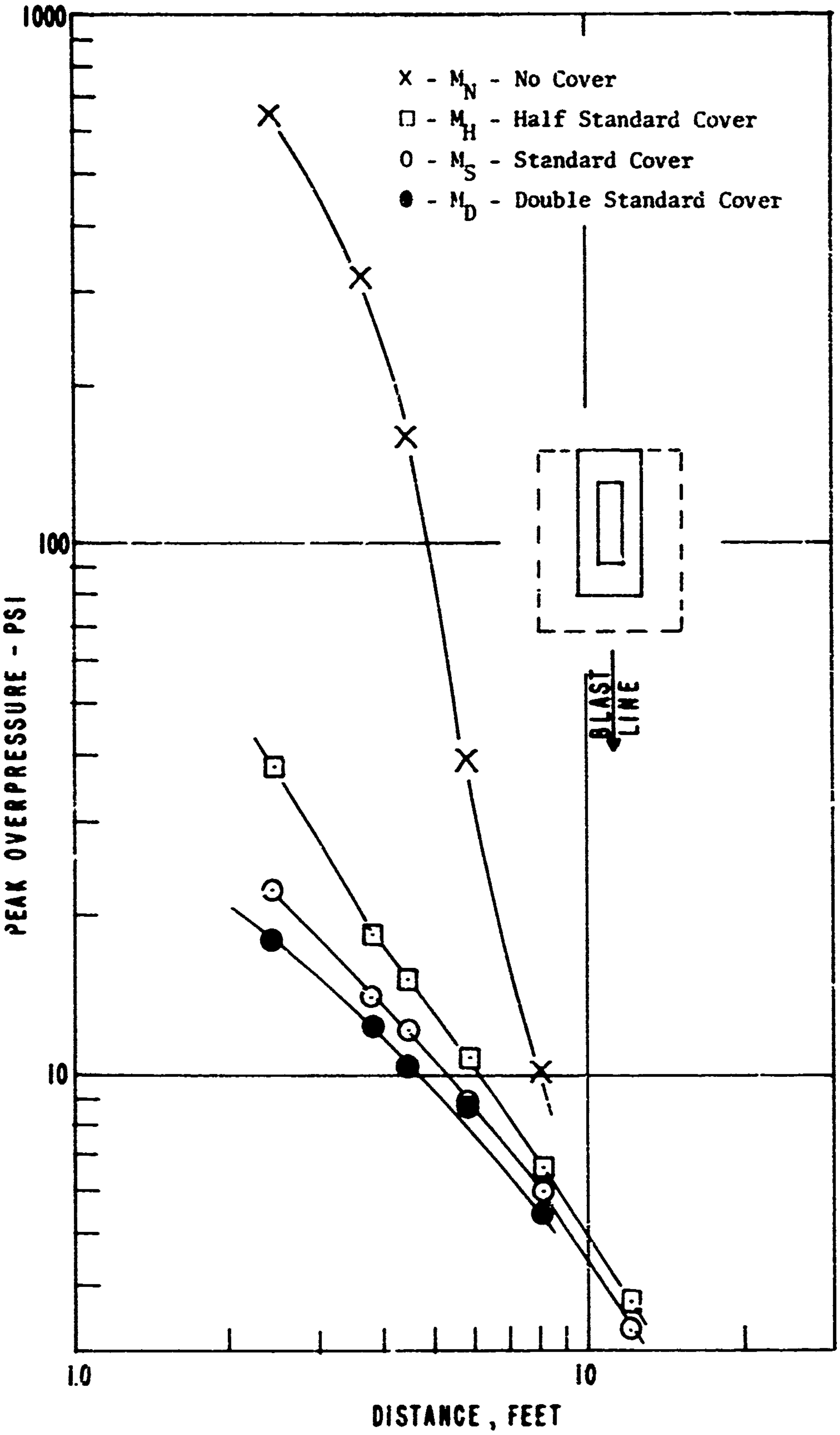


Figure 11. Pressure versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

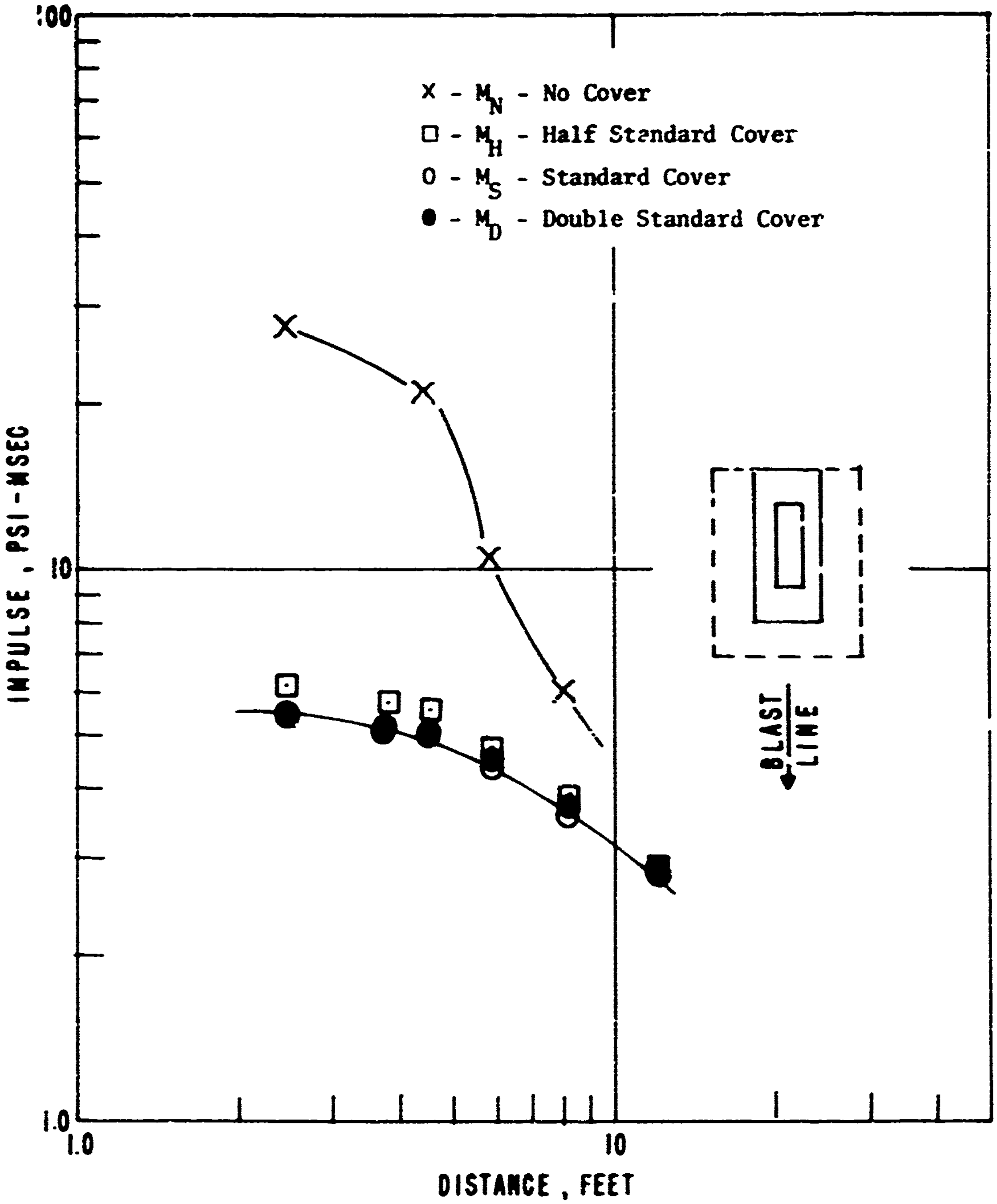


Figure 12. Impulse versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 0.8 Pound (0.363 kg) Charge

charge weight. The peak overpressure and impulse values listed in Tables V, VI, X, and XI for the uncovered charge condition have been scaled to 2.4 pound (1.088 kg) equivalent and are listed in Tables VIIa and VIIb.

Table VIIa. Peak Overpressure and Impulse from 0.8 Pound (0.363) Charge Scaled to 2.4 Pound (1.088 kg)

Station No.	Distance		Pressure		Impulse	
	feet	metres	psi	bars	psi-msec	bar-msec
0-1	3.55	1.08	84.7	5.84	37.2	2.56
0-2	5.44	1.66	47.9	3.28	15.1	1.04
0-3	6.36	1.94	29.3	2.02	11.8	.814
0-4	8.48	2.58	20.4	1.41	12.8	.882
0-5	11.8	3.60	9.88	.681	9.96	.687
90-1	2.05	.625	832.	57.4	49.4	3.41
90-2	3.55	1.08	334.	23.0	19.5	1.34
90-3	5.44	1.66	101.	6.96	16.0	1.10
90-4	6.74	2.05	47.4	3.27	12.8	.882
90-5	9.36	2.85	-	-	-	-
90-6	13.1	3.99	10.6	.731	8.94	.616
90-7	19.2	5.85	5.16	.356	6.20	.427
90-8	33.5	10.2	1.94	.134	3.75	.259
90-9	60.1	18.3	0.79	.054	2.31	.159
180-1	3.55	1.08	639.	44.1	39.0	2.69
180-2	5.44	1.66	312.	21.5	-	-
180-3	6.36	1.94	158.	10.9	29.6	2.04
180-4	8.48	2.58	38.4	2.65	15.7	1.08
180-5	11.8	3.60	10.0	.689	8.65	.596

Table VIIb. Peak Overpressure and Impulse from a 4.0 Pound (1.814 kg) Charge Scaled to 2.4 Pound (1.088 kg)

Station No.	Distance		Pressure		Impulse	
	feet	metres	psi	bars	psi-msec	bar-msec
0-1	3.18	.969	175.	12.1	23.0	1.59
0-2	3.72	1.13	133.	9.17	30.4	2.10
0-3	4.96	1.51	72.6	5.01	21.4	1.47
0-4	6.88	2.10	28.6	1.97	13.8	.951
0-5	10.1	3.08	12.1	.834	11.2	.772
90-1	1.89	.576	900.	62.1	37.8	2.61
90-2	3.18	.969	483.	33.3	60.2	4.15
90-3	3.94	1.20	229.	15.8	25.2	1.74
90-4	5.63	1.72	67.5	4.65	18.8	1.30
90-5	7.68	2.34	37.6	2.59	13.1	.903
90-6	11.2	3.41	15.2	1.05	10.8	.745
90-7	19.6	5.97	4.40	.303	6.41	.442
90-8	35.2	10.7	1.91	.132	3.88	.265
90-9	62.0	18.9	0.52	.036	1.60	.110
180-1	3.18	.969	659.	42.1	62.2	4.29
180-2	3.72	1.13	635.	43.8	39.1	2.70
180-3	4.96	1.51	467.	32.2	35.1	2.42
180-4	6.88	2.10	138.	9.51	24.6	1.70
180-5	10.1	3.08	21.8	1.50	10.1	.696

1. Blast Parameters Along the 0 Degree Line The peak overpressures and impulses measured along the 0 degree instrumentation line from the detonation of a 2.4 pound (1.088 kg) charge for the model magazine with a standard earth cover and with a one-half standard earth cover are listed in Tables VIII and IX. The peak overpressure values listed are plotted in Figure 13 with peak overpressure as a function of distance for the three conditions. There was no significant difference in pressure measured between the standard earth cover model and the one-half standard earth cover along the 0 degree line. The peak overpressures were approximately 30 percent higher than those measured for the uncovered condition.

The positive impulse values listed in Table VIIb for the uncovered condition and in Table IX for the standard and one-half earth cover model are presented in Figure 14. The positive impulse is plotted as a function of distance for the three conditions. There was no significant difference measured in the standard and one-half earth cover models. A comparison of the covered and uncovered condition indicate similar values close-in and beyond 8 feet (2.44 metres), but the values of impulse for the uncovered condition are lower than the covered condition over the mid-range distance.

