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Final Technical Report

TNT EQUIVALENCY OF BLACK POWDER
Volume I: Management Summary and Technical Discussion

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Under the technical direction of
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FOREWORD

IIT Research Institute has conducted an experimental study to determine the TNT equivalency of Black Powder. The work was conducted for Indiana Army Ammunition Plant under a modification to Purchase Order 01-46628. Work was carried out during the period January 1 to June 1, 1972. This work was conducted as part of the engineering support required for establishing a new Black Powder manufacturing facility at the Indiana Army Ammunition Plant. Technical guidance was provided by Mr. R. Rindner and Mr. L. Silberman of Picatinny Arsenal. This document entitled "TNT Equivalency of Black Powder" is the final report on this effort. In addition to the authors, personnel who have made material contributions to the program are R. Babler, D. Morita, A. Humphreys, R. Joyce, D. Hrdina, J. Daley and D. Baker.

The results of this effort are presented in two volumes: Volume I, Management Summary and Technical Discussion, presents a brief, concise review of the study content, summarizes the principal conclusions and recommendations, and provides a discussion of the test data and the data analysis. Volume II, Appendices, contains summaries of the raw data, computational method, computed equivalencies, and detailed description of the instrumentation system.

Respectfully submitted,
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ABSTRACT

The purpose of this investigation was to experimentally determine the maximum output from Black Powder explosive reactions in terms of airblast overpressure and impulse. The measured pressure and impulse values are compared with those produced by a hemispherical surface burst of TNT in order to determine the TNT equivalency of Black Powder.

Black Powder charges ranging in weight from 8 lbs to 150 lbs were evaluated under different levels of confinement. The TNT equivalencies for the final product were found to range between zero to 43 percent for impulse and zero to 24 percent for pressure, depending upon the level of confinement, the weight of explosive and booster, and the distance from the explosion. A limited number of tests were carried out on 27 lb charges of the jet milled product, an in-process form of Black Powder. Its TNT equivalency ranged from zero to 22 percent for impulse and zero to 11 percent for pressure. It is recommended that a maximum impulse equivalency value of 24 percent be used for the process building and glaze house design since tests carried out under conditions existing in these buildings indicate that these values are applicable. However the value of 43 percent impulse equivalency should be applied to the pack house and loading dock. The application of this TNT equivalency data to the design of the improved Black Powder process manufacturing plant, would result in the reduction in the cost of construction of the new facility.

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1. OBJECTIVE

The purpose of this investigation was to experimentally determine the maximum output from Black Powder explosive reactions in terms of airblast overpressure and impulse. The measured pressure and impulse values are compared with that produced by TNT in order to determine the TNT equivalency of Black Powder, which is defined as the ratio of the weight of TNT to the weight of Black Powder that would produce the same overpressure (or impulse) at the same distance.

2. SUMMARY

In order to meet the objectives of this program a total of 72 tests were carried out. This number consisted of 42 tests on CIL* Black Powder; six tests on the jet milled material, an in-process form of Black Powder; 19 tests on an inert simulant, sand, to isolate the booster output effect; and five calibration tests, using a C-4 booster, to check on the accuracy of the pressure gages and recording system. The major parameters evaluated for their effect on TNT equivalency were the weight of the Black Powder, the amount of confinement and the weight of the explosive booster used to initiate the Black Powder. A limited number of tests were carried out to evaluate secondary effects; these were booster geometry and type of booster explosive.

These effects were measured in terms of airblast overpressure and impulse at six gage station locations. These stations were spaced at selected scaled distances ranging from approximately 2 to 15 $ft/lb^{1/3}$. The TNT equivalency was found to depend upon charge weight, scaled distance and amount of confinement. Equivalencies for Black Powder ranged from zero to 43 percent for impulse and zero to 24 percent for pressure. The equivalencies for the jet milled material ranged from zero to 22 percent for impulse and zero to 11 percent for pressure. The condition for which the maximum value of 43 percent was found applies to the pack house and loading dock. For actual production in the process building and glaze

*CIL - Canadian Industries Limited

house a maximum value of 24 percent for impulse equivalency should be used because of the small quantities and/or a lack of confinement.

- Confinement effects are significant, small increases in the degree of confinement substantially increase the TNT equivalency.
- Pressure and impulse equivalency increases with increase in both Black Powder charge weight and booster weight. The maximum values obtained were 24 percent for pressure equivalency at a scaled distance of 7 and 43 percent for impulse equivalency at a scaled distance of 2.
- When all data are compared on the basis of equal ratio of booster weight to Black Powder weight, the TNT equivalencies for 75 and 150 lb charges are essentially equal whereas 25 lb charges have lower equivalency values.
- Pressure equivalency increases with scaled distance, reaching a maximum value at a scaled distance of between 7 and 10 $ft/lb^{1/3}$ and then decreases.
- Impulse equivalency does not vary appreciably with scaled distance, but it is always greater than the pressure equivalency.

3. CONCLUSIONS, RECOMMENDATIONS, AND APPLICATIONS

The TNT equivalency of Black Powder was found to range between zero and 43 percent for impulse and zero to 24 percent for pressure. The limited number of tests on the jet milled material showed that its impulse equivalency ranged between zero and 22 percent and zero to 11 percent for pressure. The TNT equivalency depended primarily upon the degree of confinement, the quantity of explosive, booster material and the distance from the explosion. It should be noted that the conditions for which the maximum values of 43 percent equivalency were obtained are never realized in the process building or glaze house, that is heavy confinement, large concentrated weights, and large initiation sources. Although substantial quantities of Black Powder exist in the glaze house (4500 lbs) the Black Powder is in a wood barrel, which does not constitute confinement.

The quantities of Black Powder evaluated in this investigation were large enough to constitute a full-scale evaluation of the quantities to be processed in the process building of the improved Black Powder manufacturing facility. It is recommended that the test results reported herein be incorporated into the final facility design. It is believed that the cost of the new manufacturing facility could be reduced if building construction and quantity-distance siting were based on the data acquired on this program.

On the basis of the concept studies for the improved Black Powder manufacturing facility, the approximate accumulation of material in the process building is shown in Table 1. The maximum value of impulse equivalency associated with the given weights and confinement levels are also provided in this table. Thus it is seen that the data reported herein has direct application and can provide significant guidance to the optimization of the new facility design.

The following recommendations are not critical to the design of the new facility, however additional savings in cost of construction may be possible after more TNT equivalency data are acquired. These tests should be carried out for selected conditions, so as to fill in the voids in the data. These evaluations should include:

- Test on Black Powder charges weighing more than 150 lbs to determine if maximum equivalencies have been achieved, and/or to determine if the critical mass for maximum output has been found. These data would have particular application to the load dock, pack house and to the glaze house where approximately 4500 lbs will be polished, dried, and glazed at one time. This evaluation would not be necessary if a continuous glazing and drying process is developed. At least one full-scale 4500 lb test should be carried out.
- An evaluation should be made to determine the TNT equivalencies of the in-process forms of Black Powder. This includes the jet mill product, press cakes, prebreaker chips and green grains. It is believed that even lower values of TNT equivalency would be found for all in-process forms of Black Powder. To increase the validity of this work, tests should be carried out under the same conditions of confinement, geometry, and weights as exist in the process.

TABLE 1

IN-PROCESS MATERIAL QUANTITY AND TNT EQUIVALENCY

Area Description	Weight of In-Process Material in Each Bay	TNT Impulse Equivalency (%)	TNT Pressure Equivalency (%)
A. Process Building			
• Blending and jet mill stations	50 lbs if continuous blending is used (200 lbs if a batch type air blender is used)	22	11
• Press Bay 1	8 lbs each cake; 90 lbs total accumulation	22	11
• Press Bay 2	8 lbs each cake; 90 lbs total accumulation	22	11
• Prebreaker corning mill, screens and conveyors	30 lbs minimum to 150 lbs maximum on vertical conveyor; depending upon the performance characteristics of the conveyor total distributed accumulation 130 to 250 lbs	24	15
• Between bays material transfer	20 lbs maximum on a single piece of transport equipment. Total distributed 50 lbs.	24	15
B. Glaze House	4500 lbs	24	15
C. Pack House	10,000 lbs estimate	43	24
D. Loading Dock	100,000 lbs estimate	43	24

As secondary recommendations:

- The distances at which pressure measurements are made should be extended to scaled distances less than 2 and to intraline distances of 20 ft/lb$^{1/3}$ for all charge weights.
- To fill in voids in the data, larger size boosters should be used to confirm that maximum output has in fact been determined.

