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BLAST PRESSURES INDUCED BY THE IMPACT OF KINETIC ENERGY PENETRATORS ON STEEL TARGETS IN AN ENCLOSED RANGE

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February 1981

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

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The impact of a kinetic energy penetrator on a steel target in an enclosure produces high temperature fragments that in turn heat the surrounding air, causing the air pressure to rise. Additionally, pyrophoric penetrators like those made of depleted uranium burn rapidly, causing a further increase in air pressure. This report documents and analyzes the pressures measured during tests in which laboratory tungsten and depleted uranium kinetic energy penetrators impacted steel targets inside of an enclosed test range, and

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) compares them with pressures measured during tests using pentolite in the same enclosure.

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I. INTRODUCTION

A. Background

The use of depleted uranium (D.U.) in laboratory kinetic energy (K.E.) penetrators has added a problem in testing - that of contamination of the test site and its surroundings with toxic, radioactive material following a test. Some of this finely divided material may be borne off on the winds. A large steel enclosure, Figure 1, has been built by the Ballistic Research Laboratory on Spesutie Island, APG, to eliminate transport of D.U. material beyond the immediate test area. The target is placed within this enclosure. The gun-launched penetrator travels through a 46 m long 2.4 m diameter steel tube welded to a wall of the enclosure. It enters the enclosure through a 0.5 m diameter hole in the wall on the centerline of the 2.4 m diameter tube. The interaction of the penetrator with the target is monitored photographically with flash x-ray equipment and the penetrator velocity is obtained using velocity screens and electronic counters. There is an air exhaust system mounted on the roof of the enclosure that operates during the test. It's primary function is to draw aerosolized D.U. material out of the enclosure after a test and to trap it in filters in the exhaust ducting. It also draws back aerosolized material that may have gone into the 2.4 m diameter tube through the small entrance hole in the wall. The air exhaust system also plays a minor role in reducing the extent and duration of the induced overpressure within the chamber following the violent interaction of the penetrator with the target. There is a personnel access door in one wall which is made airtight with rubber seals and locking lugs. A large sliding equipment access door on another wall is sealed with a water-pressurized hose seal along its perimeter. The door is held against this seal by large screw wheels. The entire structure then is built to contain fragments from the target and penetrator, to trap aerosolized materials, and to permit the photographic observation of the interaction of the penetrator and the target.

One of the problems associated with the enclosed range tests is the overpressure that results[1,2] from the very rapid heating of the air within the enclosure as the penetrator and the target are torn apart during their encounter, and as very hot post-encounter fragments burn in the case of a pyrophoric material like D.U. The structure and the seals must bear the load and the comparatively delicate filters

1 *R. Pearson and G. Coulter, "Tank Interior Pressure History Induced by Depleted Uranium Rod Penetrators and 105 mm Armor Piercing Discarding Sabot Round", BRL Memo Report ARBRL-MR-02866, October 1978 (AD# B033172L).*

2 *R. Abrahams, R. Peterson, and B. Bertrand, "Measurement of Blast Pressure Produced by Impact of Kinetic Energy Penetrator on a Steel Target", BRL Memo Report ARBRL-MR-02983, Jan 1980, AD# B045141L.*

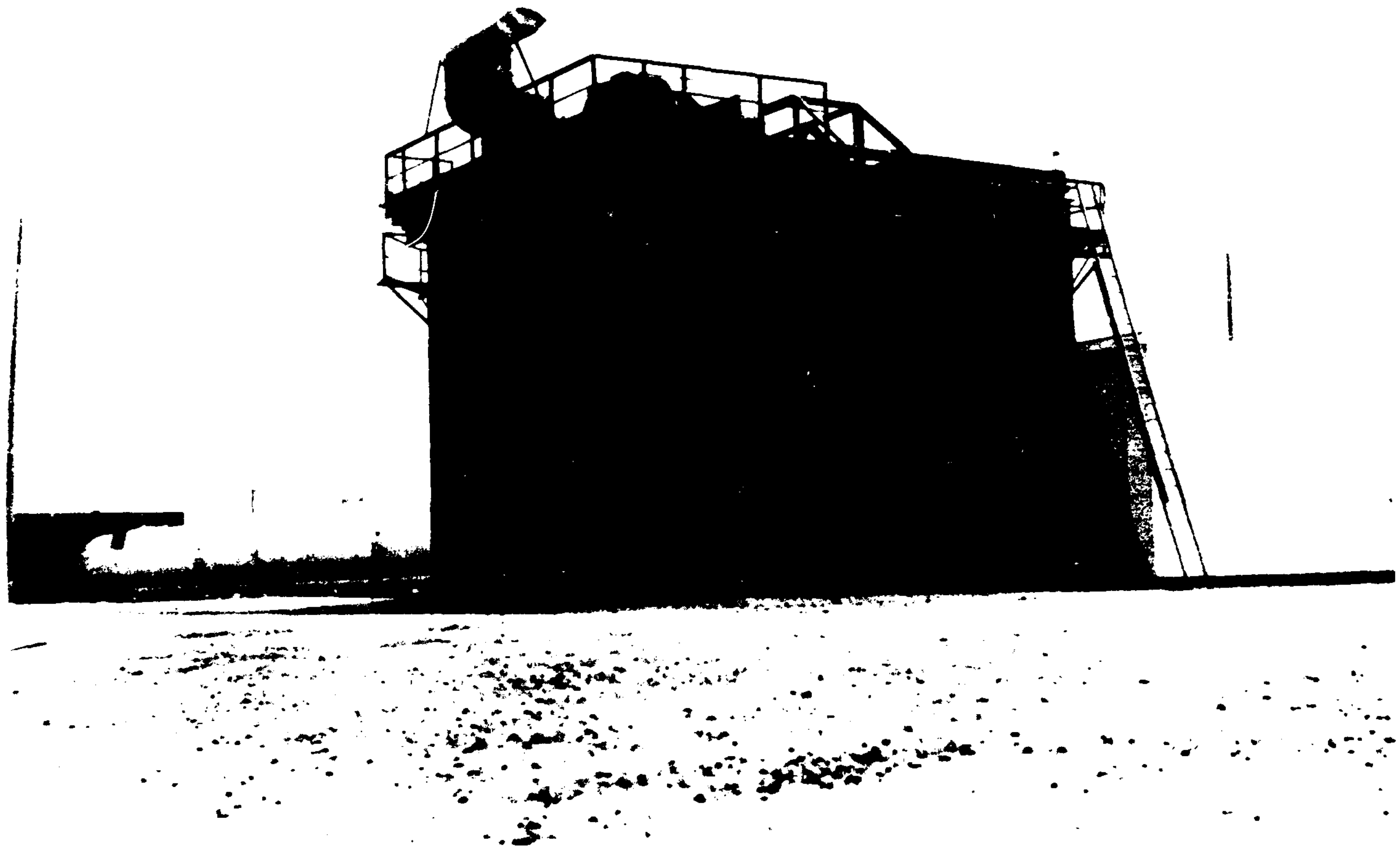

Figure 1. Enclosed Range.

must survive the pressure during the tests. The pressure induced by the heating of the air in the enclosure by the interaction remains until the air becomes cooled by heat transfer to the steel enclosure walls and by mass loss due to venting through the exhaust system.

B. Objectives

The Target Loading and Response Branch of Terminal Ballistics Division was assigned to make measurements during preliminary tests in the enclosure.

One test objective was to measure the pressure histories at several points within the enclosure, using as the pressure source the impact of tungsten K.E. penetrators and two different sizes of D.U. penetrators on steel targets, and also the detonation of three different weights of bare spherical pentolite explosive. The pentolite measurements would be used for comparison with those from the penetrator tests.

A second test objective was to measure strain histories at a point on a wall in which a rectangular cut-out had been made for x-ray photography.

II. PROCEDURE

A. Instrumentation

Pressure transducers were installed at several locations in the enclosure as depicted in Figure 2. The transducers in the enclosure that were mounted with their sensitive surfaces flush with the inside wall were subjected to reflected pressure. Positions 3 and 4 each had a transducer installed with its sensitive surface flush with the center of a disc-shaped baffle plate mounted on a stand, the plane of the disc being aligned with the blast source. Positions 3 and 4 then were subjected initially to side-on blast pressure.

Other information concerning the transducers is listed in Table I. Transducer damage due to fragment impact was expected to be a serious problem so the initial transducer selection and mounting arrangements were made to minimize damage. This included installing them in shock isolation mounts having protective shield on them, Figure 3, or using transducers that had such shields as an integral part of their construction. When it became apparent that fragment impact damage was not quite as severe a problem as had been expected, some transducers were used without shields in order to obtain better response to the initial blast.

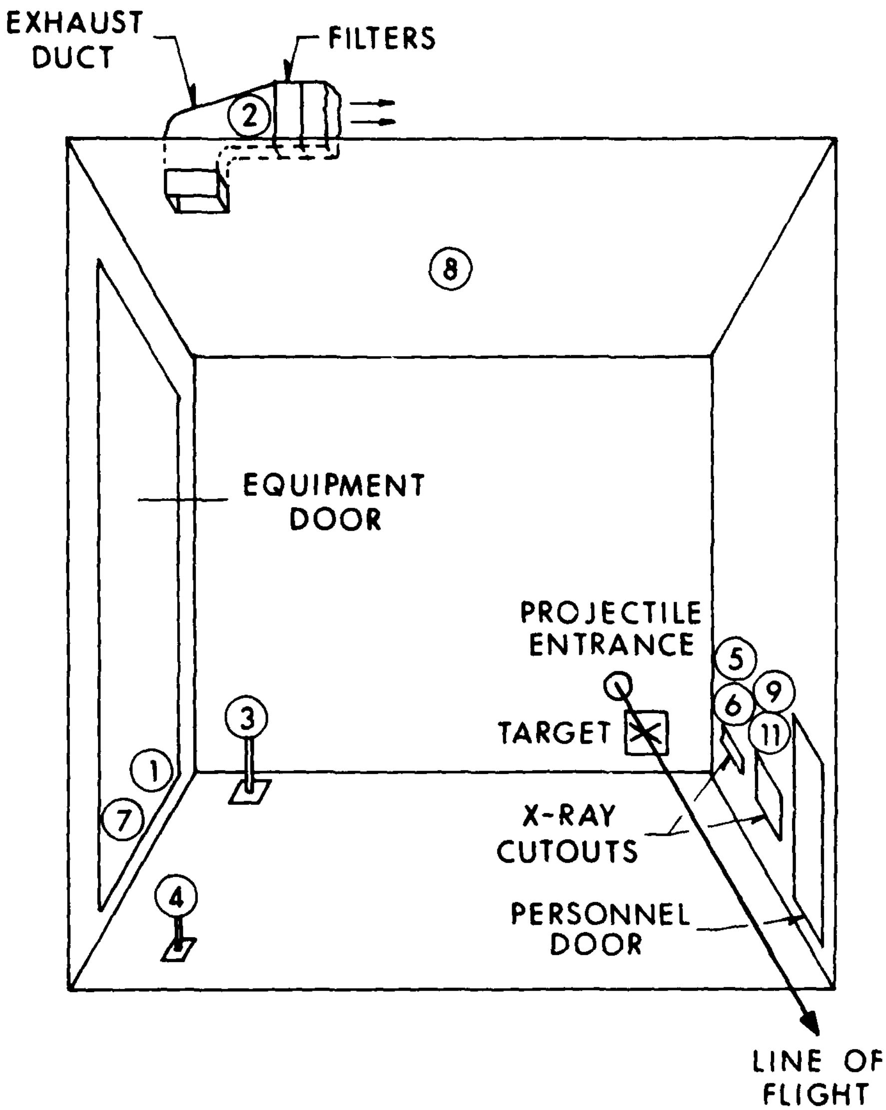

Figure 2. Instrumentation Locations.

