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TNT EQUIVALENCY OF PENTOLITE HEMISPHERES

Charles Kingery
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December 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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This report presents the results of a limited study designed to determine the TNT equivalency of Pentolite hemispheres detonated on a sand base. Three Pentolite charges with an average mass of 1.129 kg and two TNT charges with an average mass of 1.146 kg were detonated over a sand base test area. Blast parameters were measured along two blast lines. An average value of the TNT equivalency of Pentolite based on peak overpressure is 1.11. The average value based on impulse is 1.07.

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I. INTRODUCTION

A. Background

Airblast parameters from the detonation of hemispherical TNT charges have been well documented in Reference 1 for yields ranging from 4536 kg to 453590 kg. These charges were detonated at the center of the flat side which was placed on a clay surface. Airblast parameters from the detonation of spherical TNT charges[2] and spherical Pentolite charges[3] in free-air have also been well documented but there is a lack of data from the detonation of Pentolite hemispheres on the surface. The TNT equivalency of Pentolite is listed in Reference 2 as 1.17 based on peak overpressure and 1.15 based on overpressure impulse. When using Pentolite to simulate TNT on one of the small scale model tests[4] the equivalency values listed above did not appear to be valid for surface burst hemispheres.

B. Objectives

Because of the differences noted in Reference 4, the Department of Defense Explosives Safety Board (DDESB) agreed to sponsor an experimental program at the Ballistic Research Laboratory (BRL) to determine the TNT equivalency of Pentolite hemispheres. The test area used in Reference 4 had a sand base and therefore the current series of tests were also conducted over a controlled sand base. This will determine any difference in blast output for TNT hemispheres detonated over sand and the established standard curves where the charges were detonated over a clay base, as well as establish a TNT equivalency for Pentolite detonated over sand.

II. TEST PROCEDURE

Discussed in the test procedures are three areas required for this experimental program. They are: The site preparation, the test charges, and the instrumentation.

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[1] *C. N. Kingery, "Air Blast Parameters versus Distances for Hemispherical TNT Surface Burst," BRL Report No. 1344, September 1966.*

[2] *"Structures to Resist the Effects of Accidental Explosions," Dept. of the Army Technical Manual, TM5-1300, June 1969.*

[3] *H. G. Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite," BRL Report No. 1092, February 1960.*

[4] *Charles Kingery, and George Watson, "Blast Leakage into Hardened Aircraft Shelter Models," Tech Report ARBRL-TR-02392, February 1982.*

A. Test Site

The test site was designed for small charge programs. The blast lines have a heavy crushed rock base with a fine crushed gravel on top of that and finished with a sand layer approximately 20 cm thick. Two blast lines were instrumented for this series of tests to check the symmetry of the blast wave as it propagated from ground zero, defined to be the center of the flat side of the hemisphere. A photograph of the test charge and close-in station is presented in Figure 1. A test layout showing the gage station locations on the two blast lines is shown in Figure 2.

B. Test Charges

1. Pentolite Charges. The Pentolite charges (50 PETN/50 TNT) were cast at the Hot Melt Laboratory, a high explosive casting facility at the BRL. The mass of the three charges were 1134.1 gm, 1125.4 gm, and 1128.1 gm giving an average of 1129.2 gm which was used for the cube root scaling. A small hole was cast in the center of the flat face for insertion of the detonator. All charges went high order and produced consistent results.

2. TNT Charges. A total of four TNT charges was cast for use on this series of tests. The first TNT test configuration is shown in Figure 3A. The detonator was placed with the end flush against the PBX booster. This resulted in a low order detonation and therefore the booster configuration was changed for the next TNT test. The plastic ring detonator holder was replaced with a ring of Comp B as shown in Figure 3B. This configuration did not result in an acceptable detonation, so the last two charges were modified to take a small hemispherical charge of Pentolite as the booster. This booster configuration shown in Figure 3C was successful in producing two high order detonations. The two successful test charges were 1151 gm and 1141 gm mass giving an average value of 1146 gm.

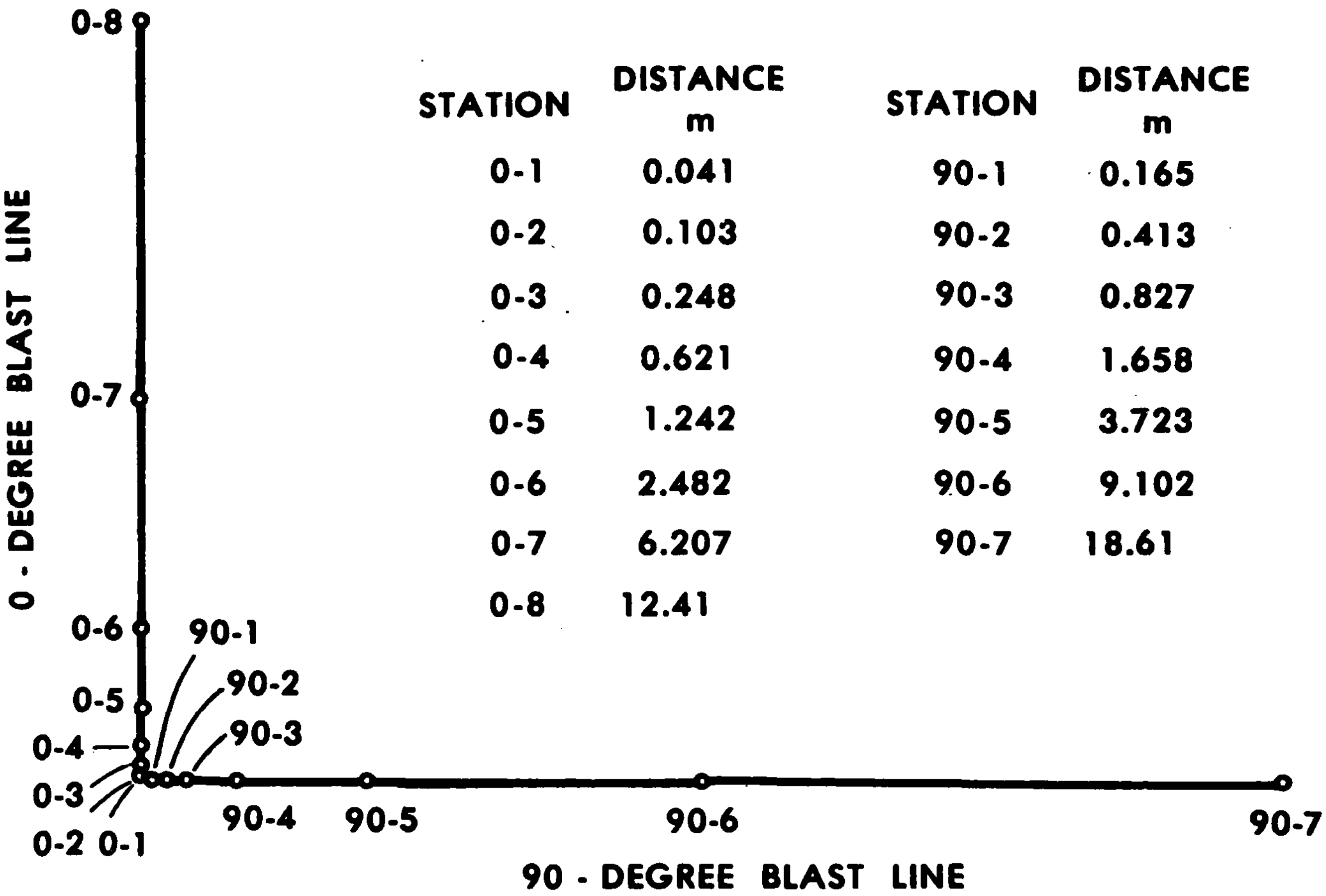
C. Instrumentation

Established procedures for airblast instrumentation at the BRL were followed for this series of tests. The blast transducers were PCB Piezotronics Series 113A, with quartz crystal sensing elements and built-in voltage amplifiers. The transducers were mounted in lead bricks with nylon brushings to electrically insulate the transducer from ground. The bricks were buried in the sand with the top face flush with sand surface as shown in Figure 1. The signal cables were buried to a depth sufficient to eliminate any disturbances that might be generated from the blast wave or ground shock.

Honeywell 7600, 80 kHz, FM tape recorders were used to record and playback the pressure versus time signals from the transducer. A Honeywell 1858 Visicorder was used to transfer the data from the tape to an analog form for a quick look of the results at the test site.

For the final data output, the tape signals were processed through an analog to digital converter, to a digital recorder reproducer, then to a computer. The computer was programmed to apply the calibration values and

Figure 1. Photograph of the test charge and close-in gage stations.



STATION	DISTANCE m	STATION	DISTANCE m
0-1	0.041	90-1	0.165
0-2	0.103	90-2	0.413
0-3	0.248	90-3	0.827
0-4	0.621	90-4	1.658
0-5	1.242	90-5	3.723
0-6	2.482	90-6	9.102
0-7	6.207	90-7	18.61
0-8	12.41		

Figure 2. Test layout showing gage stat[illegible]n the two blast lines.

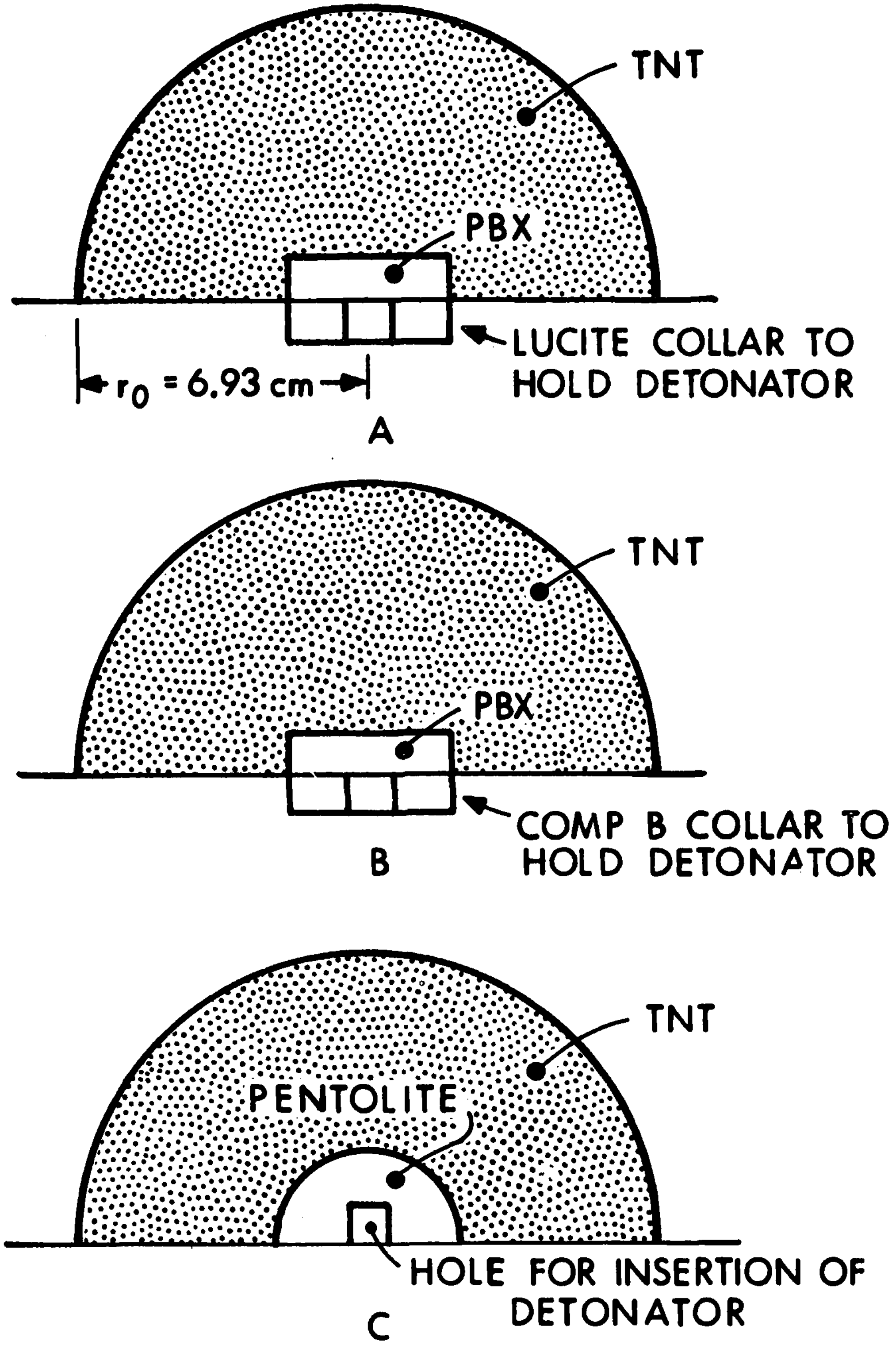


Figure 3. TNT booster configurations.

present the data in the proper units for analysis. From the computer the data is put on a digital tape from which the final form can be plotted or tabulated. The digital tape can also be stored for future analysis.

III. RESULTS

The results will be presented in the form of tables and graphs and direct comparisons will be made between the two explosives. The blast parameters to be compared are shown in Figure 4. A table of blast parameters versus scaled distance from Reference 1 has been converted to metric units and presented in Appendix A for comparison with the following results.

A. TNT Results

The measured TNT blast parameters obtained from Test 6 and Test 7 are listed in Table I in metric units. The average of values from Table I have been listed in Table II and scaled to 1 kg. For ease in comparing the average values with standard references, the results in Table I have also been converted to English units, scaled to 1 pound mass and listed in Table III. The first three gage locations 0-1, 0-2, and 90-1 were not instrumented after the first two tests because the bricks were blown out of position causing gage damage and questionable results.

B. Pentolite Results

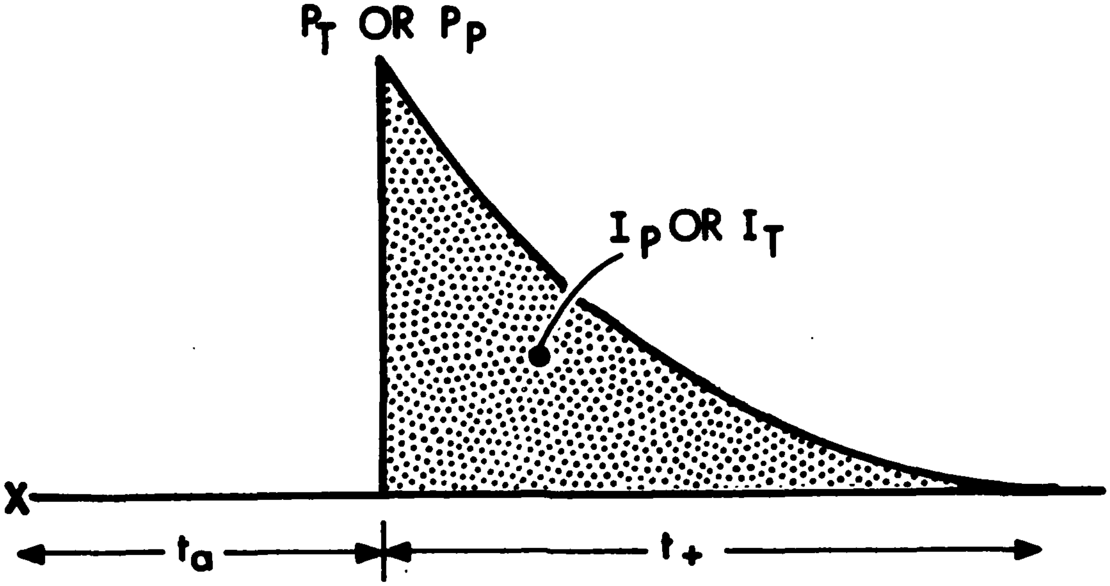
Presentation of the Pentolite blast parameters will be in the same format as used for TNT. Measured data from Tests 2, 3, and 4 are listed in Table IV. The average values of the results in Table IV have been scaled to 1 kilogram and listed in Table V. The same values in English units have been scaled to one pound mass and listed in Table VI.

C. Comparison of Arrival Times

The arrival time of the blast wave at the gage stations along the blast lines is a good indication of the symmetry of the blast wave as well as differences in the yield of two explosives. Data listed in Tables II and V are plotted in Figure 5. The only significant differences in arrival times noted in Figure 5 are at the first three stations where the average arrival times for the Pentolite tests are shorter than the average arrival times for TNT. This would imply a higher shock front velocity and a higher peak overpressure. At many of the stations the recorded values overlap. At Station 90-5 the TNT values of arrival time are 5.28 and 5.31 ms while the Pentolite values are 5.24, 5.17, and 5.29 ms. Although the values overlap, the average value for TNT is greater than the average value for Pentolite. The solid line is plotted from values taken from Reference 1. These values are listed in the tables of Appendix A.

D. Comparison of Peak Overpressures

The average peak overpressures recorded along the blast lines from the TNT and Pentolite tests are listed in Tables II and V. The values from these tables are plotted in Figure 6. The peak overpressures recorded at the first



P_P = PEAK OVERPRESSURE FROM PENTOLITE CHARGE
P_T = PEAK OVERPRESSURE FROM TNT CHARGE
I_P = IMPULSE FROM PENTOLITE CHARGE
I_T = IMPULSE FROM TNT CHARGE
D_P = STATION DISTANCE FOR PENTOLITE CHARGE
D_T = STATION DISTANCE FOR TNT COMPARISON
t_a = ARRIVAL TIME
t_+ = DURATION

Figure 4. Measured blast parameters.

TABLE I. Measured TNT Blast Parameters

	DISTANCE	ARRIVAL TIME		PEAK OVERPRESSURE		OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
TEST NO.		6	7	6	7	6	7	6	7
STATION	R	t_a	t_a	P_T	P_T	I_T	I_T	t_+	t_+
	m	ms	ms	kPa	kPa	kPa-ms	kPa-ms	ms	ms
0-3	0.248	0.070	--	7878	21429	469	--	0.33	0.23
90-2	0.413	0.125	0.120	6113	5876	165	158	0.24	0.24
0-4	0.621	0.185	0.187	2808	3079	203	198	0.43	0.32
90-3	0.827	0.325	0.310	2016	1640	224	185	0.72	0.51
0-5	1.242	0.735	0.700	853	861	166	174	0.99	1.10
90-4	1.658	--	1.197	--	506	--	130	--	1.36
0-6	2.482	2.675	2.637	169	170	104	103	2.20	2.34
90-5	3.723	5.280	5.310	79.6	85.5	79.2	78.5	2.76	2.99
0-7	6.207	11.79	11.81	37.8	39.5	52.0	48.2	4.11	3.80
90-6	9.102	19.72	19.64	20.2	21.0	34.3	34.1	4.35	4.18
0-8	12.41	29.32	29.34	10.8	10.9	23.2	22.4	4.46	4.51
90-7	18.61	47.31	47.16	6.01	6.03	15.1	14.7	5.88	5.73

NOTE: Average Charge Mass Q = 1.146 kg TNT

TABLE II. TNT Blast Parameters Scaled to 1 kg

	DISTANCE (P_T)		ARRIVAL TIME (t_a)		PEAK OVERPRESSURE (P_T)	OVERPRESSURE IMPULSE (I_T)		OVERPRESSURE DURATION (t_+)	
STATION	m	m/kg$^{1/3}$	ms	ms/kg$^{1/3}$	kPa	kPa-ms	kPa-ms/kg$^{1/3}$	ms	ms/kg$^{1/3}$
0-3	0.248	0.238	0.070	0.067	14653	469	448	0.28	0.27
90-2	0.413	0.395	0.122	0.117	5994	161	154	0.26	0.25
0-4	0.621	0.593	0.186	0.178	2943	200	191	0.37	0.35
90-3	0.827	0.790	0.317	0.303	1828	204	195	0.61	0.58
0-5	1.242	1.187	0.717	0.685	857	170	162	1.04	0.99
90-4	1.658	1.584	1.197	1.144	506	130	124	1.36	1.30
0-6	2.482	2.372	2.660	2.542	169	104	99.4	2.27	2.17
90-5	3.723	3.558	5.295	5.060	82.5	78.8	75.3	2.88	2.75
0-7	6.207	5.931	11.80	11.28	38.6	50.1	47.9	3.96	3.78
90-6	9.102	8.698	19.68	18.71	20.6	34.2	32.7	4.27	4.08
0-8	12.41	11.86	29.33	28.03	10.9	22.8	21.8	4.49	4.29
90-7	18.61	17.78	47.23	45.13	6.03	14.9	14.2	5.81	5.55

Charge mass Q = 1.146 kg

$Q^{1/3}$ = 1.0465 kg

TABLE III. TNT Blast Parameters Scaled to 1 Pound Mass

	DISTANCE		ARRIVAL TIME		PEAK OVERPRESSURE	OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
STATION	Ft	$Ft/lbm^{1/3}$	ms	$ms/lbm^{1/3}$	psi	psi-ms	$psi\text{-}ms/lbm^{1/3}$	ms	$ms/lbm^{1/3}$
0-3	0.814	0.598	0.070	0.051	2125	65.6	48.1	0.28	0.21
90-2	1.355	0.995	0.123	0.090	735	22.5	16.5	0.26	0.19
0-4	2.037	1.496	0.186	0.137	427	29.0	21.3	0.46	0.34
90-3	2.713	1.992	0.317	0.233	265	29.6	21.7	0.76	0.55
0-5	4.075	2.992	0.717	0.526	124	24.7	18.1	1.04	0.77
90-4	5.440	3.994	1.197	0.879	23.4	18.9	13.8	1.36	1.00
0-6	8.143	5.979	2.660	1.953	24.5	15.1	11.1	2.27	1.67
90-5	12.22	8.972	5.310	3.899	12.0	11.4	8.39	2.88	2.11
0-7	20.36	14.95	11.80	8.664	5.73	7.27	5.34	3.96	2.91
90-6	29.86	21.92	19.68	14.45	3.05	4.96	3.64	4.27	3.14
0-8	40.72	29.90	29.33	21.53	1.58	3.31	2.43	4.49	3.30
90-7	61.06	44.83	47.23	34.68	0.87	2.16	1.59	5.81	4.27