4. INTRODUCTION

A series of 72 tests were carried out to determine the TNT equivalency of CIL Black Powder and jet milled material, an in-process form of Black Powder produced by the improved Black Powder process. The experimental work was carried out at the IIT Research Institute's explosive research laboratory, located near LaPorte, Indiana, for IAAP, under the technical supervision of Picatinny Arsenal.

The 72 tests consisted of 42 tests on CIL Black Powder; six tests on the jet milled material; 19 tests on sand, as an inert simulant, to isolate the booster output effect; and five calibration tests, using a C-4 explosive booster, to check on the accuracy of the pressure gages and recording system.

The parameters that were evaluated for their effect on TNT equivalency, with respect to blast overpressure and impulse, were the weight of the Black Powder, the type of confinement and the explosive booster weight. A limited number of tests were carried out to evaluate secondary effects: booster geometry and type of booster explosive. Table 2 shows the range of major parameters evaluated. Each entry in the table represents more than one test, as tests at each condition were repeated two or three times.

TABLE 2

RANGE OF TEST PARAMETERS EVALUATED

Booster Explosive		Black Powder Weight (lbs)				Jet Mill Product Weight (lbs)
Weight (lbs)	Type	8	25*	75*	150	27
--	Squib		C[+]			C
0.024	Tetryl	C	U[+] C	U C	U C	C U
0.25	C-4		U			
0.50	C-4		U	U		
0.54	9404 PBX		U			
1.00	C-4		U	U		
1.50	C-4			U	U	
3.00	C-4				U	

*Initial series of 15 tests were for 27 and 64 lbs. The remainder were at the specified values.

+The letter U stands for unconfined test configurations and C for confined tests.

5. TEST CONFIGURATIONS

A schematic diagram of the physical arrangement of the test area is shown as Figure 1. It consists of a concrete slab 75 ft long by 10 ft wide. Pressure transducers were installed flush with the top surface of the concrete slab in mechanically isolated steel plates. The steel plates cover a channel in which gage leads are placed. The test item is placed adjacent to one end of the concrete slab. Before each test this sandy area is leveled even with the concrete slab.

For these tests six gages were mounted on the blast pads. Overpressure was measured and total positive impulse was electronically computed. See Appendix D for a complete description of the overpressure and impulse measurement systems.

Fastax motion pictures were taken of all the experiments. Fiducial markers were located behind the charge with respect to the camera,in the camera's field of view,as shown in Figure 1.

5.1 Confined/Unconfined Test Series

Two explosive materials were tested in this series. The principal one was the Black Powder manufactured by CIL in a conventional processing plant. The second, was the jet milled material, an in-process form of Black Powder manufactured in a pilot plant facility at IAAP. It is obtained by running a premix of potassium nitrate,charcoal, and sulfur through an air agitated jet mill. The jet milled particles are approximately 15 microns in diameter.

A typical test setup for this series is illustrated in Figure 2. The Black Powder or jet milled mixture was placed in cubical steel boxes for the confined tests. The steel boxes were fabricated from 1/2-inch-thick steel plates which were welded together at the edges. A hole, just large enough to accept the booster, was drilled into the middle of one side of the box as shown. The boxes were also loaded through this hole.