Table VIII. Peak Overpressure from a 2.4 Pound (1.088 kg) Charge

Station	Distance from Ground Zero		Std. Cover Peak Overpressure		One-Half Std. Cover Peak Overpressure	
	feet	metres	psi	bar	psi	bar
0-1	3.28	1.00	178.	12.3	198.	13.7
0-2	4.41	1.34	121.	8.34	123.	8.40
0-3	5.88	1.79	72.0	4.96	58.0	4.00
0-4	8.16	2.49	28.5	1.96	28.9	1.99
0-5	12.0	3.66	13.3	.917	10.1	.696
0-6	18.0				4.83	.333
90-1	1.43	.588	63.4	4.37	79.0	5.45
90-2	3.28	1.00	39.8	2.74	43.6	3.01
90-3	4.67	1.42	25.8	1.78	28.8	1.99
90-4	6.68	2.04	15.1	1.04	20.9	1.44
90-5	9.10	2.77	12.3	.848	16.0	1.10
90-6	13.3	4.05	8.04	.554	8.46	.583
90-7	23.2	7.07	3.85	.265	4.26	.294
90-8	41.7	12.7	1.81	.125	1.85	.128
90-9	73.5	22.4	0.76	.052	0.78	.054
180-1	3.28	1.00	31.9	2.20	40.1	2.76
180-2	4.41	1.34	19.3	1.33	26.7	1.84
180-3	5.88	1.79	12.4	.855	16.7	1.15
180-4	8.16	2.49	9.40	.648	11.3	.779
180-5	12.0	3.66	5.63	.388	6.58	.454
180-6	18.0				3.76	.259

Table IX. Impulse from a 2.4 Pound (1.088 kg) Charge

Station	Distance from Ground Zero		Std. Cover Impulse		One-Half Std. Cover Impulse	
	feet	metres	psi-msec	bar-msec	psi-ms	bar-ms
0-1	3.28	1.00	25.8	1.78	22.3	1.54
0-2	4.41	1.34	31.9	2.20	30.5	2.10
0-3	5.88	1.79	21.5	1.48	21.9	1.51
0-4	8.16	2.49	14.9	1.03	13.7	.945
0-5	12.0	3.66	9.13	.629	8.93	.616
0-6	18.0	5.49			3.83	.264
90-1	1.93	.588	16.4	.841	19.5	1.24
90-2	3.28	1.00	14.5	1.00	16.4	1.13
90-3	4.67	1.42	13.2	.910	14.7	1.01
90-4	6.68	2.04	10.1	.696	12.9	.889
90-5	9.10	2.77	11.3	.779	12.2	.841
90-6	13.3	4.05	9.0	.620	8.79	.600
90-7	23.2	7.07	5.29	.365	6.19	.427
90-8	41.7	12.7	3.42	.236	3.68	.254
90-9	73.5	22.4	1.93	.133	2.05	.141
180-1	3.28	1.00	10.6	.731	9.86	.680
180-2	4.41	1.34	8.4	.579	9.77	.674
180-3	5.88	1.79	8.26	.570	8.50	.586
180-4	8.16	2.49	7.69	.530	7.58	.523
180-5	12.0	3.66	6.80	.469	6.34	.437
180-6	18.0	5.49			5.26	.363

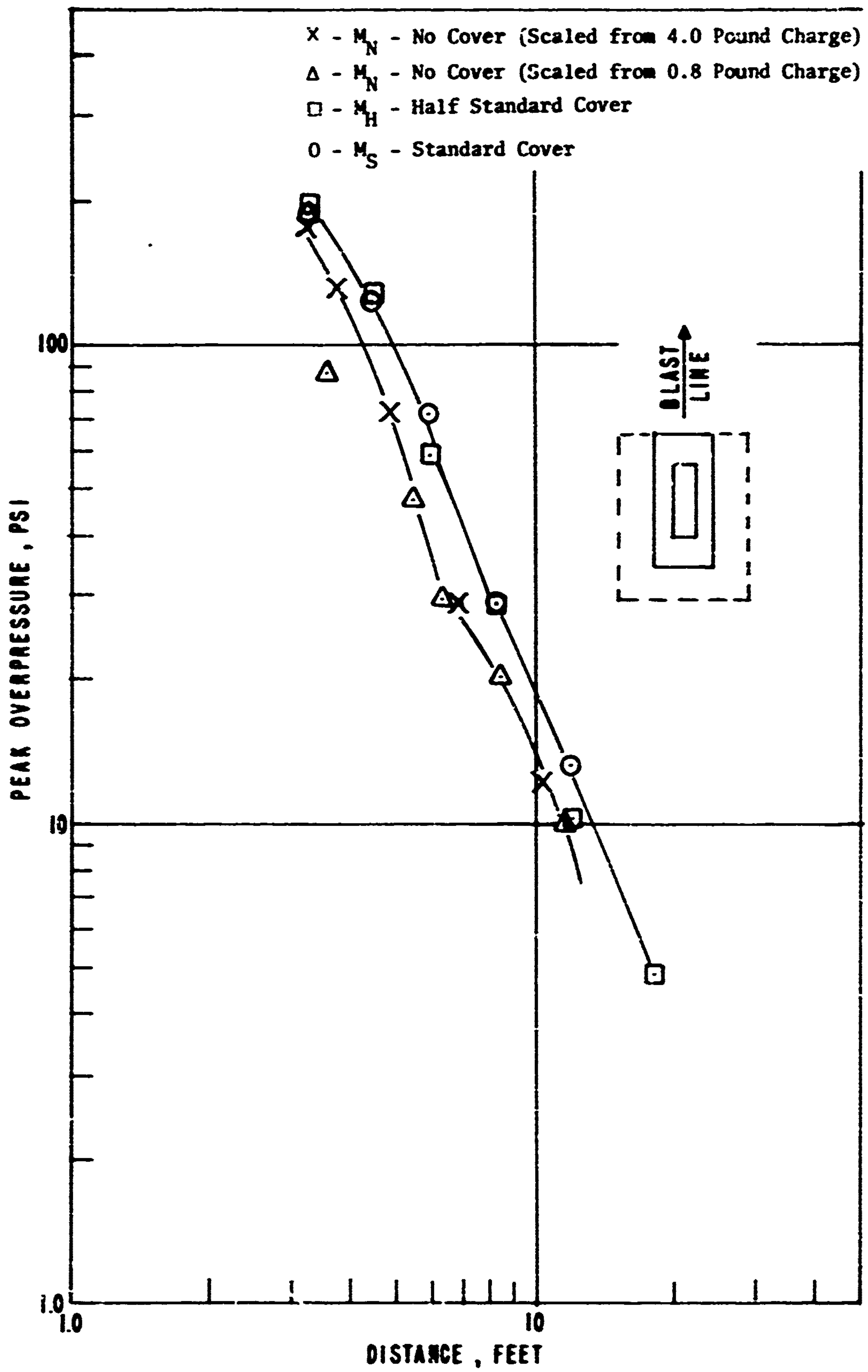


Figure 13. Pressure versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

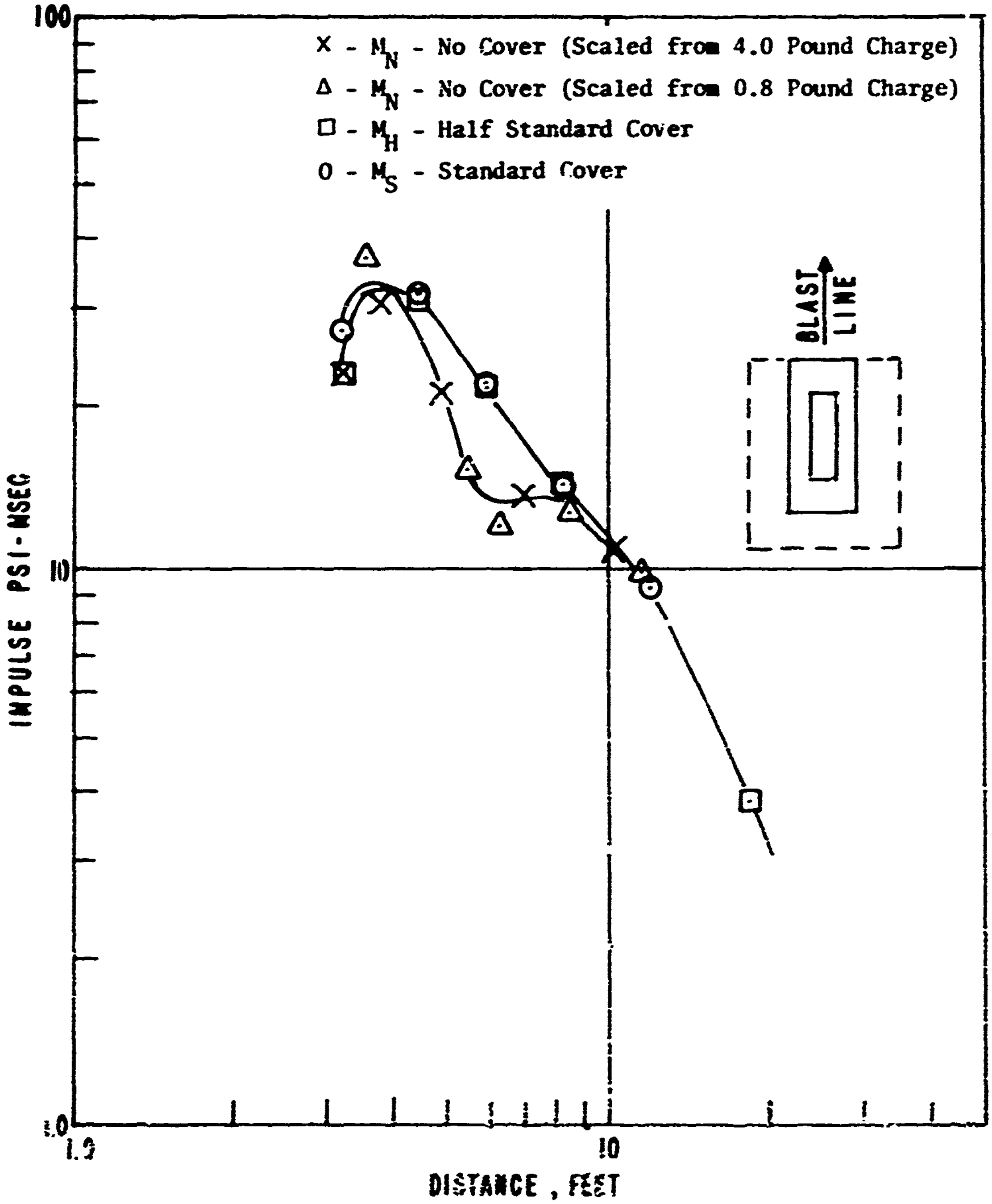


Figure 14. Impulse versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

2. Blast Parameters Along the 90 Degree Line The peak overpressures and impulses predicted along the 90 degree instrumentation line for the 2.4 pound (1.088 kg) charge in the uncovered condition, were based on scaled data measured from the detonation of 0.8 pound (0.363 kg) and 4.0 pound (1.814 kg) charges. These data are listed in Tables VIIa and VIIb and plotted in Figures 15 and 16.

The values of peak overpressure as a function of distance along the 90 degree line for the standard and one-half earth cover models are listed in Table VIII and plotted in Figure 15. The attenuation of peak overpressure measured in going from a one-half earth cover model to the standard cover is approximately 20 percent at the first 5 stations and 5 percent at the last 4 stations. There is an attenuation of peak overpressure by a factor of 10 at the first station between the covered and uncovered condition. This factor rapidly decreases with distance and becomes 1 at a distance of 17 feet (5.182 metres). Beyond that distance the peak overpressure becomes greater for the covered charge than for the uncovered charge. This was not expected and should have significant impact on the relative locations of earth covered munition magazines and residential or inhabited structures.

The impulse versus distance for the 2.4 pound (1.088 kg) charge in the uncovered configuration was established by scaling the impulse versus distance measured from the .8 pound (.363 kg) and 4 pound (1.814 kg) charges to that weight. These values are listed in Table VIIb and plotted in Figure 16. There is wide scatter of data points at the first two stations and therefore a curve has not been drawn through those points. The impulse measurements for the standard and one-half covered magazine are listed in Table XI. These values are plotted in Figure 16. The trend to be noted here is that measured impulse from the covered and uncovered charges converge at a value of 9 psi-msec (.621 bar-msec) at a distance of 13 feet (3.96 metres). There is no significant difference in the data from the three conditions from that point on with the one value from the 4 pound (1.814 kg) charges appears low at a distance of 62 feet (18.9 metres).

3. Blast Parameters Along the 180 Degree Line. The peak overpressure versus distance along the 180 degree line for the 2.4 pound (1.088 kg) charge uncovered was established from the values recorded from the .8 pound (.363 kg) and 4 pound (1.814 kg) charges. The scaled values are listed in Table VIIa and plotted in Figure 17. The scaled values show a reasonable decay of peak overpressure versus distance and is concluded to be representative of a 2.4 pound (1.088 kg) charge.

The peak overpressures versus distance measured from the 2.4 pound (1.088 kg) charge in a standard and one-half standard earth cover magazine are listed in Table VIII. These values are plotted in Figure 17. There is a significant attenuation in peak overpressure to the rear of the structure when the charge is fired in the covered magazine models. The attenuation becomes less with increasing distance and it appears that