NOTE: Charge Mass W = 2.5265 lbm
$W^{1/3}$ = 1.362 lbm

TABLE IV. Measured Pentolite Blast Parameters

	DISTANCE	ARRIVAL TIME			PEAK OVERPRESSURE			OVERPRESSURE IMPULSE			OVERPRESSURE DURATION		
TEST		2	3	4	2	3	4	2	3	4	2	3	4
STATION	R	t_a	t_a	t_a	P_p	P_p	P_p	I_p	I_p	I_p	t_+	t_+	t_+
	m	ms	ms	ms	kPa	kPa	kPa	kPa-ms	kPa-ms	kPa-ms	ms	ms	ms
0-3	0.248	0.065	0.051	0.065	11491	11831	14866	325	294	442	0.37	0.26	0.33
90-2	0.413	0.074	0.122	0.109	6708	7897	7328	---	168	204	0.26	0.21	0.27
0-4	0.621	0.169	0.161	0.176	3806	4217	3347	206	208	184	0.36	0.29	0.27
90-3	0.827	0.312	0.317	0.312	2089	2187	1964	184	194	188	0.55	0.60	0.70
0-5	1.240	0.677	0.644	0.677	985	847	1008	201	194	204	1.51	1.56	1.47
90-4	1.655	1.150	1.170	1.190	466	465	502	133	131	137	1.68	1.60	1.69
0-6	2.481	2.450	2.420	2.500	187	200	200	110	110	107	2.40	2.22	2.50
90-5	3.722	5.240	5.170	5.290	88.1	87.7	80.7	79.1	78.2	80.4	2.79	2.81	3.07
0-7	6.205	11.42	11.25	11.50	42.1	43.4	40.7	52.7	51.1	50.6	3.93	3.83	4.00
90-6	9.100	19.46	19.50	19.90	20.1	19.4	19.2	34.7	35.0	35.1	4.28	4.40	4.45
0-8	12.41	28.72	28.39	28.74	11.6	12.9	12.4	23.4	23.2	23.1	4.49	4.40	4.55
90-7	18.61	46.79	47.22	48.09	5.99	5.28	5.18	14.9	15.4	15.4	5.83	6.15	6.15

NOTE: Average Charge Mass Q = 1.1292 kg Pentolite

TABLE V. Pentolite Blast Parameters Scaled to 1 kg

STA.	DISTANCE(D_p) m	DISTANCE(D_p) $m/kg^{1/3}$	ARRIVAL TIME(t_a) ms	ARRIVAL TIME(t_a) $ms/kg^{1/3}$	PEAK OVERPRESSURE(P_p) kPa	OVERPRESSURE IMPULSE(I_p) kPa-ms	OVERPRESSURE IMPULSE(I_p) $kPa\text{-}ms/kg^{1/3}$	OVERPRESSURE DURATION(t_+) ms	OVERPRESSURE DURATION(t_+) $ms/kg^{1/3}$
0-3	0.248	0.238	0.060	0.058	12729	354	340	0.32	0.31
90-2	0.413	0.397	0.102	0.098	7311	186	179	0.25	0.24
0-4	0.621	0.596	0.169	0.162	3790	199	191	0.31	0.29
90-3	0.827	0.794	0.314	0.301	2080	189	181	0.62	0.59
0-5	1.240	1.191	0.666	0.640	947	200	192	1.49	1.43
90-4	1.655	1.589	1.170	1.124	478	134	128	1.66	1.59
0-6	2.481	2.382	2.457	2.359	196	109	105	2.37	2.28
90-5	3.722	3.574	5.233	5.025	85.5	79.2	76.1	2.89	2.78
0-7	6.205	5.958	11.39	10.94	42.1	51.5	49.4	3.92	3.77
90-6	9.100	8.738	19.62	18.84	19.6	34.9	33.5	4.38	4.20
0-8	12.41	11.92	28.62	27.48	12.3	23.2	22.3	4.48	4.30
90-7	18.61	17.87	47.37	45.48	5.48	15.2	14.6	6.04	5.80

NOTE: Charge Mass Q = 1.1292 kg

$Q^{1/3}$ = 1.0414 kg

TABLE VI. Pentolite Blast Parameters Scaled to 1 Pound Mass

	DISTANCE		ARRIVAL TIME		PEAK OVERPRESSURES	OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
STA.	Ft	Ft/lbm$^{1/3}$	ms	ms/lbm$^{1/3}$	psi	psi-ms	psi-ms/lbm	ms	ms/lbm$^{1/3}$
0-3	0.814	0.600	0.060	0.044	1846	51.3	37.9	0.32	0.24
90-2	1.355	1.000	0.102	0.075	1060	27.0	19.9	0.25	0.18
0-4	2.037	1.503	0.169	0.125	550	28.9	21.3	0.31	0.23
90-3	2.713	2.002	0.314	0.232	302	27.4	20.2	0.62	0.46
0-5	4.068	3.002	0.666	0.491	137	29.0	21.4	1.40	1.10
90-4	5.430	4.006	1.170	0.863	69.3	19.4	14.3	1.66	1.22
0-6	8.140	6.006	2.457	1.813	28.4	15.8	11.7	2.37	1.75
90-5	12.21	9.010	5.233	3.861	12.4	11.5	8.48	2.89	2.13
0-7	20.36	15.02	11.39	8.404	6.11	7.47	5.51	3.92	2.89
90-6	29.86	22.03	19.62	14.48	2.84	5.06	3.73	4.38	3.23
0-8	40.71	30.04	28.62	21.12	1.78	3.36	2.48	4.48	3.31
90-7	61.06	45.05	47.37	34.95	0.79	2.20	1.63	6.04	4.46

NOTE: Charge Mass W = 2.4895 lbm

$W^{1/3}$ = 1.3553 lbm

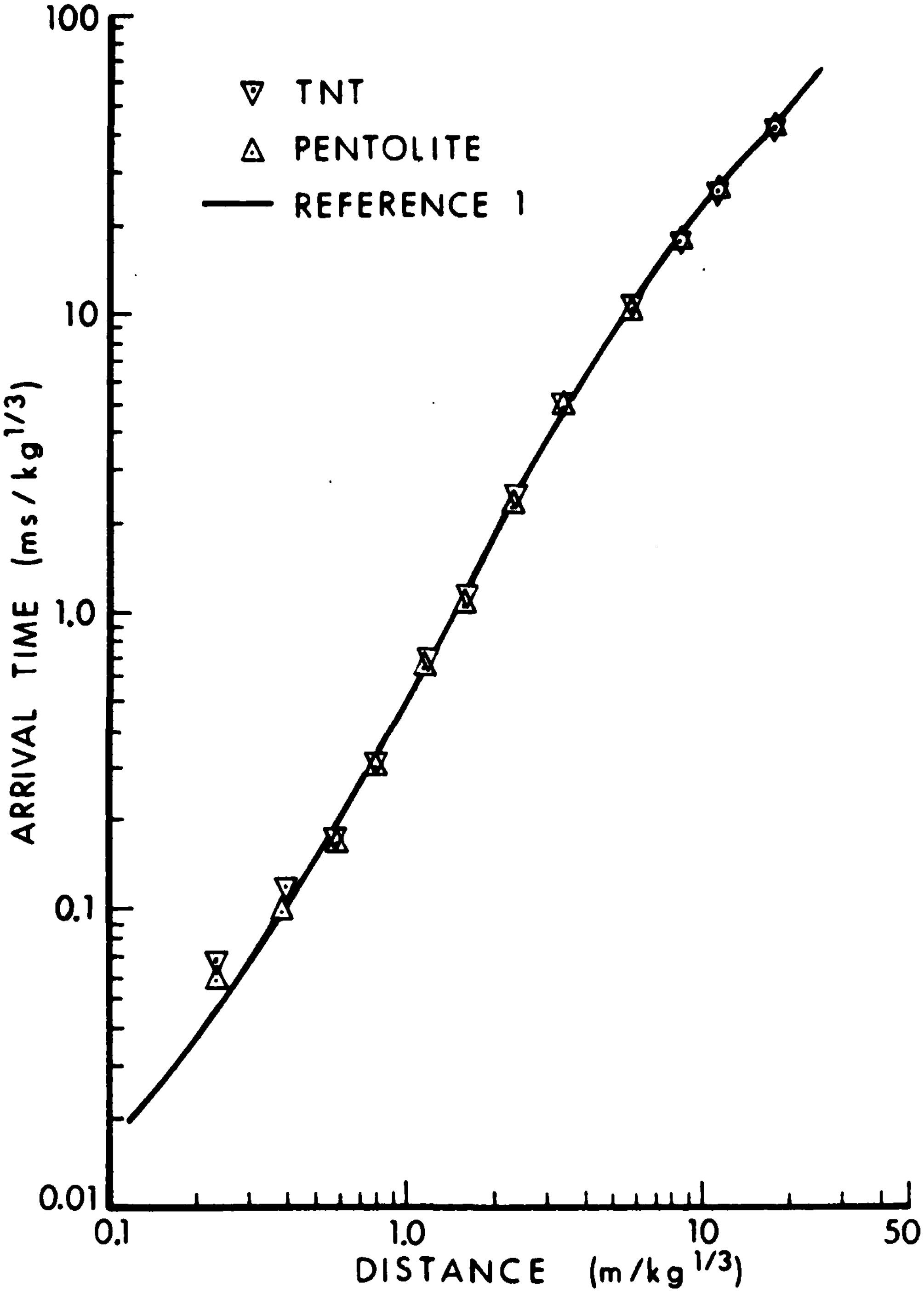


Figure 5. Scaled arrival time versus scaled distance for TNT and Pentolite hemispherical charges.

three stations plotted in Figure 6 show that the Pentolite tests gave higher peak values than the TNT tests. Beyond the first three stations the trend is not consistent. There are three stations where the measured peak overpressure values overlap, three stations where the TNT values are higher, and two stations where the Pentolite values of peak overpressure are higher.

Also plotted in Figure 6 are the peak overpressure values versus scaled distance, for TNT hemispheres tested over hard packed clay surface, taken from Table A-I.

E. Comparison of Overpressure Impulses

The overpressure impulse (I) as shown in Figure 4 is the area under the overpressure versus time curve recorded at a specific station. Impulse values for each test and each station are listed in Tables I and IV. The average values from Tables I and IV have been scaled to 1 kg and listed in II and V. These values have been plotted in Figure 7 where direct comparisons can be made. Of the twelve stations instrumented, nine recorded values that overlapped between the two explosives. At one station the TNT impulse value was higher and at two stations it was lower than the Pentolite impulse value.

The solid curve in Figure 7 is taken from Table A-I which was converted from Reference 1.

F. Comparison of Overpressure Durations

The duration of the overpressure pulse, t_+, as shown in Figure 4 is listed for each shot in Tables I and IV. The average values were scaled to 1 kg and are listed in Tables II and V. The scaled durations versus scaled distance are plotted in Figure 8 for the two explosives. Ten of the twelve stations have values of t_+ that overlap.

The scaled duration versus scaled distance plot has the same trend as the standard plot with the exception of the values between a scaled distance of 1 $m/kg^{1/3}$ to 2 $m/kg^{1/3}$. The measured values from these small charge tests are lower at all stations except the first two. No reason is given for this phenomenon.

G. Equivalent Mass Factors (EMF), Peak Overpressure-Distance

The TNT equivalency or the EMF of an explosive relative to TNT is defined in this report as the mass (kg) of a hemispherical TNT charge required to produce a specific blast parameter at a given distance as a 1 kg charge of Pentolite.

$$1 \text{ kg Pentolite} = \text{EMF} (1 \text{ kg TNT})$$

Using the cube root scaling law, the equivalent mass factor based on peak overpressure can be determined by selecting the mean peak overpressure, P_P, for Pentolite at a mean scaled distance, D_P, from Table V. Then from an expanded plot of peak overpressure versus scaled distance for TNT, from Table II, a scaled distance (D_T) at which the same peak overpressure occurs for TNT is obtained. The equivalent weight factor $EMF=(D_P/D_T)^3$. These values are

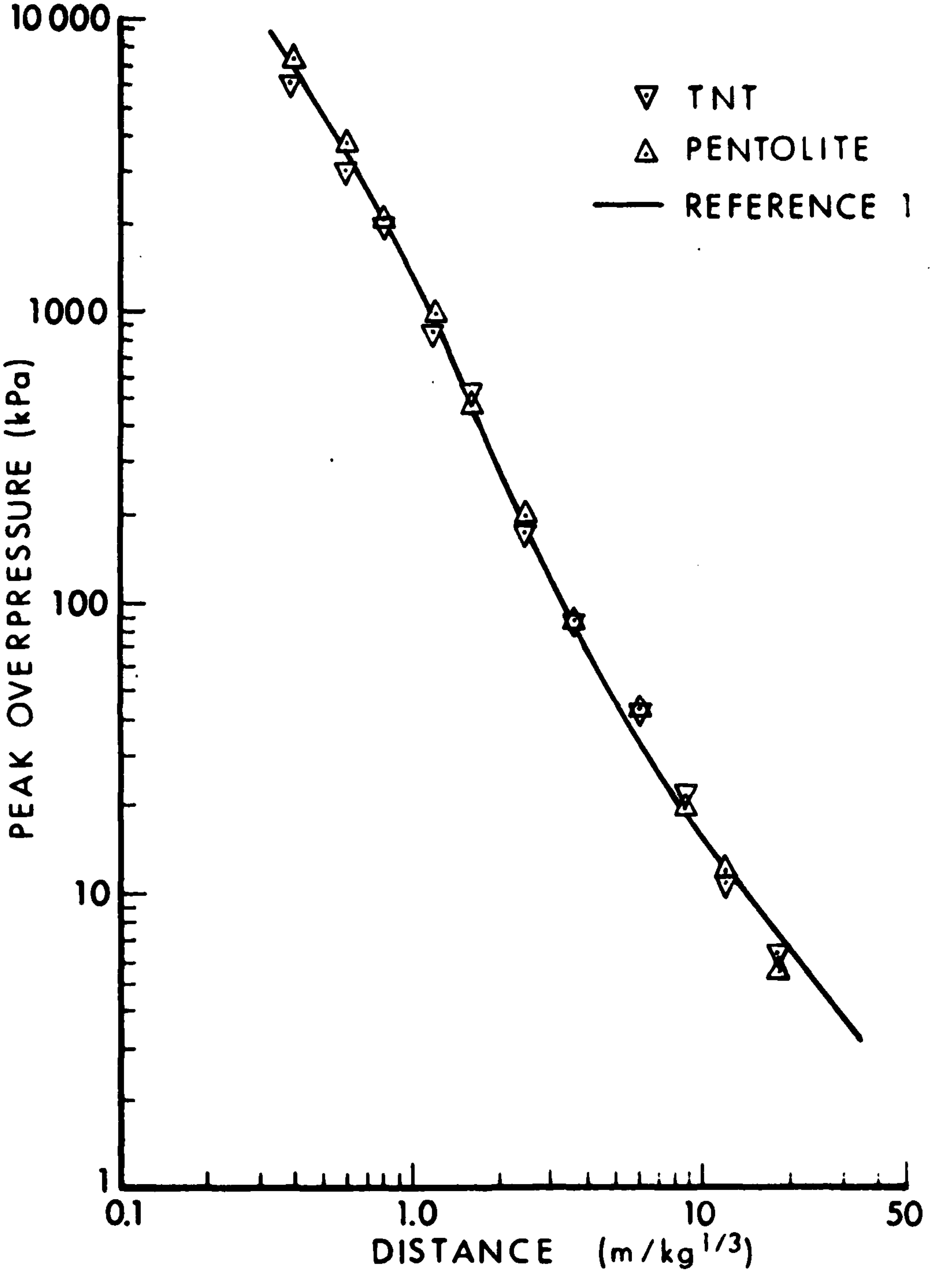


Figure 6. Peak overpressure versus scaled distance for TNT and Pentolite hemispherical charges.

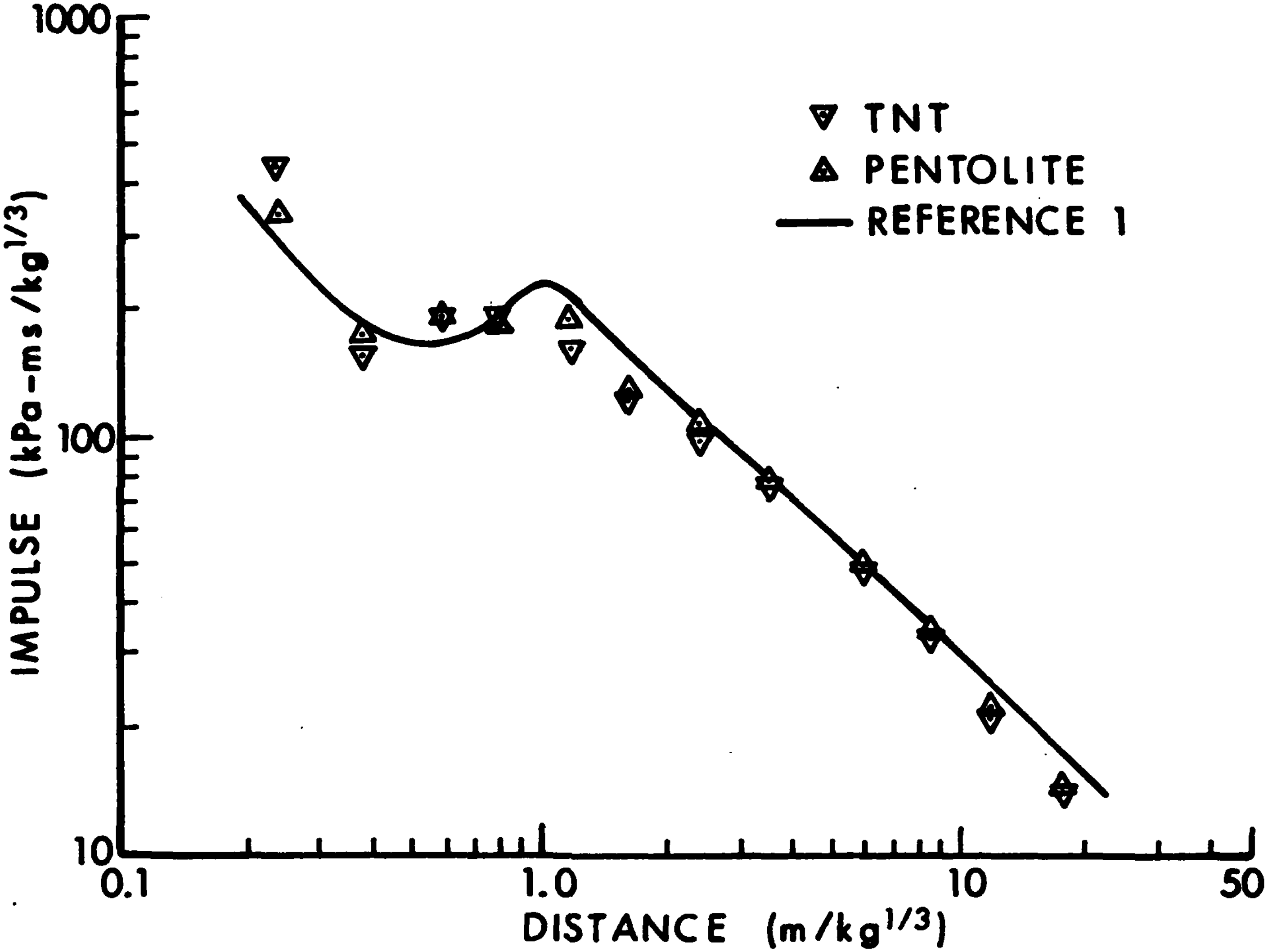


Figure 7. Scaled overpressure impulse versus scaled distance for TNT and Pentolite hemispherical charges.

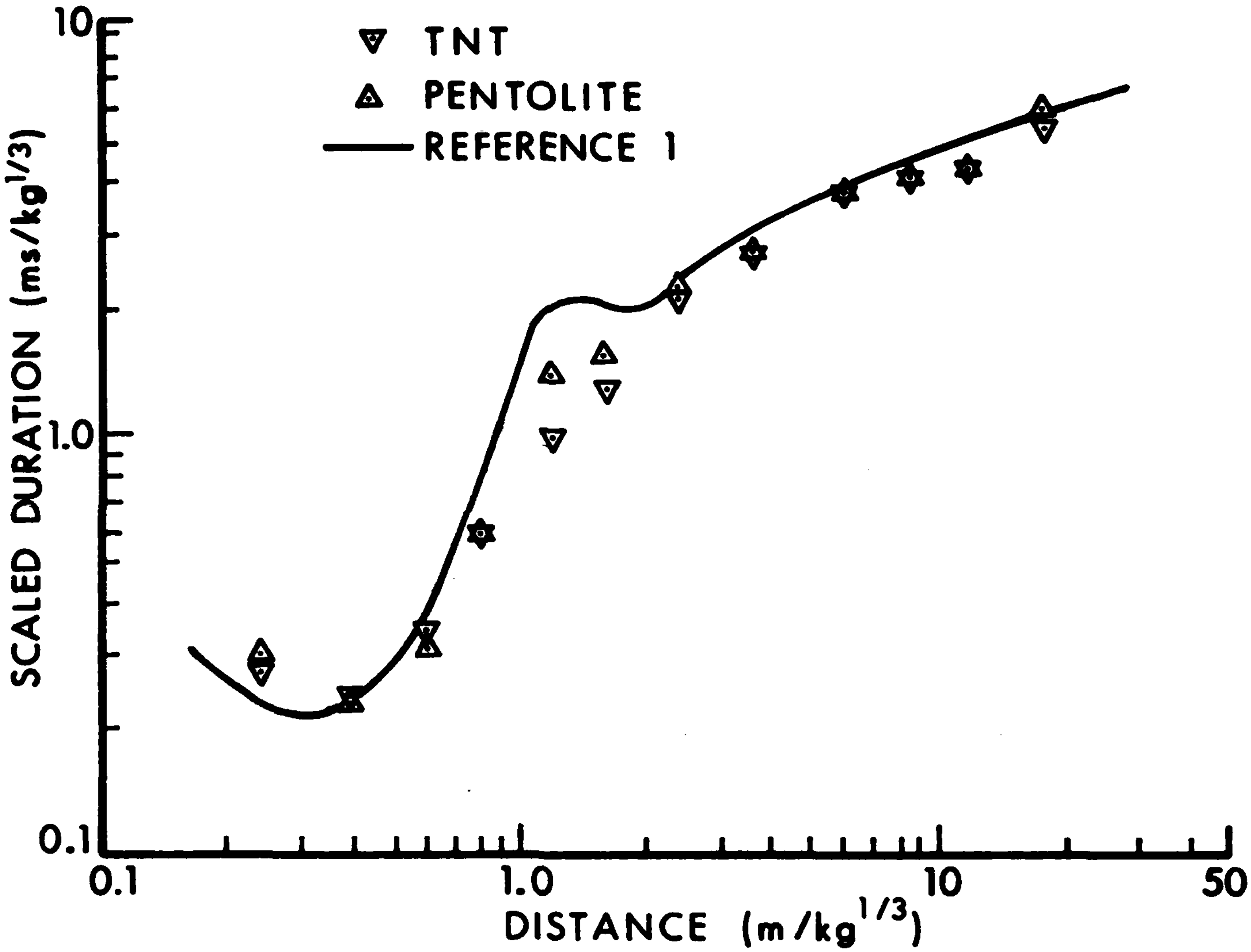


Figure 8. Scaled overpressure duration versus scaled distance for TNT and Pentolite hemispherical charges.

listed in Table VII. The peak overpressures used for this EMF determination were from 2080 kPa (302 psi) down to 5.48 kPa (0.795 psi). The equivalent mass factors listed in Table VII are plotted in Figure 9 as a function of scaled distance. The average value for the range considered is 1.11, which is slightly less than the accepted value of 1.17 published in Reference 2 for free-air TNT equivalency of Pentolite.