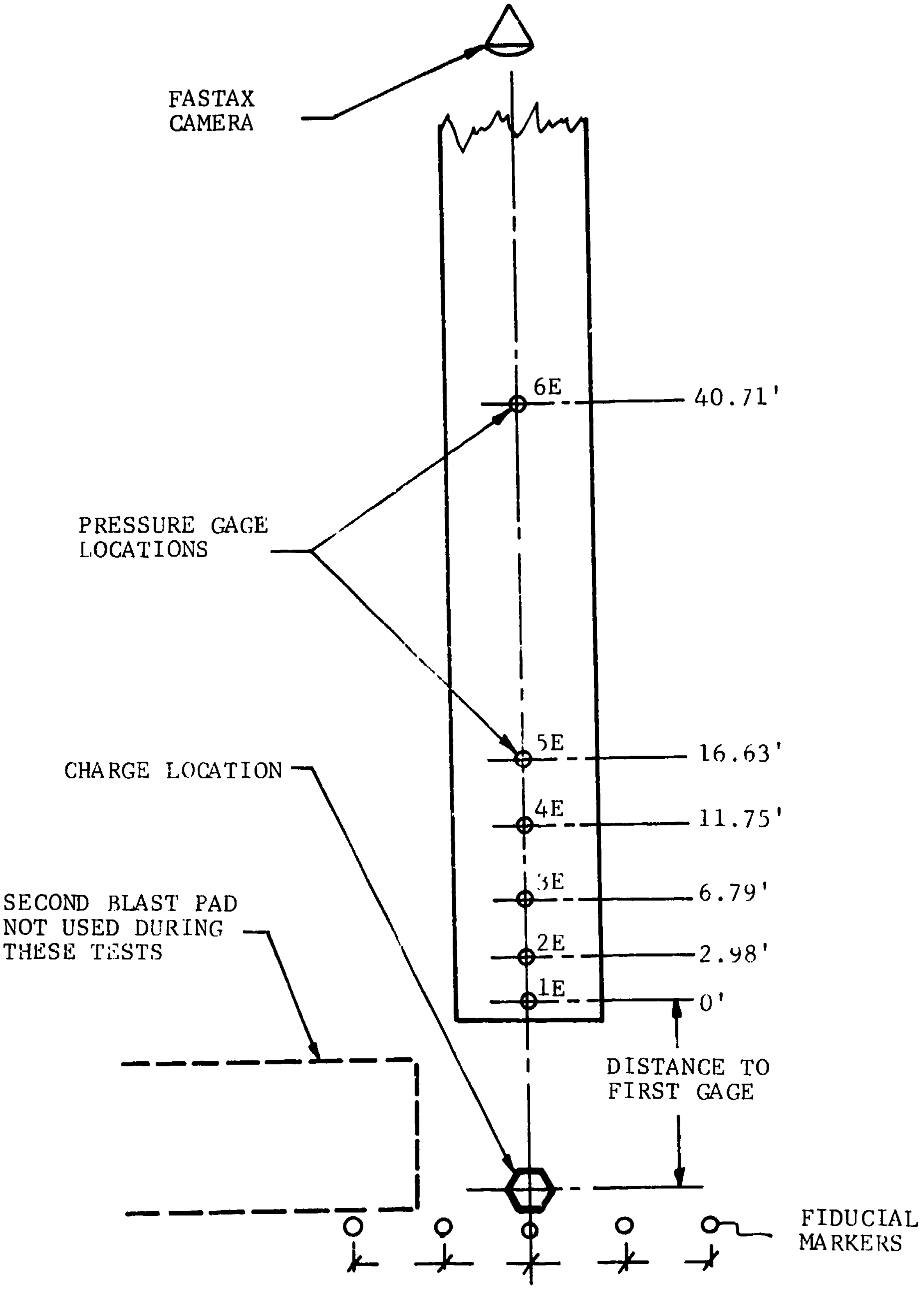

Figure 1 TEST AREA

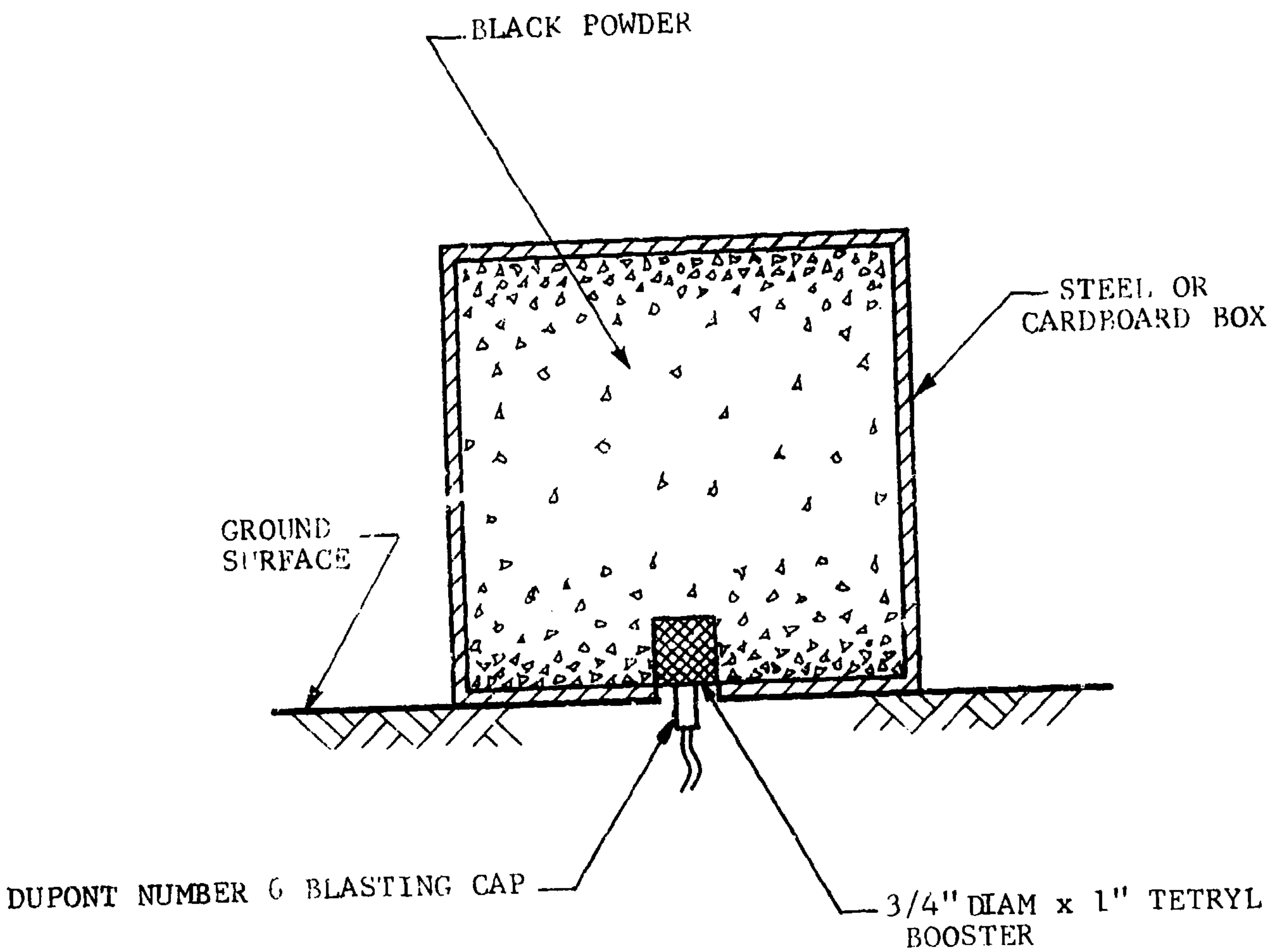

Figure 2 CONFINED/UNCONFINED TEST SETUP

Corrugated cardboard boxes were used for the unconfined shots. Holes were cut in the bottom of each box to accept the booster. There was no top on the cardboard boxes. The cubical cardboard and steel boxes were sized so as to just accept the quantity of Black Powder being shot.

The Black Powder for the test series, where the effect of confinement was determined, was ignited with a DuPont S65 electric squib* or a DuPont number 6 electric blasting cap and a 3/4-inch-diameter by 1-inch-long Tetryl booster.

Table 3 is a test schedule for this test series. Initiation sources, confinement, and quantity of material tested are tabulated. Two calibration tests CAL 1 and CAL 2 were performed to confirm the accuracy of the pressure measuring system. They consisted of placing a 2 lb bare spherical C-4 charge on a steel witness plate. Pressure and impulse data from these calibration shots were recorded and compared with previously established pressure-distance and impulse-distance curves for C-4 explosive. A third calibration shot, CAL 3 was conducted to determine the output of the Tetryl booster.

Note that four of the tests in this series were conducted with the cubical Black Powder charge placed off the ground on a wooden platform. The standoff height, to the centroid of the charge, was to be equal to one and one-half times the diameter of an equivalent weight of a spherical TNT charge. This test condition was discontinued because it was not possible to predict in advance the equivalent TNT weight of the charge.

5.2 Booster Size and Shape Effects Test Series

This series of tests was performed to determine the effects of booster type, size and shape, and Black Powder weight on TNT equivalency. Typical test configurations are shown in Figure 3.

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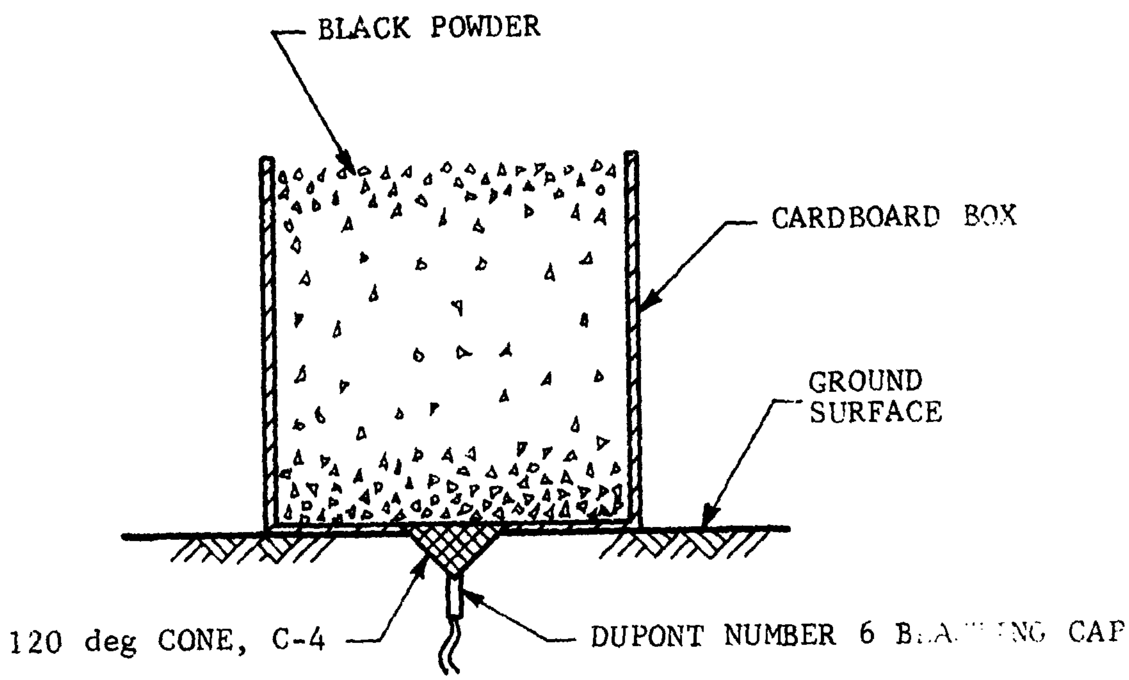
* Contained 0.2 grain initiating mix