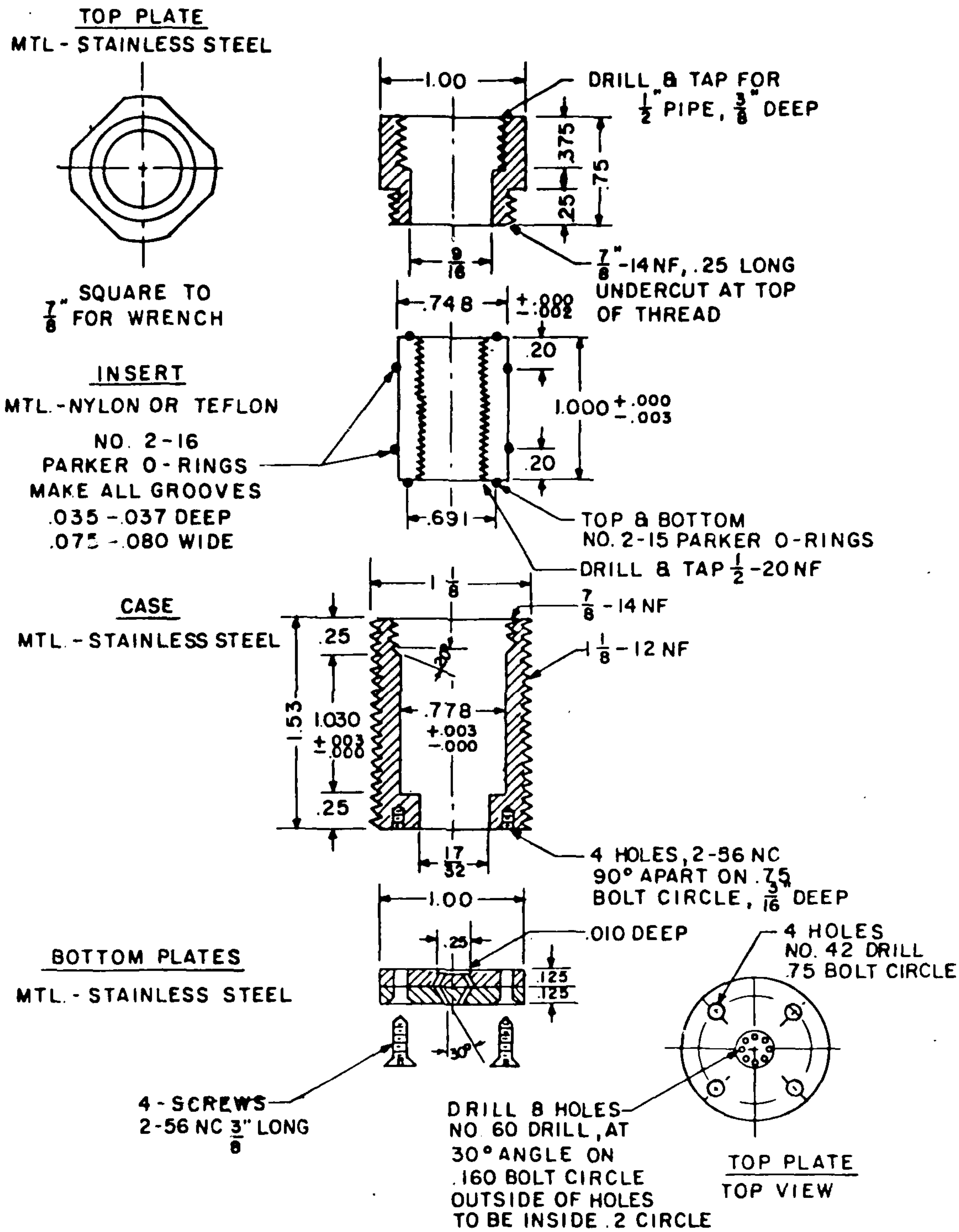

Figure 3. Transducer Shock Isolation Mount.

Table I. Transducer Type and Mounting For Each Test

	TEST															
POS	A	B	C	1	2	3	4	5	6	7	8	9	10	11	12	13
1	B1	B1	B1	B1	B1	A3	A3	A3	A3	A3	--	A3	A3	B1	B1	B1
2	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5	C5
3	B1	B1	B1	B1	B1	--	--	--	--	--	--	--	--	--	--	--
4	B1	B1	B1	B1	B1	--	--	--	--	--	--	--	--	--	--	--
5	B1	B1	B1	B1	B1	B1	A3	B1	B1	B1	B1	B1	B1	B1	B1	B1
6	B1	B1	B1	B1	B1	B1	B1	A3	A3	A3	--	A3	A3	A3	A3	A3
7	D2	D2	D2	D2	D2	--	D2	D2	D2	D2	D2	D2	D2	D2	D2	D2
8	B1	B1	B1	B1	B1	B1	A3	A3	A3	A3	--	A3	A3	B1	B1	B1
9*	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4
10	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	--	--
11	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	--	--
12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	E4	E4

*NOTE: S - strain gage rosette.
NOTE: Blank spaces indicate position not instrumented.

MANUFACTURER	MODEL	TYPE	CODE
Susquehannah Instruments	ST4	piezoelectric (Bar)	A
Pcb	113A24	piezoelectric	B
Endevco	8510	Strain	C
Tyco-Bytrex	HFG	Strain	D
Entran	EPF 200-10	Strain	E

Mounting:

Shock isolation mount with orifice face plate	1
Nylon insert	2
Shock isolation mount	3
Surface mounted	4
Steel insert	5

One strain gage rosette was installed close to a corner of a rectangular cut-out, Figure 1, where the rather sharp corner was expected to result in high strain levels during the initial blast load.

The data acquisition system is depicted in Figure 4. The basic data acquisition was accomplished with a Honeywell 101 tape recorder at 80 kHz band width.

B. Test Series

The test series included the following explosives and laboratory penetrator rods:

Tests A-C : bare spherical pentolite detonated at the approximate impact point of the K.E. penetrator tests.

Tests 1-3 : 2.1 kg tungsten K.E. penetrators impacting steel targets.

Tests 4-9 : 2.01 kg D.U. K.E. penetrators impacting steel targets.

Tests 10-13: 3.4 kg D.U. K.E. penetrators impacting steel targets.

The bare spherical pentolite charges were detonated to check out the instrumentation and to obtain baseline pressure and strain data with which the K.E. penetrator test data could be compared. These bare charge tests would also help to uncover any problems with door seal leaks, with filter response to blast and with structural integrity.

III. RESULTS AND ANALYSIS

Table I lists transducer type and mounting for each position and test. Table II lists the values of input parameters for each test. The quality of the pressure data varied considerably and following each test the transducers were changed if it was thought that the data from the following tests could be improved. Records of typical pressure and strain histories are placed in the APPENDIX. Initial blast pressure records are digitized at 2.5 μs rate and plotted out to 10 ms to obtain detail close to the blast front. Records were also digitized and plotted at slower rates to obtain quasi-steady pressure histories.

The pressure records are characterized by many pressure excursions as the blast waves reflect repetitively from the inner surfaces of the enclosure and as the vibrations of the walls cause some acceleration induced transducer output. The pressure records obtained with transducers within the main enclosure exhibit an initial rapid pressure rise, typical of blast waves, followed by decay toward ambient pressure. This decay toward ambient pressure is usually interrupted by the