Calculations were also made to determine the EMF of Pentolite compared to the standard TNT hemispherical surface burst data from Reference 1. These EMF's $(D_P/D_{TS})^3$ are listed in Column 6 of Table VII. The mean value of the last nine stations is 1.08. This is smaller than determined for the TNT and Pentolite tested over sand. The values in Table VII are plotted in Figure 10 as a function of scaled distance.

A third equivalent weight factor of interest was the comparison of the TNT hemispherical charge tested over sand and the large scale TNT charges fired over hard packed clay. These EMF's are listed in column seven of Table VII. The mean value of 0.97 based on the last nine stations means that 0.97 kg of TNT detonated over hard packed clay would give the same average peak overpressures as 1 kg detonated over sand. The values of EMF from column seven of Table VII are plotted in Figure 11.

H. Equivalent Mass Factors (EMF), Impulse-Distance

The determination of the EMF for Pentolite based on overpressure impulse (I_P) is one of the objectives of this project. Since the impulse and distance are both scaled by the cube root of the mass, of the explosive, the following approach was taken. A ratio of the Pentolite impulse I_P and the scaled distance (D_P) from Table V is calculated. A reference TNT impulse (I_T) versus scaled distance (D_T) curve based on data from Table II is then searched to find an equal ratio of impulse I_T and distance D_T. The distance (D_T) at which a ratio equal to the reference ratio is determined is then used as in the previous section to determine EMF from $(D_P/D_T)^3$. The results of these calculations are listed in Table VIII. The EMF determined from the impulse-distance values are plotted in Figure 9. The average EMF determined from the last nine stations is 1.07, which is less than the value of 1.15 published in Reference 2 for free-air TNT equivalency of Pentolite.

Pentolite charges are usually used at the BRL for model tests, to simulate blast propagation and structure loading, although TNT is the usual explosive source on a full-size test. Therefore it is of interest to determine the TNT equivalency of Pentolite and the standard curve from Reference 1. The previously described method was used and the EMF's are listed in Column 9 of Table VIII. The mean value of 0.80 based on the last nine stations implies that it would require only 0.80 kg of TNT detonated over a hard packed surface to produce the impulse that 1 kg of Pentolite would produce when detonated over sand. EMF values from Table VIII are plotted in Figure 10.

The third comparison to be made is the TNT hemisphere detonated over sand and one detonated over hard packed clay. In Figure 7 it can be seen that the scaled impulses versus scaled distance for TNT hemispherical charges fired over a sand base are in general lower than the values based on data

TABLE VII. Equivalent Mass Factors, Peak Overpressure-Distance

P_P	D_P	D_T	D_{TS}	$(D_P/D_T)^3$	$(D_P/D_{TS})^3$	$(D_T/D_{TS})^3$
12729	0.237	0.250	0.255	0.85	0.80	0.99
7311	0.397	0.350	0.375	1.46	1.19	0.81
3790	0.596	0.540	0.590	1.34	1.03	0.77
2080	0.795	0.725	0.81	1.31	0.94	0.72
947	1.190	1.11	1.18	1.23	1.03	0.83
487	1.589	1.61	1.57	0.96	1.04	1.08
196	2.382	2.22	2.36	1.24	1.03	0.83
85.5	3.574	3.46	3.50	1.10	1.06	0.97
42.1	5.958	5.59	5.05	1.21	1.64	1.36
19.6	8.738	8.95	8.15	0.93	1.23	1.32
12.3	11.92	11.20	11.4	1.21	1.14	0.95
5.48	17.87	19.00	21.6	0.83	0.57	0.68
				1.11	1.08	0.97

D_P = Distance pentolite on Sand, $m/kg^{1/3}$

D_T = Distance TNT on Sand, $m/kg^{1/3}$

D_{TS} = Distance TNT Standard Curve, $m/kg^{1/3}$

P_p = Pentolite peak overpressure, kPa

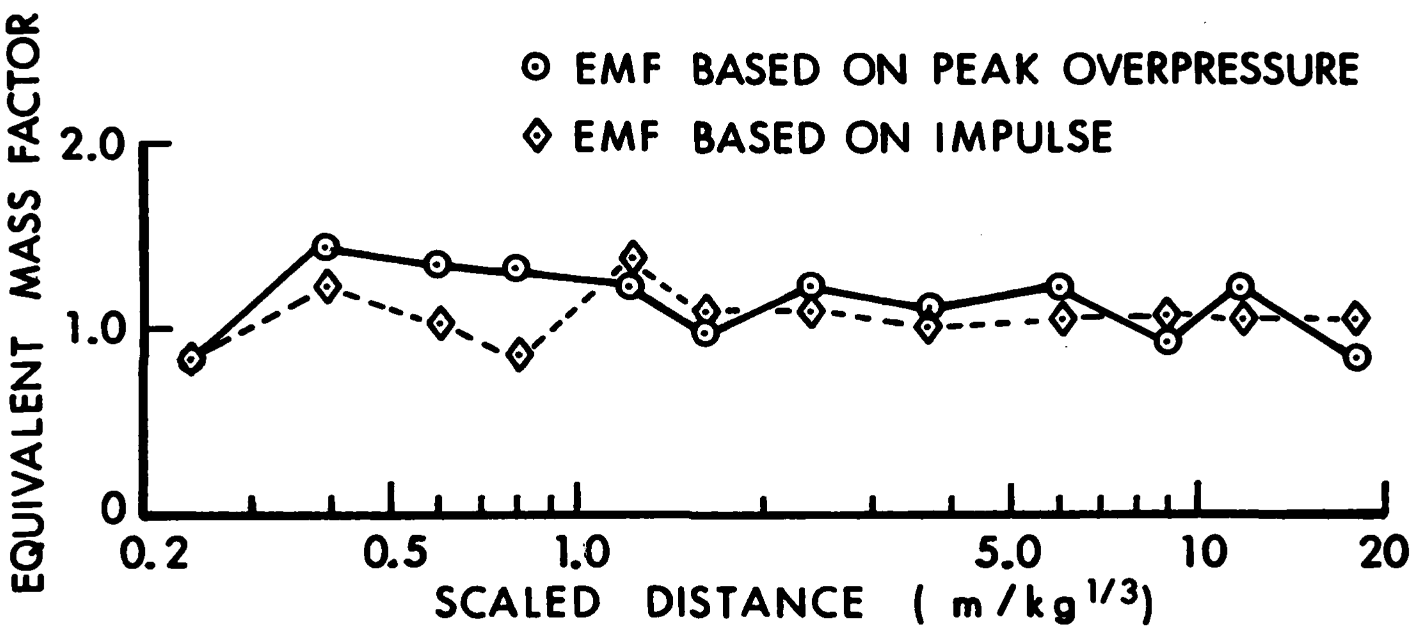


Figure 9. TNT equivalent mass factors versus scaled distance for Pentolite hemispheres on a sand base.

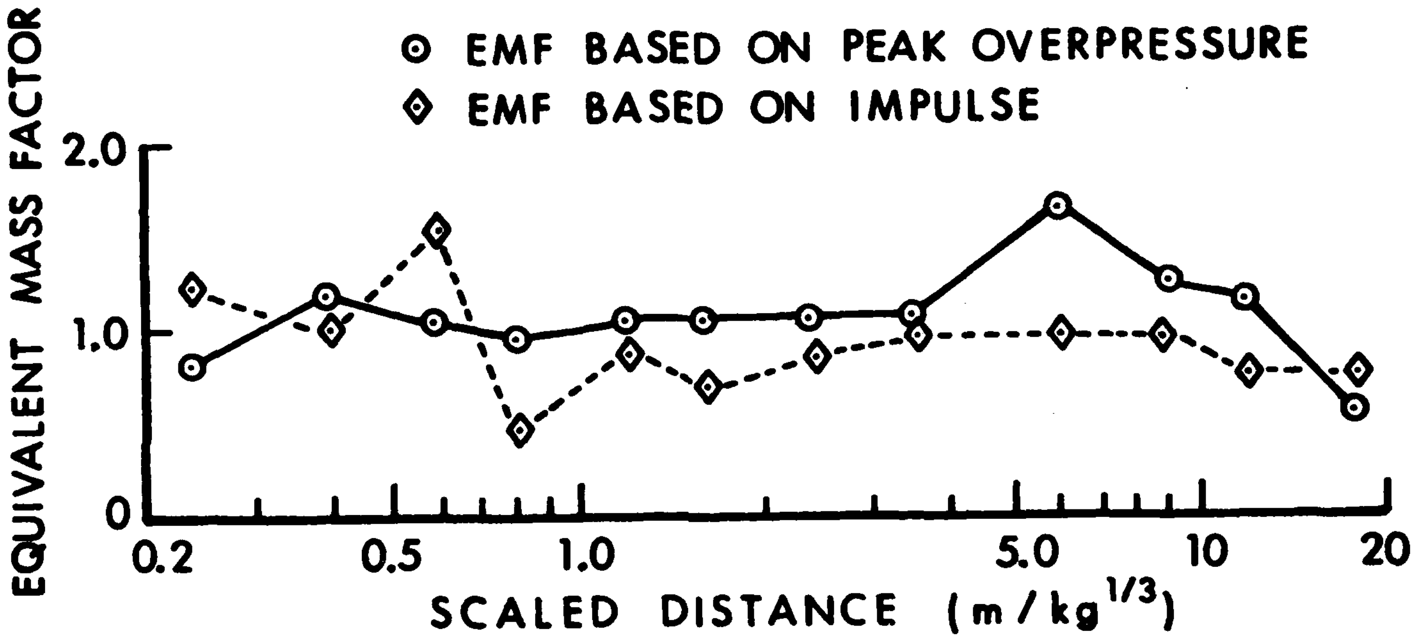


Figure 10. TNT equivalent mass factors versus scaled distance for Pentolite on a sand base and TNT on a clay base.

TABLE VIII. Equivalent Mass Factors, Impulse-Distance

I_P kPa-ms/kg$^{1/3}$	D_P m/kg$^{1/3}$	I_P/D_P	I_T kPa-ms/kg$^{1/3}$	D_T m/kg$^{1/3}$	$(D_P/D_T)^3$	I_{TS} kPa-ms/kg$^{1/3}$	D_{TS} m/kg$^{1/3}$	$(D_P/D_{TS})^3$
340	0.238	1429	358	0.25	0.85	317	0.22	1.23
179	0.397	451	167	0.37	1.24	179	0.40	1.00
191	0.596	320	191	0.59	1.00	166	0.52	1.52
181	0.794	228	191	0.84	0.84	236	1.04	0.45
192	1.191	161	175	1.08	1.32	202	1.25	0.86
128	1.589	80.6	125	1.55	1.08	148	1.81	0.68
105	2.382	44.1	102	2.31	1.10	111	2.52	0.85
76.1	3.574	21.3	75.4	3.54	1.03	77	3.62	0.97
49.4	5.958	8.29	48.0	5.80	1.08	50	6.03	0.96
33.5	8.738	3.83	32.9	8.60	1.05	34.2	8.93	0.94
22.3	11.92	1.87	22.0	11.75	1.04	24.2	12.94	0.78
14.6	17.87	.817	14.3	17.50	1.06	16.0	19.63	0.75
					1.07			0.80

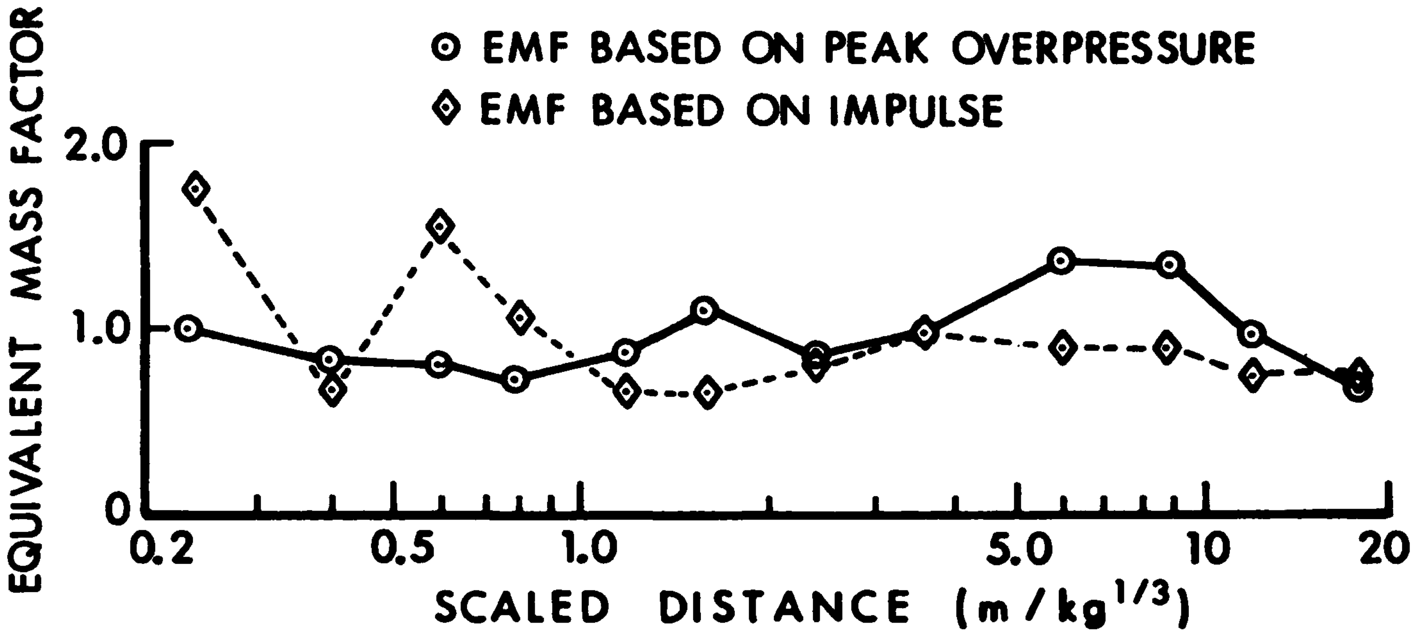


Figure 11. Equivalent mass factors versus scaled distance for TNT hemispherical charges fired on a sand base and a clay base.

from large scale tests fired over a hard packed clay base. The equivalent mass factor can be seen in Table IX where the data recorded from this series of tests are compared with data compiled from large scale TNT tests ranging from 4536 to 453590 kg. The mean value of the EMF's based on the last nine stations is 0.80 which implies that a 0.80 kg TNT hemisphere fired over hard packed clay would produce the same impulse as 1 kg fired over hard packed sand.

I. Peak Overpressure versus Time Comparisons

As mentioned in the preceding text, many of the stations had peak overpressure values that overlapped between the TNT and Pentolite tests. This section will present some selected records from specific stations to illustrate the similarities between the detonation of a TNT hemisphere and a Pentolite hemisphere on a sand base. All pressure versus time records are presented in Appendix B.

1. TNT vs Pentolite, Station 0-3. A comparison of the overpressure versus time recorded at Station 0-3 is presented in Figure 12 to show the similarity between the two explosives at a distance of 0.248m.

2. TNT vs Pentolite, Station, 90-2. In Figure 13 a comparison is presented to show again the similarity in the overpressure versus time recorded at a 0.413m horizontal distance.

3. Pentolite vs Pentolite, 90-2. At some stations there was a greater variation in the repeat tests with the same explosive than between different explosives. This is shown in Figure 14 where the overpressure versus time from Shot 2 and Shot 4, both Pentolite tests, are presented. Similar differences are also evident when comparing two TNT tests especially at the close-in stations.

4. TNT vs Pentolite, Station 90-5. At a distance of 3.72m the test repeatability of the same explosive, and the similarity of the two different explosives are shown in Figure 15. The primary difference is in the time of arrival of the second shock. From Table I and IV the values of peak overpressure and impulse listed for Station 90-5 show the excellent correlation between the two explosives as well as the repeatability of the same explosive.

IV. DISCUSSION AND CONCLUSIONS

The data presented in the Results section and the calculated equivalent mass factors are based on a very limited number of tests. Therefore, some of the conclusions presented could change if larger samples were available to analyze.

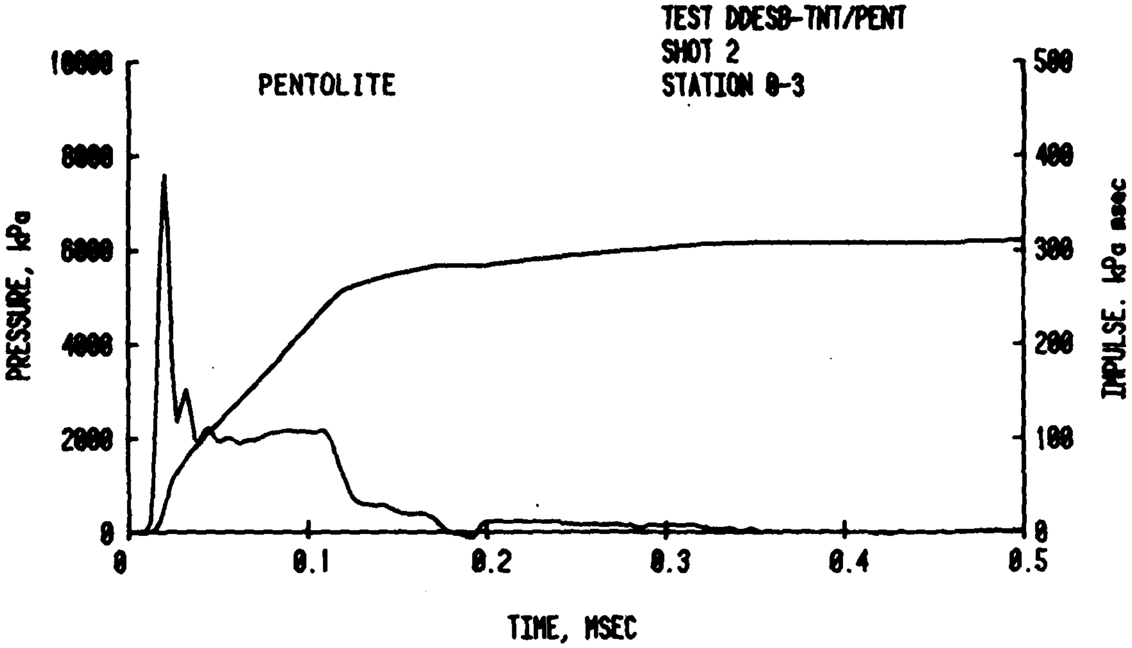
A. TNT vs Pentolite over Sand

One of the primary objectives of this report was to determine the TNT, EMF for Pentolite hemispheres detonated on a sand base. The results of these tests are that it would require 1.11 kg of TNT to produce the blast overpressure from 1.0 kg Pentolite.