TABLE 3

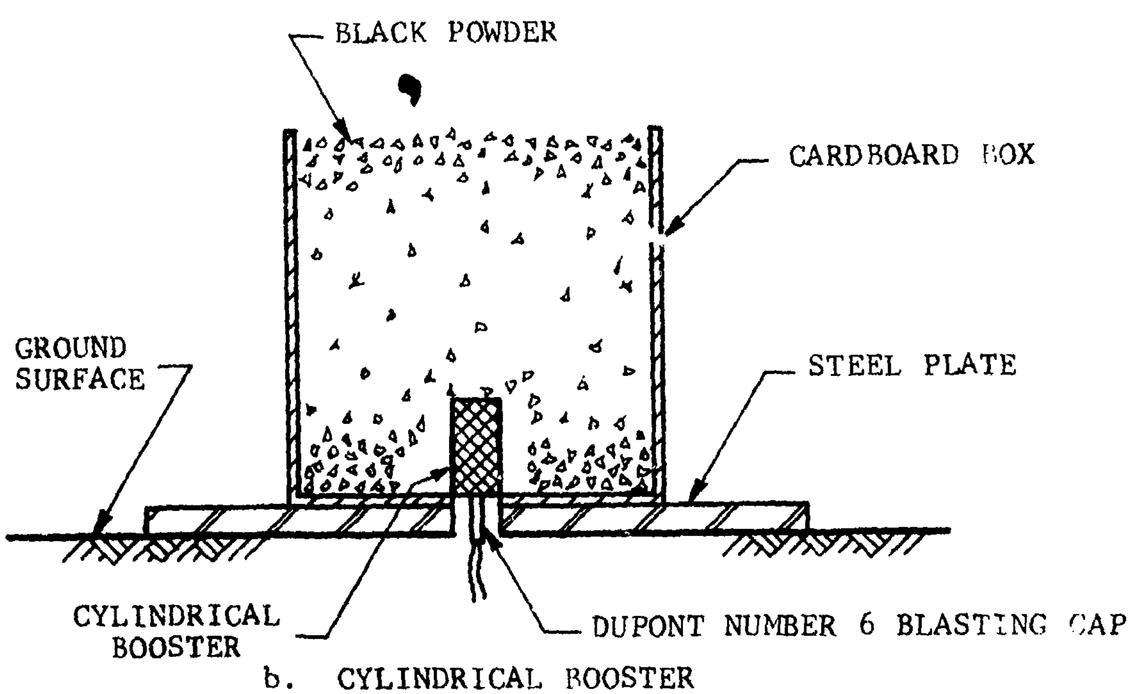
CONFINED/UNCONFINED TESTS, INITIAL SERIES

Test Number	Test Configuration	Sample	Sample Weight (lbs)	Ignitor
UNC 1	Unconfined on Standoff	Black Powder	27	Tetryl, 0.024 lb
UNC 2	Unconfined on Standoff	Black Powder	27	Tetryl, 0.024 lb
UNC 3	Unconfined	Black Powder	27	Tetryl, 0.024 lb
UNC 4	Unconfined on Standoff	Black Powder	64	Tetryl, 0.024 lb
UNC 5	Unconfined	Black Powder	27	Tetryl, 0.024 lb
UNC 6	Unconfined	Black Powder	140	Tetryl, 0.024 lb
UNC 8	Unconfined	Jet Milled	27	Tetryl, 0.024 lb
UNC 9	Unconfined	Jet Milled	27	Tetryl, 0.024 lb
CON 1	Confined	Black Powder	8	Tetryl, 0.024 lb
CON 2	Confined	Black Powder	8	Tetryl, 0.024 lb
CON 3	Confined	Black Powder	27	Tetryl, 0.024 lb
CON 4	Confined	Black Powder	27	Tetryl, 0.024 lb
CON 5	Confined	Black Powder	27	Tetryl, 0.024 lb
CON 6	Confined	Black Powder	64	Tetryl, 0.024 lb
CON 7	Confined	Black Powder	64	Tetryl, 0.024 lb
CON 8	Confined	Black Powder	64	Tetryl, 0.024 lb
CON 9	Confined	Black Powder	140	Tetryl, 0.024 lb
CON 10	Confined	Black Powder	140	Tetryl, 0.024 lb
CON 11	Confined	Jet Milled	27	Tetryl, 0.024 lb
CON 12	Confined	Jet Milled	27	Tetryl, 0.024 lb
SQ* 1	Confined	Black Powder	27	Squib
SQ 2	Confined	Black Powder	27	Squib
SQ 3	Confined	Black Powder	27	Squib
SQ 4	Confined	Jet Milled	27	Squib
SQ 5	Confined	Jet Milled	27	Squib
CAL 1	Surface Burst	C-4	2	M6 Cap
CAL 2	Surface Burst	C-4	2	M6 Cap
CAL 3	Unconfined on Standoff	Sand	27	Tetryl, 0.024 lb

*SQ, Squib initiated series, S65 DuPont squib.



a. 120 deg CONE BOOSTER



b. CYLINDRICAL BOOSTER

Figure 3 BOOSTER SIZE AND SHAPE TEST SETUP

In all tests the Black Powder was shot unconfined in cubical corrugated cardboard boxes. Both conical and cylindrical shaped boosters were used. The conical shaped boosters were formed from C-4 explosive. The flat side of the 120 deg cone was in contact with the Black Powder. The conical end of these boosters were buried in the sand as illustrated in Figure 3a. Cylinder shaped boosters were located such that the Black Powder surrounded the booster as shown in Figure 3b. Booster explosives evaluated were Tetryl, C-4, and 9404 PBX. The C-4 cylindrical boosters had a length to diameter ratio of one. The Tetryl and PBX boosters had aspect ratios of approximately 1/2 to 1. All the boosters were ignited with a DuPont number 6 electric blasting cap.

The tests performed in this series are tabulated in Table 4 The sample tested and its weight are tabulated along with basic booster information. The majority of the tests were conducted with the charge setting on a steel plate, this information is given in Table 4 also.

TABLE 4

UNCONFINED TESTS, BOOSTER EFFECT SERIES

Test Number	Sample	Sample Weight (lbs)	Booster Type	Booster Weight (lbs)	Booster Shape	Steel Base Plate
BO-* 1	Sand	25	C4	0.25	120 deg Cone	No
BO- 2	Sand	25	C4	0.25	120 deg Cone	No
BO- 3	Sand	25	C4	0.50	120 deg Cone	No
BO- 4	Sand	25	C4	0.50	120 deg Cone	No
BO- 5	Black Powder	25	C4	0.25	120 deg Cone	No
BO- 6	Black Powder	25	C4	0.25	120 deg Cone	No
BO- 7	Calibration Test	--	C4	2.0	Sphere	Yes
BO- 8	Black Powder	25	C4	0.50	120 deg Cone	No
BO- 9	Black Powder	25	C4	0.50	120 deg Cone	No
BO-10	Sand	25	C4	0.50	Cylinder	No
BO-11	Sand	25	C4	0.50	Cylinder	No
BO-12	Black Powder	25	C4	0.50	Cylinder	No
BO-13	Black Powder	25	C4	0.50	Cylinder	No
BO-14	Black Powder	27	Tetryl	0.024	Cylinder	Yes
BO-15	Black Powder	27	Tetryl	0.024	Cylinder	Yes
BO-16	Black Powder	75	C4	0.50	Cylinder	No
BO-17	Black Powder	75	C4	0.50	Cylinder	Yes
BO-18	Black Powder	75	C4	0.50	Cylinder	No
BO-19	Black Powder	75	C4	0.50	Cylinder	Yes
BO-20	Black Powder	75	C4	1.00	Cylinder	Yes
BO-21	Black Powder	75	C4	1.00	Cylinder	Yes
BO-22	Sand	75	C4	1.00	Cylinder	Yes
BO-23	Sand	75	C4	1.00	Cylinder	Yes
BO-24	Sand	75	C4	1.00	Cylinder	Yes
BO-25	Sand	75	C4	0.50	Cylinder	Yes
BO-26	Sand	75	C4	0.50	Cylinder	Yes
BO-27	Sand	75	C4	1.50	Cylinder	Yes
BO-28	Sand	75	C4	1.50	Cylinder	Yes
BO-29	Sand	75	C4	1.50	Cylinder	Yes
BO-30	Black Powder	75	C4	1.50	Cylinder	Yes
BO-31	Black Powder	75	C4	1.50	Cylinder	Yes
BO-32	Black Powder	25	C4	1.00	Cylinder	Yes
BO-33	Black Powder	25	C4	1.00	Cylinder	Yes
BO-34	Sand	25	PBX	0.54	Cylinder	Yes
BO-35	Sand	25	PBX	0.54	Cylinder	Yes
BO-36	Black Powder	25	PBX	0.54	Cylinder	Yes
BO-37	Black Powder	25	PBX	0.54	Cylinder	Yes
BO-38	Sand	150	C4	3.00	Cylinder	Yes
BO-39	Sand	150	C4	3.00	Cylinder	Yes
BO-40	Black Powder	150	C4	1.50	Cylinder	Yes
BO-41	Black Powder	150	C4	3.00	Cylinder	Yes
BO-42	Black Powder	150	C4	3.00	Cylinder	Yes
BO-43	Sand	25	C4	0.5	Cylinder	Yes