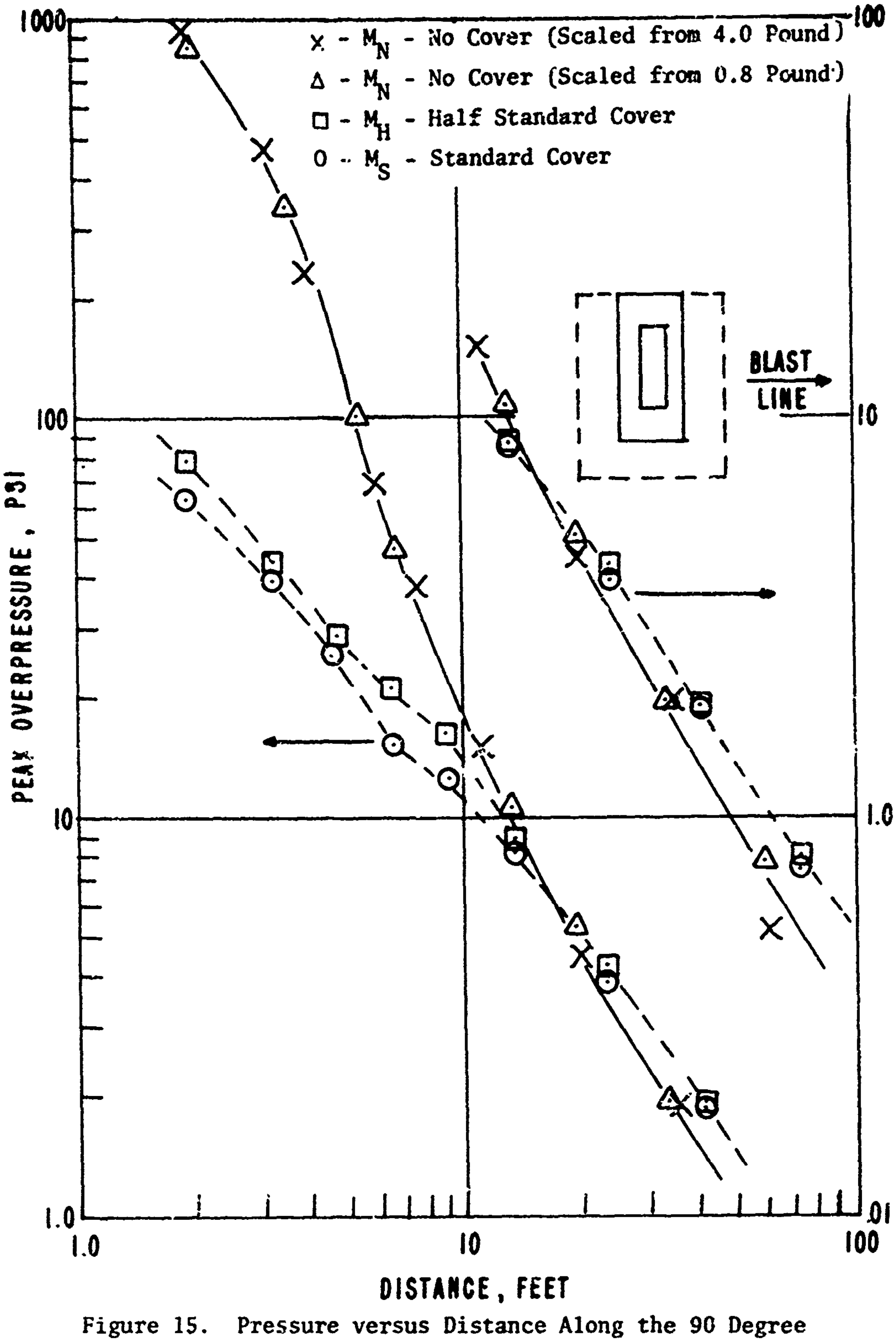


Figure 15. Pressure versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

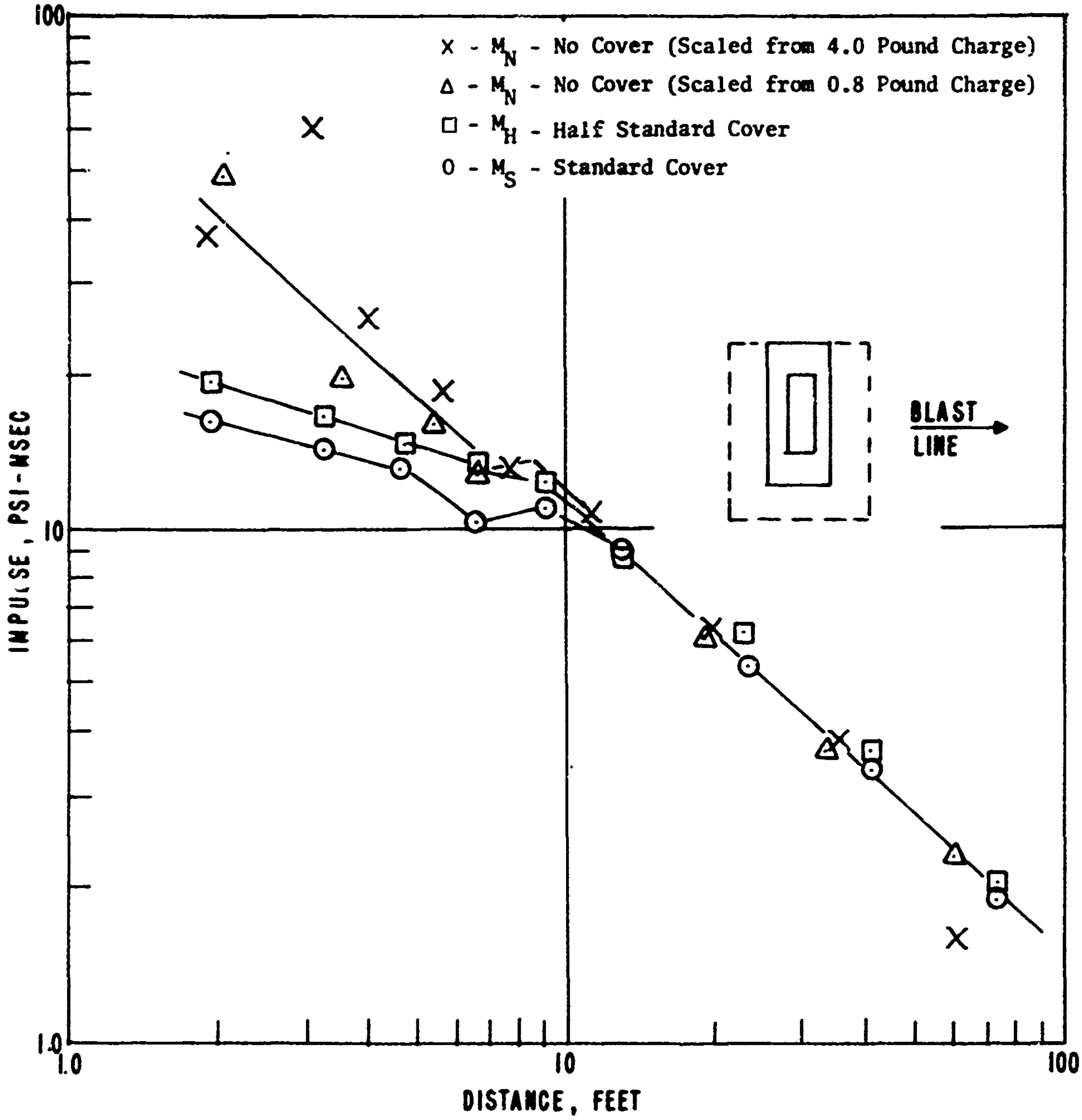


Figure 16. Impulse versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

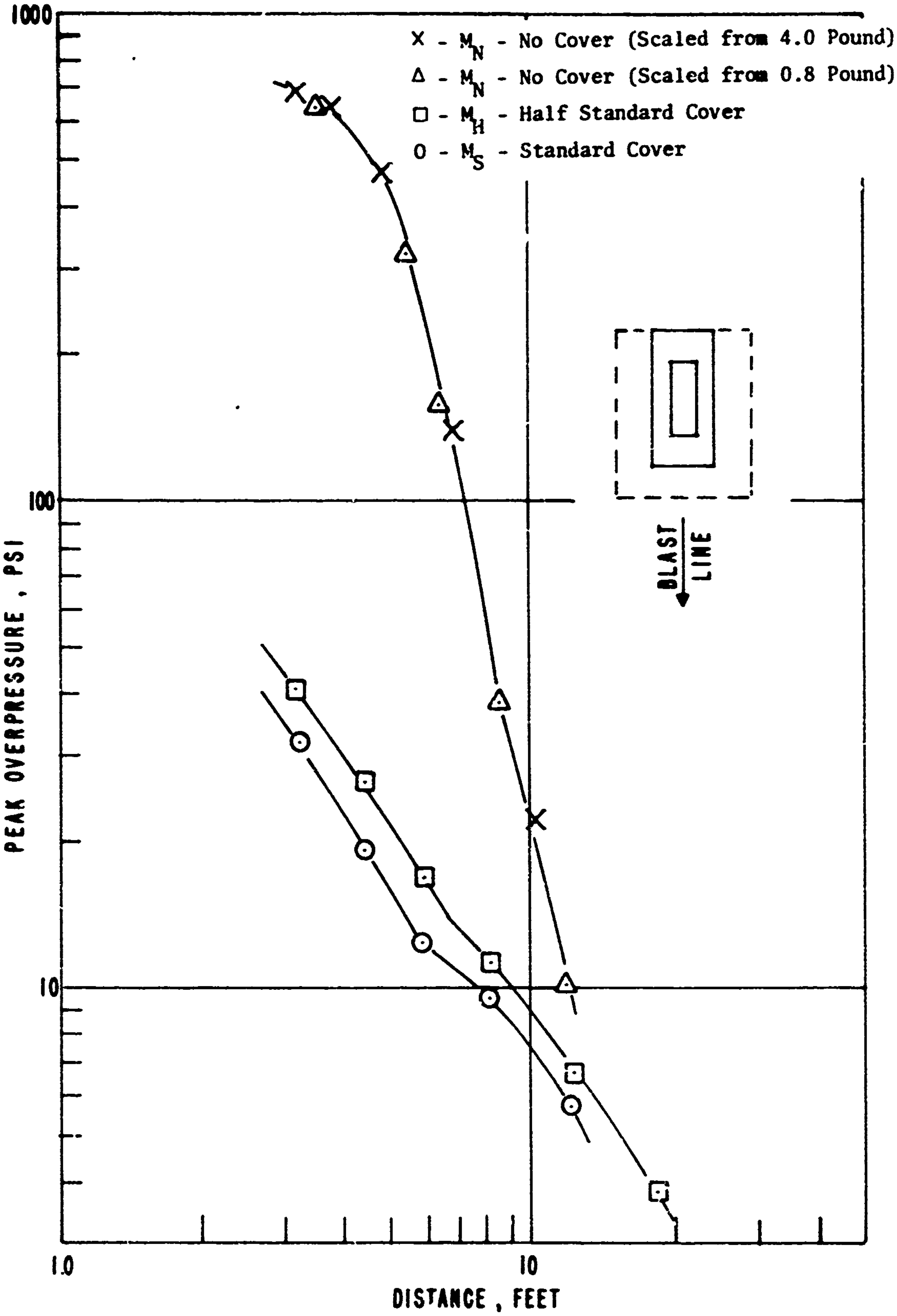


Figure 17. Pressure versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

curves for the uncovered and one-half covered conditions will converge at greater distances. The attenuation of peak overpressure in going from one-half standard earth cover model to the standard earth cover is approximately 20 percent with slightly less at the greater distances.

The impulse versus distance for the 2.4 pound (1.088 kg) charge uncovered, was established from the measurements made on the .8 pound (.363 kg) and 4 pound (1.814 kg) charges and scaled to 2.4 pounds (1.058 kg). These values are listed in Table VIIb and plotted in Figure 18.

The value of impulse versus distance measured for the 2.4 pound (1.088 kg) charge detonated in the standard earth cover and one-half standard earth cover model magazines are listed in Table IX and plotted in Figure 18. The impulse plotted at the first station for the uncovered charge is a questionable datum point based on only one measurement. There is a significant impulse attenuation at the close-in stations when the explosive is covered. But there was no measurable attenuation between the impulse recorded for the two earth covered conditions.

C. The 4.0 Pound (1.814 kg) Charge

The 4.0 pound (1.814 kg) hemicylindrical charge was designed to represent 500,000 pounds (226,800 kg) of high explosive munition stored in a standard storage magazine. The charge was detonated with the flat side on the surface without cover, in model magazines with one-half standard earth cover, standard earth cover, and double earth cover. Three tests were conducted under each condition and the average values of peak overpressure and impulse along the three blast lines are listed in Tables X and XI. The mean values listed in Tables X and XI for the 0, 90, and 180 degree directions are plotted in Figures 19 through 24.

1. Blast Parameters Along the 0 Degree Line The peak overpressures listed in Table X along the 0 degree line for the four test conditions are presented in Figure 19. Here it is quite evident that the peak overpressures along the 0 degree line are higher for the three covered magazines than for the uncovered magazine. This increase is in the order of 50 percent for the one-half standard and standard earth cover model magazines. The increase in peak overpressure along the 0 degree line for the double earth cover is an average of 80 percent over the uncovered high explosive.

The impulse measurements made along the degree line are listed in Table XI for the four test conditions and plotted as a function of distance in Figure 20. The trend established for the impulse is not as well defined as that established for the peak overpressure measurements. The impulse measured from detonations in the one-half, single cover, and double cover magazine show only minor differences along the blast line. Similar values were documented at the two close-in stations and the last station with significant differences measured at the third and fourth stations. A similar trend was noted on the 2.4 pound (1.088 kg) charge weight where the first and last stations have similar values with the covered magazine recording higher impulse values at the in-between stations.