TABLE IX. Equivalent Mass Factors, TNT Clay Base vs TNT Sand Base Impulse-Distance

I_T	D_T	I_{T}/D_T	I_{TS}	D_{TS}	$(D_T/D_{TS})^3$
448	0.238	1882	373	0.20	1.74
148	0.395	375	171	0.45	0.65
191	0.593	322	166	0.52	1.52
195	0.790	247	193	0.78	1.04
162	1.187	136	189	1.39	0.62
124	1.584	78.3	144	1.84	0.64
99.4	2.372	41.9	108	2.58	0.78
75.3	3.558	21.2	77.0	3.63	0.94
47.9	5.931	7.99	49.5	6.20	0.88
32.7	8.698	3.76	34.1	9.07	0.88
21.8	11.86	1.84	24.0	13.04	0.75
14.2	17.78	0.80	15.9	19.90	0.71
					.80

I_T = Impulse TNT on Sand, $kPa\text{-}ms/kg^{1/3}$
D_T = Distance TNT on Sand, $m/kg^{1/3}$
I_{TS} = Impulse TNT Clay, $kPa\text{-}ms/kg^{1/3}$
D_{TS} = Distance TNT Clay, $m/kg^{1/3}$



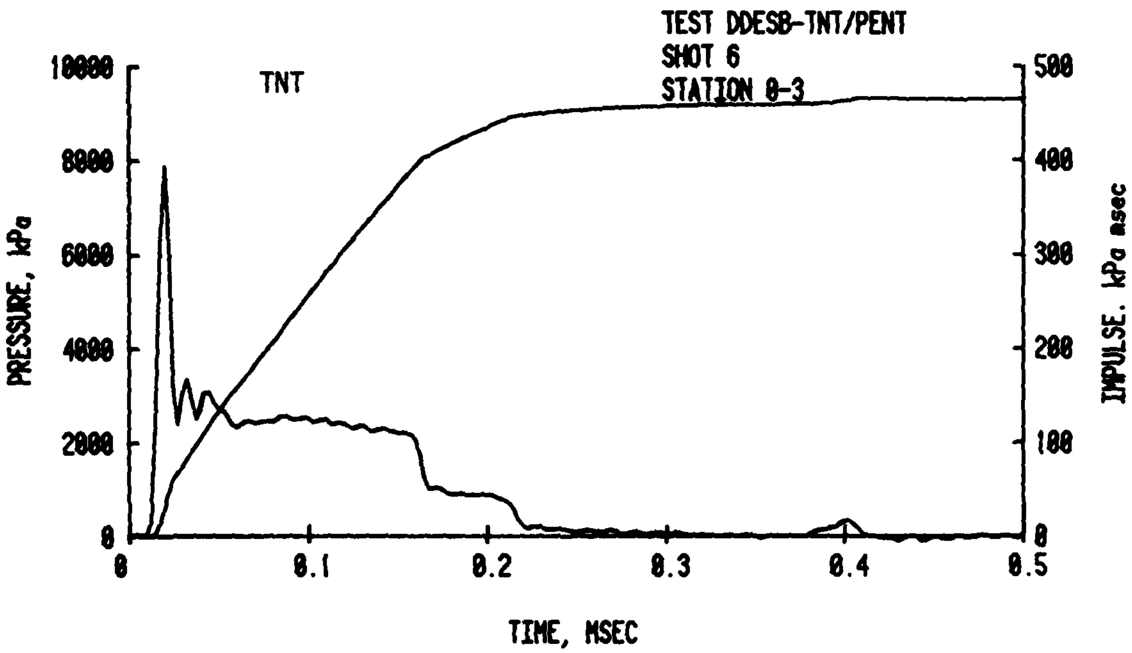
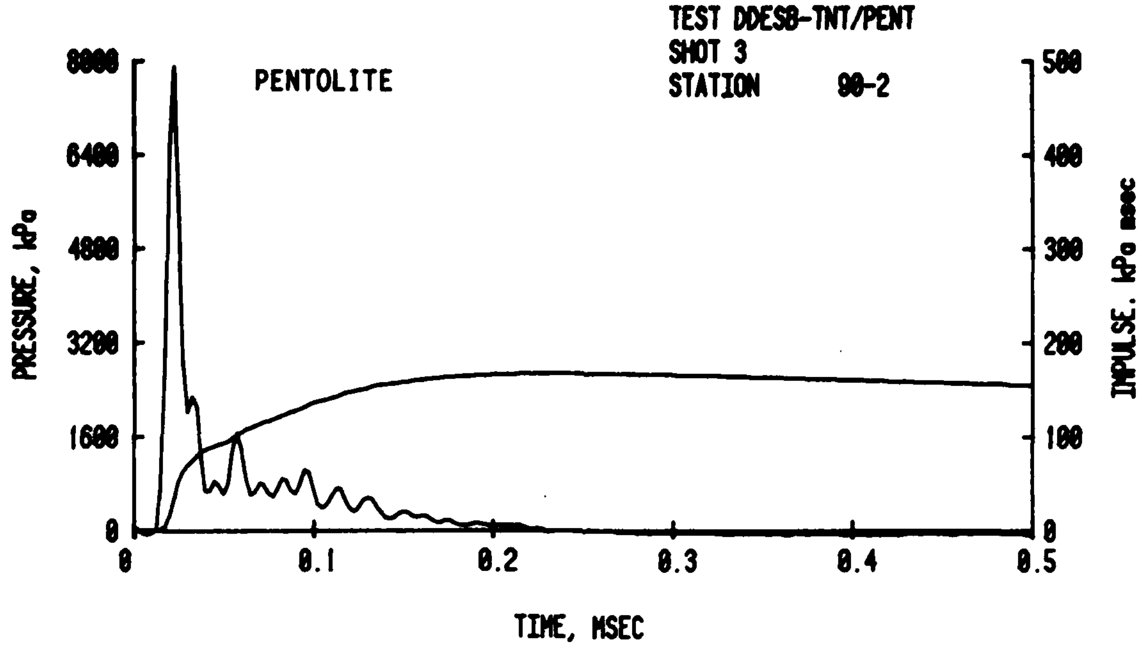


Figure 12. Comparison of TNT and Pentolite at Station 0-3.



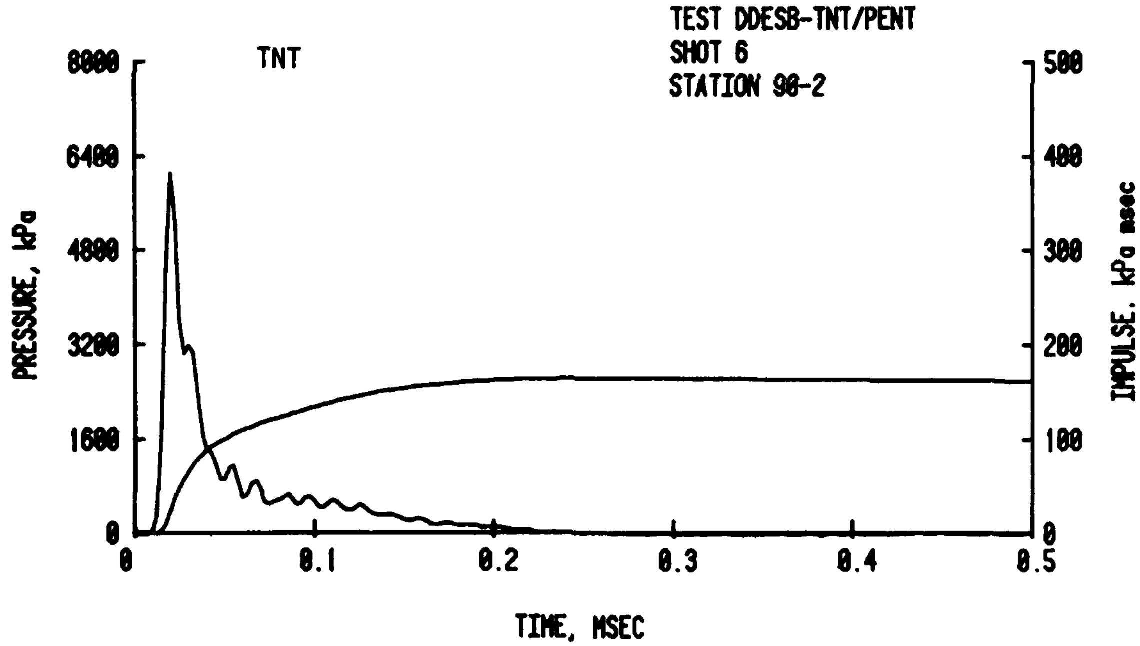
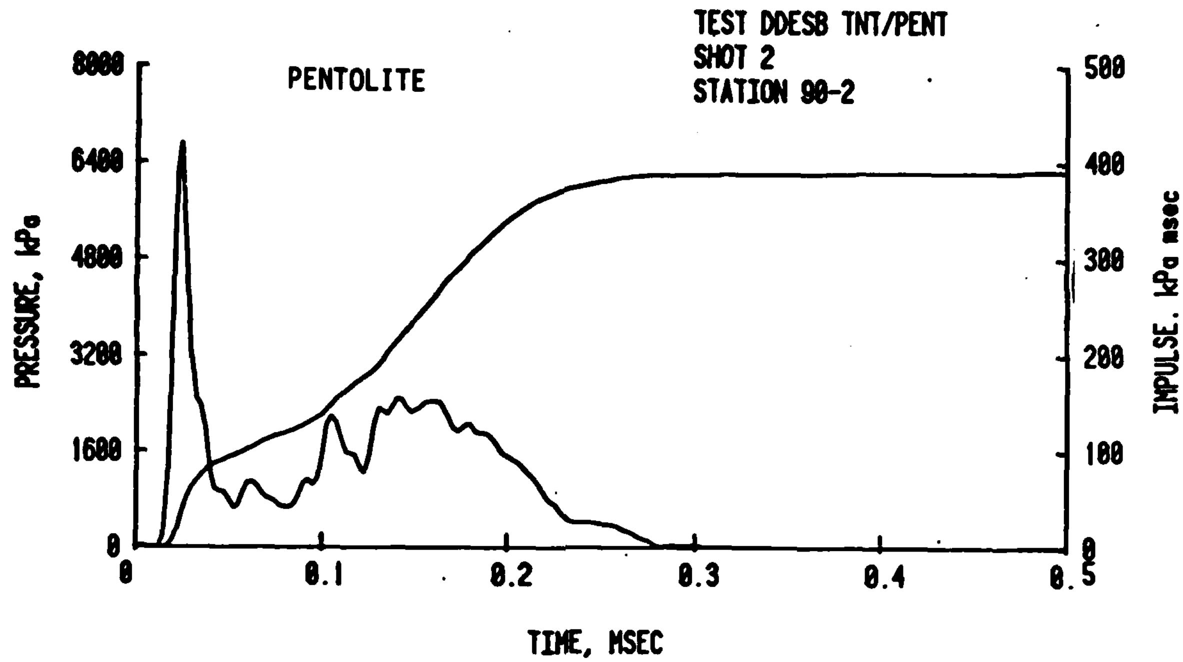


Figure 13. Comparison of TNT and Pentolite at Station 90-2.



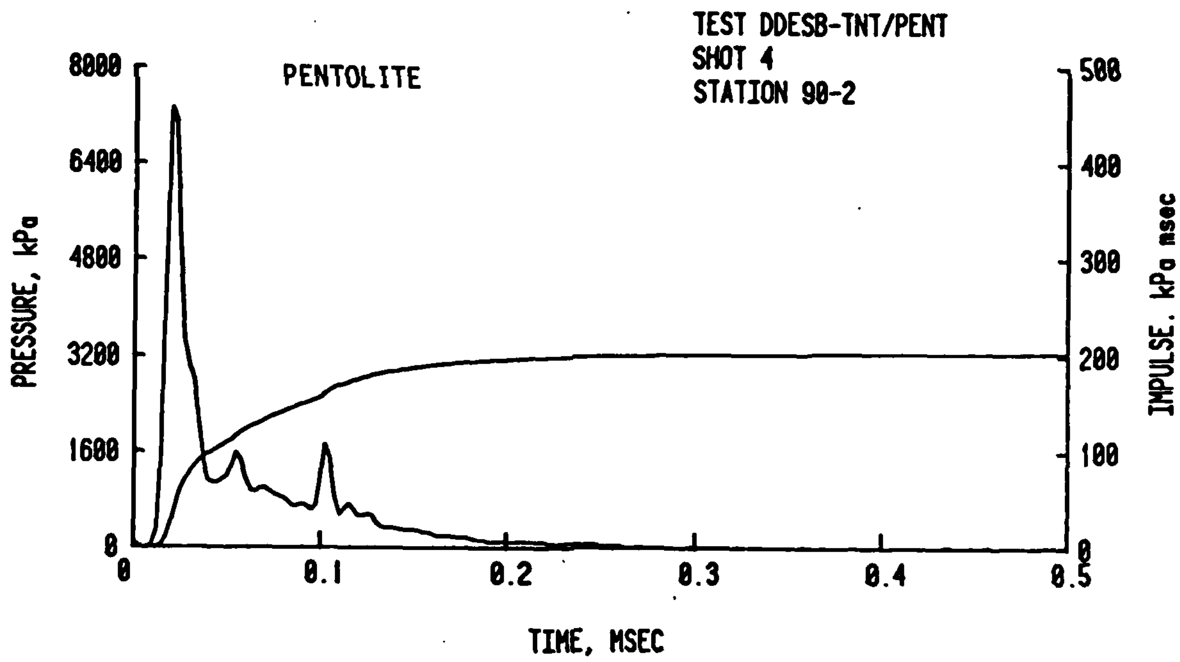


Figure 14. Comparison of Pentolite and Pentolite at Station 90-2.

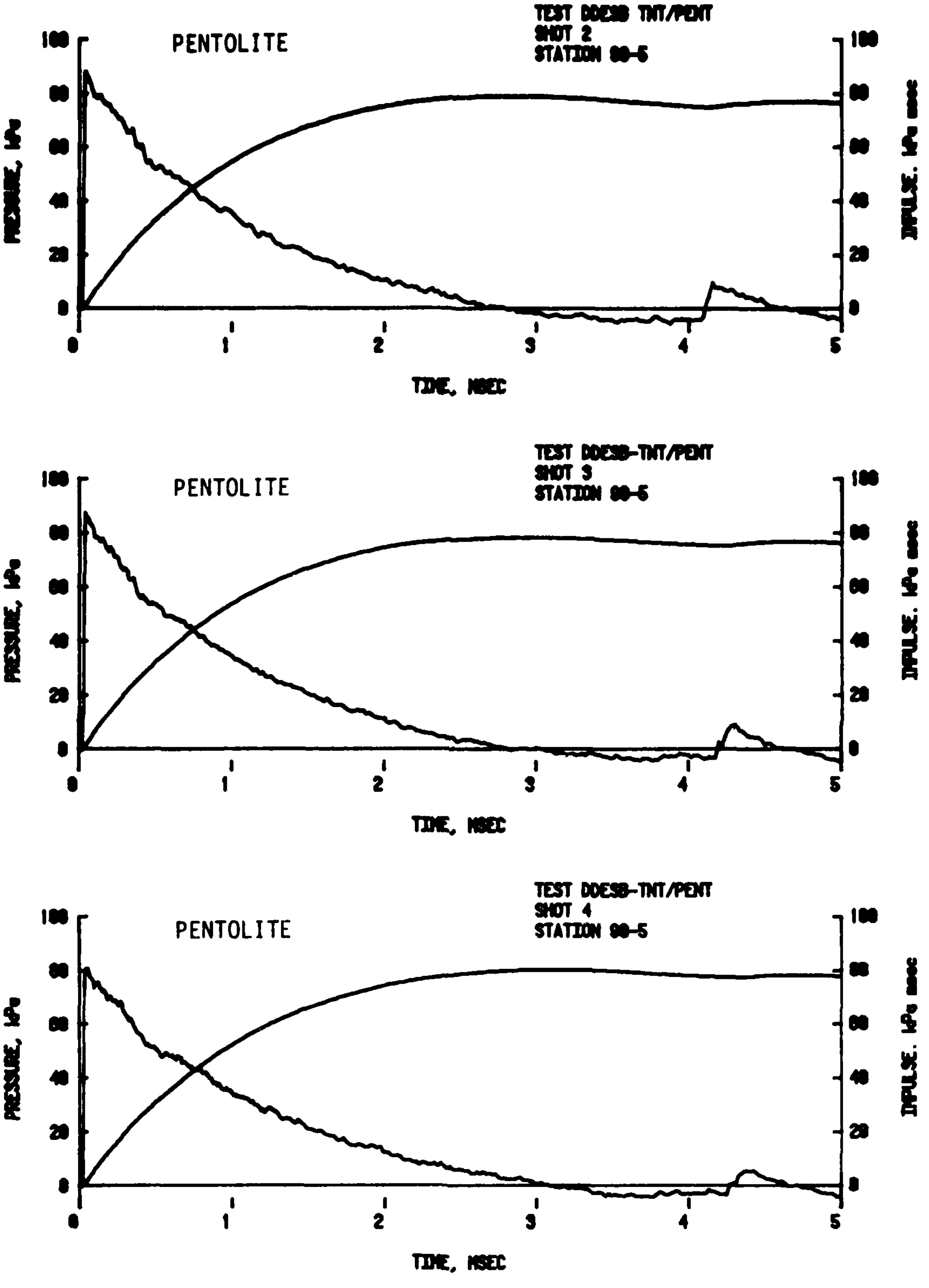
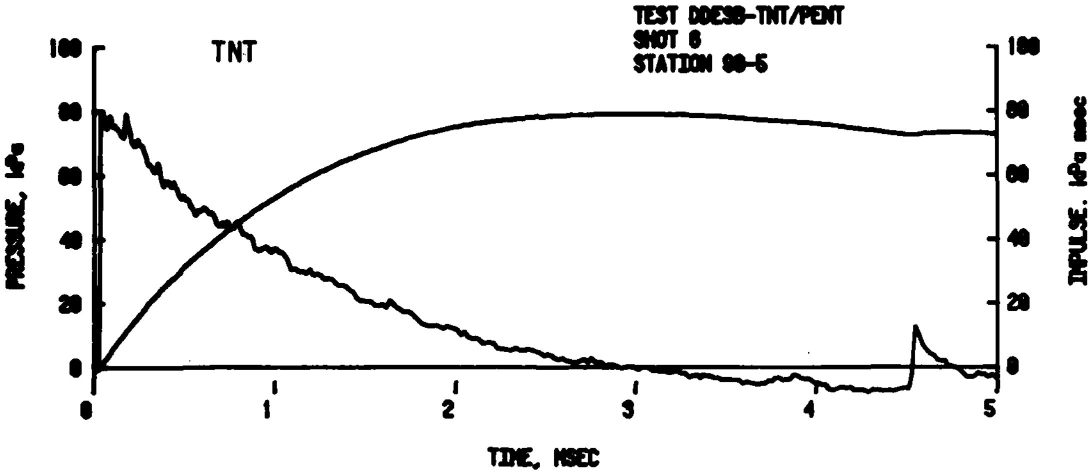


Figure 15. Comparison of all shots at Station 90-5.



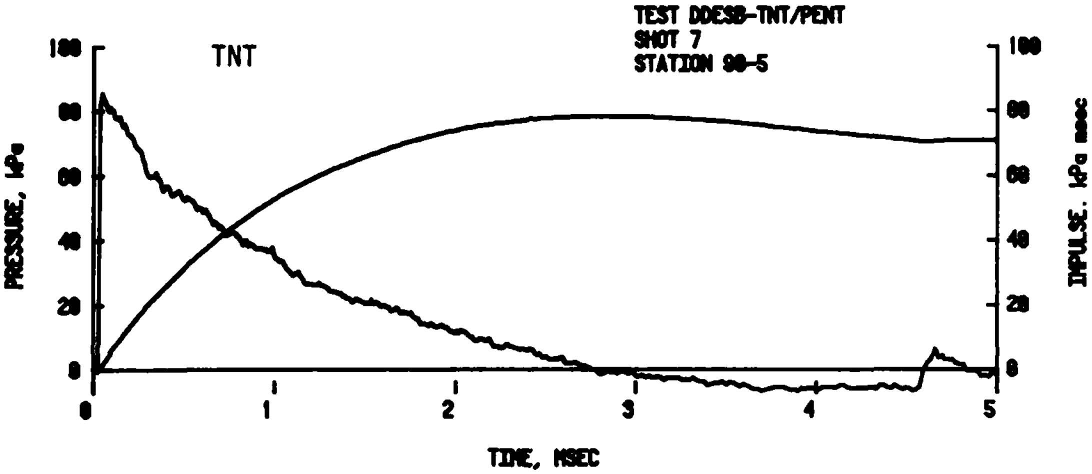


Figure 15. Comparison of all shots at Station 90-5. (cont'd)

The TNT EMF for Pentolite based on impulse-distance criteria was determined to be 1.07. The scaled overpressure impulse versus scaled distance presented in Figure 7 show a very good correlation between the two explosives but the detailed analysis indicates a mean difference of ± four percent.

B. Pentolite over Sand vs TNT over Clay

The TNT blast parameters for hemispherical charges tested over clay as presented in Reference 1 are used as a standard for DDESB quantity-distance criteria. Pentolite hemispheres are used for model studies conducted over a sand base at the BRL and therefore it is necessary to establish the equivalent mass factors for these conditions. From Table VII it was established that the TNT (standard) EMF for Pentolite based on a peak overpressure criterion is 1.08, but based on an impulse criteria it is 0.80. This means that 1.08 kg of TNT on a clay surface would simulate 1.0 kg of Pentolite (peak overpressure) on sand but that it would require only 0.80 kg TNT on clay to simulate 1.0 kg of Pentolite (impulse) on sand.

ACKNOWLEDGMENTS

The authors wish to acknowledge the following individuals for their special contributions to this report. To Mr. George T. Watson the electronic engineer whose knowledge, experience, and careful attention to details resulted in the excellent pressure-time records used in the analysis portion of this report; and to Mr. Kenneth Holbrook the explosives handler and field technician for the site preparation and field activities.