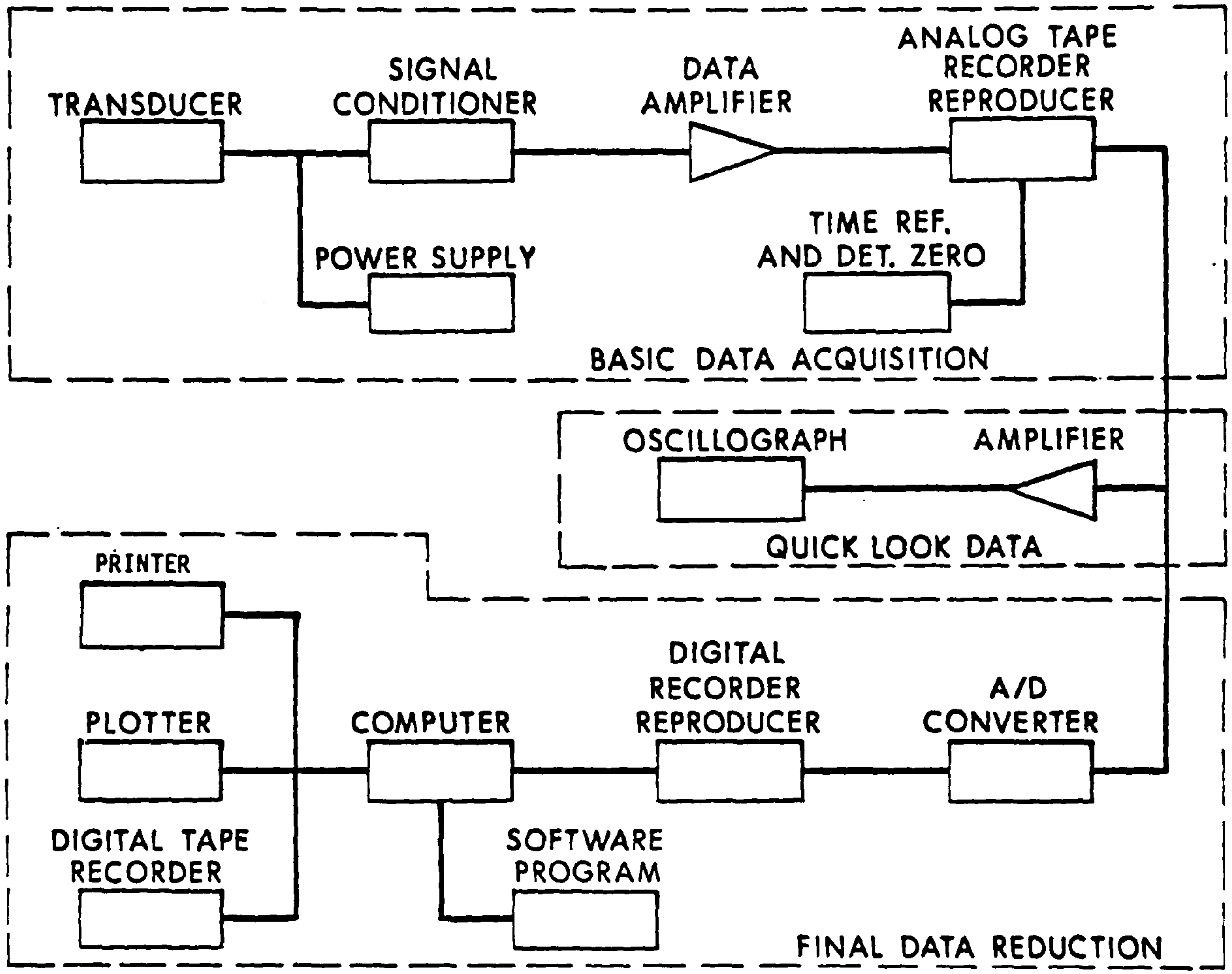

Figure 4. Schematic of Data Acquisition System.

Table II. Test Conditions

TEST	MATERIAL	WEIGHT kg	VELOCITY m/s	SHAPE
A	Pentolite	0.114	---	Sphere
B	Pentolite	0.227	---	Sphere
C	Pentolite	0.341	---	Sphere
1	Tungsten	2.11	1518	Cylinder, l/d = 20
2	Tungsten	2.11	1519	Cylinder, l/d = 20
3	Tungsten	2.15	1500	Cylinder, l/d = 20
4	Depleted Uranium (DU)	2.01	1692	Cylinder, l/d = 17.5
5	DU	2.01	1685	Cylinder, l/d = 17.5
6	DU	2.01	1703	Cylinder, l/d = 17.5
7	DU	2.01	1708	Cylinder, l/d = 17.5
8	DU	2.01	1708	Cylinder, l/d = 17.5
9	DU	2.01	1690	Cylinder, l/d = 17.5
10	DU	3.4	1502	Cylinder, l/d = 13.3
11	DU	3.4	1156	Cylinder, l/d = 13.3
12	DU	3.4	1243	Cylinder, l/d = 13.3
13	DU	3.4	1228	Cylinder, l/d = 13.3

arrival of blast waves reflected from adjacent surfaces, depending on transducer location. The multiple internal reflections of the blast waves blend into a quasi-steady overpressure within the enclosure that gradually diminishes to ambient pressure as discussed in Section II. Some quasi-steady pressure records have been filtered at 16 hz to make them easier to read.

A. Bare Spherical Pentolite Tests

Table III lists the distances from the detonation point of the pentolite charges to the instrumented positions, along with charge weights, predicted and measured blast and quasi-steady pressures. Pressure and strain records for Test C are placed in the APPENDIX.

Blast pressures were predicted using scaled distance curves[3] and the method described in Reference 4. The blast wave was assumed to arrive at the transducer positions in the wall perpendicularly, giving rise to normal reflection. This is reasonable in view of the low pressure levels and small angles of incidence, where theory[5] and experiment[6] have shown practically no change in reflected pressure with angle of incidence up to 40°.

Quasi-steady pressures for the pentolite tests were predicted assuming that the heat of combustion of the pentolite is used totally to heat the air within the enclosure[7]. A relationship for the resulting increase in pressure is

$$\Delta P = \frac{0.4\ hW}{V}\ ,\ \text{kPa},$$

where $V = 532 m^3$, the internal volume of the enclosure,
W = weight in grams of the charge, and
h = 11.7 kJ/g, the heat of combustion of pentolite.

---

3 *H.J. Goodman, "Compiled Free Air Blast Data on Bare Spherical Pentolite", BRL Report 1092, BRL, APG, MD, February 1960 (AD# 235278).*

4 *Glasstone, Samuel and Dolan, Philip J., "The Effects of Nuclear Weapons", Department of the Army Pamphlet No. 50-3, Revised March 1977.*

5 *Polacheck, H. and Seeger, R.J., "Regular Reflection of Shocks in Ideal Gases", Bureau of Ordnance Explosives Research Report 13, 1944.*

6 *Bertrand, Brian P., "Measurements of Weak Shock Wave Reflected Pressure Histories on a 2-Dimensional Surface", BRL Memorandum Report ARBRL-MR-02966, October 1979 (AD# A080539).*

7 *Edward M. Meyer, Editor in Chief, Annals of the New York Academy of Sciences, Vol. 152, "Prevention of and Protection Against Accidental Explosions of Munitions, Fuels, and Other Hazardous Mixtures", Published by the Academy, 2 East Sixty-Third St, New York, NY 10021.*

Table III. Bare Spherical Pentolite Test Data

POSITION			1,RB	2,B	2,QS	3,B	4,B	5,RB	6,RB	7,RB	7,QS	8,RB	
DIST, m			7.3	-	-	8.5	5.8	2.1	2.1	7.3	7.3	6.6	
TEST	wgt, g		PRESSURE, kPa										QUASI-STEADY DURATION,s
A	114	Pred.	15.2	-	-	6.3	9.9	99.3	99.3	15.2	1.0	17.4	
		Meas.	12	3	0.5	5	9.0	-	75	-	0.6	15.0	1.1
B	227	Pred.	20.7	-	-	8.1	13.2	168	168	20.7	2.0	23.5	
		Meas.	17	6	0.7	7.0	12.0	-	110	-	1.5	22.0	1.3
C	341	Pred.	24	-	-	9.7	15.9	233	233	24.0	3.0	28.1	
		Meas.	22	-	1.2	8.0	14.0	160	170	-	2.4	28.0	1.5

TEST	POSITION	STRAIN, X10^6 9	STRAIN, X10^6 11
A		260 -350	180 -250
B		450 -480	340 -340
C		630 -550	360 -500

RB - Reflected Blast
B - Blast
QS - Quasi-Steady

The blast pressure is that which is measured at the front of the pressure record, and this value is an average if the record is noisy.

The measured blast pressures are lower than predicted. This is because of the relatively slow response of the transducer/mounting combinations which had been selected for their ruggedness in view of the subsequent penetrator tests. They are also rather noisy records and one can only find the approximate pressure at the front of the records. Blast pressure in the exhaust duct is greatly reduced by the baffle arrangement that is built into the duct preceding the filter location.

The quasi-steady pressures are also lower than predicted. This is likely due to the fact that while the pressure of the air within the enclosure is averaging out to a quasi-steady value, it is also being diminished by cooling and mass loss. Quasi-steady pressure in the exhaust duct is less than that in the main enclosure.

The highest measured strain levels of 620×10^{-6} for the largest pentolite charge is well below yield for the armor plate wall on which the strain gages are placed. Strain Positions 9 and 11 are orthogonal, in the directions of the edges of the cut-out and Position 10 bisects the angle between 9 and 11. The strain at Position 10 is too small to read.

B. Tungsten K.E. Penetrator Tests

Table IV lists the measured blast and quasi-steady pressures at the instrumented positions for the tungsten K.E. penetrator tests. The pressure and strain records of Test 2 are placed in the APPENDIX.

An upper limit to the expected blast pressure produced by impact of the tungsten penetrators could be calculated by assuming that all the kinetic energy of the penetrator is used to produce blast. This would be done by calculating the equivalent weight of explosive whose heat of detonation equals the kinetic energy of the penetrator. This equivalent weight can then be used with the scaled distance curves as was done with the pentolite charges to calculate the upper limit of blast pressure at the instrumented positions. The three tungsten tests (Tests 1-3) had kinetic energies of 2.43 MJ. The heat of detonation of pentolite is 5.11 kJ/g, so the kinetic energy of the tungsten penetrators is equal to the heat of detonation of 476 g pentolite. An obvious problem with this calculation is that the energy transfer occurs much more slowly in the case of the penetrator than for the explosive, and a large amount of the penetrator energy is used in heating the target as work is done on it. One could expect then an inefficient energy transfer to the air within the enclosure and poor agreement between measured and predicted blast pressures.

Table IV. Tungsten K.E. Penetrator Test Data

POSITION		1,RB	2,B	2,QS	3,B	4, B	5,RB	6,RB	7,RB	7,QS	8,RB	7,QS
DIST,m		7.3	-	--	8.5	5.8	2.1	2.1	7.3	7.3	6.6	--
TEST	wgt, kg	PRESSURE, kPa										DURATION,s
1	2.11	7	-	0.45	-	2	10	28	4	0.61	12	1.0
2	2.11	7	-	0.5	-	-	10	30	4	0.64	12	1.0
3	2.12	6	-	--	-	-	10	30	-	--	13	-

TEST	POSITION	STRAIN, X10^6 9	STRAIN, X10^6 11
1		150 -160	125 -100
2		130 -140	100 -110
3		140 -150	130 -130

RB - Reflected Blast
B - Blast
QS - Quasi Steady

An example of such a calculation for Position 8, at the center of the roof, yields the reflected blast pressure P_R = 39 kPa, which is considerably higher than the measured values of 12-13 kPa. In fact, all the measured reflected pressures for the tungsten penetrator tests are lower than those measured for the smallest (114 g) pentolite charge, Test A.