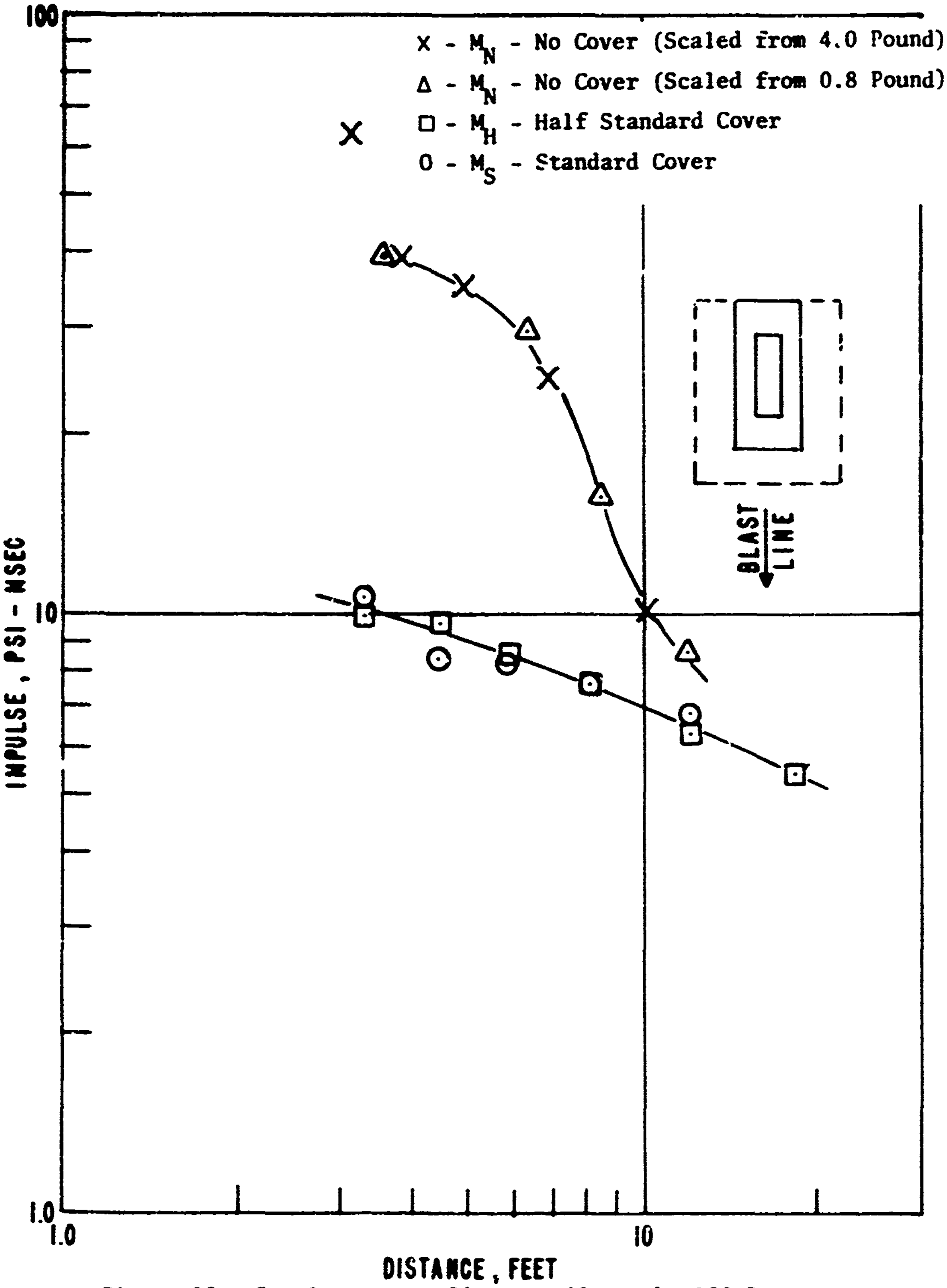


Figure 18. Impulse versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 2.4 Pound (1.088 kg) Charge

Table X. Peak Overpressure from a 4 Pound (1.814 kg) Charge

Station	Distance from Ground Zero		Uncovered Peak Overpressure		Std. Cover Peak Overpressure		Double Cover Peak Overpressure		One-Half Cover Peak Overpressure	
	feet	metres	psi	bar	psi	bar	psi	bar	psi	bar
0-1	3.77	1.15	175.	12.1	218.	15.0	221.	15.2	219.	15.1
0-2	4.41	1.34	133.	9.17	187.	12.9	204.	14.1	174.	12.0
0-3	5.88	1.79	72.6	5.01	122.	8.41	118.	8.14	104.	7.17
0-4	8.16	2.49	28.6	1.97	69.0	4.76	71.7	4.94	60.6	4.18
0-5	12.0	3.66	12.1	.834	19.0	1.31	26.2	1.81	18.5	1.28
0-6	18.0	5.49	-	-	-	-	-	-	6.14	.423
90-1	2.24	.683	900.	62.1	99.0	6.83	74.6	5.14	90.3	6.23
90-2	3.77	1.15	483.	33.3	51.0	3.52	41.5	2.86	55.1	3.80
90-3	4.67	1.42	229.	15.8	32.8	2.26	31.1	2.14	40.6	2.80
90-4	6.68	2.04	67.5	4.65	18.8	1.30	18.0	1.24	27.0	1.86
90-5	9.10	2.77	37.6	2.59	18.1	1.25	17.0	1.17	20.8	1.43
90-6	13.3	4.05	15.2	1.05	12.9	.889	11.5	.793	12.6	.869
90-7	23.2	7.07	4.40	.303	5.90	.407	6.00	.414	5.99	.413
90-8	41.7	12.7	1.87	.131	2.53	.172	2.53	.172	2.55	.176
90-9	73.5	22.4	0.52	.036	1.00	.069	0.80	.055	1.00	.069
180-1	3.77	1.15	610.	42.1	32.2	2.22	22.0	1.52	38.0	2.62
180-2	4.41	1.34	607.	41.9	28.6	1.97	19.4	1.34	32.4	2.23
180-3	5.88	1.79	467.	32.2	18.5	1.28	15.9	1.10	23.1	1.59
180-4	8.16	2.49	138.	9.51	12.3	.848	11.5	.793	16.3	1.12
180-5	12.0	3.66	21.8	1.50	8.50	.586	7.27	.503	9.79	.675
180-6	18.0	5.49	-	-	-	-	-	-	5.90	.407

Table XI. Impulse from a 4 Pound (1,814 kg) Charge

Station	Distance from Ground Zero		Uncovered Impulse		Std. Cover Impulse		Double Cover Impulse		One-Half Cover Impulse	
	feet	metres	psi-msec	bar-msec	psi-msec	bar-msec	psi-msec	bar-msec	psi-msec	bar-msec
0-1	3.77	1.15	27.4	1.89	40.0	2.76	30.1	2.06	27.5	1.90
0-2	4.41	1.34	36.0	2.48	32.8	2.26	34.1	2.35	30.8	2.12
0-3	5.88	1.79	25.4	1.75	32.6	2.25	35.7	2.46	32.5	2.24
0-4	8.16	2.49	16.4	1.13	24.2	1.67	24.1	1.66	19.5	1.34
0-5	12.0	3.66	13.3	.917	12.4	.855	13.2	.910	13.8	.951
0-6	18.0	5.49	-	-	-	-	-	-	7.41	.511
90-1	2.24	.683	57.2	3.96	23.3	1.61	20.3	1.40	22.5	1.55
90-2	3.77	1.15	71.4	4.92	19.5	1.34	18.7	1.29	20.0	1.38
90-3	4.67	1.42	29.9	2.06	16.3	1.12	15.4	1.06	18.8	1.30
90-4	6.68	2.04	22.3	1.54	12.8	.882	12.2	.841	16.1	1.11
90-5	9.10	2.77	17.5	1.21	16.0	1.10	15.3	1.05	16.5	1.14
90-6	13.3	4.05	12.8	.882	13.5	.931	13.0	.896	10.9	.751
90-7	23.2	7.07	7.60	.524	8.67	.598	8.03	.554	8.72	.601
90-8	41.7	12.7	4.60	.317	5.17	.356	4.50	.310	5.28	.364
90-9	72.5	22.1	1.87	.129	3.00	.207	2.13	.147	2.95	.203
180-1	3.77	1.15	65.4	4.51	11.4	.786	10.5	.723	12.3	.848
180-2	4.41	1.34	47.5	3.27	11.7	.807	8.5	.586	13.0	.896
180-3	5.88	1.79	41.6	2.87	11.6	.800	10.7	.738	11.7	.807
180-4	8.16	2.49	29.2	2.01	12.5	.862	10.9	.752	11.1	.765
180-5	12.0	3.66	12.0	.827	10.2	.703	9.07	.625	9.47	.653
180-6	18.0	5.49	-	-	-	-	-	-	7.91	.545

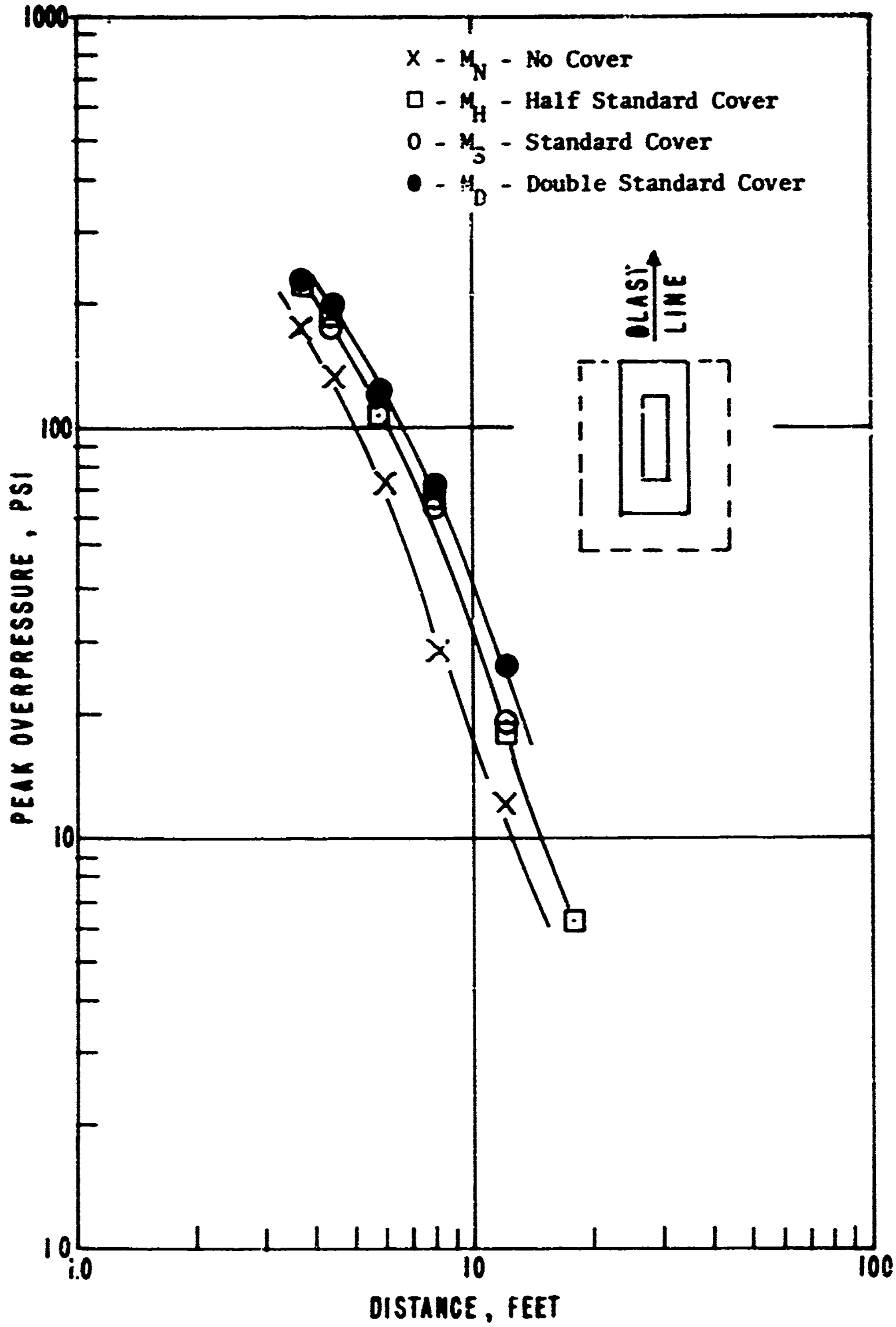


Figure 19. Fressure versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

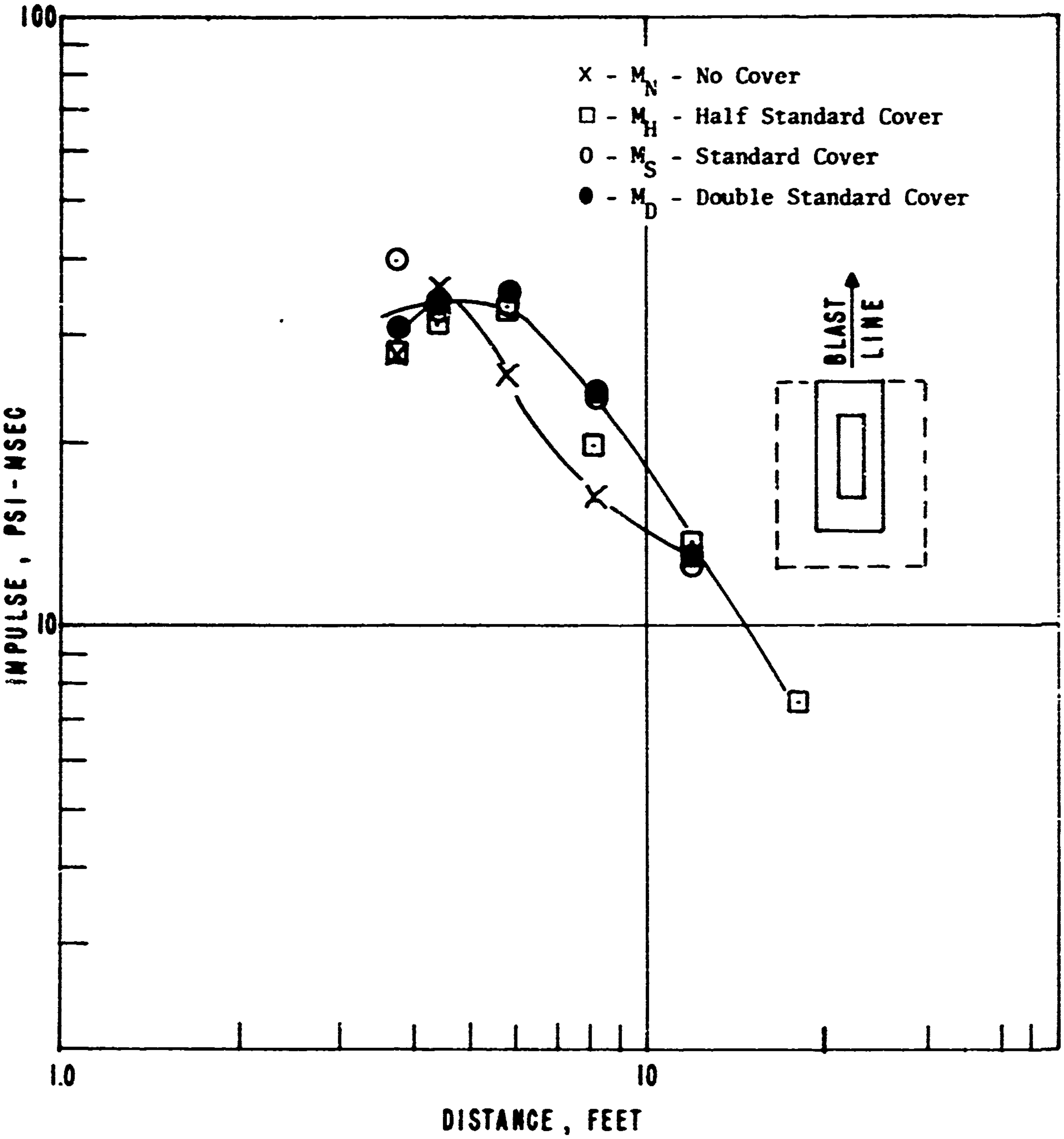


Figure 20. Impulse versus Distance Along the 0 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