APPENDIX A

DATA TABLES FOR LARGE SCALE TNT HEMISPHERES DETONATED OVER A CLAY SURFACE

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE

λ_m m/kg$^{1/3}$	ΔP_s kPa		t_a ms/kg$^{1/3}$	t_+ ms/kg$^{1/3}$	I_s kPa-ms/kg$^{1/3}$	
*		**				
7934-01	4793	5	1242-01	-----	-----	
9918-01	3860	5	1561-01	-----	-----	
1190	3188	5	1914-01	-----	-----	
1388	2687	5	2298-01	-----	-----	
1587	2304	5	2716-01	-----	-----	
1785	2002	5	3164-01	256	-----	
1984	1760	5	3642-01	246	379	3
2182	1561	5	4151-01	238	326	3
2380	1394	5	4690-01	232	288	3
2579	1253	5	5257-01	227	260	3
2777	1134	5	5854-01	223	240	3
2975	1032	5	6479-01	221	222	3
3194	9432	4	7131-01	221	209	3
3372	8653	4	7812-01	223	200	3
3570	7977	4	8520-01	224	192	3
3769	7377	4	9257-01	227	186	3
3967	6850	4	1002	232	179	3
4364	5931	4	1163	247	173	3
4760	5201	4	1370	271	170	3
5157	4604	4	1517	299	166	3
5554	4084	4	1710	333	165	3
5950	3678	4	1913	375	167	3
6347	3297	4	2126	424	170	3
6744	2980	4	2351	488	172	3
7141	2702	4	2587	560	179	3
7537	2441	4	2836	664	188	3

* 7934-01 = .07934

**4793 5 = 47930

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Con't)

λ_m $m/kg^{1/3}$	ΔP_s kPa	t_a $ms/kg^{1/3}$	t_+ $ms/kg^{1/3}$	I_s $kPa\text{-}ms/kg^{1/3}$
7934	2211 4	3095	788	201 3
8727	1813 4	3651	113 1	216 3
9521	1503 4	4258	154 1	238 3
1031 1	1264 4	4918	186 1	236 3
1111 1	1074 4	5628	207 1	225 3
1190 1	9218 3	6392	216 1	214 3
1289 1	7701 3	7419	221 1	201 3
1388 1	6507 3	8525	221 1	189 3
1488 1	5560 3	9709	217 1	178 3
1587 1	4797 3	1097 1	210 1	166 3
1785 1	3665 3	1371 1	206 1	149 3
1984 1	2885 3	1672 1	204 1	135 3
2182 1	2328 3	1999 1	210 1	124 3
2380 1	1918 3	2348 1	221 1	115 3
2579 1	1609 3	2717 1	238 1	107 3
2777 1	1371 3	3105 1	262 1	996 2
2975 1	1184 3	3510 1	281 1	933 2
3174 1	1035 3	3929 1	298 1	884 2
3372 1	9122 2	4360 1	311 1	839 2
3570 1	8150 2	4804 1	323 1	799 2
3769 1	7302 2	5256 1	333 1	758 2
3967 1	6629 2	5720 1	341 1	727 2
4364 1	5536 2	6668 1	355 1	668 2
4760 1	4706 2	7640 1	368 1	615 2
5157 1	4082 2	8635 1	381 1	519 2
5554 1	3576 2	9645 1	392 1	538 2

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Con't)

λ_m $m/kg^{1/3}$	ΔP_s kPa	t_a $ms/kg^{1/3}$	t_+ $ms/kg^{1/3}$	I_a $kPa\text{-}ms/kg^{1/3}$
5951 1	3216 2	1067 2	402 1	507 2
6347 1	2880 2	1171 2	414 1	480 2
6744 1	2618 2	1276 2	421 1	449 2
7141 1	2405 2	1381 2	431 1	428 2
7537 1	2212 2	1488 2	439 1	406 2
7934 1	2057 2	1596 2	445 1	386 2
8727 1	1790 2	1812 2	458 1	352 2
9521 1	1585 2	2031 2	474 1	325 2
1031 2	1421 2	2250 2	484 1	300 2
1111 2	1287 2	2471 2	496 1	280 2
1190 2	1176 2	2694 2	508 1	263 2
1289 2	1060 2	2972 2	519 1	243 2
1388 2	9632 1	3252 2	531 1	225 2
1488 2	8818 1	3532 2	544 1	213 2
1587 2	8122 1	3815 2	552 1	198 2
1785 2	6998 1	4380 2	573 1	178 2
1984 2	6120 1	4948 2	592 1	161 2
2182 2	5417 1	5517 2	607 1	146 2
2380 2	4842 1	6088 2	622 1	134 2
2579 2	4363 1	6660 2	634 1	124 2
2777 2	3959 1	7234 2	648 1	115 2
2975 2	3600 1	7808 2	661 1	108 2
3174 2	3288 1	8382 2	674 1	101 2
3570 2	2786 1	9534 2	694 1	848 1
3967 2	2402 1	1069 3	710 1	803 1
4364 2	2101 1	1184 3	729 1	722 1
4760 2	1856 1	1300 3	749 1	660 1

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Con't)

λ_m m/kg$^{1/3}$	ΔP_s kPa	t_a ms/kg$^{1/3}$	t_+ ms/kg$^{1/3}$	I_s kPa-ms/kg$^{1/3}$
5157 2	1658 1	1415 2	762 1	606 1
5554 2	1491 1	1531 3	775 1	561 1
5951 2	1358 1	1647 3	788 1	525 1
6347 2	1236 1	1764 3	801 1	489 1
6744 2	1136 1	1880 3	814 1	455 1
7141 2	1050 1	1996 3	824 1	431 1
7537 2	9715	2112 3	835 1	405 1
7934 2	9060	2228 3	845 1	381 1
8727 2	7912	2461 3	859 1	344 1
9521 2	7005	2693 3	876 1	315 1
1031 3	6260	2926 3	892 1	288 1
1110 3	5645	3159 3	907 1	267 1
1190 3	5123	3390 3	922 1	247 1
1289 3	4578	3682 3	927 1	226 1
1388 3	4123	3972 3	957 1	209 1
1487 3	3744	4264 3	966 1	195 1
1587 3	3420	4556 3	983 1	180 1
1785 3	2896	5138 3	101 2	160 1
1984 3	2496	5720 3	103 2	------
2182 3	2186	6303 3	105 2	------
2380 3	1931	6884 3	107 2	------
2579 3	1724	7468 3	------	------
2777 3	1558	8050 3	------	------
3174 3	1289	9217 3	------	------
3570 3	1089	1038 4	------	------
3967 3	9446-01	1155 4	------	------

APPENDIX B

PRESSURE VERSUS TIME CURVES

LIST OF ILLUSTRATIONS

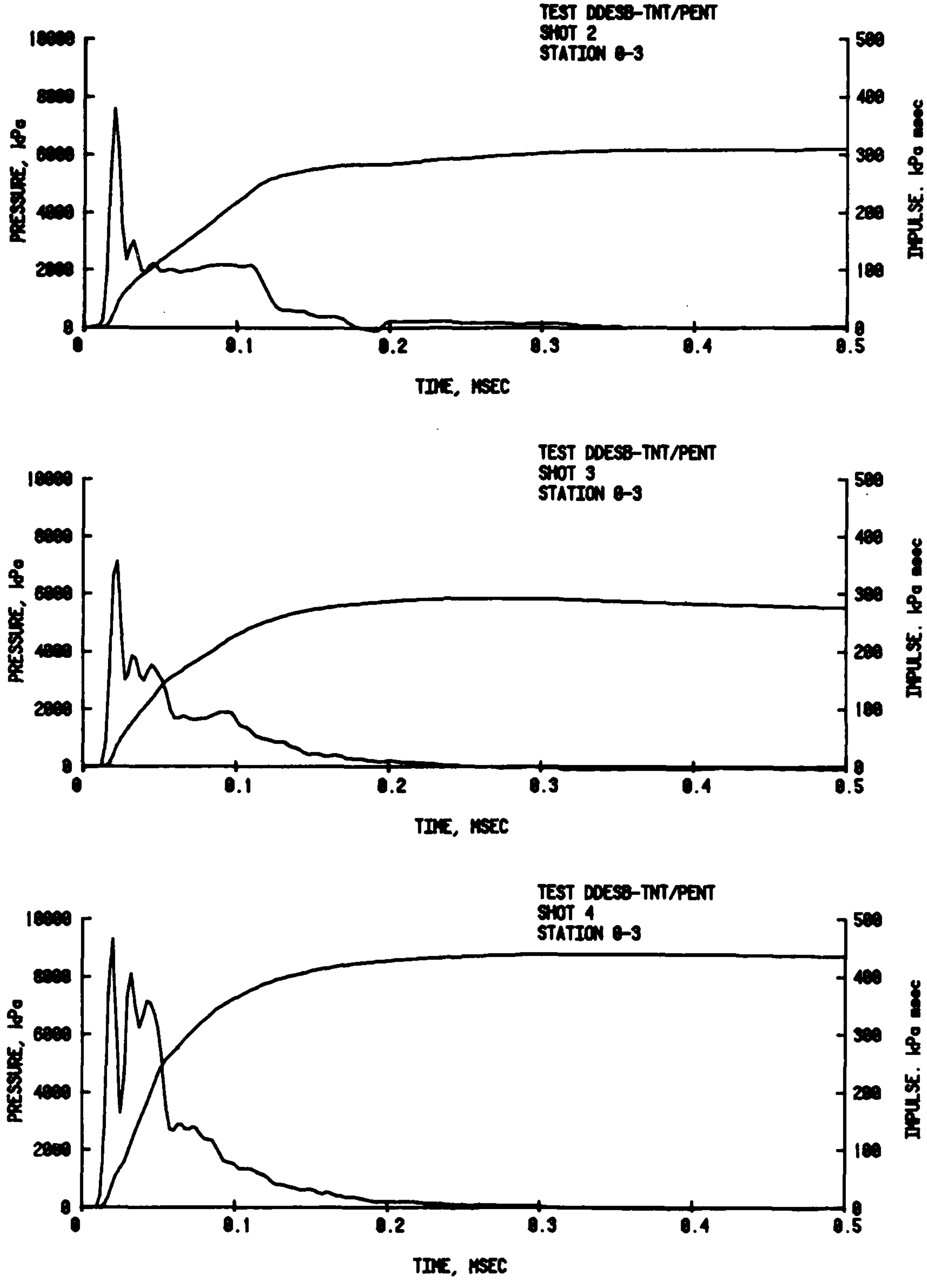


Figure B-1. Pressure and impulse versus time, Station 0-3, Pentolite.

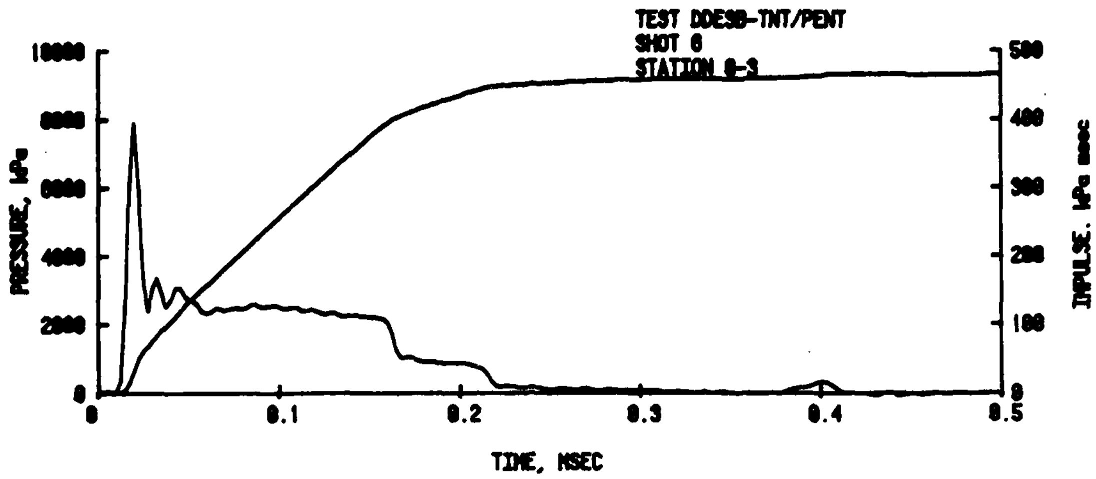


Figure B-2. Pressure and impulse versus time, Station 0-3, TNT

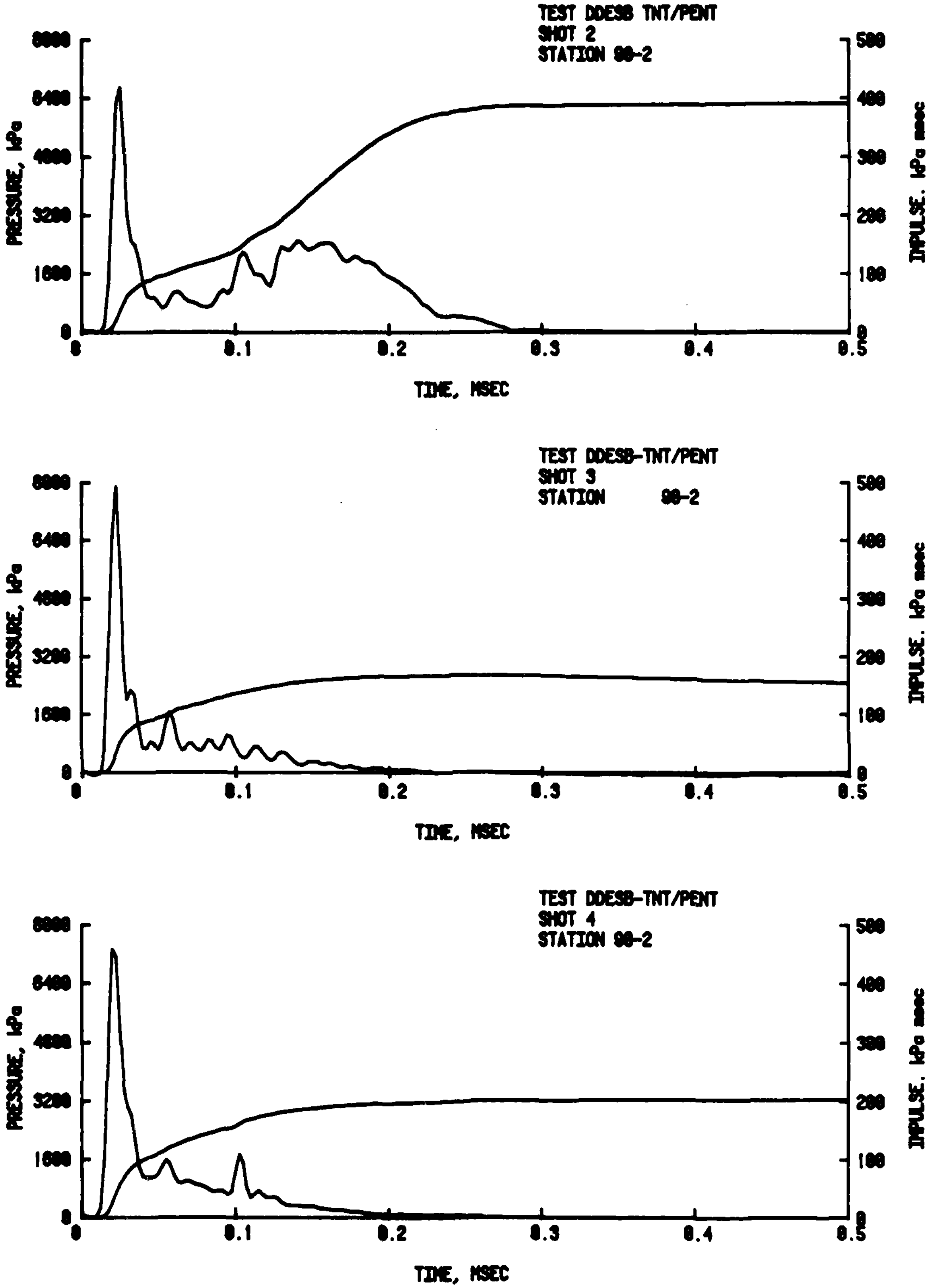


Figure B-3. Pressure and impulse versus time, Station 90-2, Pentolite.

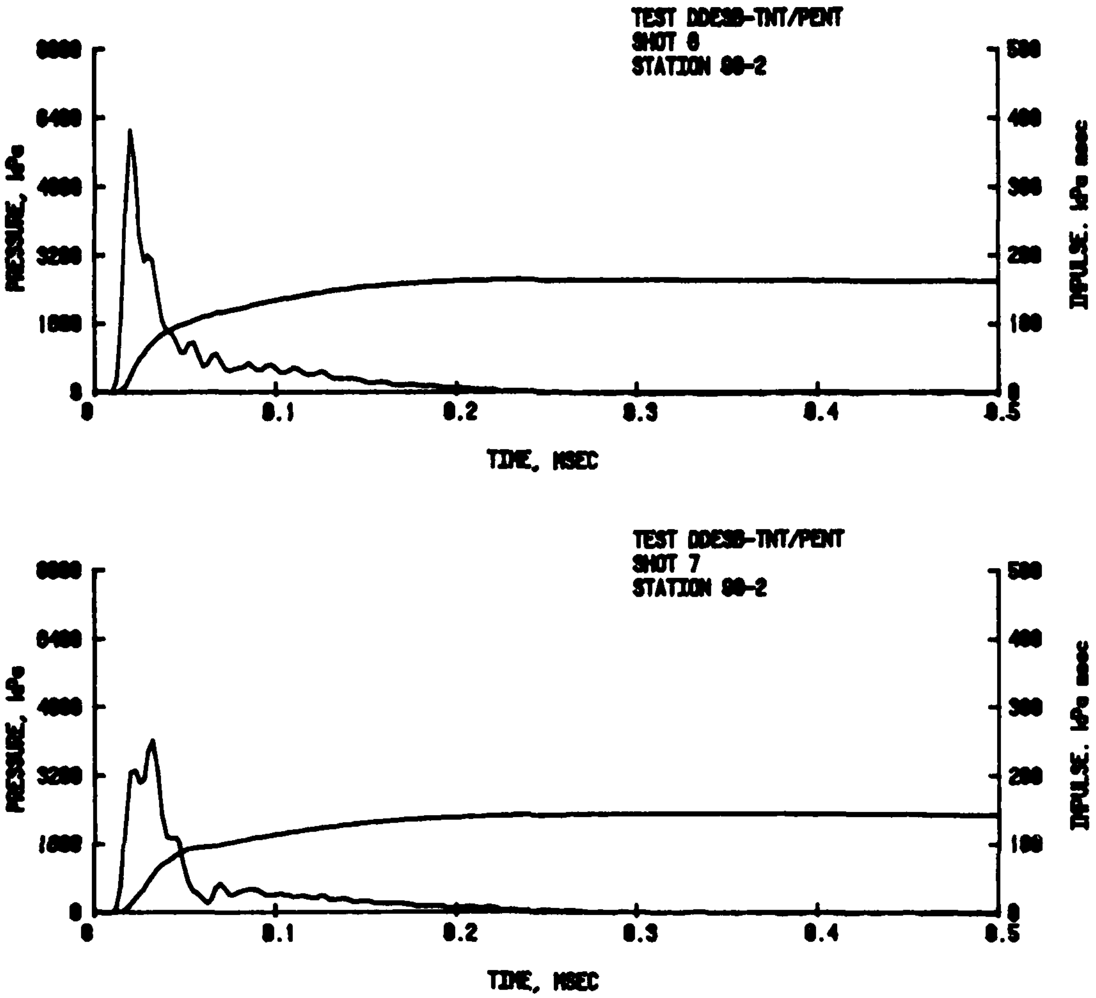


Figure B-4. Pressure and impulse versus time, Station 90-2, TNT.

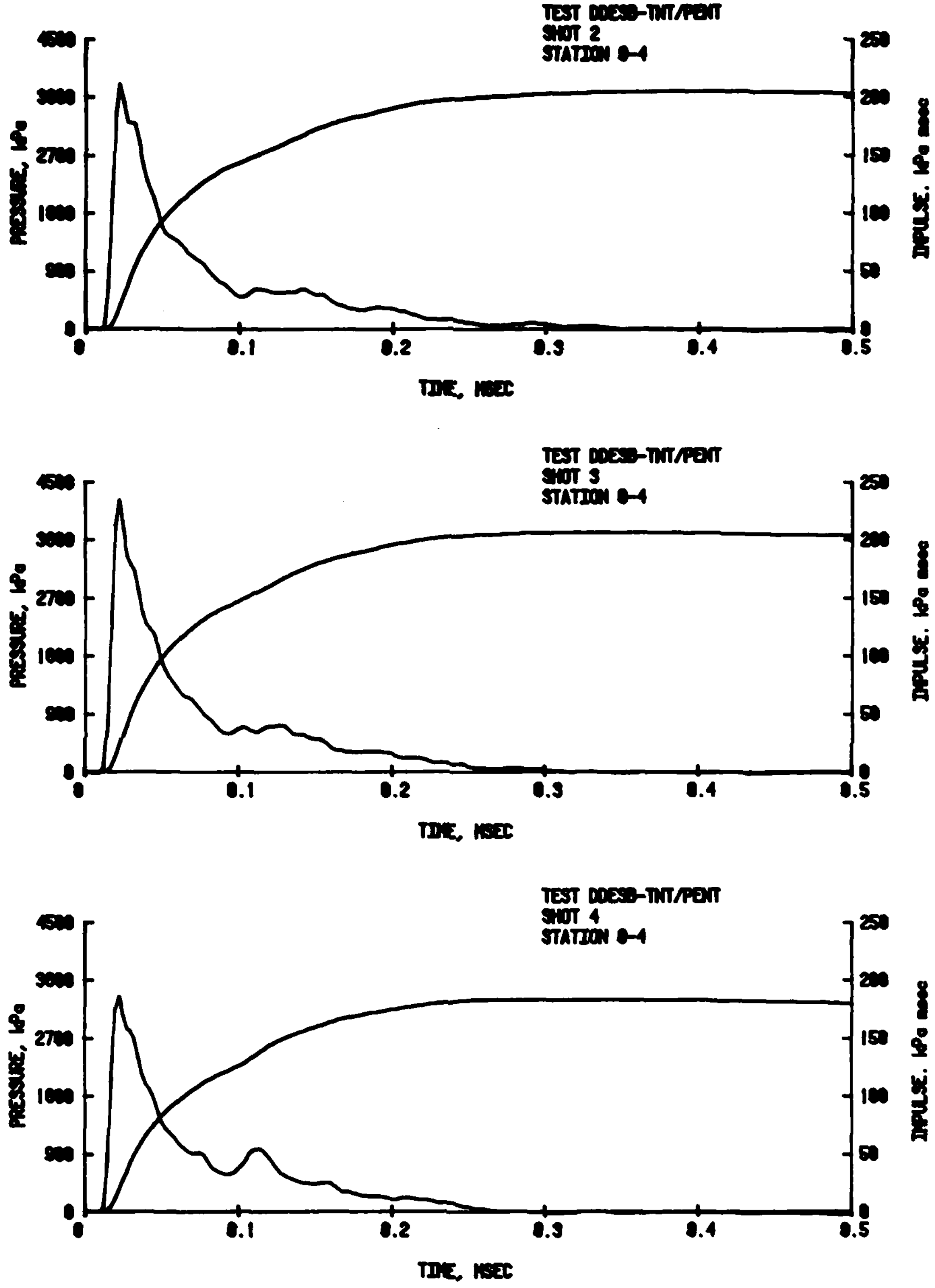


Figure B-5. Pressure and impulse versus time, Station 0-4, Pentolite.