The maximum quasi-steady pressure for the penetrators may be calculated using the same method used for the pentolite tests, but replacing the total pentolite heat of combustion, hW, with the kinetic energy of the penetrator[8]. For the tungsten tests,

$$\Delta P = \frac{0.4\ K.E.}{V} = 1.83\ \text{kPa}.$$

The measured quasi-steady pressures for the tungsten tests in the main enclosure, Position 7, are about 0.6 kPa, or one-third the calculated maximum. This is likely due to slow heat transfer to the enclosed air, venting of pressurized air while equilibrium is being approached and heat loss to the enclosure walls. The measured quasi-steady pressure is slightly less than that measured for the smallest (114 g) pentolite charge, Test A. Quasi-steady pressure in the exhaust system, Position 2, is lower than in the main enclosure.

Positions 3 and 4 were discontinued after Test 1 because of the vulnerability and damage to cables leading to them.

Strain levels measured during the tungsten penetrator tests are lower than those of the smallest (114 g) pentolite test.

The relationship of the target and penetrator geometries as well as kinetic energy, would affect the percentage of kinetic energy that is used for blast and quasi-steady pressure production. In the Tests 1-3, about 10% of the energy is effective in producing blast based on measurements at Position 8, and 35% in producing quasi-steady pressure.

C. Depleted Uranium Penetrator Tests

There were two sets of D.U. penetrator tests: Tests 4-9 were tests of 2.01 kg and Tests 10-13 were of 3.4 kg penetrators. Table V lists the measured blast and quasi-steady pressures for the D.U. tests. Pressure and strain records for Tests 5 and 11 are placed in the APPENDIX.

[8] W.F. Morrison, "Estimation of Maximum Overpressures Arising from Impact of DU Penetrators", Unpublished, BRL, [illegible].

D.U. is a pyrophoric material. If the rate of oxidation of the D.U. fragments is rapid enough, then some of the heat of combustion (4.44 kJ/g) could augment the blast and quasi-steady pressure levels produced by the impact of the penetrator on the steel target. The upper limit of blast pressure may be calculated by using the total kinetic and chemical energies of the D.U. penetrator and then determining an equivalent weight of pentolite by dividing this total energy by the heat of detonation of pentolite, 5.11 kJ/g. Then the scaled distance curves[3] can be used to predict blast pressure at the instrumented position for that equivalent weight as was done for the pentolite and tungsten penetrator tests.

As an example, for a 2.01 kg D.U. penetrator, Test 5, the total kinetic and chemical energy is 11.8 MJ which equals the heat of detonation of 2.3 kg of pentolite. This would produce a reflected blast pressure of 78 kPa at Position 8. The measured pressure was 28 kPa, equal to what one would predict for detonation of only 450 g of pentolite.

The 3.4 kg D.U. penetrators were fired with lower velocities than the 2.01 kg penetrators. Only one of these, Test 10, had a higher kinetic energy then those of the 2.01 kg penetrators. Blast pressures for the 3.4 kg penetrators were about the same as or lower than those of the 2.01 kg penetrators.

An upper limit to quasi-steady pressures for the D.U. penetrators may be calculated in the same manner as for the pentolite tests, but using the sum of the kinetic and chemical energies[8],

$$\Delta P = \frac{0.4\ (K.E. + C.E.)}{V} .$$

For Test 5 for instance,

$$\Delta P = \frac{0.4\ (2.82 + 8.92)\ MJ}{532\ m^3} = 8.8\ kPa.$$

The measured quasi steady pressure for Test 5 is 3.5 kPa, about 37% of the calculated value. Here again one would expect that the calculated pressure would not be achieved for reasons mentioned earlier. In addition, there is no way to determine the rate of combustion of the D.U., or for that matter, the amount that actually burns. If the rate of combustion is very slow then the losses mentioned earlier would have a greater effect on the maximum pressure achieved. Pressures measured for the 2.01 kg penetrators are fairly close to one another. Quasi steady pressure durations are between 2 and 2.2 s.

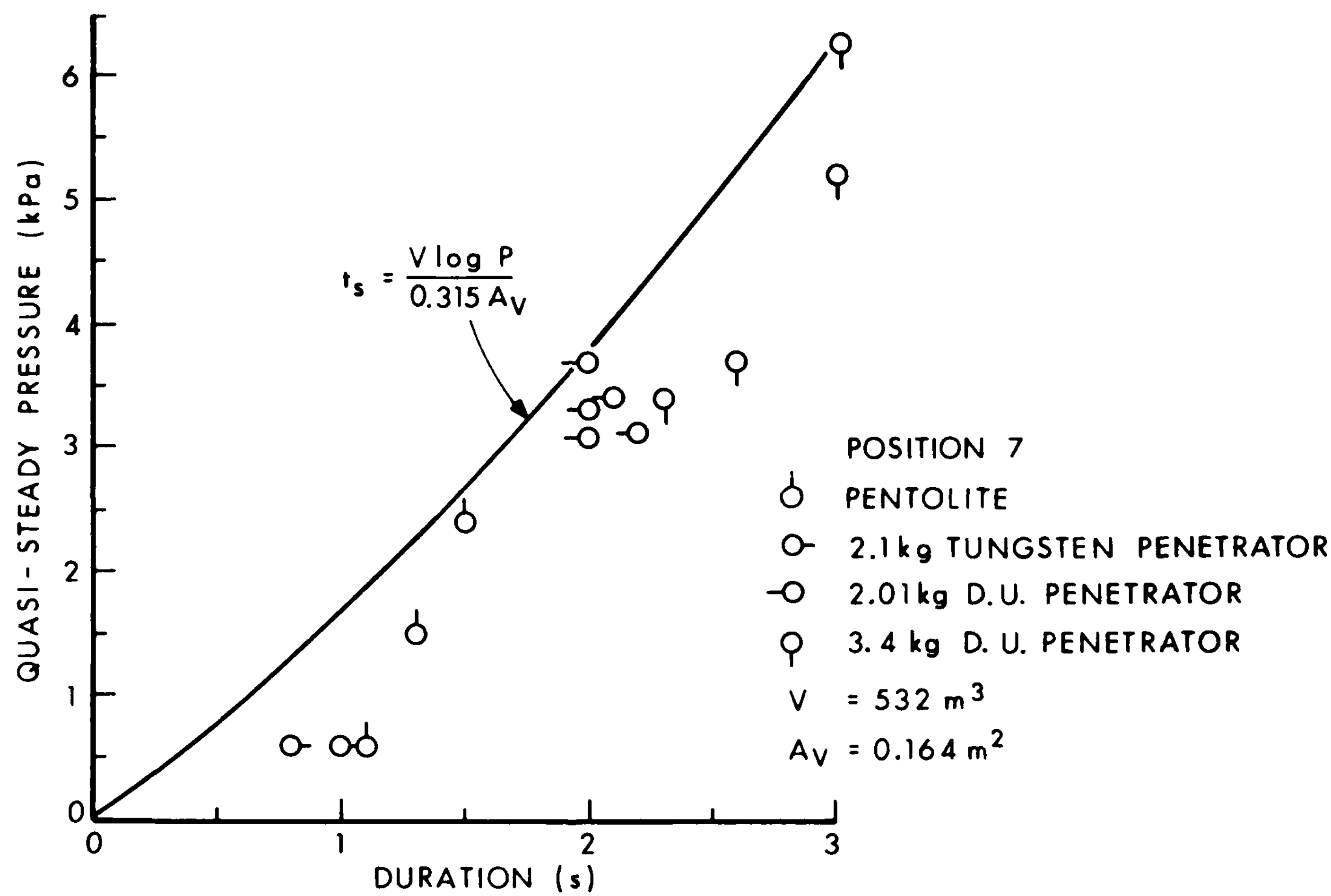

Figure 5. Duration of Quasi-Steady Pressures.

Table V. D.U. Penetrator Test Data

	POSITION	1,RB	2,B	2,QS	5,RB	6,RB	7,RB	7,QS	8,RB	9	11	7,QS
	DISTANCE,m	7.3	-	-	2.1	2.1	7.3	7.3	6.6	-	-	-
TEST	WGT, kg	PRESSURE, kPa								STRAIN, X10^6		DURATION,s
4	2.01	13	-	2	1.8	46	8	3.1	23	200, -230	256 -220	2.0
5	2.01	10	-	2	25	43	12	3.3	28	230 -230	220 -250	2.0
6	2.01	15	-	2.1	2.0	46	12	3.7	-	230 -250	210 -250	2.0
7	2.01	13	4	1.9	35	-	8	3.4	-	200 -150	150 -190	2.1
8	2.01	-	4	1.8	30	-	8	3.1	-	200 -100	200 -120	2.2
9	2.01	18	5	-	45	70	14	-	28	230 -130	---	---
10	3.4	12	5.5	4.1	35	38	6.5	6.3	-	300 -260	---	3.0
11	3.4	17	5	3.5	30	30	5	5.2	30	300 -260	---	3.0
12	3.4	12	5	2.5	30	25	5	3.7	30	200 -200	---	2.6
13	3.4	11	5	2.2	28	20	6	3.4	18	200 -180	---	2.3

RB - Reflected Blast
B - Blast
QS - Quasi-Steady

The 3.4 kg D.U. penetrator tests produced quasi-steady pressures also less than the calculated maximum. A rather interesting result is that Tests 10 and 11, having the highest and lowest kinetic energies respectively, both produced the highest quasi-steady pressure, Table V. Then Tests 12 and 13, having equal kinetic energies, had close to the same quasi-steady pressures. The duration of overpressure for the 3.4 kg D.U. penetrators ranged from 5 s for Tests 10 and 11 to 2.5 s for Test 13. Figure 5 depicts positive quasi-steady pressure duration versus pressure for all the shots, compared to a curve that had been developed for venting[9]. Other work concerning venting may be found in Reference 10. The rather wide variation in the quasi-steady pressures measured for the 3.4 kg D.U. shots may be due to differences in target construction as well as kinetic energy. Higher kinetic energy might tend to pulverize the penetrators into smaller fragments that would burn more rapidly to completion and produce the highest quasi-steady pressure quickly. On the other hand, if a weak target is broached with larger fragments of penetrator remaining, the quasi-steady pressure achieved would be lower because of the longer time for the large fragments to burn, during which cooling and venting would dominate. Table VI summarizes quasi-steady pressures and total energies of the shots.