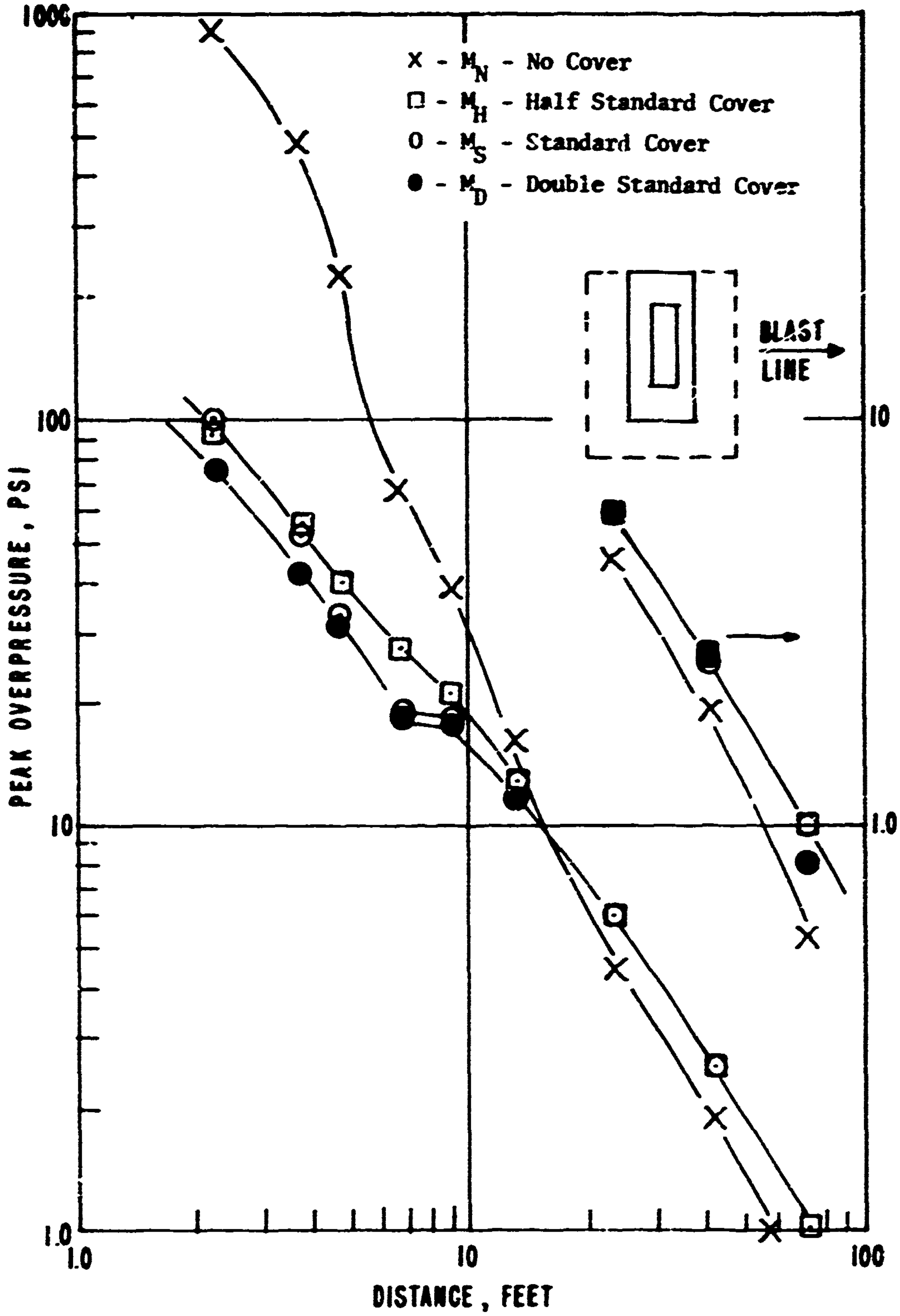


Figure 21. Pressure versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

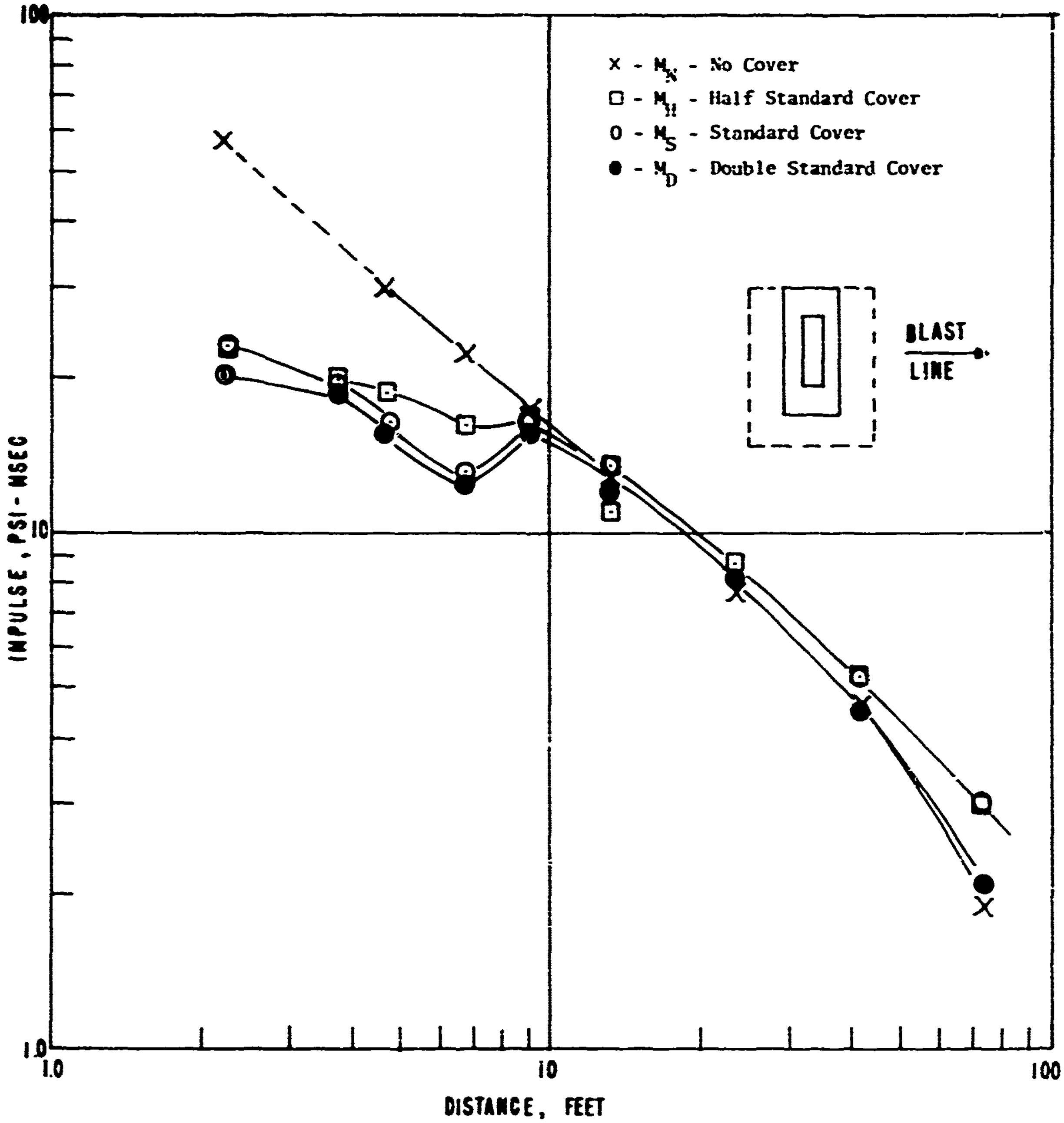


Figure 22. Impulse versus Distance Along the 90 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