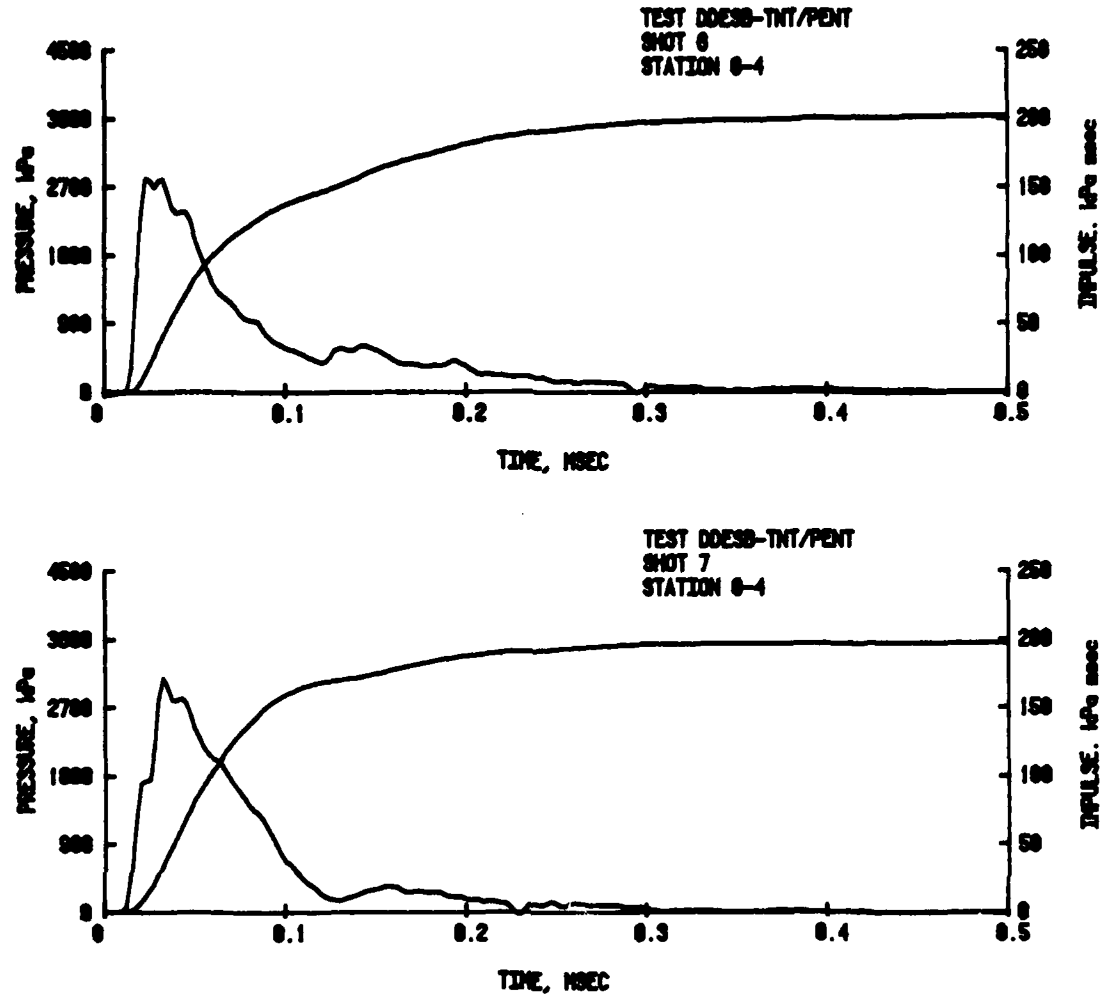


Figure B-6. Pressure and impulse versus time, Station 0-4, TNT.

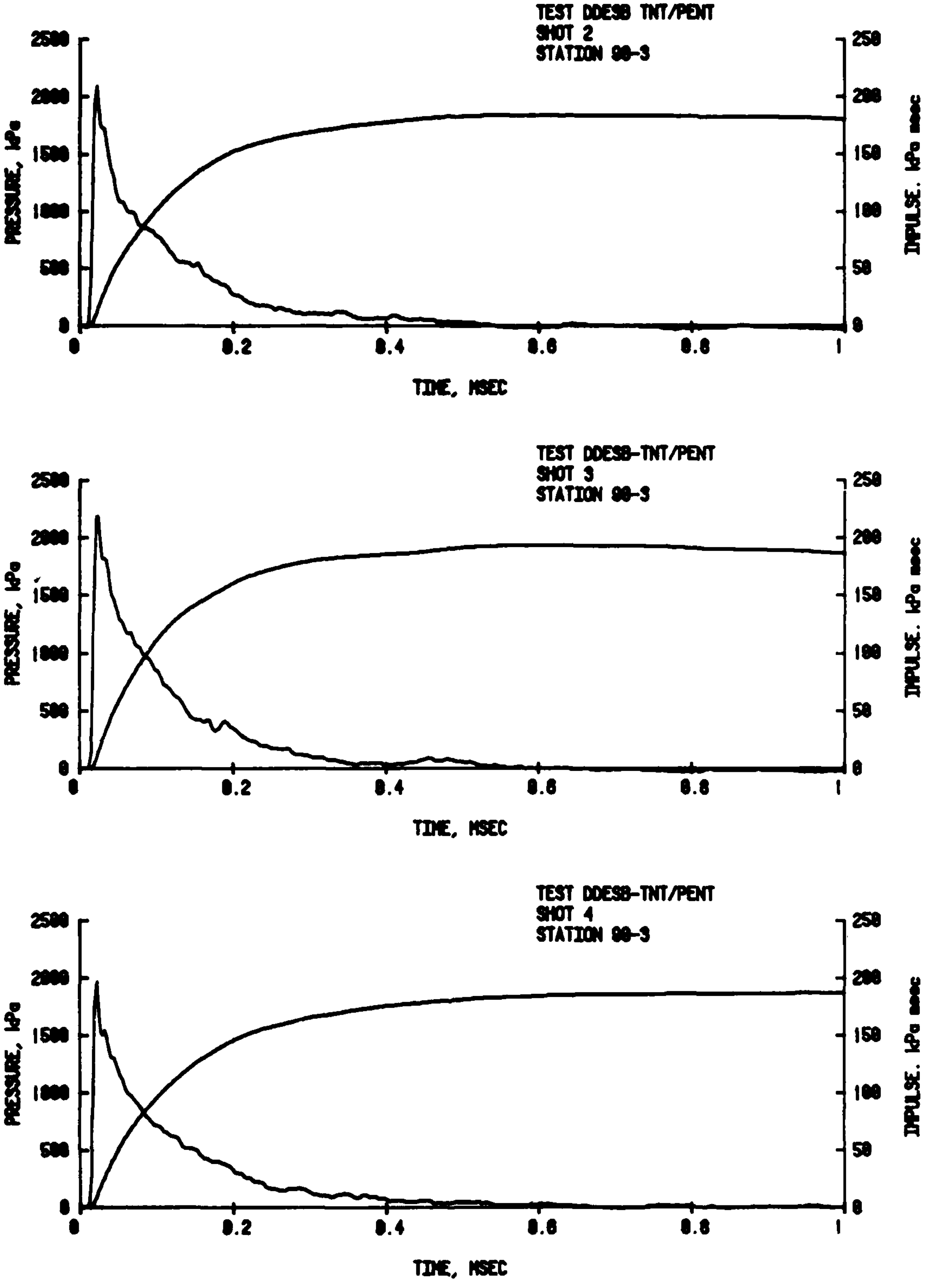


Figure B-7. Pressure and impulse versus time, Station 90-3, Pentolite.

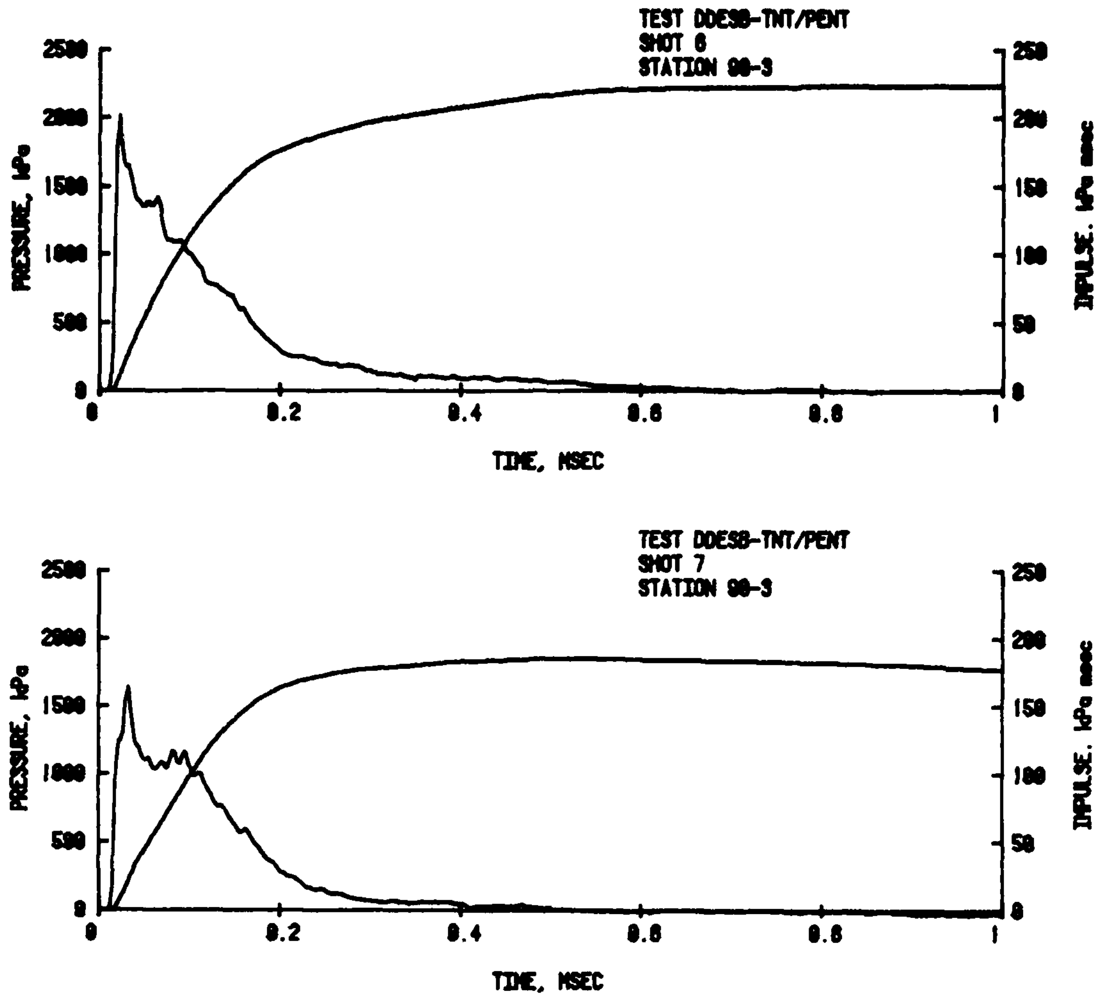


Figure B-8. Pressure and impulse versus time, Station 90-3, TNT.

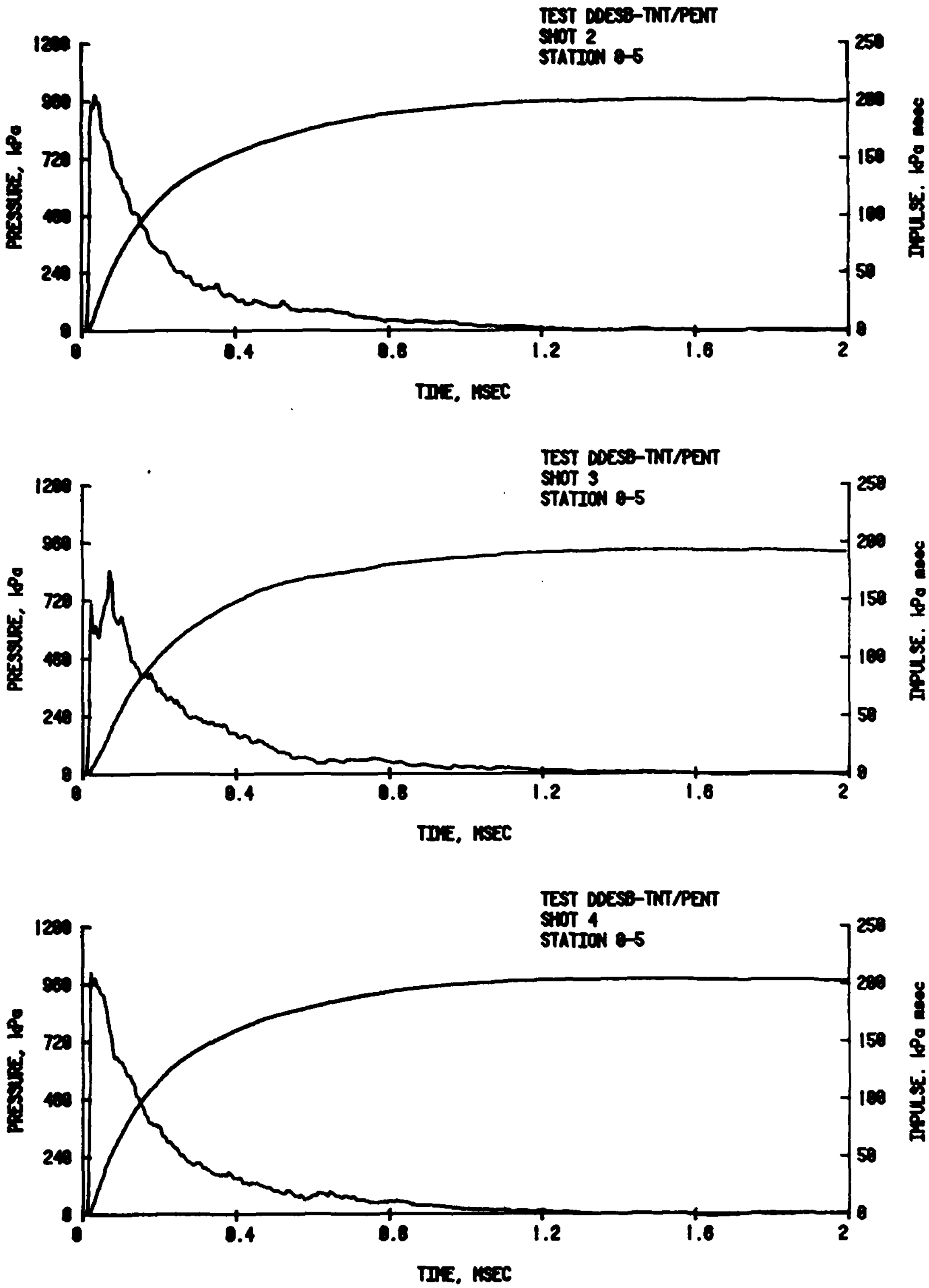
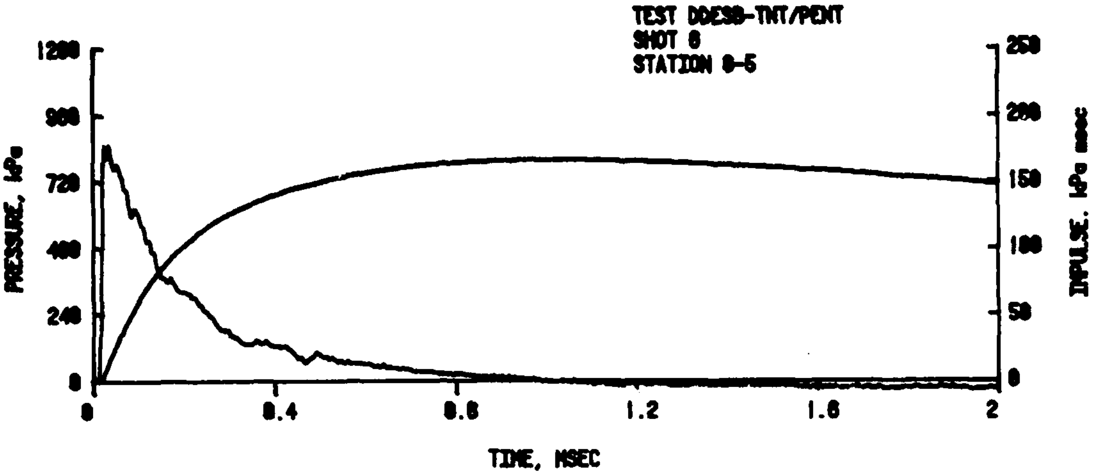


Figure B-9. Pressure and impulse versus time, Station 0-5, Pentolite.



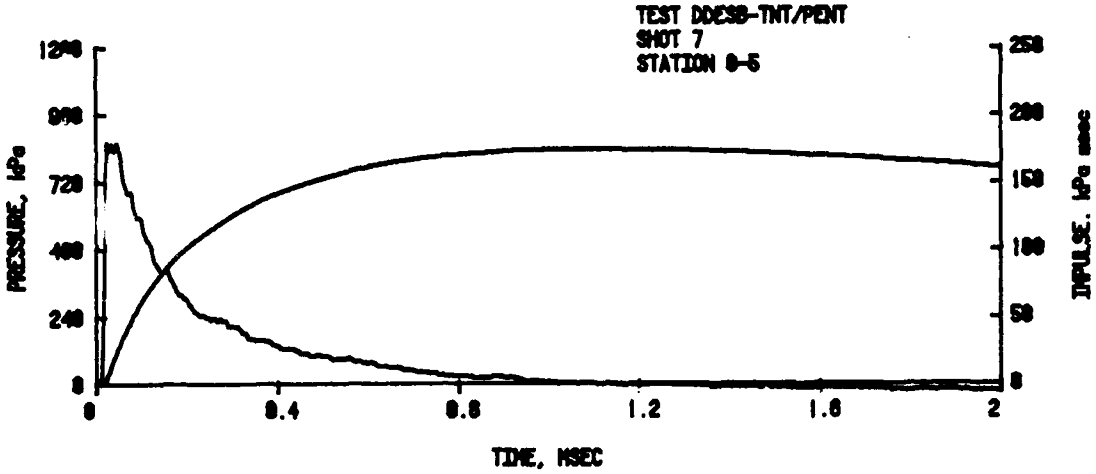


Figure B-10. Pressure and impulse versus time, Station 0-5, TNT.

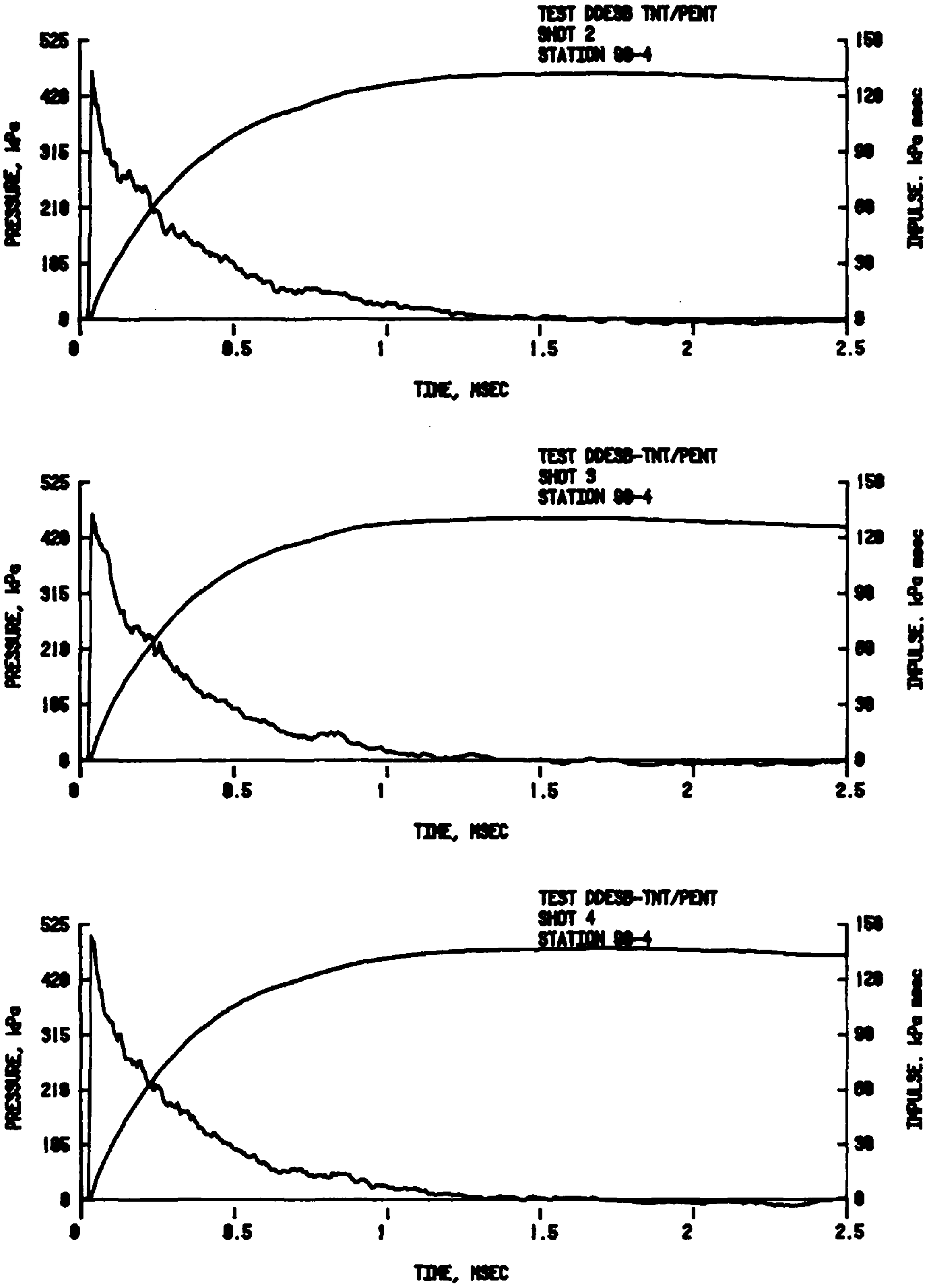


Figure B-11. Pressure and impulse versus time, Station 90-4, Pentolite.

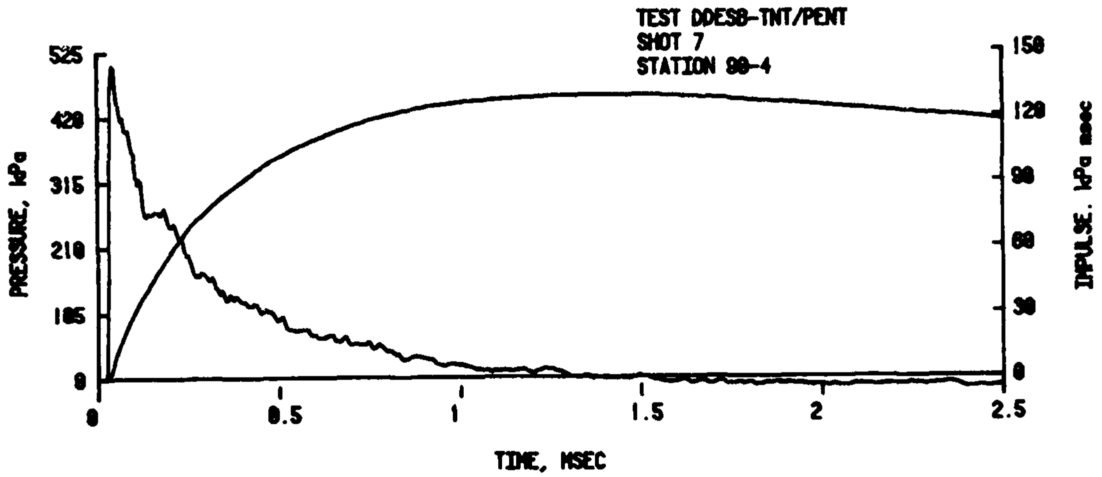


Figure B-12. Pressure and impulse versus time, Station 90-4, TNT.