IV. CONCLUSIONS

Blast pressure within an enclosed chamber have been measured for blast waves produced by the impact of K.E. penetrators made of tungsten and depleted uranium on steel targets, and compared to blast waves produced in the chamber by detonation of pentolite charges. The quasi-steady pressures produced by the same three sources were also measured. The blast pressures obtained with 2 kg D.U. penetrators appear to be augmented by combustion of the D.U. when compared to pressures from the tungsten penetrators of the same approximate weight and velocity. Slower-moving 3.4 kg D.U. penetrators produced the same as, or less blast pressure than the 2 kg D.U. penetrators, but tended to produce higher quasi-steady pressures than the 2 kg D.U. penetrators. No definite conclusions can be drawn on the percentages of kinetic and of chemical energy that produce blast because the targets were not identical from test to test.

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9 *Kinney, G.F. and Sewell, R.G.S., "Venting of Explosions", NWC Technical Memorandum [illegible]448, July 1974.*

10 *Kingery, Charles; Schumacher, Robert; and Ewing, William Jr., "Internal Pressure From Explosions in Suppressive Structures", BRL Memorandum Report ARBRL-MR-[illegible], June [illegible], AD# [illegible].*

Table VI. Summary of Total Energy and Quasi-Steady Pressures

TEST	W, kg	C.E. MJ	V m/s	K.E. MJ	E_{TOTAL} MJ	ΔP_{CALC} kPa	ΔP_{MEAS} kPa	$\frac{\Delta P_{MEAS}}{\Delta P_{CALC}}$
A	0.114	1.33	-	-	1.33	1.0	0.6	0.6
B	0.227	2.66	-	-	2.66	2.0	1.5	0.75
C	0.341	3.98	-	-	3.98	3.0	2.4	0.8
1	2.11	-	1518	2.43	2.43	1.83	0.61	0.33
2	2.11	-	1519	2.43	2.43	1.83	0.64	0.35
3	2.15	-	1500	2.42	2.42	1.82	-	-
4	2.01	8.92	1692	2.88	11.8	8.9	3.1	0.35
5	2.01	8.92	1685	2.85	11.8	8.9	3.3	0.37
6	2.01	8.92	1703	2.91	11.8	8.9	3.7	0.42
7	2.01	8.92	1708	2.93	11.9	8.9	3.4	0.38
8	2.01	8.92	1708	2.93	11.9	8.9	3.1	0.35
9	2.01	8.92	1690	2.87	11.8	8.9	-	-
10	3.4	15.1	1502	3.84	18.9	14.2	6.3	0.44
11	3.4	15.1	1156	2.27	17.4	13.1	5.2	0.4
12	3.4	15.1	1243	2.63	17.7	13.3	3.7	0.28
13	3.4	15.1	1228	2.56	17.7	13.3	3.4	0.26

APPENDIX

Pressure and Strain Records

NOTE: Pressure records of Positions 3 and 4 are plotted only for Test C, Figure A-3. Otherwise, pressure and strain records are plotted four to a page each page containing records of the same position for the four different test series.

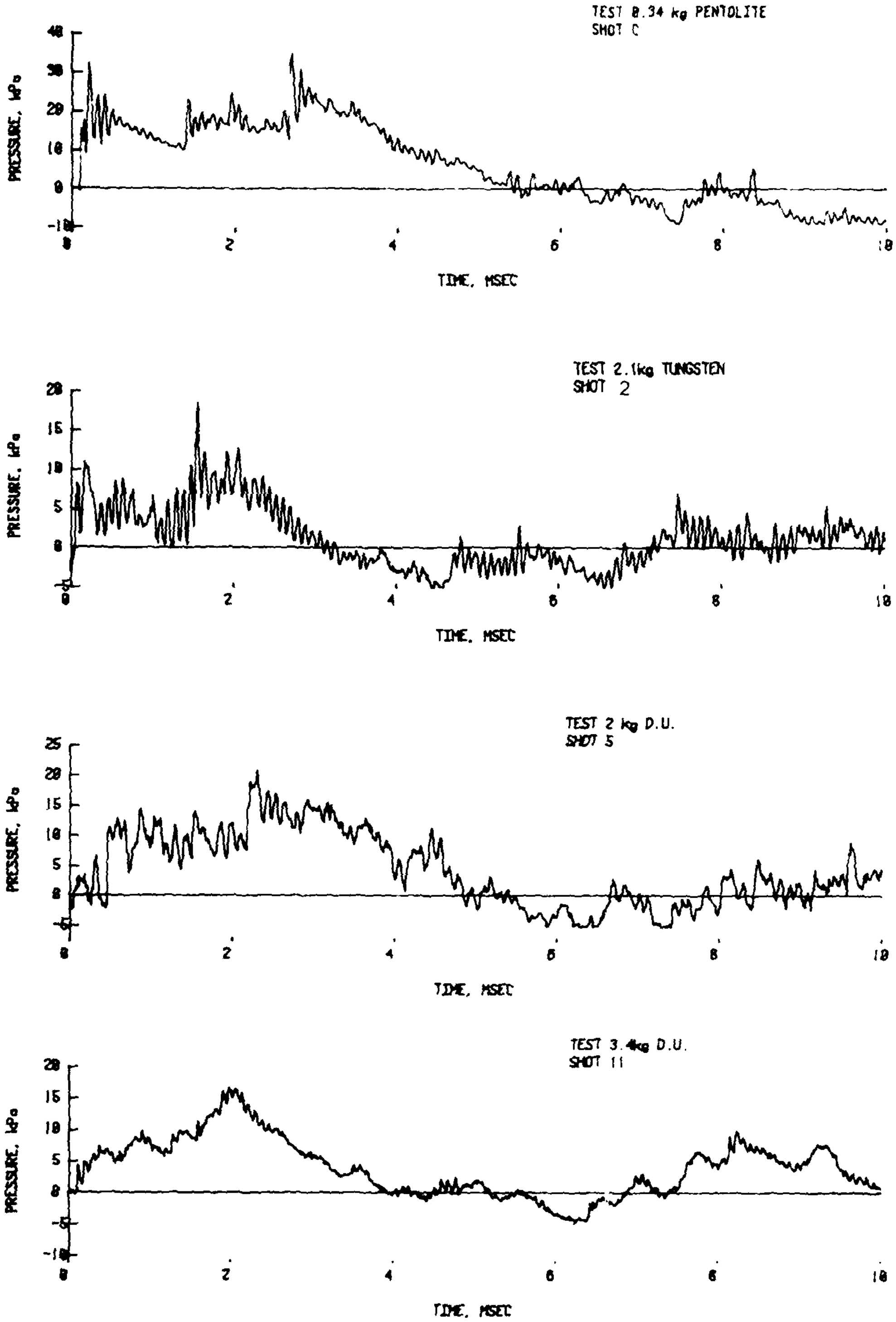


Figure A-1. Pressure History Records, Position 1.

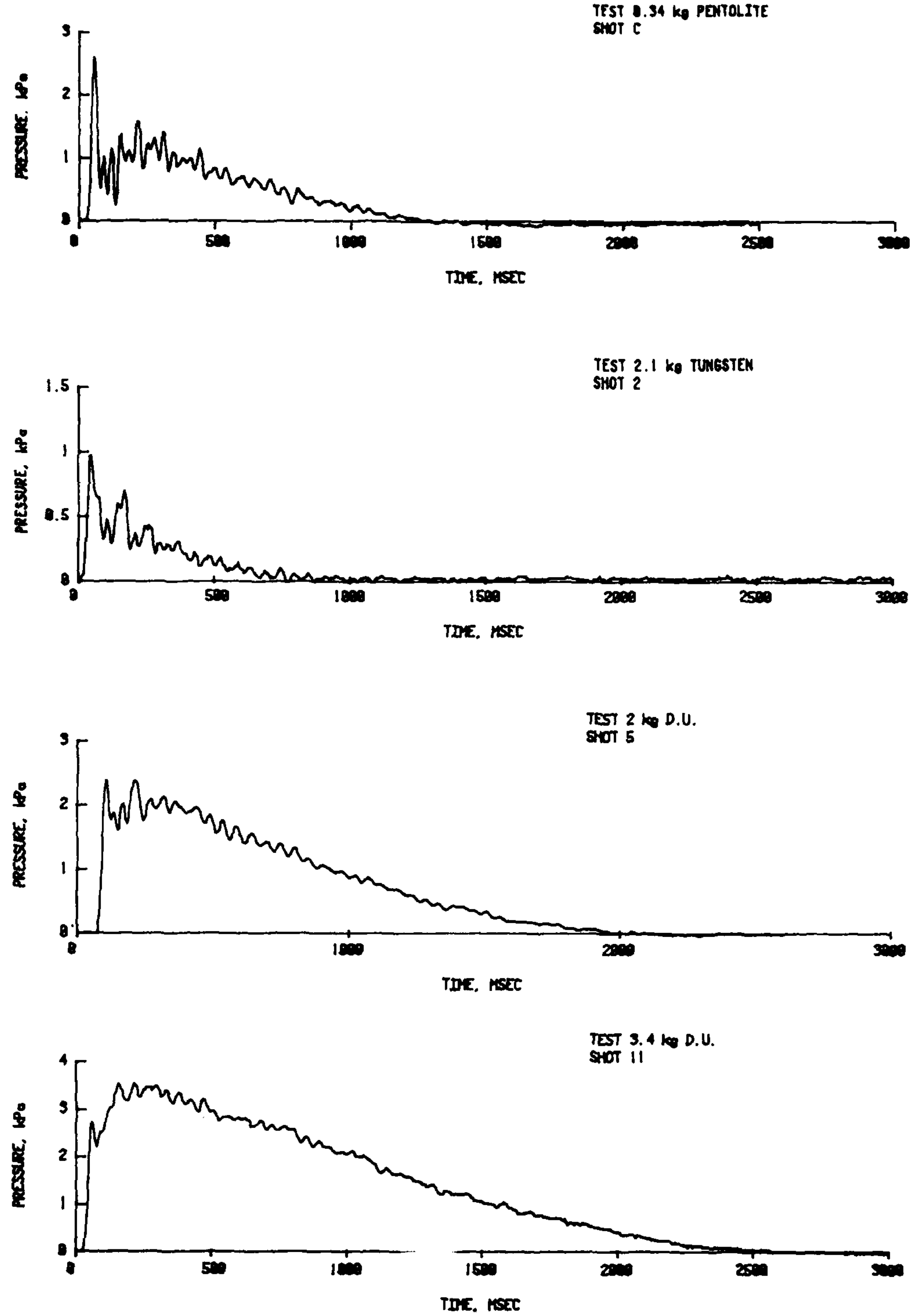
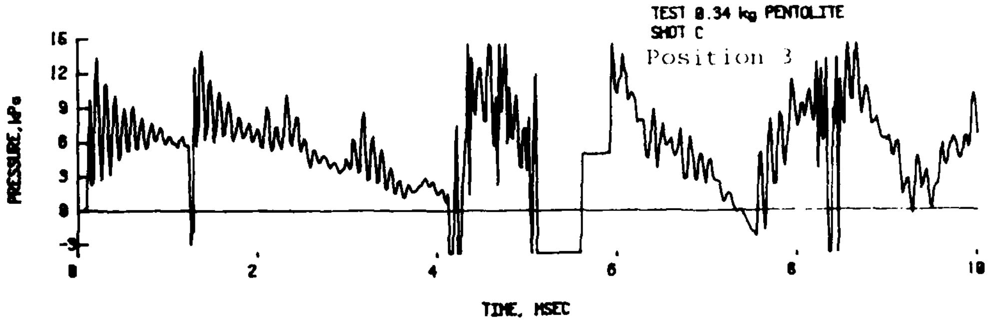
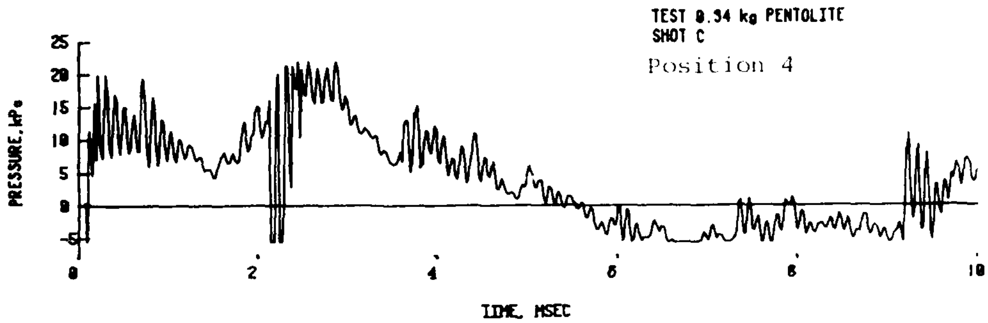
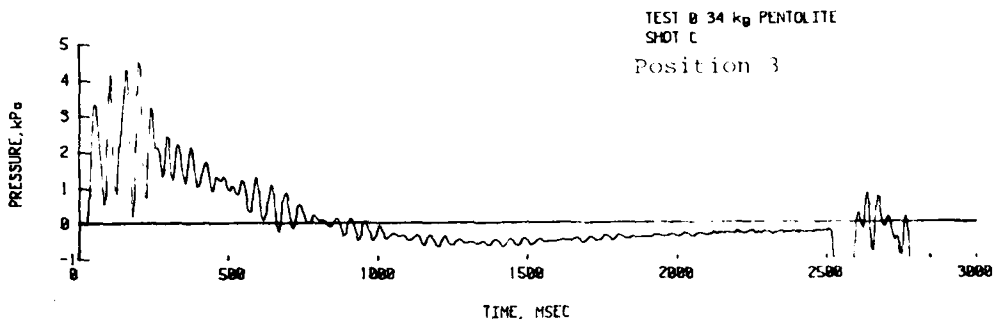