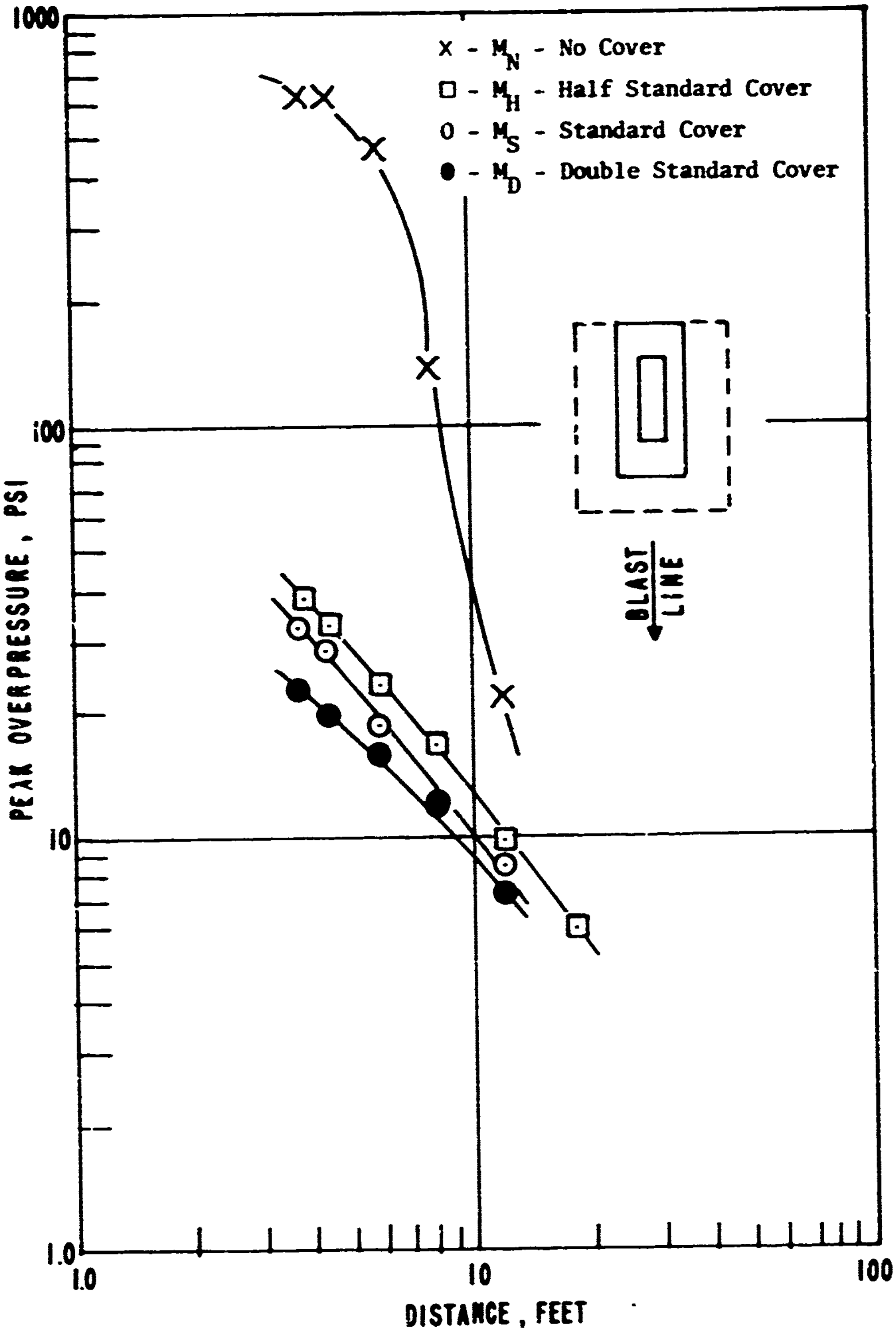


Figure 23. Pressure versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

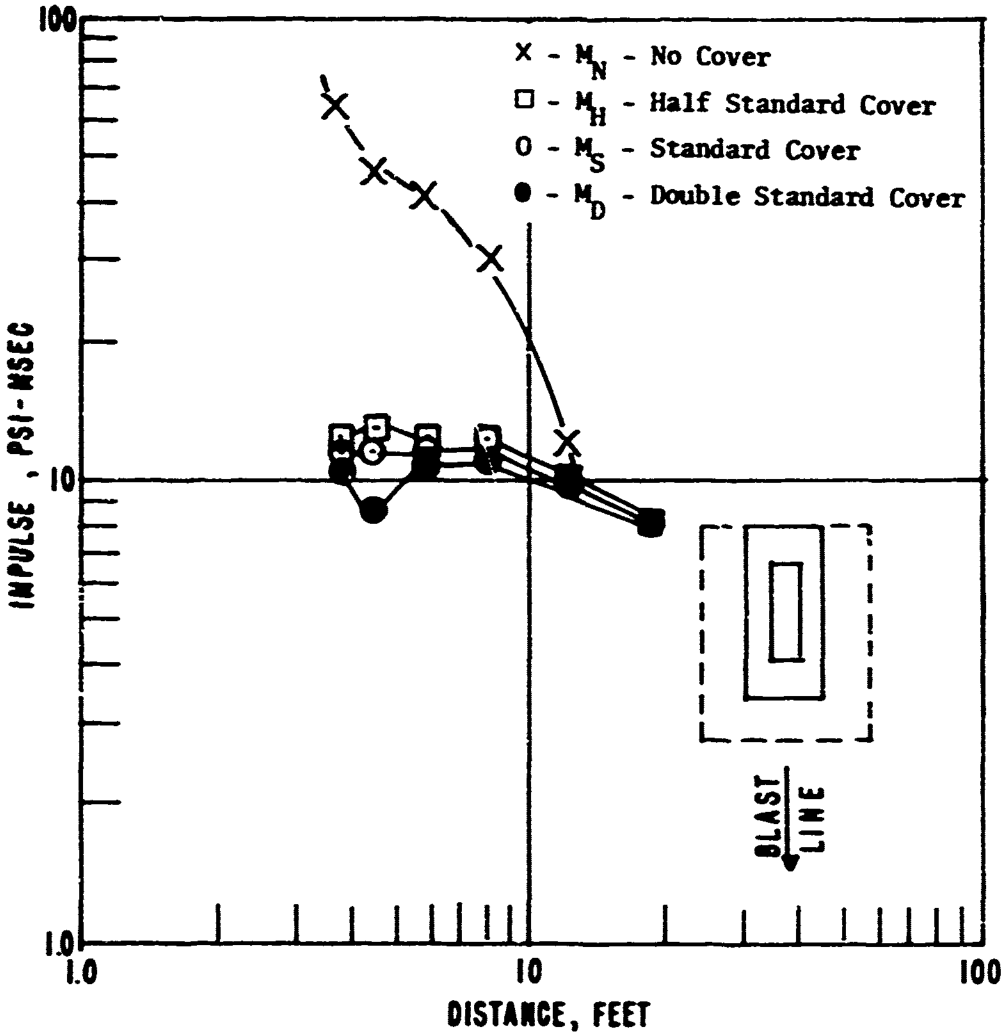


Figure 24. Impulse versus Distance Along the 180 Degree Line as a Function of Earth Cover for a 4.0 Pound (1.814 kg) Charge

2. <u>Blast Parameters Along the 90 Degree Line</u> The peak overpressures measured along the 90 degree line are listed in Table X for the four test conditions and plotted as peak overpressure versus distance in Figure 21. There are three things to note in Figure 21. First, the charge is larger and therefore the earth cover will have less effect in attenuating the peak overpressure. This can be seen at the first station where 900 psi (62 bars) measured on the uncovered condition has been reduced to 100 psi (6.89 bars) measured with the standard cover. On the .8 pound (.363 kg) the 900 psi (62 bars) pressure was attenuated to 48 psi (3.3 bars). A second point to note in that the change in cover thickness has less effect in blast attenuation with increase in charge weight. Most of the peak overpressure values measured along the 90 degree line fall within a ±10 percent band. A third point to note is the crossover point where the peak overpressure is greater from the covered magazines than from the uncovered charge. The .8 pound (.363 kg) charge did not show a crossover but the peak-overpressure versus distance curves for the covered magazines became parallel with the one for uncovered. The 2.4 pound (1.088 kg) charge showed a crossover, but at 5 psi (.345 bars), and remained approximately 30 percent higher than the uncovered charge. For the 4 pound (1.814 kg) charge the crossover occurs at 9 psi (.620 bars) and then the pressure versus distance curves become almost parallel with the covered magazine data being approximately 40 percent higher than the uncovered condition with the exception of the last station where it is greater than 40 percent.

The impulse measurements made along the 90 blast line for the four test conditions are listed in Table XI and plotted in Figure 22. The impulse measured at the second station on the uncovered condition is of questionable validity and therefore the impulse versus distance curve is not drawn through it.

The general shape of the impulse versus distance curve for the earth covered magazines are similar to the .8 pound (.363 kg) and 2.4 pound (1.088 kg) charges with the exception of the last two stations where uncovered and double earth models give similar values. The one-half and standard earth cover models show the same trend as established for peak overpressure in that higher impulse values were measured on covered models than the uncovered condition at the greater distance.

3. <u>Blast Parameters Along the 180 Degree Line</u> The peak overpressure and impulse propagated along the 180 degree line is of prime interest because of the blast load developed on the door and headwall of an acceptor magazine when located at the rear of a donor magazine. The peak overpressures measured along the 180 degree blast line for the four conditions tested with a 4 pound (1.814 kg) charge are listed in Table X and plotted in Figure 23. All three covered magazines cause significant pressure attenuation at the close-in stations. The double earth cover model attenuates the peak overpressure from 40 to 10 percent more than the standard earth cover model. The larger attenuation occurs at the first station. The standard earth cover model attenuates an average of 20 percent more than the one-half earth cover model.

The impulse values recorded to the rear of the structure (180 degree line) for the four test conditions are listed in Table XI and plotted in Figure 24 as function of distance for each test condition. It is of interest to note that although the peak overpressure along the 180 degree line decreased with distance the impulse remains almost constant over the first four stations, with a small decay occuring at the last two stations. There is less than a ±10 percent spread in the data points plotted for the three earth cover conditions with the exception of the second station with a double earth cover model.

D. Comparison of Model and Full-Scale Magazine Results

When this experimental program was first proposed and designed it was the opinion of the authors that relative differences in the effects of earth cover on blast parameters could be obtained from the 1/50 scaled models if the charge weights to interior structure volume ratios were maintained. It was also the opinion of the authors that these relative differences could be applied to full-size munition magazines. It was hoped, but not as strongly anticipated, that direct correlation of results from the model tests and full-scale tests could be achieved.

Results from a series of full-scale tests conducted during 1962 - 1963 are reported in Reference 2. In test six, of the series; a doner charge of 100,000 pounds (45,360 kg) in a standard 60 foot (18.29 m) storage magazine was detonated and the blast parameters to the front, side, and rear were measured This charge weight to structure volume ratio matches the 0.8 pound (0.363 kg) charge detonated in the 1/50th scale model magazine. Both the full scale and the 1/50th scale conditions have been scaled to a 1.0 pound (0.454 kg) charge at sea level and comparisons of blast parameters are made in the following sections.

1. Blast Parameters Along the 0 Degree Line The peak overpressure and impulse measured along the 0 degree line from the 0.8 pound (0.363 kg) charge have been scaled to 1.0 pound (0.454 kg) and listed in Table XII. The same blast parameters measured on the full-scale test 100,000 pounds (45,360 kg) have also been scaled to 1.0 pound (0.454 kg) and listed in Table XIII. The results of measured peak overpressure recorded from both scaled and full-size are plotted in Figure 25 as a function of scaled distance ($R/W^{1/3}$) where R is the distance in feet from the charge that the measurement was made and W is the weight of the explosive in pounds.

In Figure 25 it can be seen that excellent correlation was obtained between the model and full-scale results. The obvious low value of the full-scale test (Reference 2) at a scaled distance of 6.29 is a questionable datum point since the self-recording gage pre-initiated and recorded only a peak value.

Table XII. Scaled Blast Parameters - 0.8 Pound (0.363 kg) to 1.0 Pound (0.454 kg) - Standard Earth Cover

Station No.	Scaled Distance	Scaled Distance	Peak Overpressure		Scaled Impulse	
	$ft/lb^{1/3}$	$m/kg^{1/3}$	psi	bar	$psi\text{-}msec/lb^{1/3}$	$bar\text{-}msec/kg^{1/3}$
0-1	2.65	1.05	179.	12.3	25.4	2.12
0-2	4.06	1.61	84.4	5.82	21.3	1.77
0-3	4.75	1.88	59.0	4.07	16.3	1.35
0-4	6.33	2.51	34.5	2.38	11.6	.970
0-5	8.79	3.49	18.5	1.28	7.97	.664
0-6	12.9	5.13	5.70	.393	5.60	.466
90-1	1.53	.607	45.2	3.12	11.2	.933
90-2	2.65	1.05	29.6	2.04	8.72	.726
90-3	4.06	1.61	17.6	1.21	8.19	.682
90-4	5.03	1.99	14.0	.965	6.46	.539
90-5	7.20	2.86	10.4	.717	6.57	.548
90-6	9.80	3.88	7.0	.483	5.28	.440
90-7	14.3	5.68	4.23	.292	3.88	.323
90-8	25.0	9.91	1.73	.119	2.48	.207
90-9	44.9	17.8	0.78	.054	1.51	.125
180-1	2.65	1.05	22.2	1.53	5.82	.484
180-2	4.06	1.61	13.6	.938	5.71	.475
180-3	4.75	1.88	12.0	.827	5.28	.440
180-4	6.33	2.51	8.73	.601	4.63	.385
180-5	8.79	3.49	5.93	.409	3.77	.314
180-6	12.9	5.13	3.24	.223	2.91	.242

Table XIII. Scaled Blast Parameters - 100,000 Pounds (45,359 kg) to 1.0 Pound (0.454 kg)

Station No.	Scaled Distance	Scaled Distance	Peak Overpressure		Scaled Impulse	
	$ft/lb^{1/3}$	$m/kg^{1/3}$	psi	bar	$psi\text{-}msec/lb^{1/3}$	$bar\text{-}msec/kg^{1/3}$
0-N1	6.29	2.49	22.8	1.57	-	-
0-N2	10.5	4.18	9.62	.663	6.45	.578
0-N2A	10.5	4.18	7.12	.491	4.29	.384
0-N3	15.7	6.26	3.98	.274	3.93	.352
0-N4	21.0	8.37	2.71	.187	3.45	.309
0-N5	38.9	15.5	1.32	.091	2.09	.187
0-N6	76.1	30.3	0.43	.030	0.90	.081
90-W1	6.29	2.49	8.39	.578	-	-
90-W2	10.5	4.18	5.95	.410	5.45	.488
90-W2A	10.5	4.18	6.12	.422	5.54	.496
90-W3	15.7	6.26	4.04	.279	3.15	.282
90-W4	21.0	8.37	2.43	.168	-	-
90-W5	38.9	15.5	0.99	.068	1.59	.142
180-S1	6.29	2.49	11.1	.765	4.99	.447
180-S2	10.5	4.18	5.09	.351	3.11	.279
180-S3	15.7	6.26	2.69	.185	2.41	.216
180-S4	21.0	8.37	1.94	.134	2.07	.185
180-S5	38.9	15.5	0.60	.041	-	-

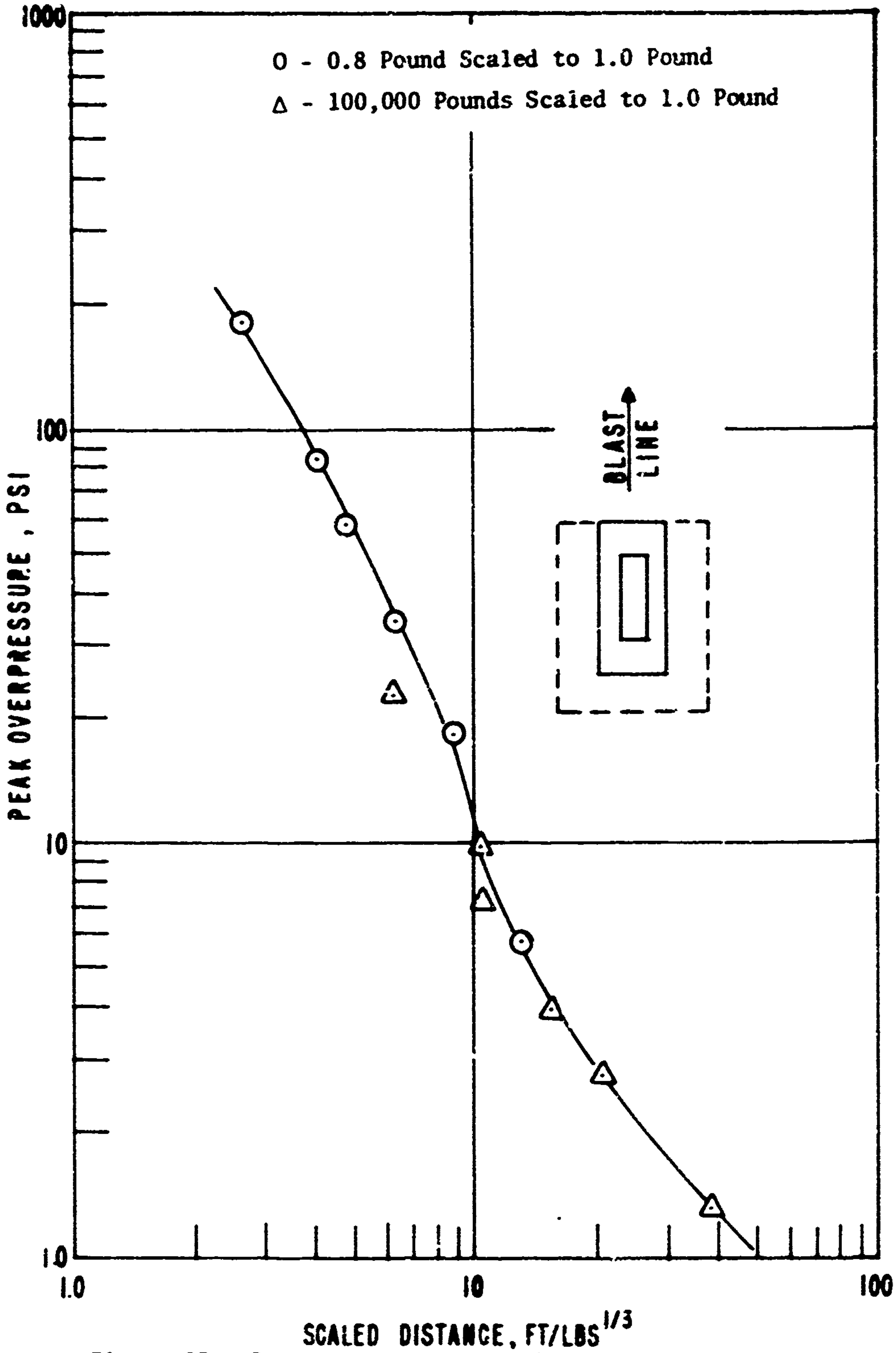


Figure 25. Pressure versus Scaled Distance Along the 0 Degree Line from a Full-Size Magazine and a 1/50 Scaled Model

The scaled impulse values $I/W^{1/3}$ where I is measured impulse from a charge weight of W pounds listed in Table XII and XIII are plotted in Figure 26 as a function of scaled distance. Here again the correlation of impulse measured to the front of the structures is excellent.