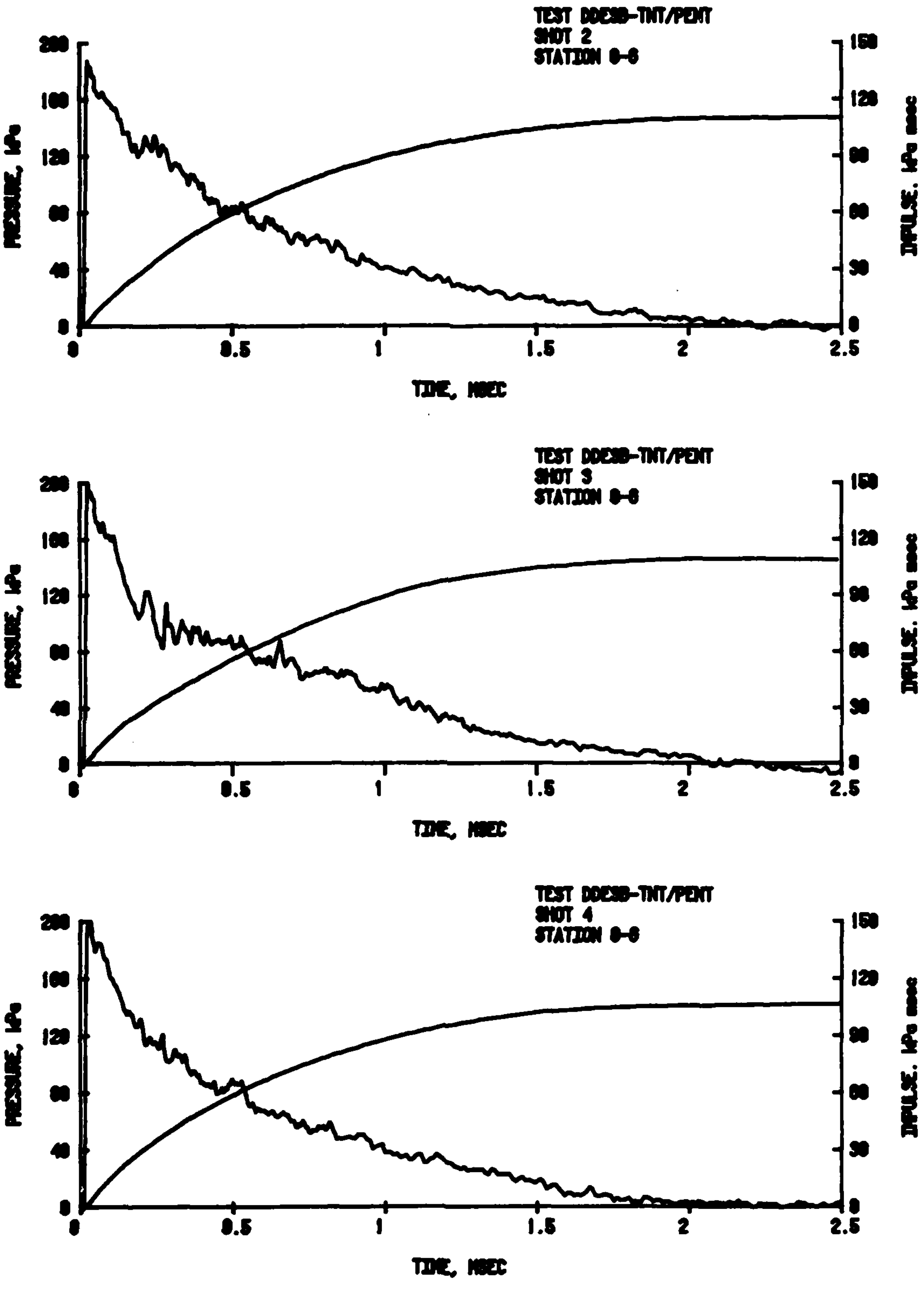
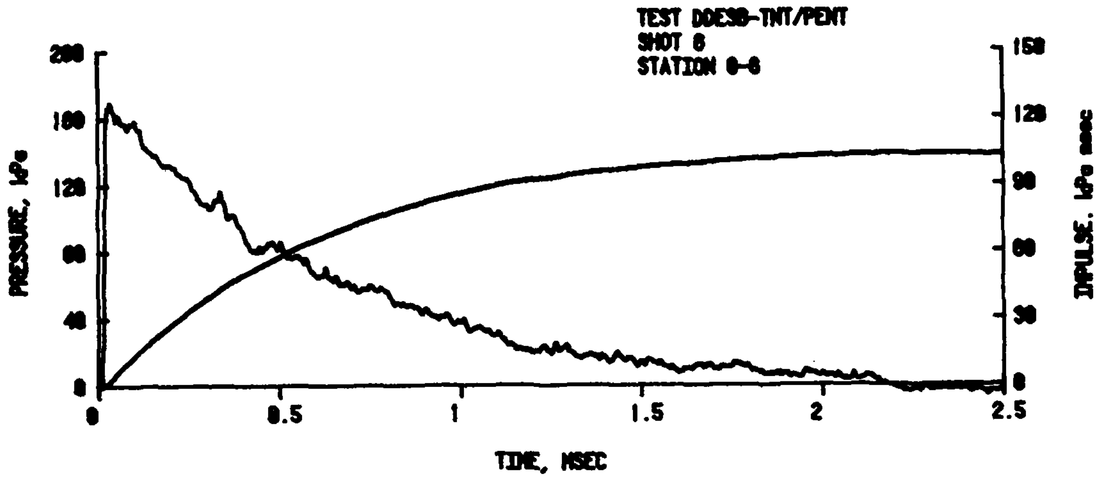


Figure B-13. Pressure and impulse versus time, Station 0-6, Pentolite.



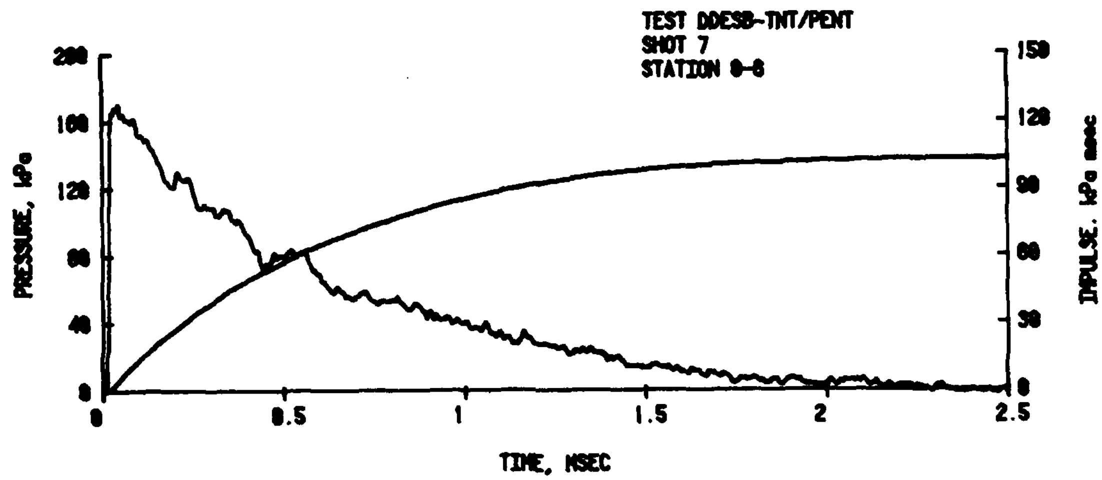


Figure B-14. Pressure and impulse versus time, Station 0-6, TNT.

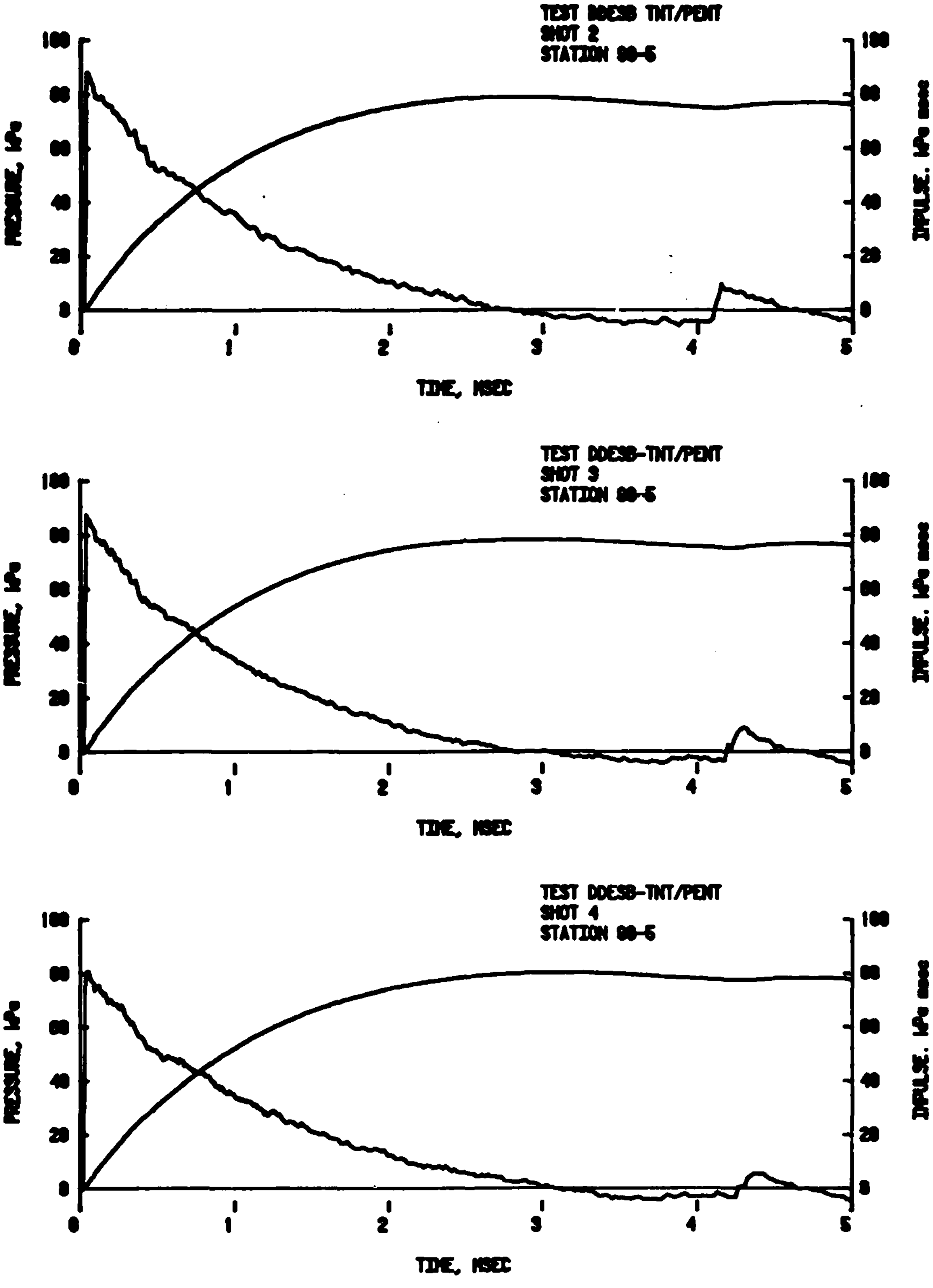


Figure B-15. Pressure and impulse versus time, Station 90-5, Pentolite.

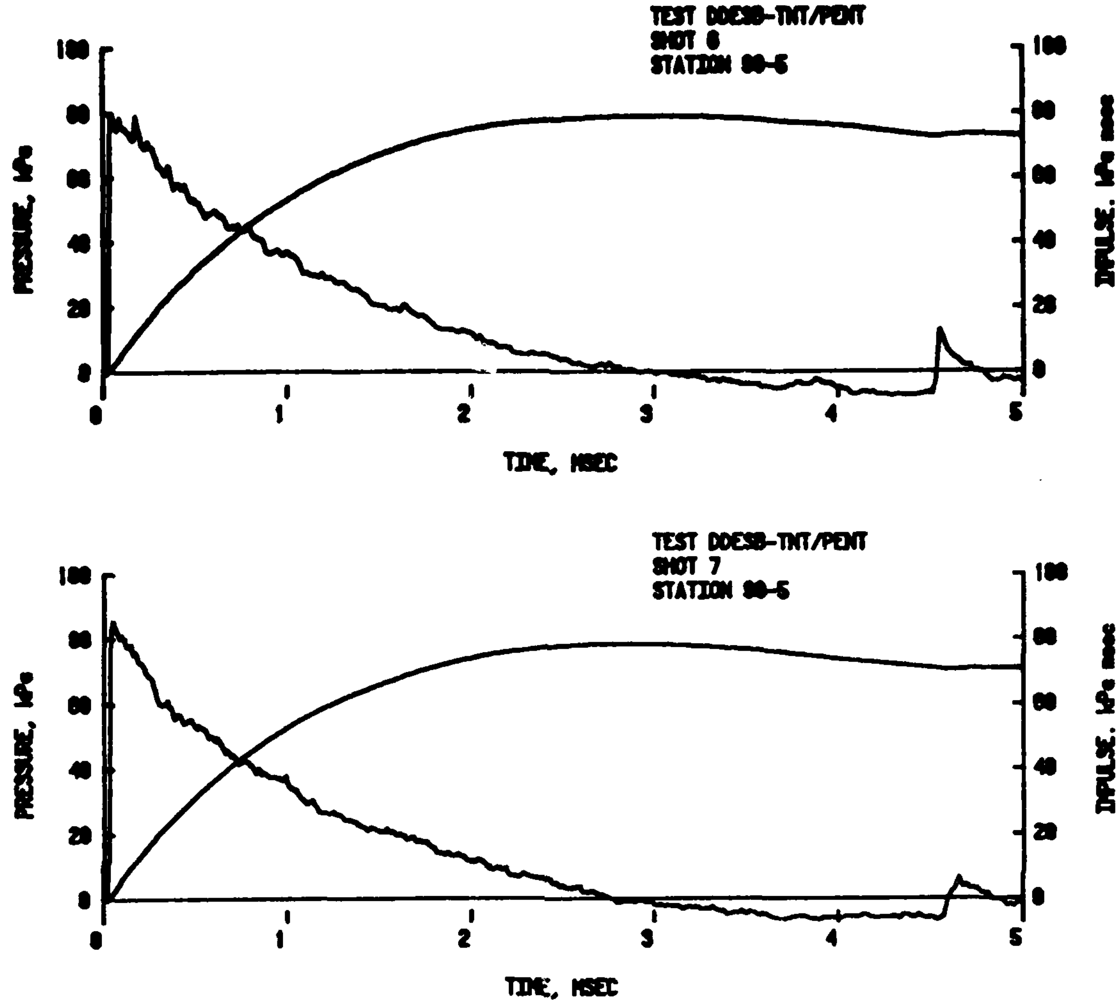


Figure B-16. Pressure and impulse versus time, Station 90-5, TNT.

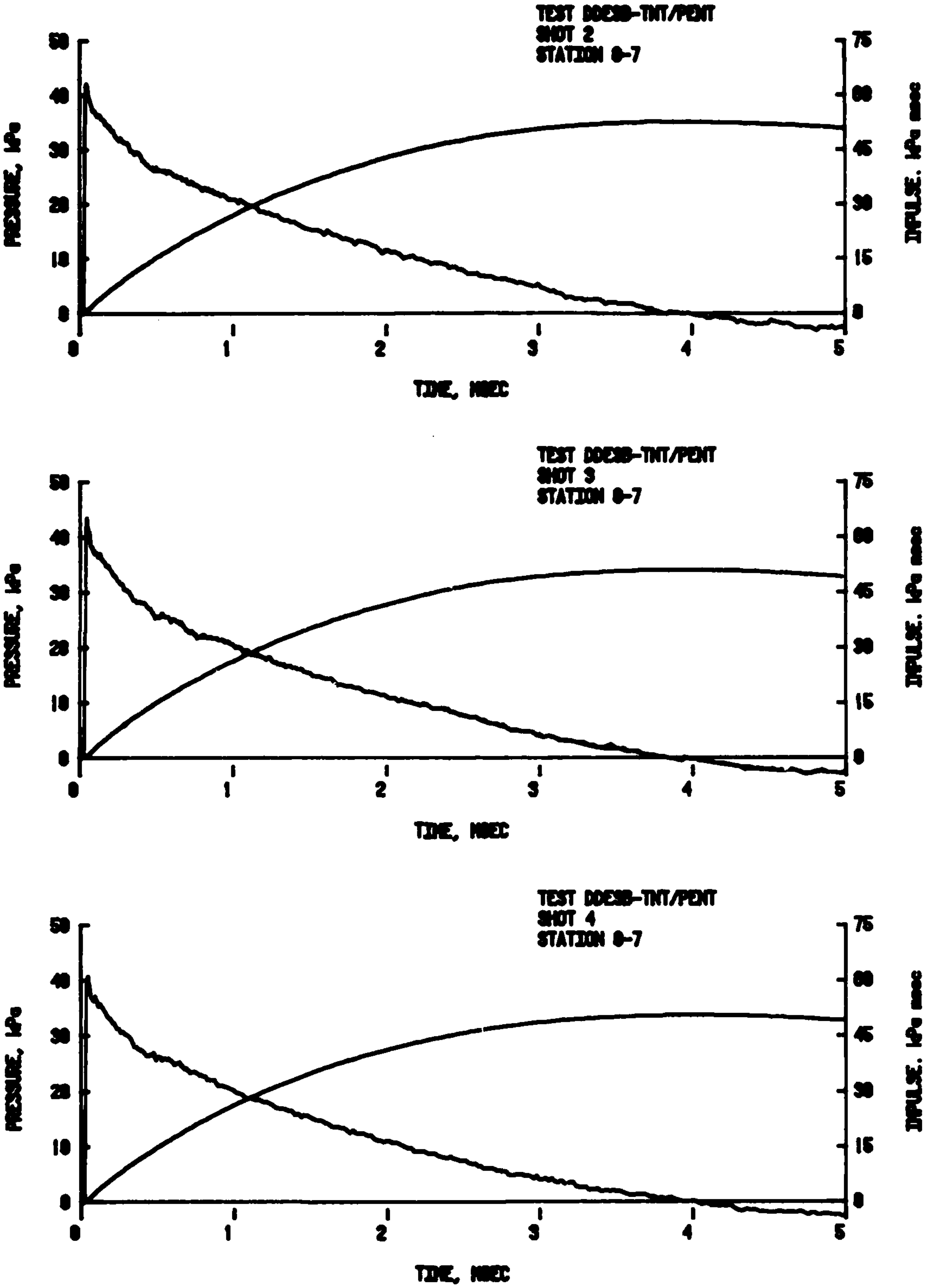


Figure B-17. Pressure and impulse versus time, Station 0-7, Pentolite.

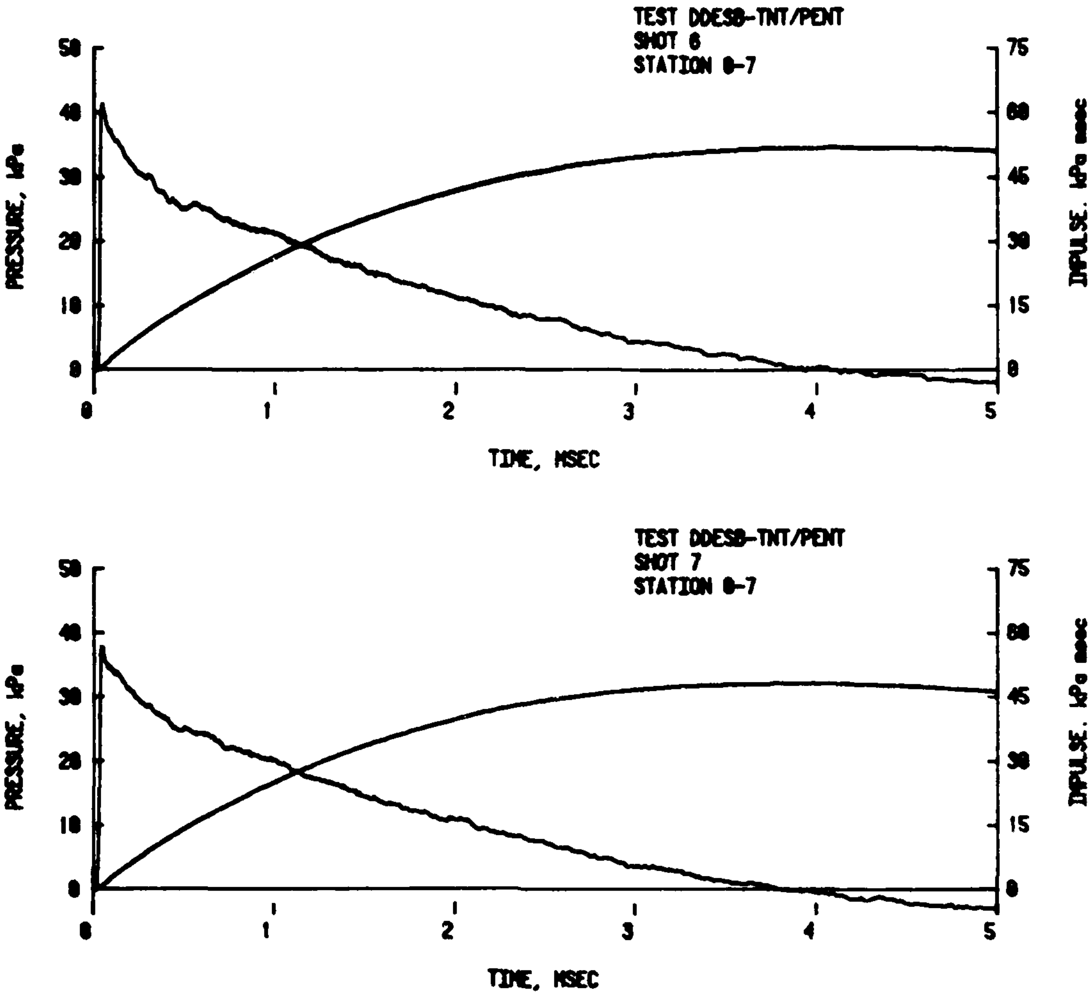


Figure B-18. Pressure and impulse versus time, Station 0-7, TNT.