Figure A-2. Pressure History Records, Position 2.







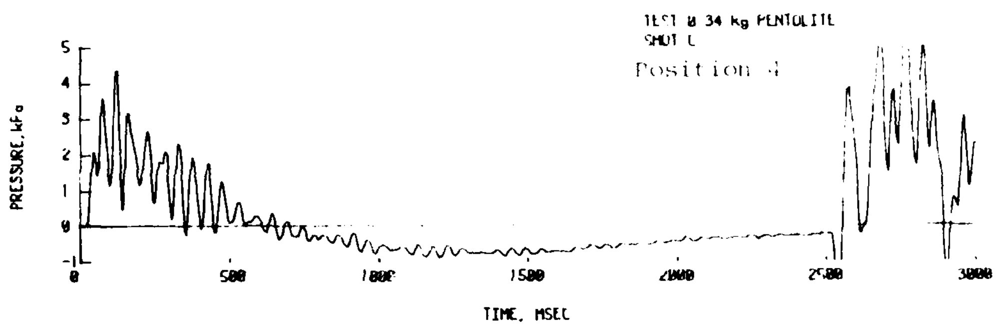


Figure A-3. Pressure History Records, Position 3 and 4.

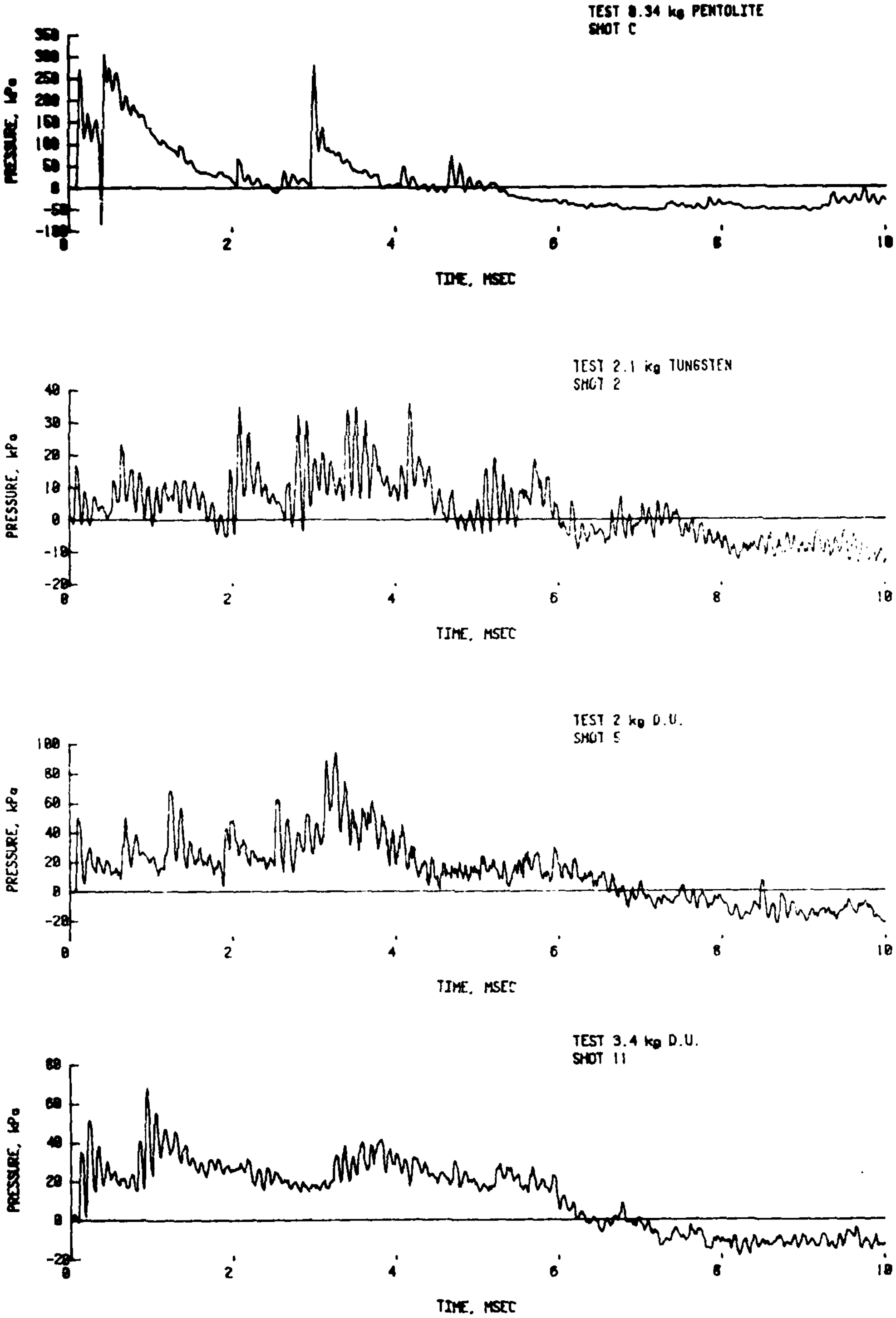


Figure A-4. Pressure History Records, Position 5.