*BO is shot designation reference.

5. TNT EQUIVALENCY TEST RESULTS

Summary tables listing shots fired according to test conditions are shown in Table 5 for Black Powder and Table 6 for sand tests. Appendix A (Volume II) contains a tabulation of all raw test data in terms of the peak pressure and impulse at each of the six gage station locations. Appendix A also has these data plotted in the form of curves of pressure and scaled impulse as a function of scaled distance. The scaled distances and scaled impulses shown for the data points are based on total charge weight, and have not been adjusted to take into account the weight of the booster explosive.

Figure 4 is a typical summary curve of pressure-impulse data for 25 lb charges of Black Powder. The curves shown in the appendix however, have results of each test plotted on a separate sheet. It is displayed in this manner so that comparisons can be made between different test conditions by superposing any combination of curves of interest.

The TNT peak pressure and impulse equivalencies are obtained by determining the weight of TNT that would produce the same peak pressure (or impulse) at the same distance as a given Black Powder charge. It is the ratio of this weight of TNT to the weight of Black Powder (wt TNT/wt Black Powder) that defines the TNT equivalency. Thus, for example, if the TNT pressure equivalency is 10 percent, 1 lb of TNT would give the same overpressure at the same distance as 10 lbs of Black Powder. The reference curves for TNT are based on hemispherical surface burst.

A typical summary curve of pressure equivalency as a function of scaled distance for 25 lbs of Black Powder initiated by various booster weights is shown in Figure 5. A cross plot of these data in terms of pressure equivalency as a function of booster weight, at selected scaled distances, is shown in Figure 6.

Appendix B (Volume II) is a description of the procedure used to calculate TNT equivalencies and includes a sample problem. Appendix C contains the computed values of pressure and impulse equivalency.

TABLE 5

BLACK POWDER AND JET MILLED MATERIAL, RANGE OF TEST PARAMETERS EVALUATED AND THEIR SHOT NUMBERS

Black Powder Weight (lbs)	Booster Explosive Type and Weight								
	Confined Samples		Unconfined Samples						
	Squib	11 gm (0.024 lb) Tetryl	11 gm (0.024 lb) Tetryl	0.25 lb C-4	0.50 lb C-4	0.54 lb 9404 PBX	1.00 lb C-4	1.50 lb C-4	3.00 lb C-4
8		Con 1,2							
25				BO 5,6[4] cone[2]	BO 8,9 cone BO 12,13	BO 36,37 SP[1]	BO 32,33 SP		
27	Squib 1, 2,3	Con 3,4,5	Unc 1,2 Unc 3,5[3] BO 14,15 SP						
64		Con 6,7,8	Unc 4						
75					BO 16,18 BO 17,19 SP		BO 20,21	BO 30,31 SP	
140		Con 9,10	Unc 6[3]						
150								BO 40 SP	BO 41,42 SP
Jet Milled Material									
27	Squib 4,5	Con 11,12	Unc 8[3],9						

Notes:
(1) SP - Steel plate 1 in. thick whose top surface is flush with ground. Sample rests on steel plate.
(2) All boosters were cylindrical in shape, except in four tests where they were cone shaped.
(3) Poor records, electronics saturated.
(4) BO is shot designation reference.

TABLE 6

CALIBRATION TESTS USING SAND AS AN INERT SIMULANT,
RANGE OF PARAMETERS EVALUATED AND THEIR SHOT NUMBERS

Sand Weight (lbs)	Booster Type and Weight						
	11 gm 0.024 lb Tetr°1	0.25 lb C-4	0.50 lb C-4	0.54 lb 9404 PBX	1.00 lb C-4	1.50 lb C-4	3.00 lb C-4
25		BO 1,2 cone	BO 3,4 cone BO 1),11 BO 43 SP	BO 34,35 SP			
27	Cal 3						
75			BO 25,26 SP		BO 22,23, 24 SP	BO 27,28, 29 SP	
150							BO 38,39 SP

Notes: (1) SP = Steel plate 1 in. thick whose top surface is flush with ground. Sample rests on steel plate.

(2) BO is shot designation reference.