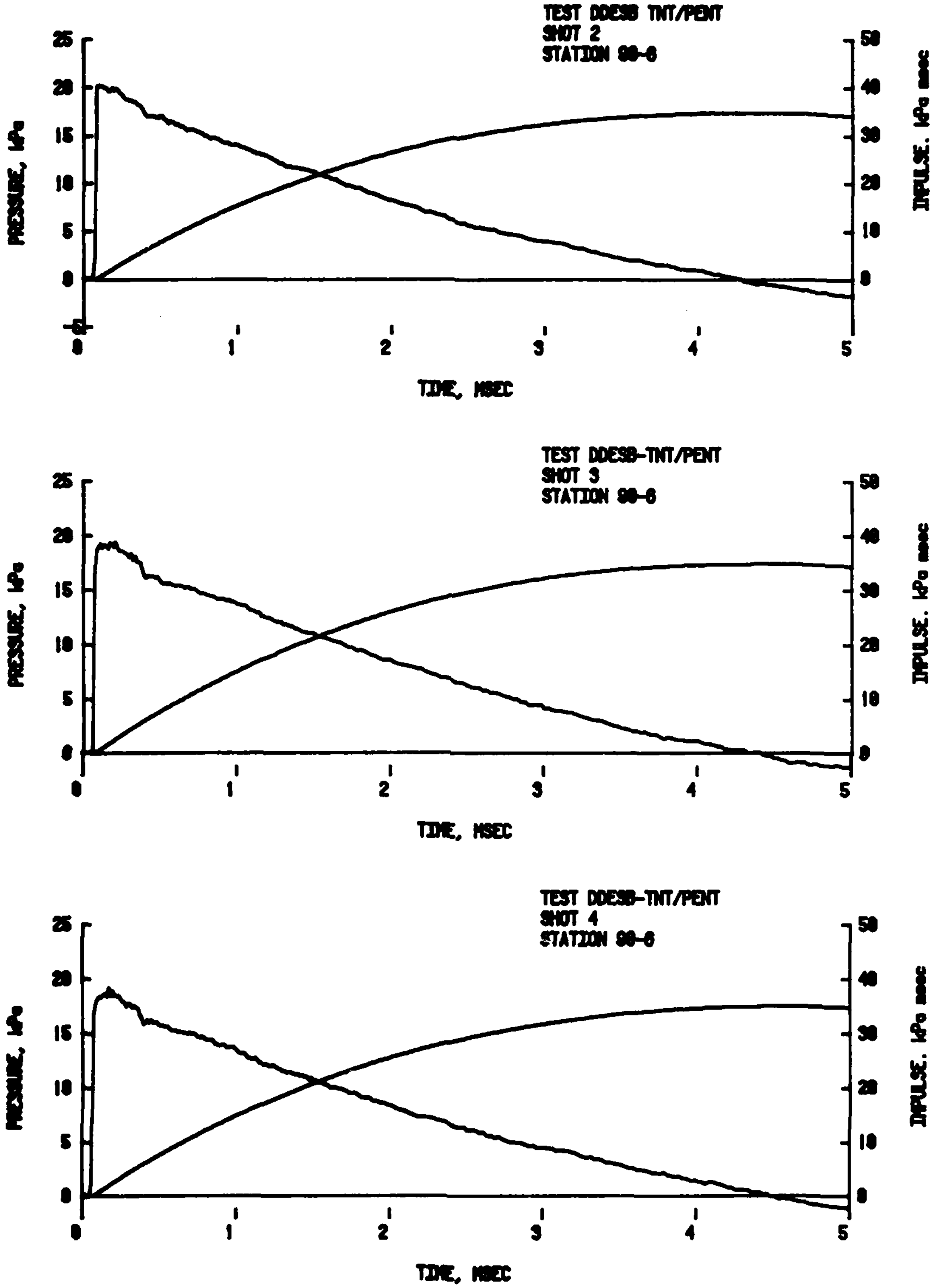
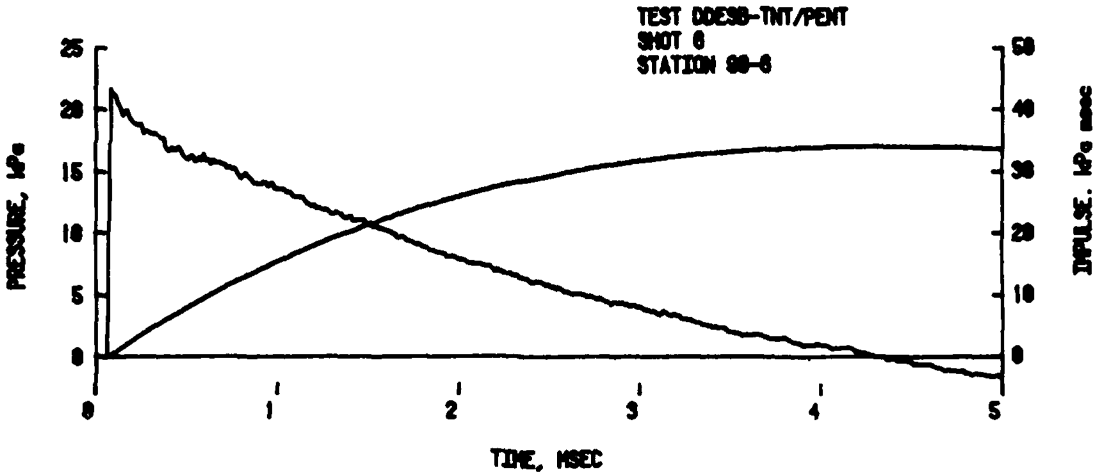


Figure B-19. Pressure and impulse versus time, Station 90-6, Pentolite.



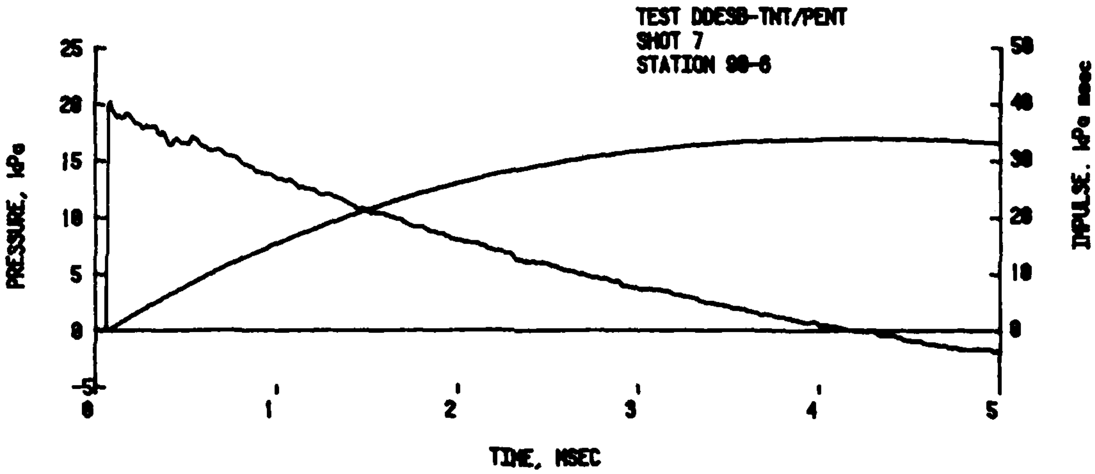


Figure B-20. Pressure and impulse versus time, Station 90-6, TNT.

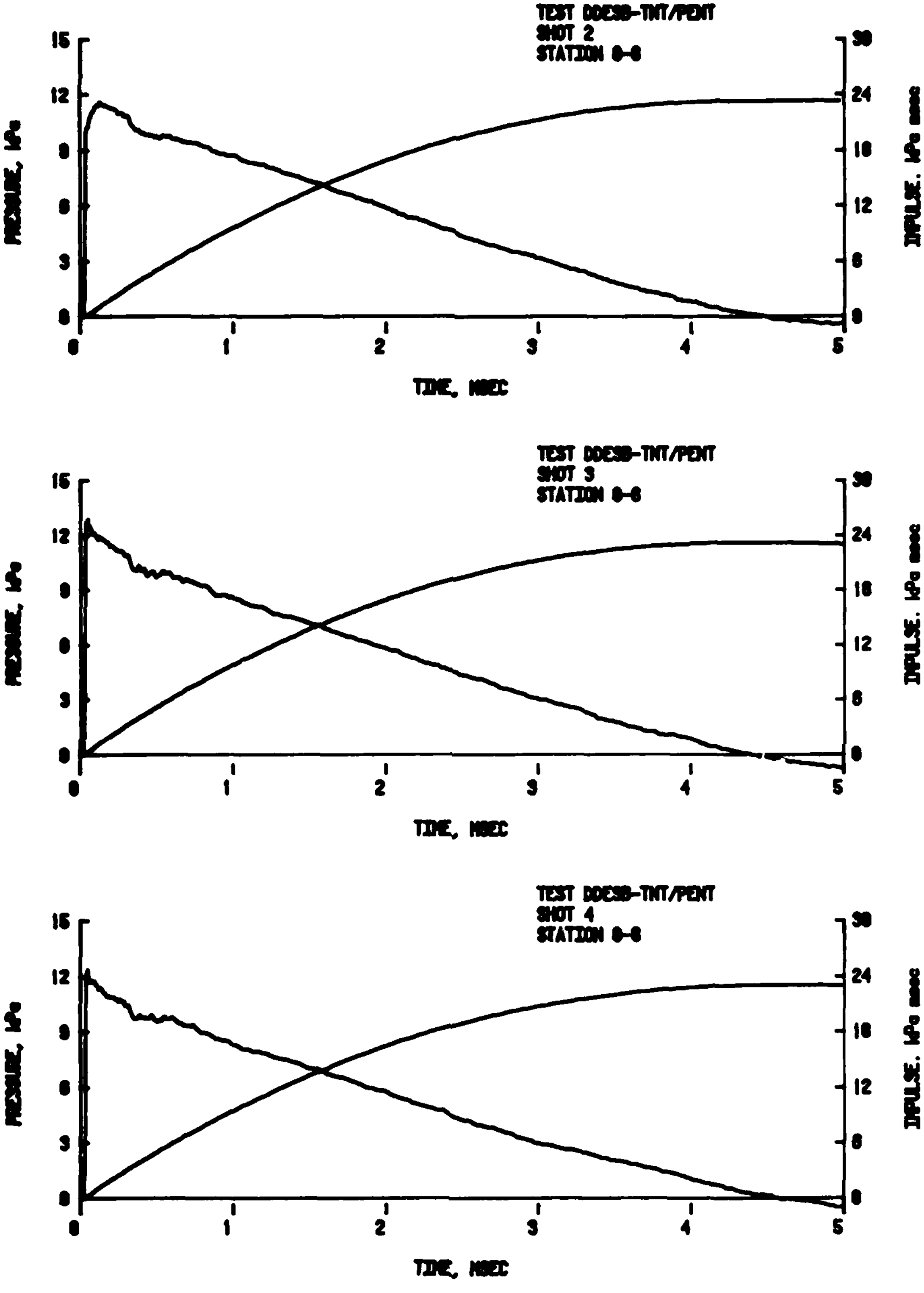
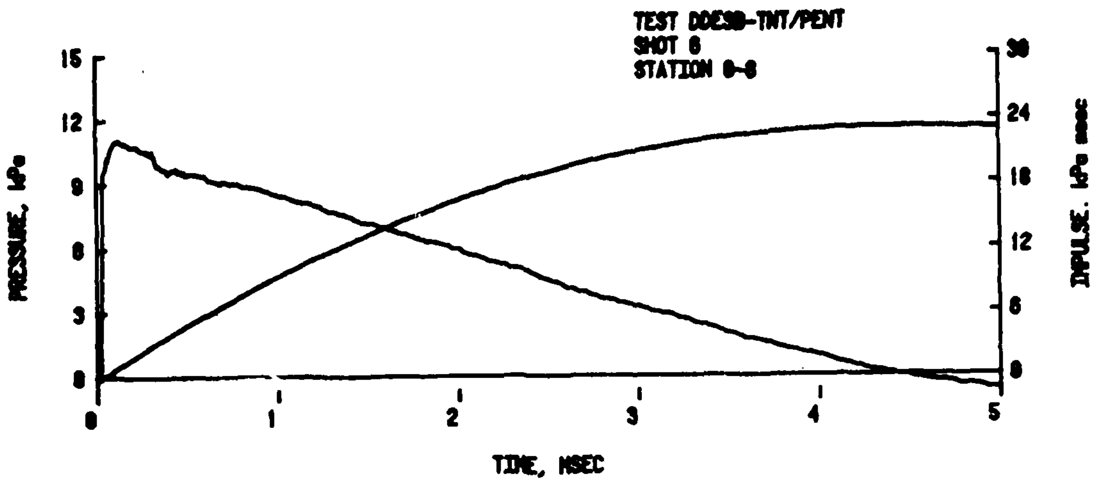


Figure B-21. Pressure and impulse versus time, Station 0-8, Pentolite.



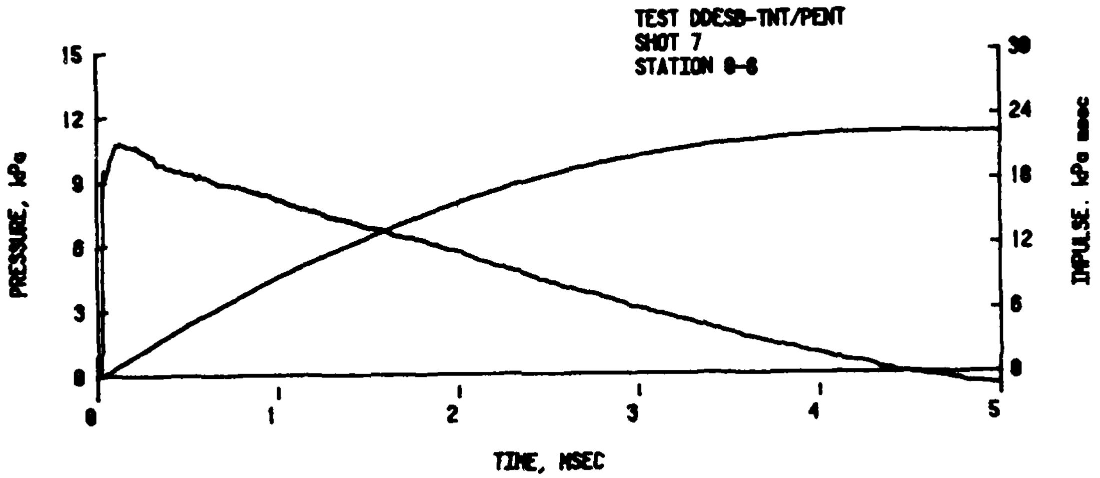


Figure B-22. Pressure and impulse versus time, Station 0-8, TNT.

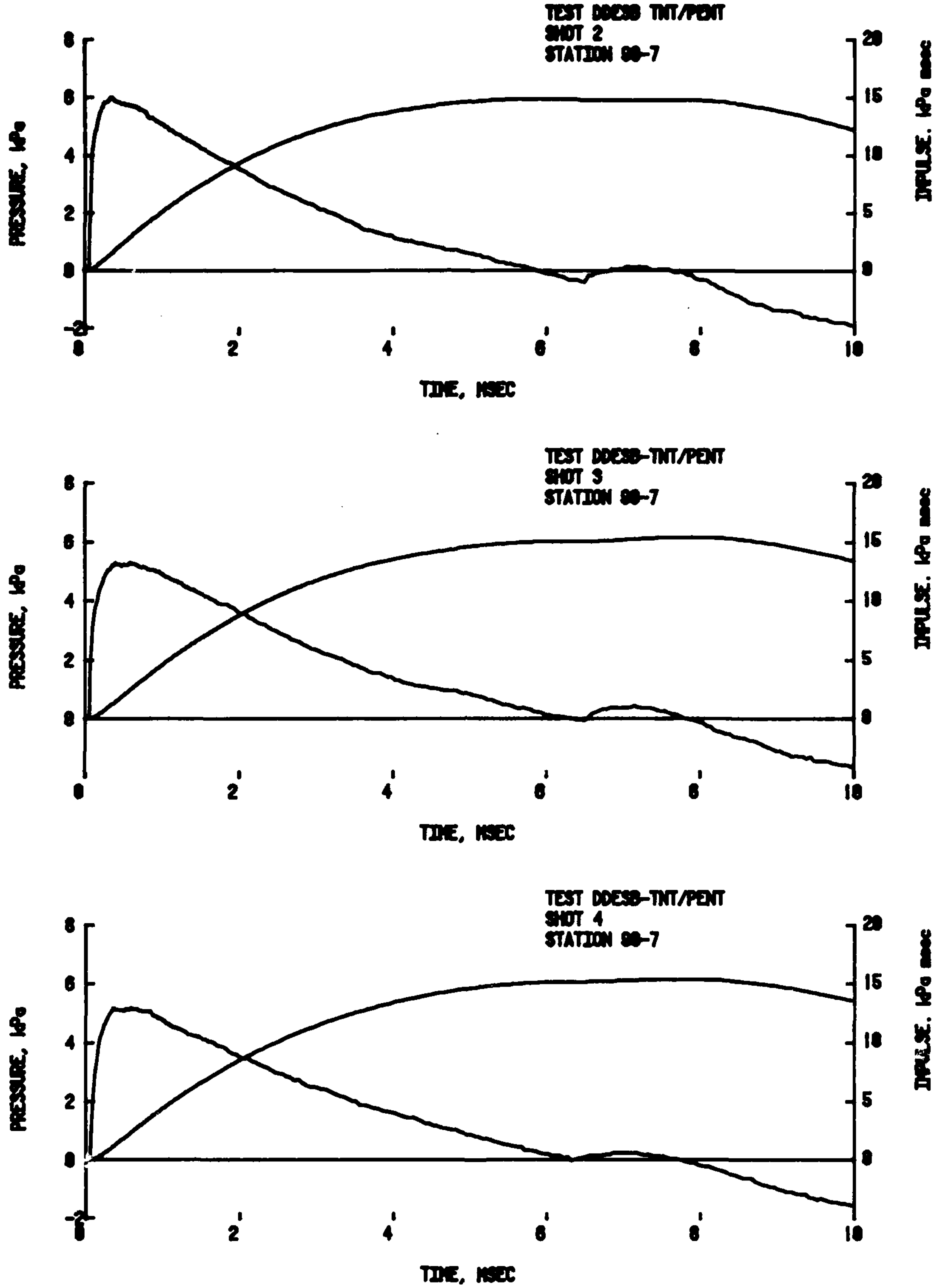
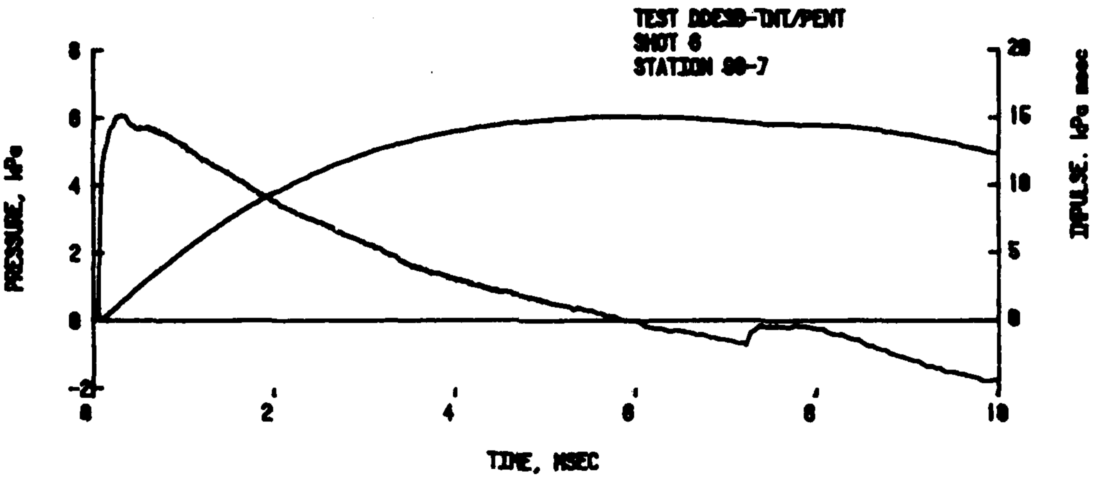


Figure B-23. Pressure and impulse versus time, Station 90-7, Pentolite.



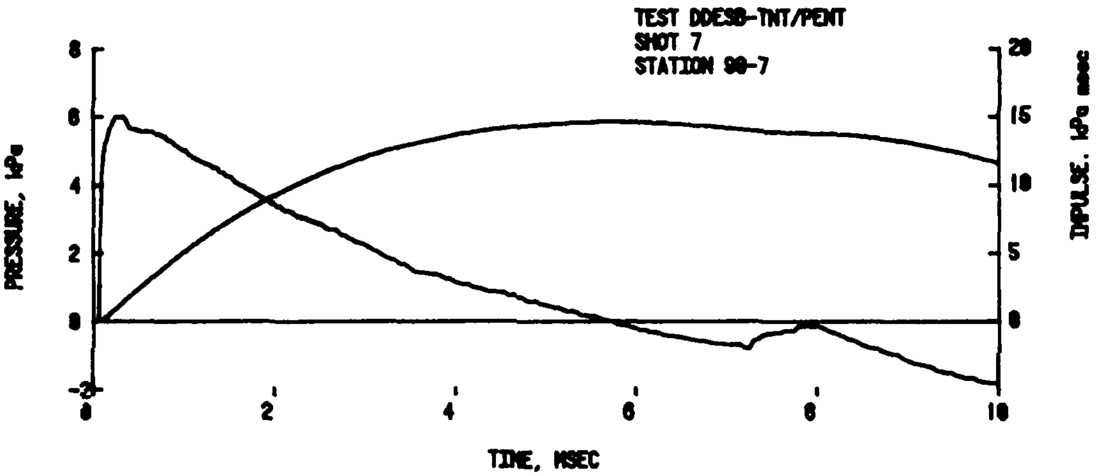


Figure B-24. Pressure and impulse versus time, Station 90-7, TNT.

LIST OF SYMBOLS

D_P	distance from Pentolite charge
D_T	distance from TNT charge
EMF	equivalent mass factor
I_P	impulse from Pentolite charge
I_S	impulse from Standard TNT curve
I_T	impulse from TNT charge
P_P	peak overpressure from Pentolite charge
P_S	peak overpressure from Standard TNT curve
P_T	peak overpressure from TNT charge
t_a	blast wave arrival time
t_+	blast wave positive duration
λ_m	scaled distance, $m/kg^{1/3}$, Standard TNT Table

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4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

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