2. Blast Parameters Along the 90 Degree Blast Line The peak overpressures, scaled distances and scaled impulses recorded along the 90 degree blast line for both the model and full-size structure are listed in Tables XII and XIII.

The peak overpressures are plotted as a function of scaled distance in Figure 27. The peak overpressure measured at a scaled distance of 6.29 on the full scale test (Reference 2) is low but here again only a peak value was obtained because the gage failed to run. There was also an acceptor magazine in place along side of the donor magazine which could have caused a decrease in the peak overpressure at that distance. The solid curve was developed from the results of the scaled model tests but it fits the scaled results from the full size tests quite well.

The scaled impulse and scaled distance along the 90 degree line for both model and full-size tests are listed in Tables XII and XIII and plotted in Figure 28. Here again it can be seen that using simple cube root scaling gives good correlation of impulse as well as peak overpressure.

3. Blast Parameters Along the 180 Degree Blast Line The blast parameters recorded to the rear (180 degrees) of the full size and model structure have been scaled to a 1 pound (.454 kg) charge equivalent and listed in Tables XII and XIII.

The peak overpressures are plotted as a function of scaled distance in Figure 29. The correlation of the two sets of data is excellent with the exception of the peak overpressure measured at the first station from the full-size test.

In Figure 30 the scaled impulse is plotted as a function of scaled distance. It can be seen that there is good correlation between the two sets of data.

IV. SUMMARY AND CONCLUSIONS

In summary, it can be stated that the results of this series of tests have established many trends and the effects of varying the earth cover on blast parameters to the front, side, and rear of the structure have been documented. Some specific conclusions on earth cover effects along the three blast lines are given in the following sections.

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[2] *A. R. Sound, "Summary Report of Earth-Covered Steel-Arch Magazine Tests," NOTS TP 3843, July 1965.*

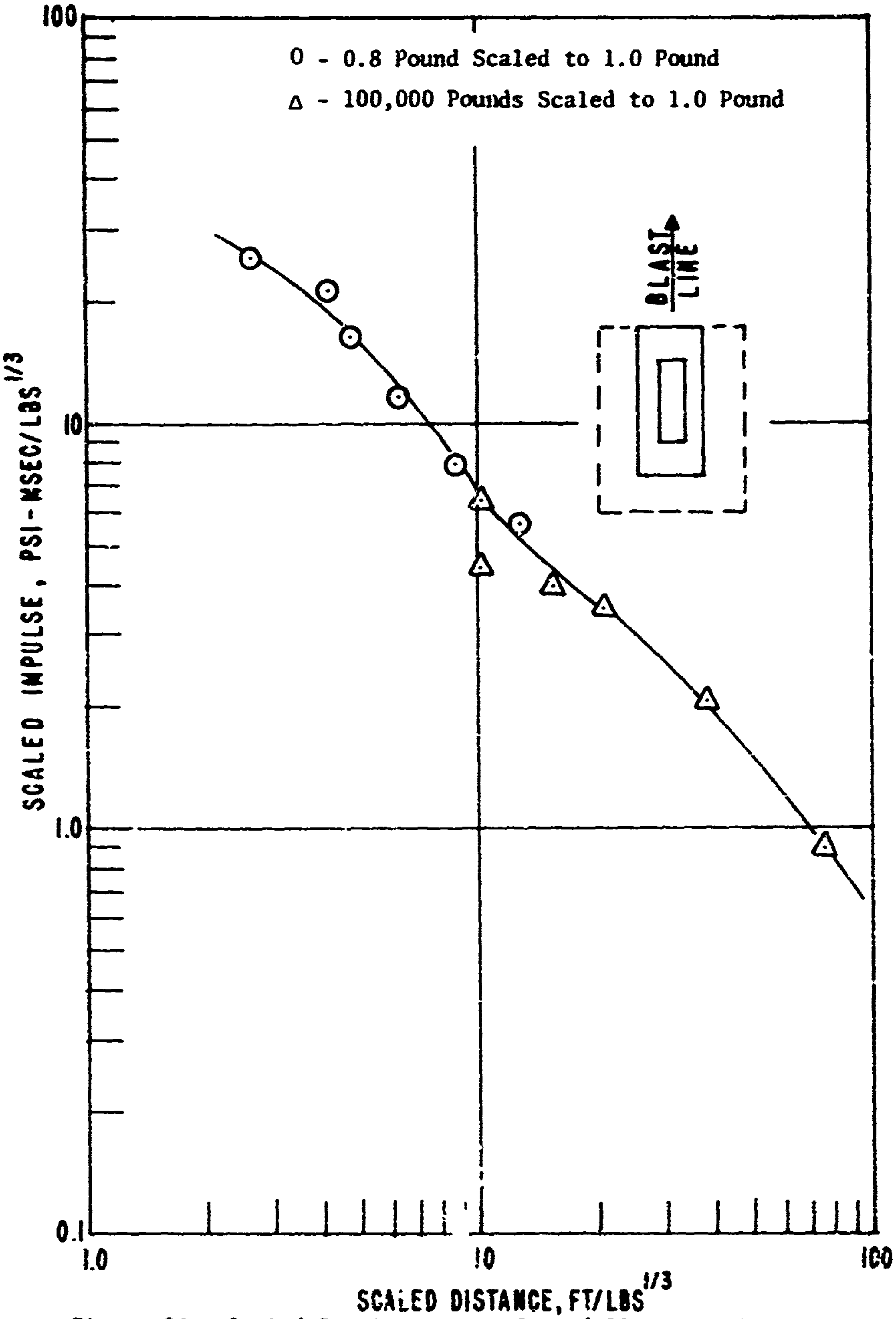

Figure 26. Scaled Impulse versus Scaled Distance Along the 0 Degree Time from a Full-Scale Magazine and a 1/50 Scaled Model

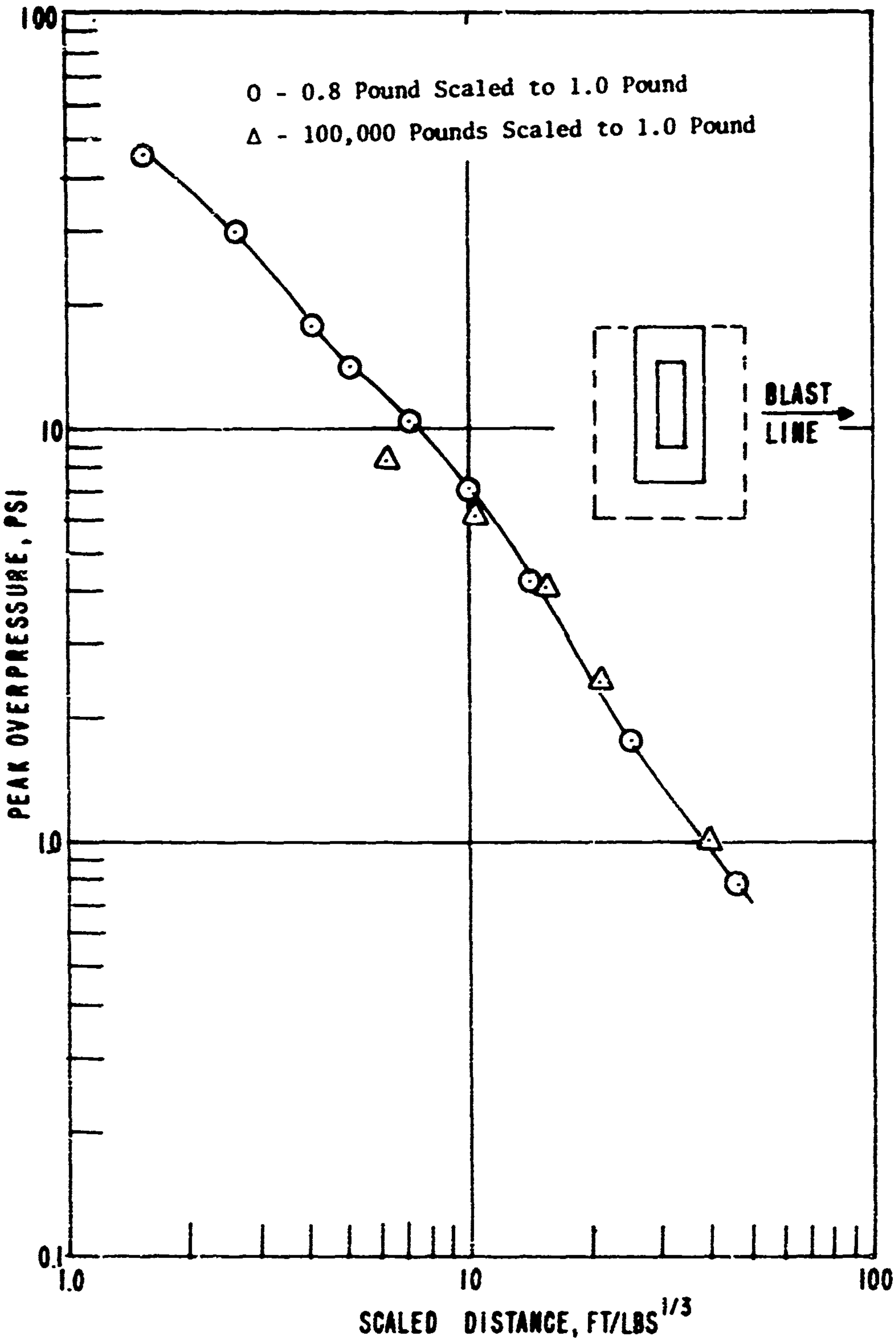

Figure 27. Pressure versus Scaled Distance Along the 90 Degree Line from a Full-Size Magazine and a 1/50 Scaled Model

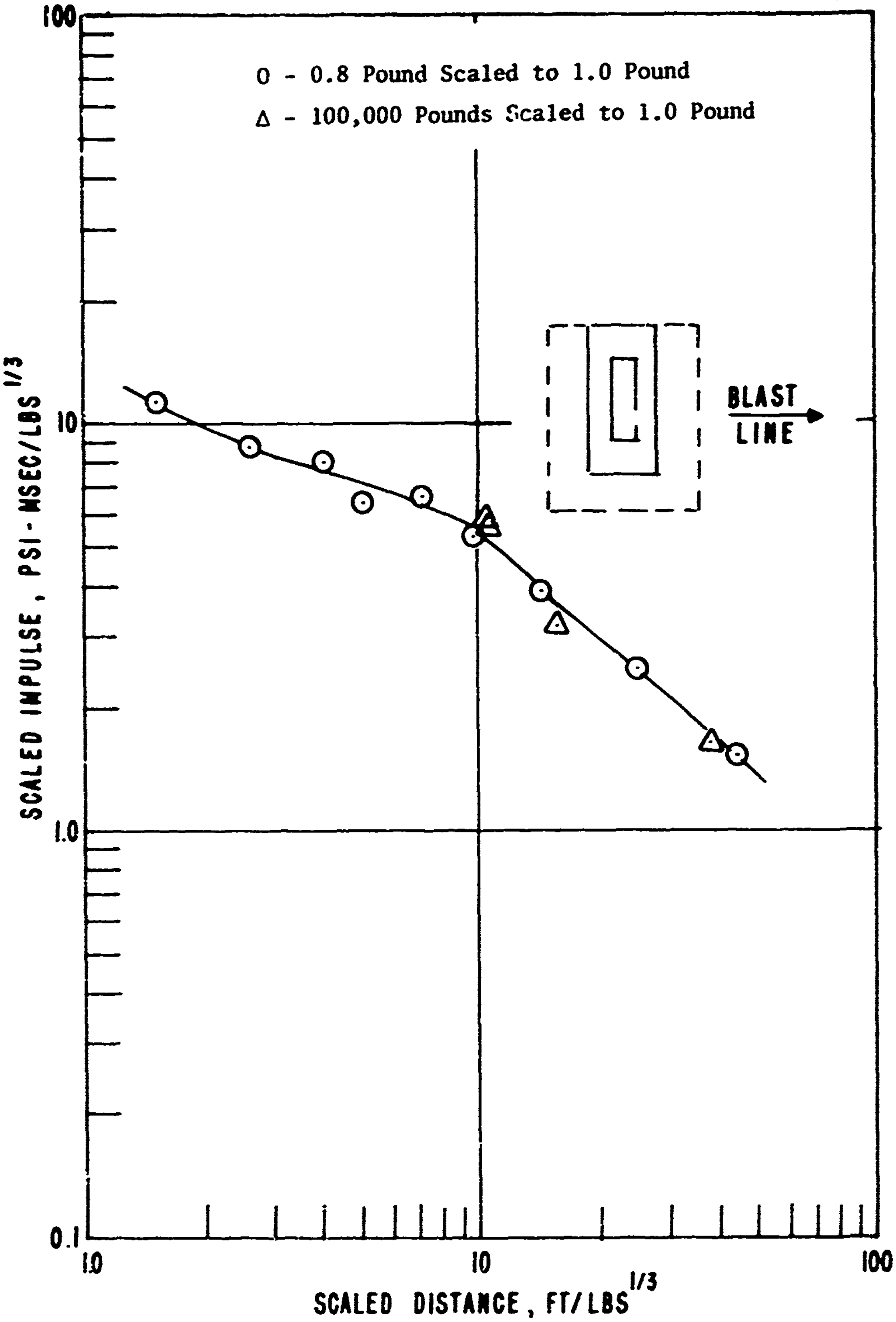

Figure 28. Scaled Impulse versus Scaled Distance Along the 90 Degree Line from a Full-Size Magazine and a 1/50 Scaled Model