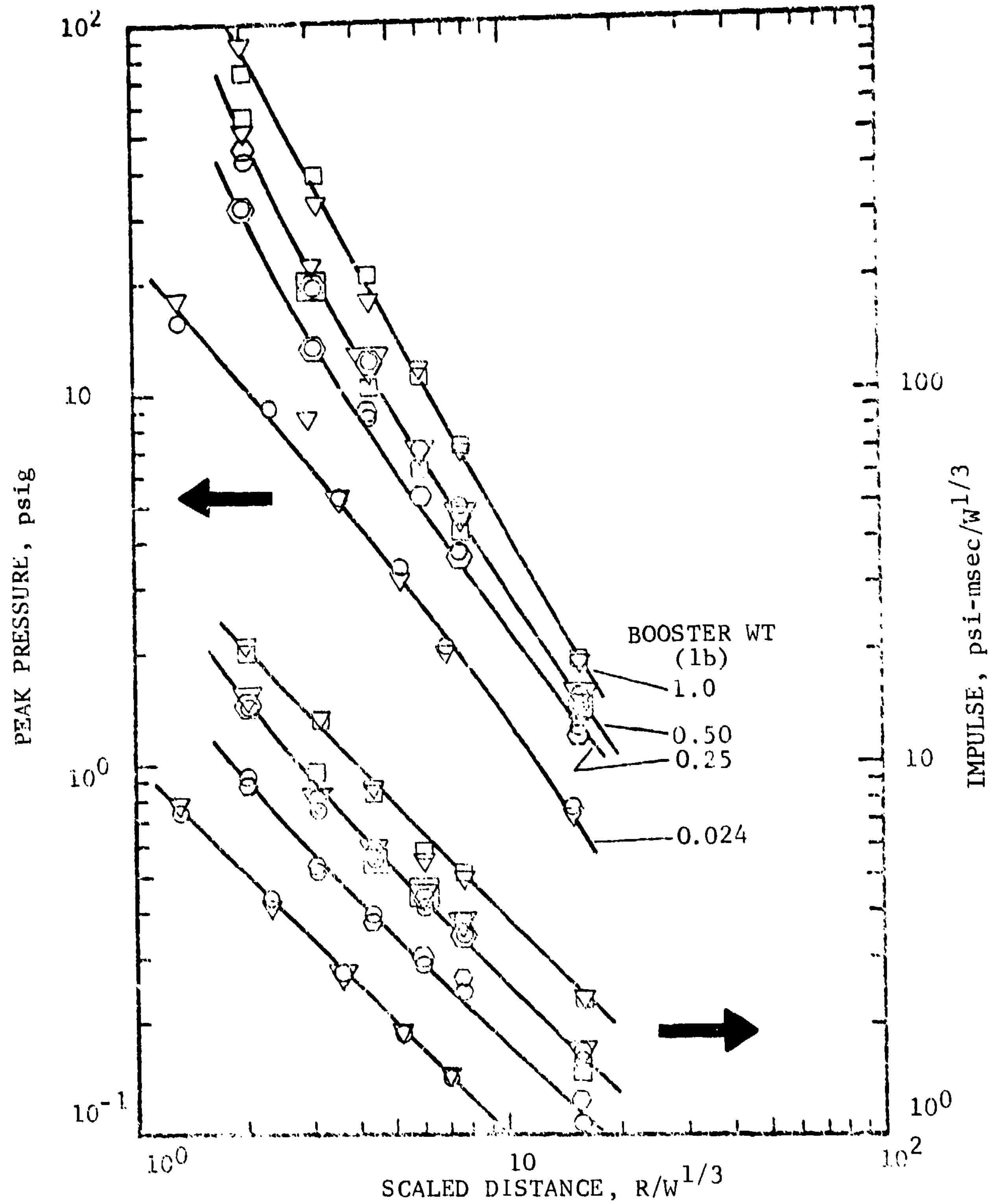


Figure 4 PRESSURE AND SCALED IMPULSE FOR VARIOUS BOOSTER WEIGHTS, 25 LB BLACK POWDER

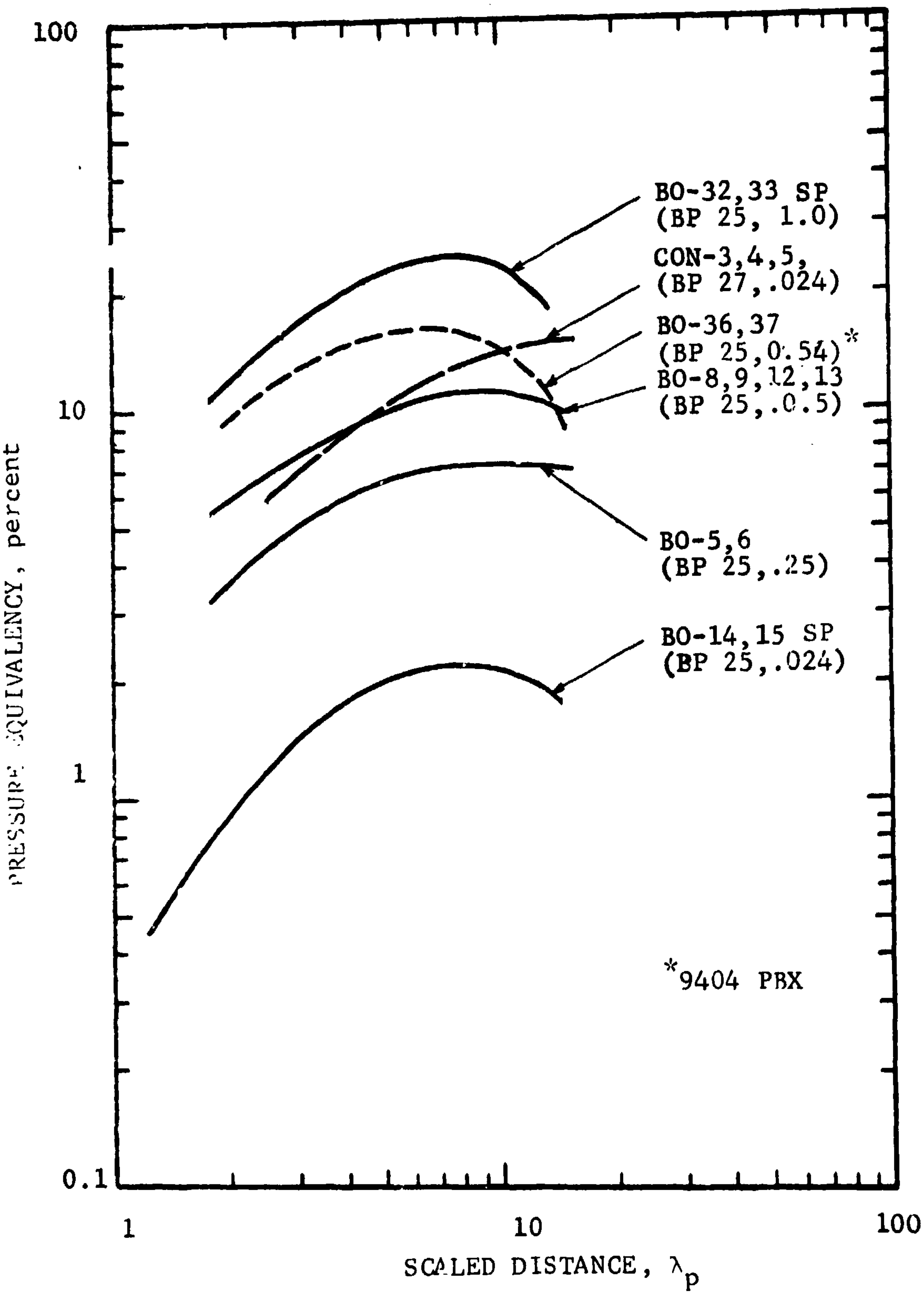


Figure 5 EFFECT OF BOOSTER WEIGHT ON TNT PRESSURE EQUIVALENCY, CONFINED AND UNCONFINED 25-27 LB BLACK POWDER

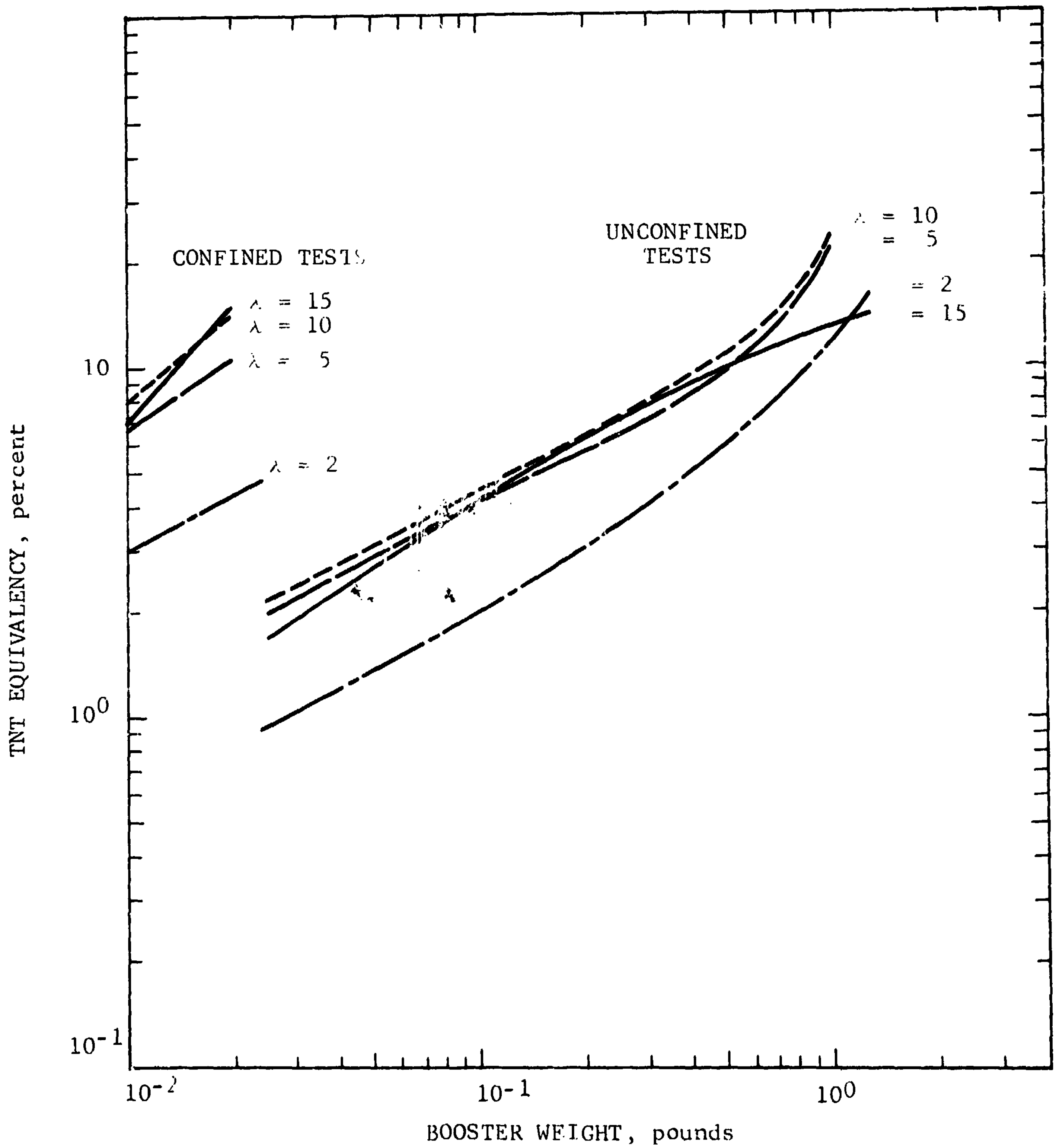


Figure 6 TNT PRESSURE EQUIVALENCY OF 25 LB BLACK POWDER, AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

Equivalencies are given in tabular and graphical form. The pressure and scaled impulse shown in the tables are based on the best first or second order polynomial curve fitted to the data points, as described in Appendix B. The scaled quantities, i.e., impulse and distances, are based on the total charge weight which includes a correction for the booster weight. The curves of equivalency as a function of scaled distance are plotted so that data from one initial test condition are shown on each page. This allows the reader to make comparisons, other than those described in this report, by superposing any combination of curves.

In addition to equivalencies being calculated according to points on the curve fitted to the pressure and impulse data, calculations of pressure and impulse equivalency were also made for each of the measured data points. Because there was some scatter in the raw data, which is amplified when equivalencies