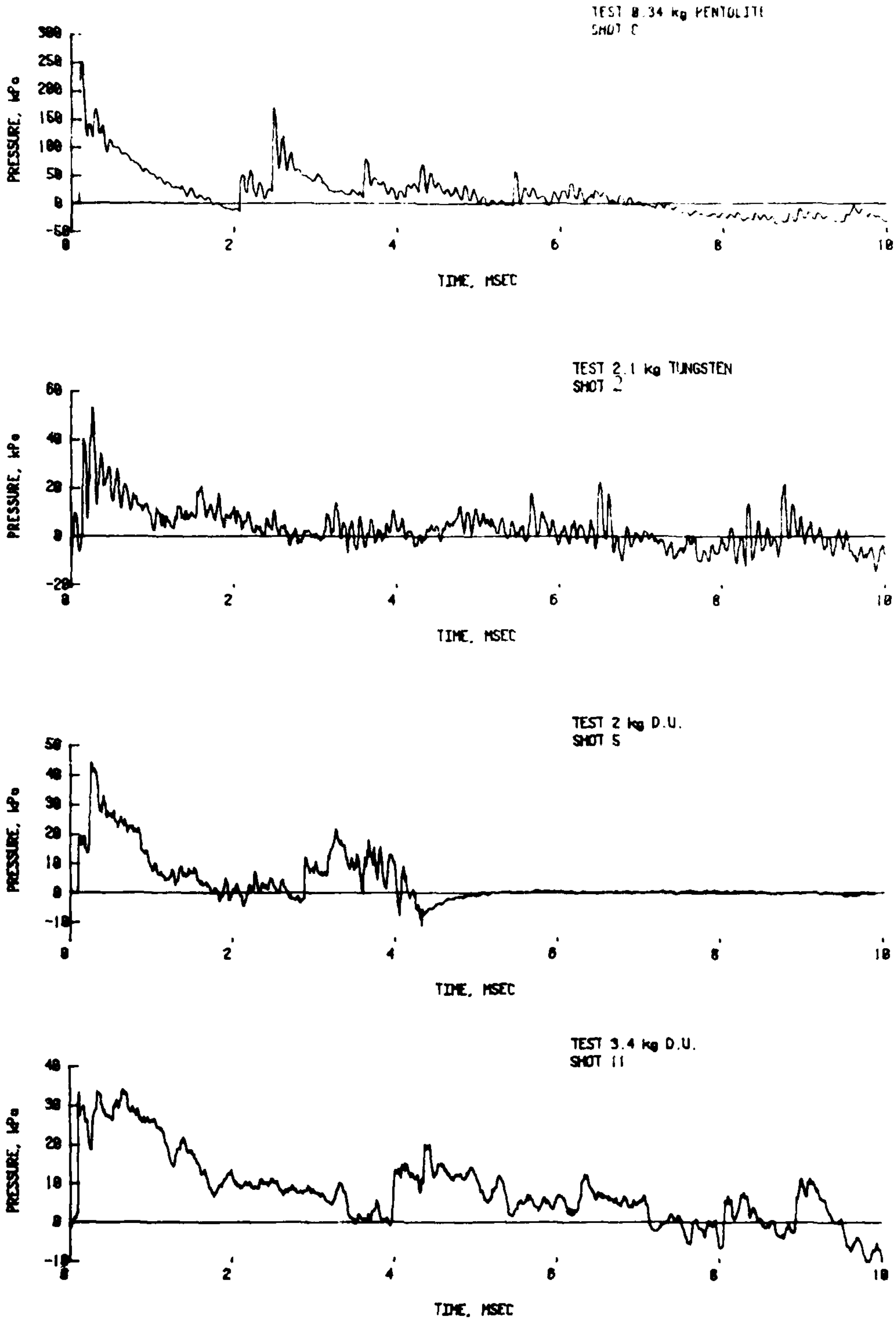


Figure A-5. Pressure History Records, Position 6.

Shot C, Position 7 not recorded.

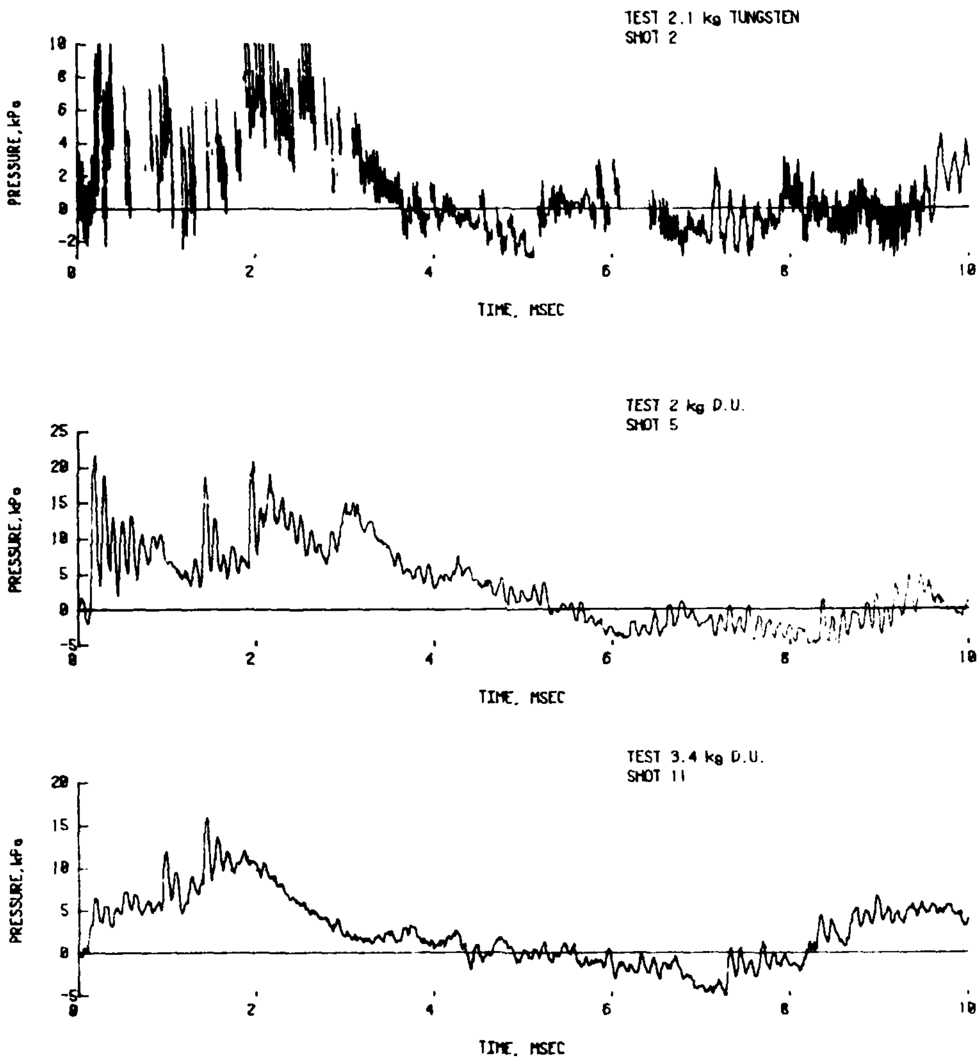


Figure A-6. Pressure History Records, Position 7.

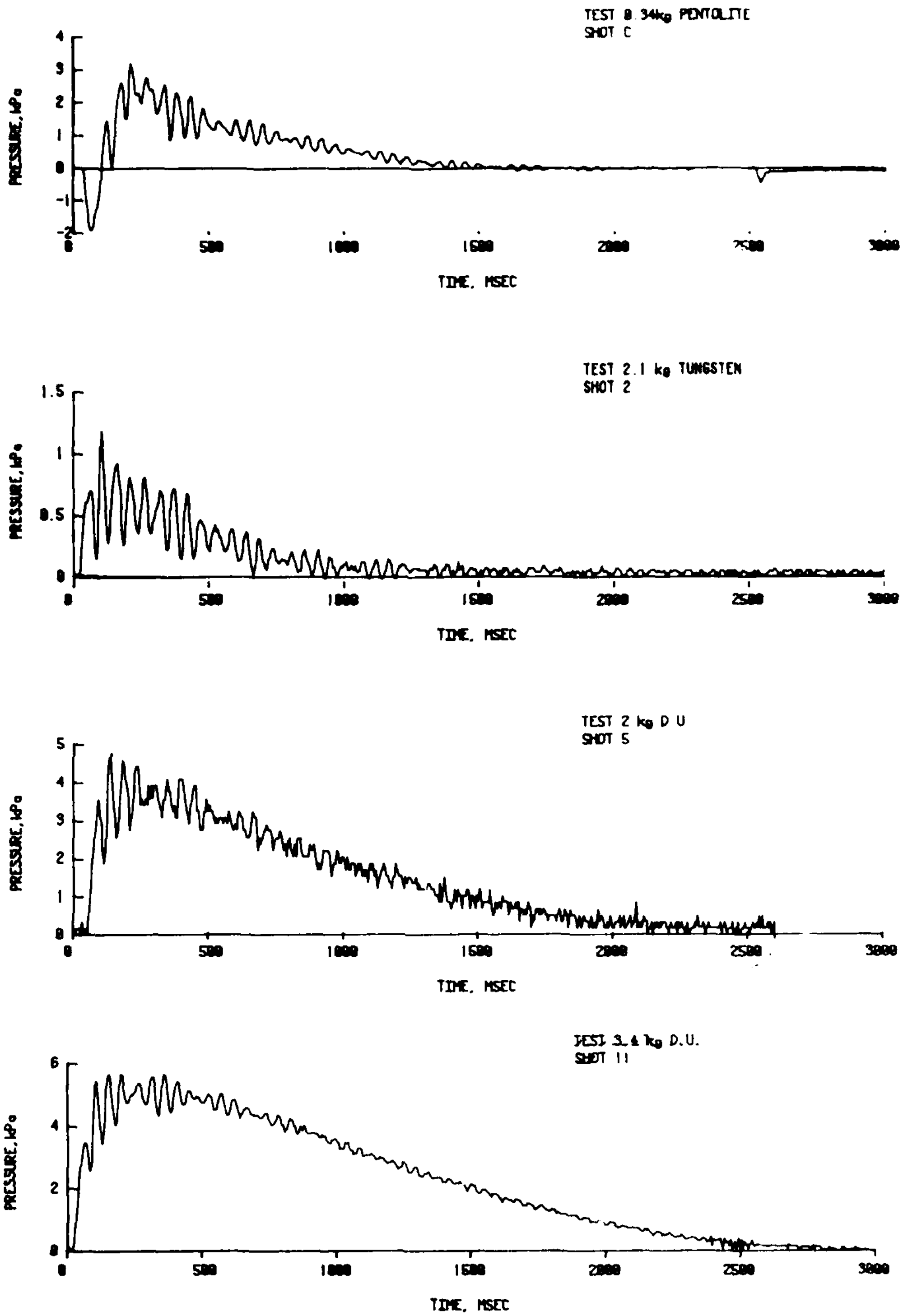


Figure A-7. Pressure History Records, Position 7.