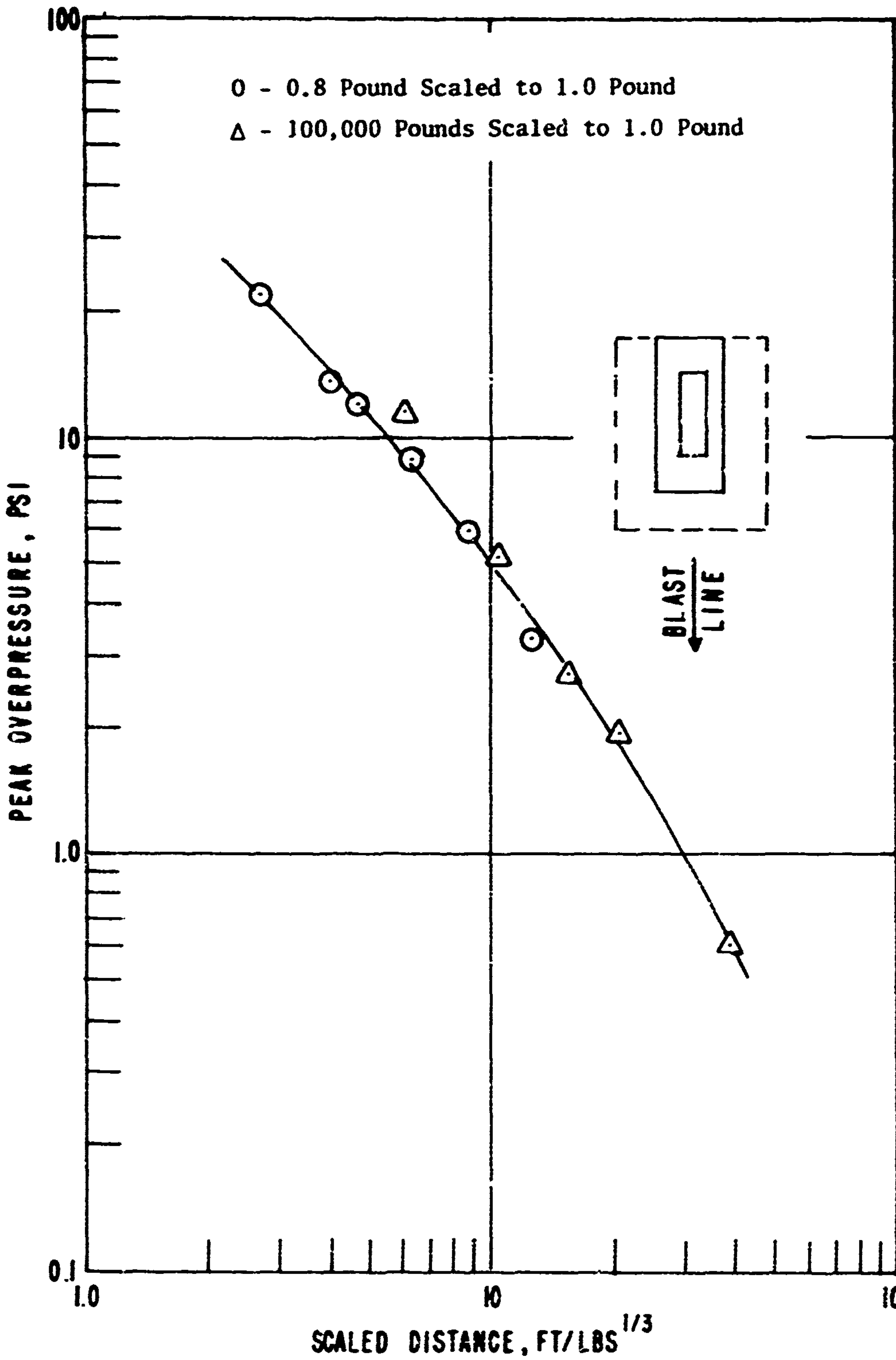

Figure 29. Pressure versus Scaled Distance Along the 180 Degree Line from a Full-Size Magazine and a 1/50 Scaled Model

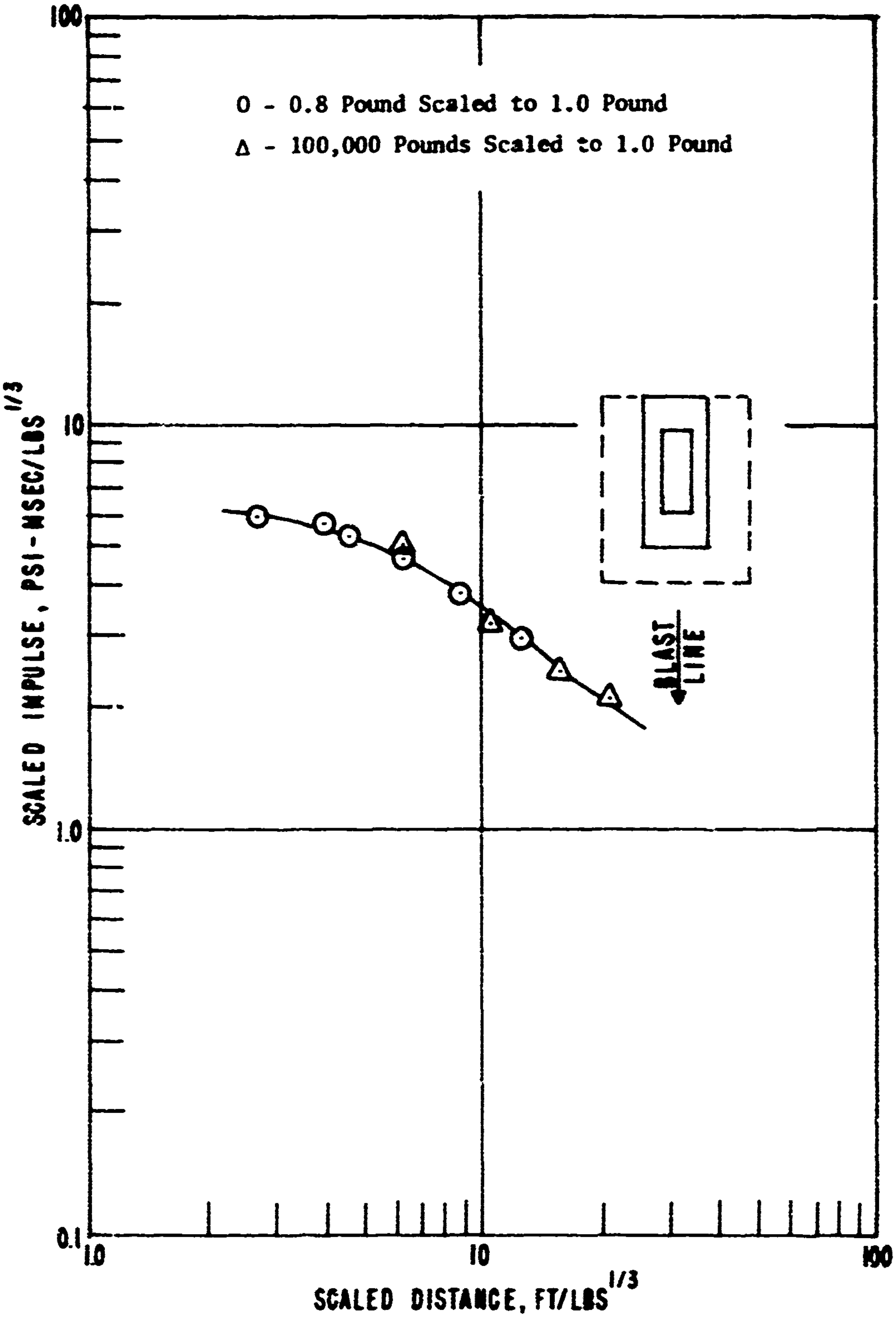

Figure 30. Scaled Impulse versus Scaled Distance Along the 180 Degree Line from a Full-Size Magazine and a 1/50 Scaled Model

A. The 0 Degree Blast Line

The peak overpressure and impulse recorded at the first five stations along the blast line to the front of the structure were always greater when the earth cover was placed over the charge than when it was uncovered. This is apparently due to earth walls focussing the blast energy from the three sides to the front headwall where there is no earth cover. The one-half earth cover model produced an increase in peak overpressure and impulse over the uncovered charge while the standard earth cover model produced an increase in values over the one-half earth cover model. The double earth cover model did not produce an increase in values over the standard cover model. This leads to the conclusion that the addition of earth cover greater than the standard thickness does not increase the pressure and impulse to the front of the structure.

B. The 90 Degree Blast Line

The peak overpressures and impulses measured from the side of the structure will be discussed separately because different trends were established as a function of charge weight and earth cover.

1. Peak Overpressure The peak overpressure recorded from the 0.8 pound (0.363 kg) charge as a function of distance for the three earth covers followed the expected trend. That is the more earth cover the more blast attenuation. The attenuation became less as the distance increased. At the last station the pressure values were 0.054, 0.052, 0.054, and 0.051 pounds per square inch going from the uncovered charge to the half, standard, and double cover model.

The peak overpressure recorded on the 2.4 pound (1.088 kg) tests as a function of distance produced an unexpected trend. The half earth cover model tests produced slightly less blast attenuation than the standard earth cover. At the first six stations the peak overpressures from both model tests were lower than the uncovered charge but beyond station 6 the trend reversed and the values recorded for the covered models were greater than the uncovered charge. This same trend was noted on the results from the 4 pound (1.814 kg) charge (see Figures 15 and 21).

2. Overpressure Impulse The impulses measured along the 90 degree line from the detonation of the 0.8 pound (.363 kg) charge showed the same trend as established for peak overpressure in that the three earth covered models recorded impulses less than the uncovered charge.

The impulse recorded along the 90 degree line from the 2.4 pound (1.088 kg) charge followed the same trend as the peak overpressure over the first five stations. At the greater distances the uncovered charge, the one-half earth cover model, and the standard earth cover model record similar impulses as a function of distance (see Figure 16).

The impulses recorded along the 90 degree line for the 4.0 pound (1.814 kg) charge as a function of distance and earth cover did not establish a trend similar to the peak overpressure. At station six and beyond the uncovered charge and the double standard earth cover model produced similar values while the other two models produced higher impulse values. The reason for this trend has not been established.

There is an anomaly in the impulse recorded at the fourth and fifth stations along the 90 degree line for the three charge weights. At the fourth station there is an apparent decrease in the impulse recorded for the double and standard earth cover followed by an increase of the impulse recorded at the fifth station. There is no explanation offered for this behavior at this time.

C. The 180 Degree Line

Blast measurements made along the 180 degree line were to the rear of the structure.

1. Peak Overpressure The peak overpressure followed the same trend for all three charge weights. There was a very large attenuation observed at the close-in station, becoming less as the distance from the charge increased (see Figures 11, 17, and 23). The attenuation of peak overpressure became greater as the earth cover was increased.

2. Overpressure Impulse The overpressure impulse recorded along the 180 degree line was greatly attenuated at the close-in stations when the charges were covered with the models. As noted with the peak overpressure, this attenuation became less with increasing distance. The difference to be noted here is that the impulse is not very sensitive to the change in earth cover. It does not decay as rapidly with distance when covered as compared to uncovered models (see Figures 12, 18, and 24).

REFERENCES

1. R. Reisler, L. Giglio-Tos, and G. Teel, "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground," BRL MR-2471, April 1975. AD #B003883L.

2. A. R. Sound, "Summary Report of Earth-Covered Steel-Arch Magazine Tests," NOTS TP 3843, July 1965.

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1. On or about 28 October 1976, copy(s) of BRL Memorandum Report No. 2680, entitled, "Blast Parameters From Explosions in Model Earth Covered Magazines", dated September 1976 were forwarded to your organization. Report is Unclassified.

2. It is requested that the inclosed correction be inserted into to your copy of subject report.

FOR THE DIRECTOR:

Vernon J. Wyatt

1 Incl
as

VERNON J. WYATT
Chief
Technical Support Division

ERRATA SHEET FOR:

BRL Memorandum Report No. 2680, "Blast Parameters from Explosions in Model Earth Covered Magazines," Charles N. Kingery, George A. Coulter and George T. Watson, September 1976.

The values in the last column of Table XII on page 55 with the heading bar-msec/$kg^{1/3}$ were inadvertantly scaled from 0.454 kg to 1 kg rather than from 0.363 kg to 1 kg. Therefore, they must be corrected by $(0.454)^{1/3}/(0.363)^{1/3}$ or 1.077.

The corrected values are inclosed on sticky back paper which can be placed over the incorrect values.

2.28
1.91
1.46
1.04
.715
.502

1.01
.782
.735
.580
.590
.474
.348
.223
.135

.521
.512
.474
.415
.338
.261

SUPPLEMENTARY

INFORMATION