are calculated, the data point-by-point results are not considered as useful as those based on the fitted curve. However, for the sake of completeness, the equivalencies based on the raw data points are given in Appendix E, Volume II.

6.1 Overview of TNT Equivalency Test Results

Inasmuch as the TNT equivalency of Black Powder was found to be dependent upon distance from the charge, the weight of the Black Powder, the degree of confinement and the weight and type of explosive booster used to initiate the Black Powder, a single number need not be used to express the TNT equivalency of Black Powder. In addition the impulse equivalency is always greater than the pressure equivalency. However, when all of the equivalency data acquired on this program are plotted as a function of booster weight, for selected scaled distances, all data fall within two rather well defined regions, one for pressure and the other, impulse. The envelope as well as the data points are shown in Figures 7, 8 and 9. The maximum value of impulse equivalency occurs at scaled distances $\lambda = 2$ and is less than 43 percent. The maximum value for pressure equivalency is 24 percent at $\lambda = 7$.

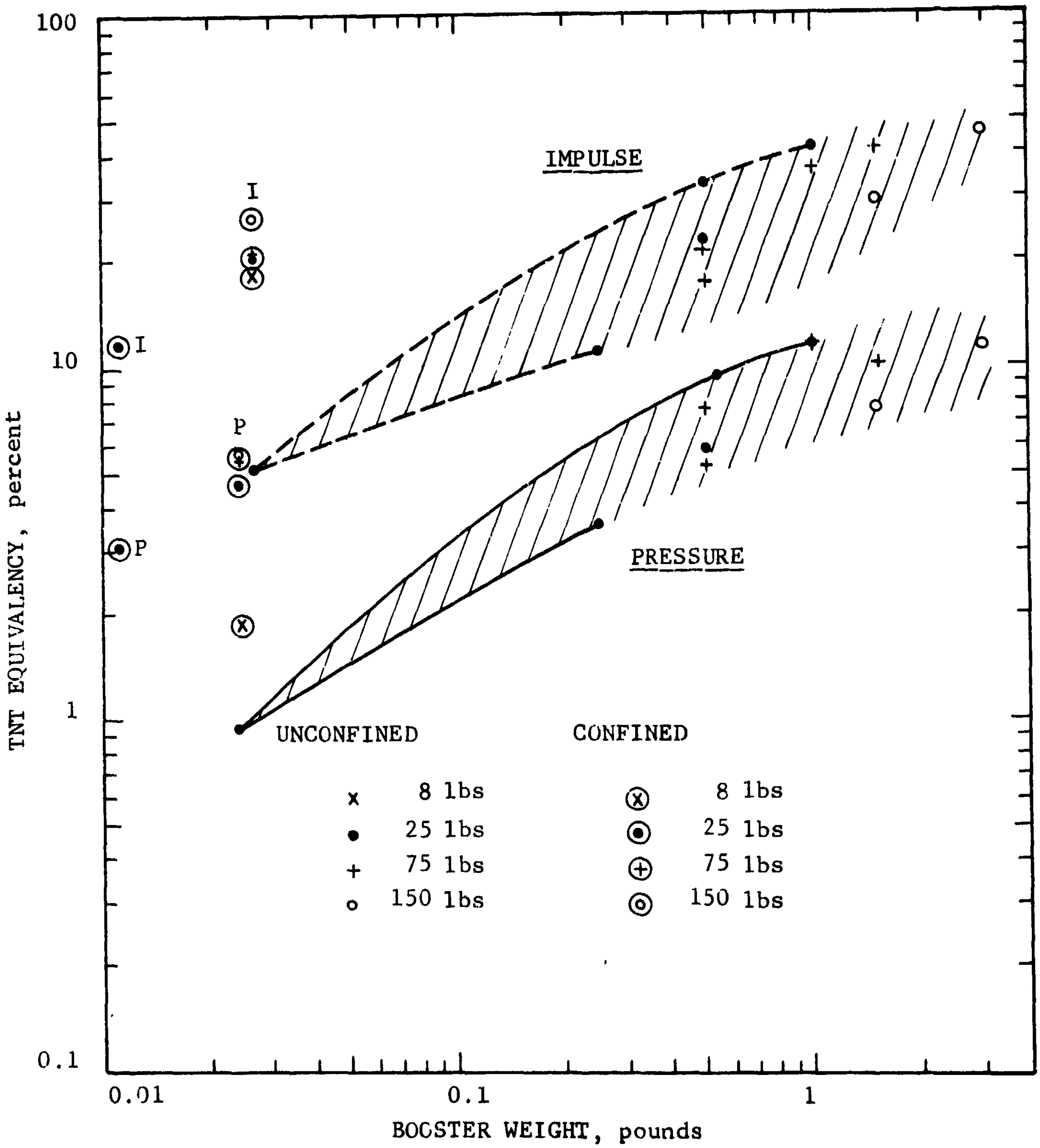


Figure 7 ENVELOPE OF PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF BOOSTER WEIGHT FOR ALL TESTS, SCALED DISTANCE $\lambda=2$