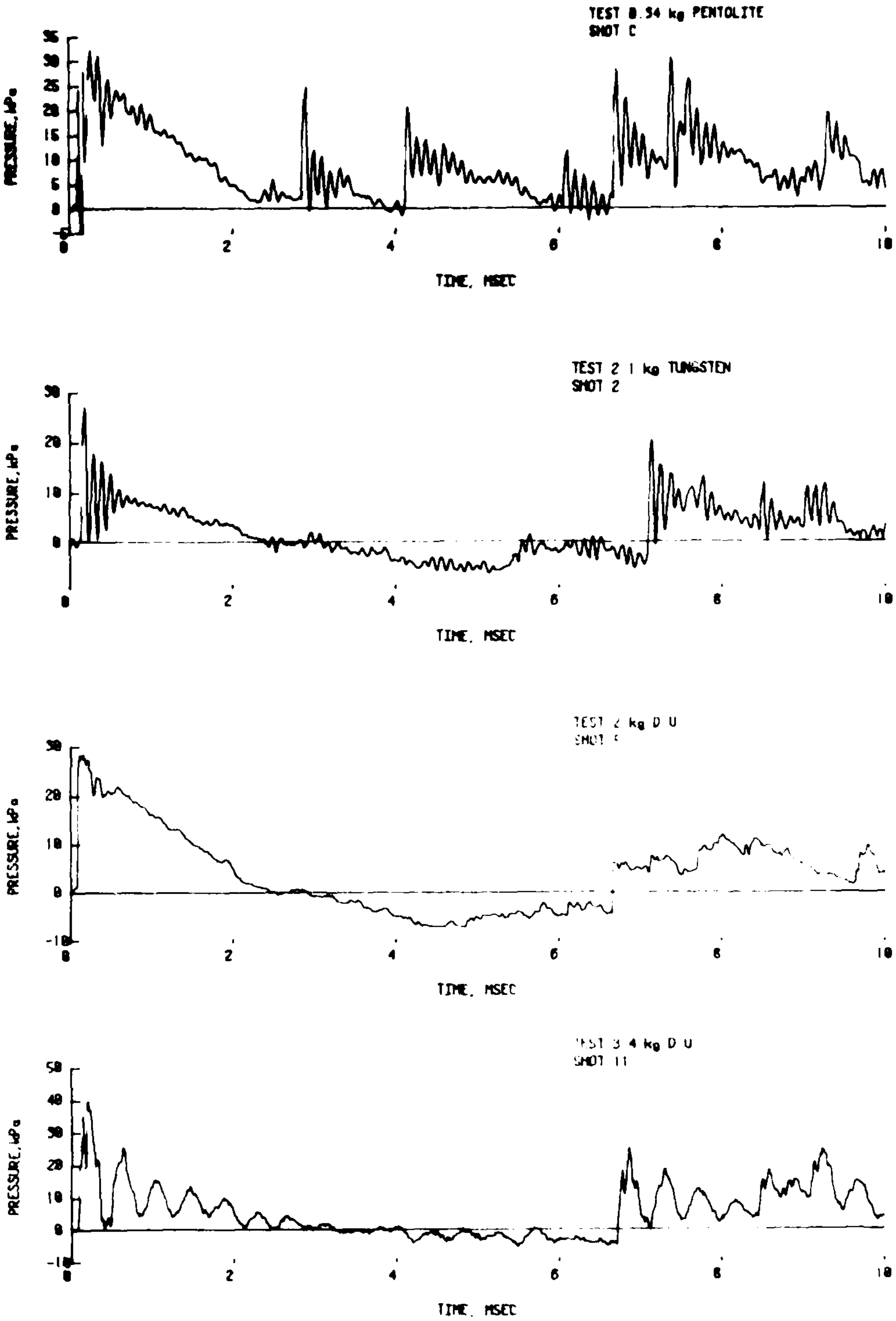


Figure V-8. Pressure History Records, Position 8.

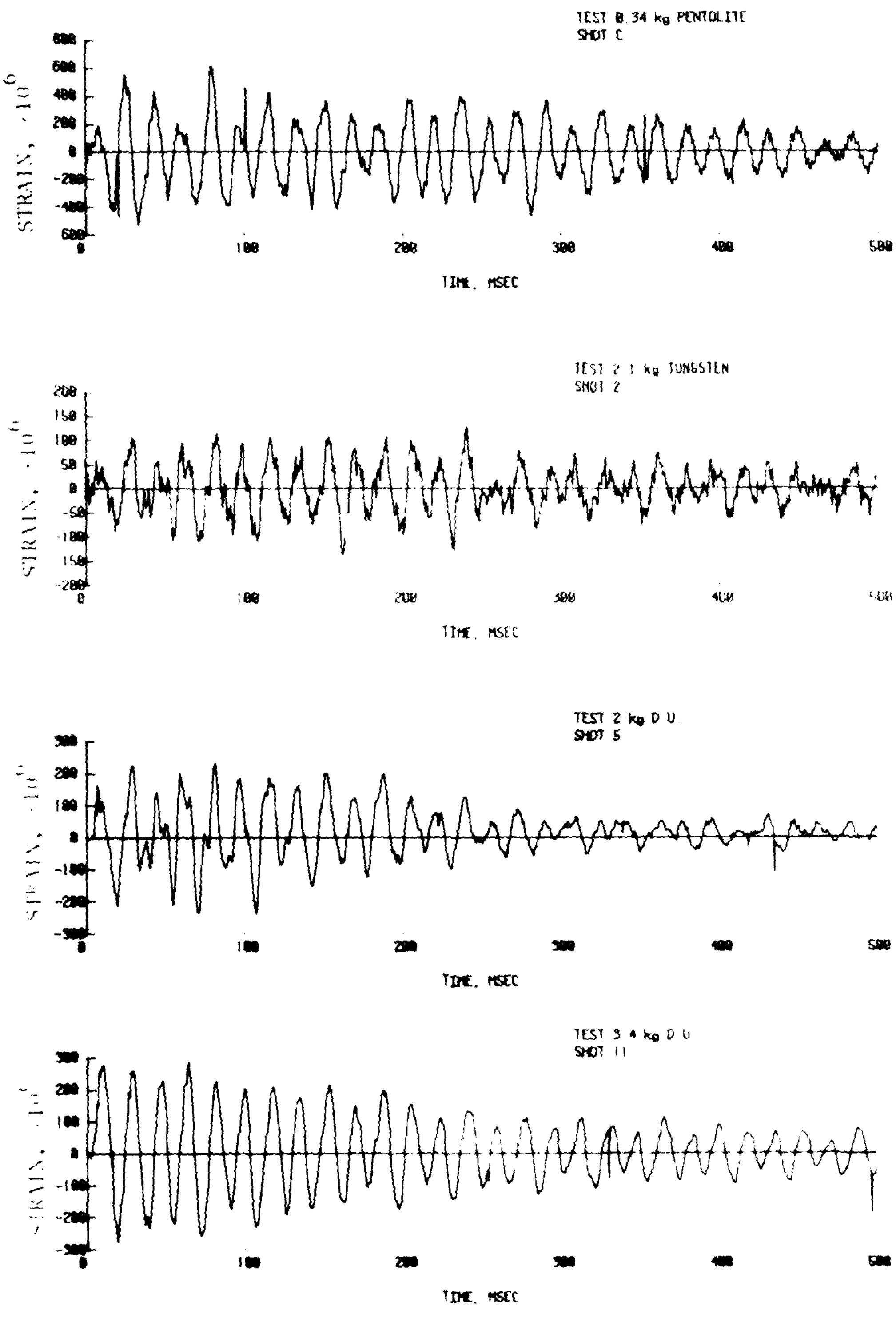
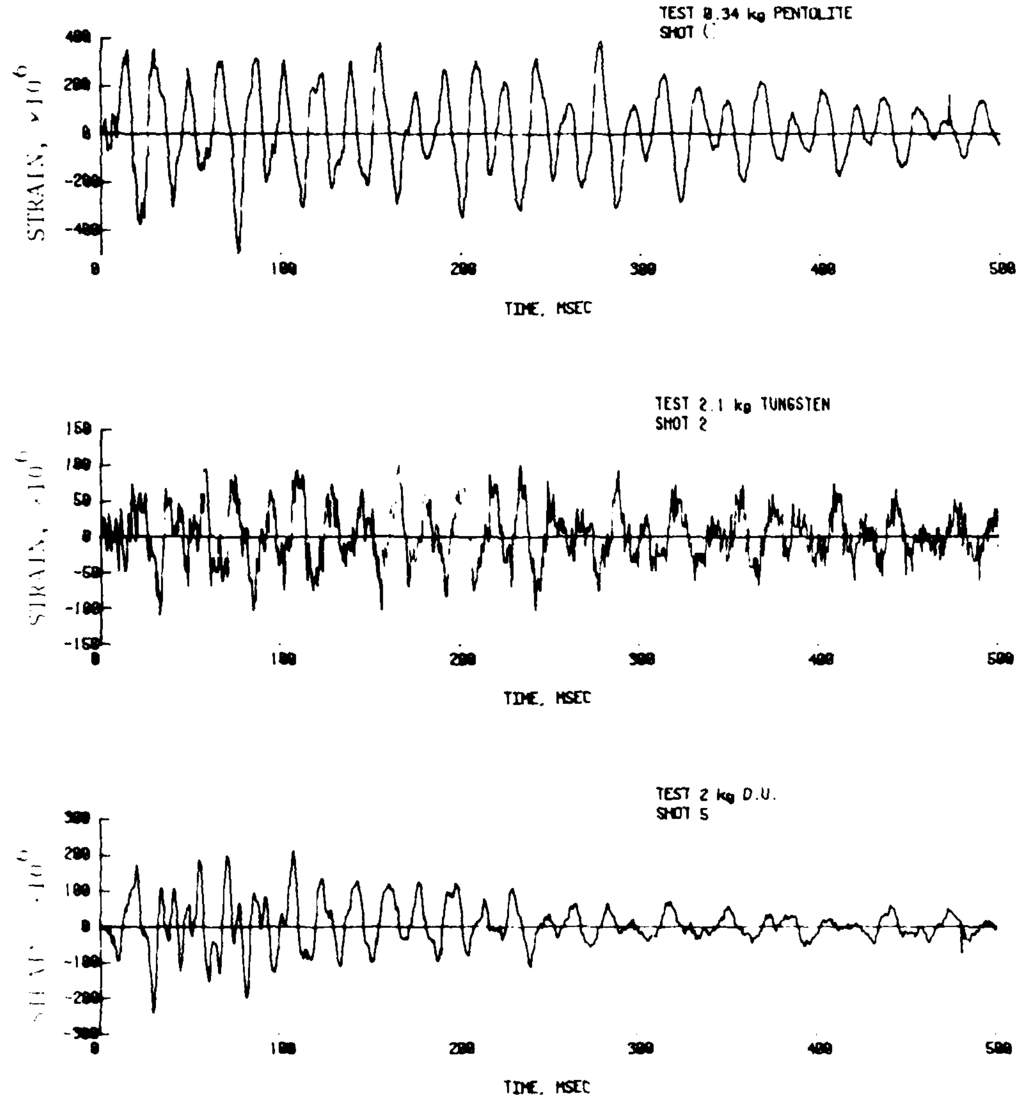


Figure A-9. Strain History Records, [illegible]



Position 11, Test 11 not recorded.

Figure A-10. Strain History Records, Position 11.

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