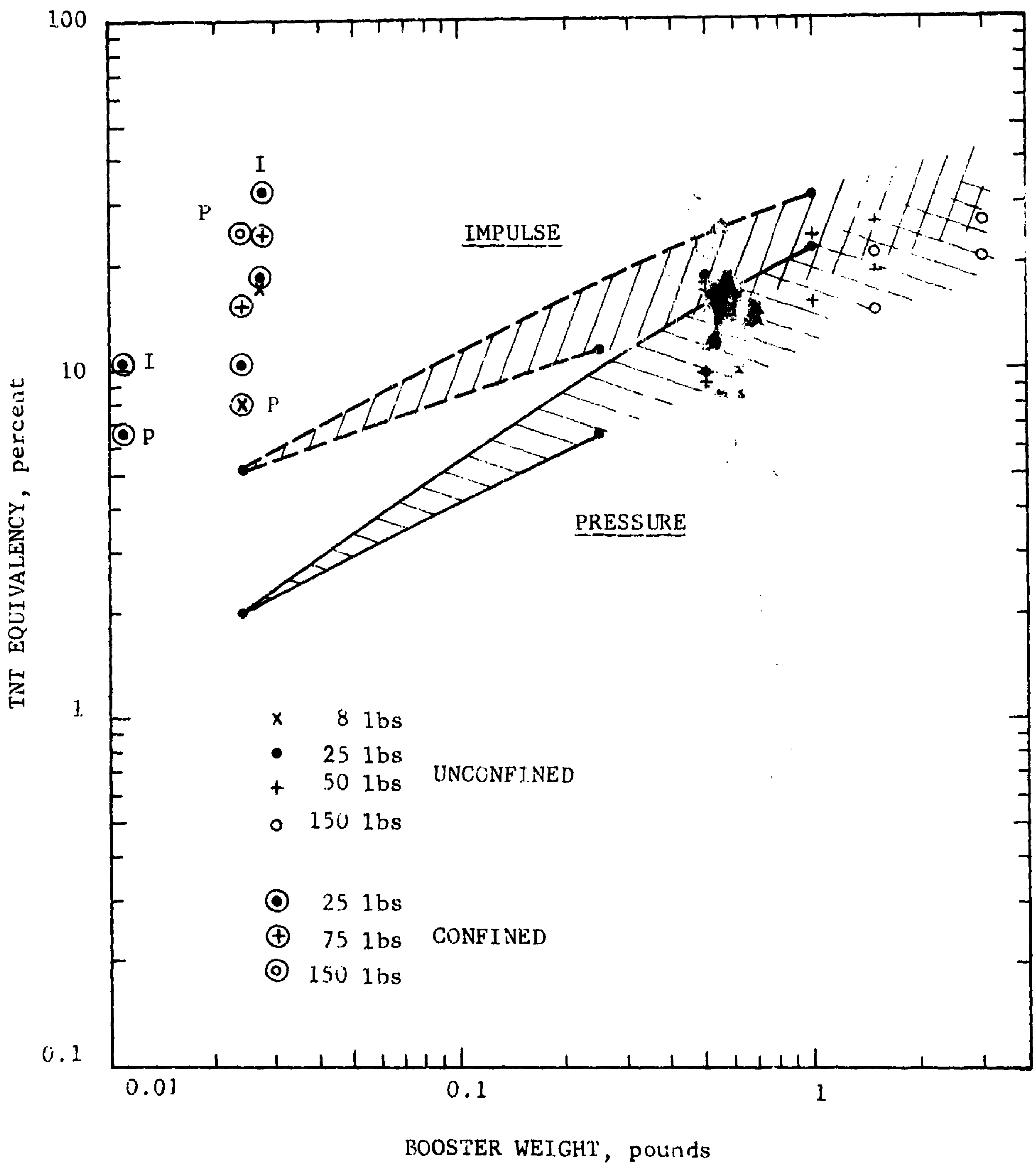


Figure 8 ENVELOPE OF PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF BOOSTER WEIGHT FOR ALL TESTS, SCALED DISTANCE $\lambda = 5$

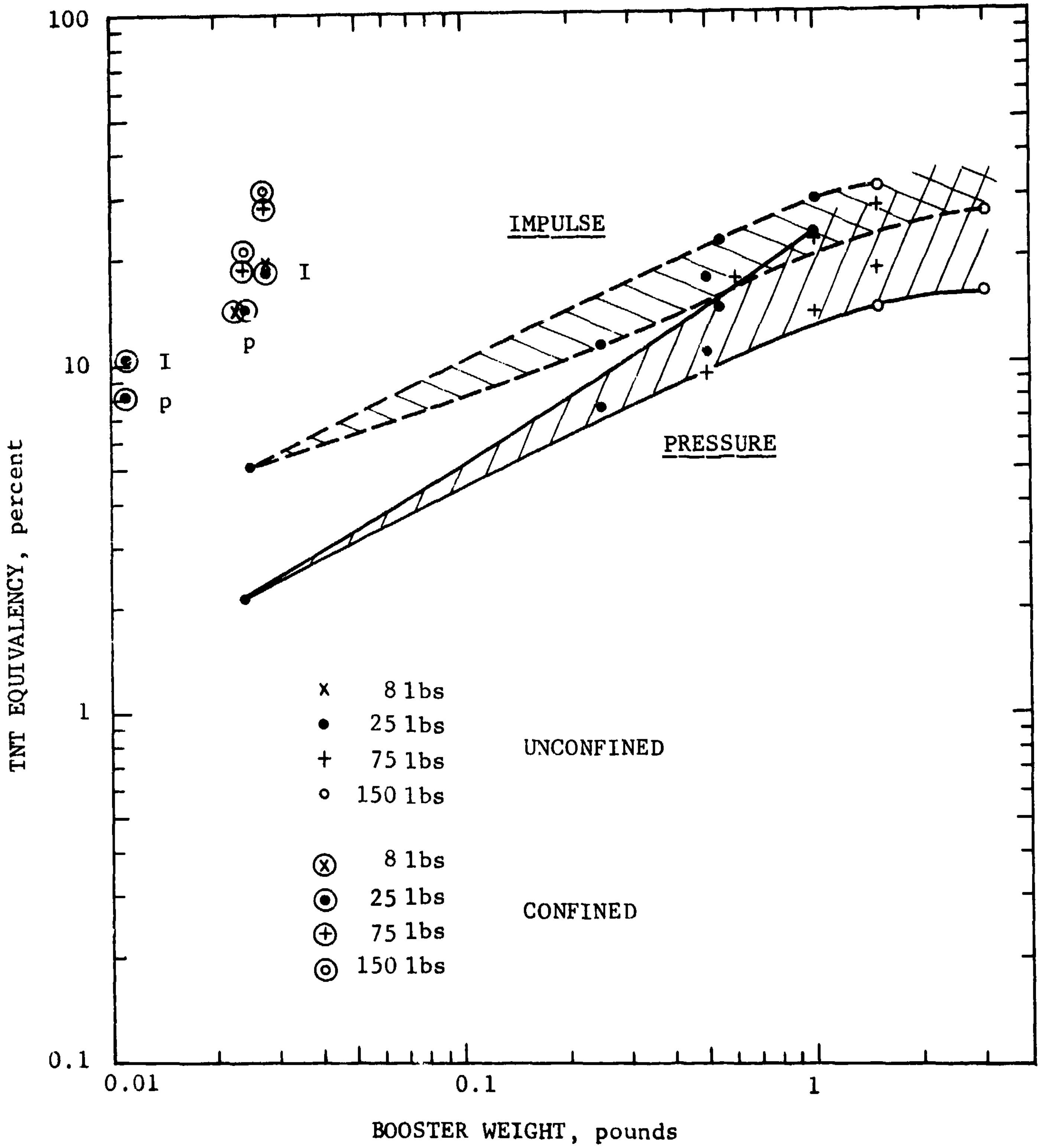


Figure 9 ENVELOPE OF PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF BOOSTER WEIGHT FOR ALL TESTS, SCALED DISTANCE λ=10

The impulse equivalencies are generally at their maximum at scaled distances $\lambda = 2$, and then decrease with distance. On the other hand the pressure equivalencies increase with scaled distance reaching a maximum value at scaled distance of between 7 and 10 $ft/lb^{1/3}$ and then decrease.

Another data summarizing method is to plot the data in the form of equivalency as a function of weight ratio, i.e., the ratio of booster weight to Black Powder weights, Figures 10, 11 and 12. This approach to interpreting the data provides guidance as to the combined effects of booster and Black Powder weights. For the same weight ratios, the TNT equivalencies for 75 and 150 lb charges are essentially equal, whereas 25 lb charges have lower values.

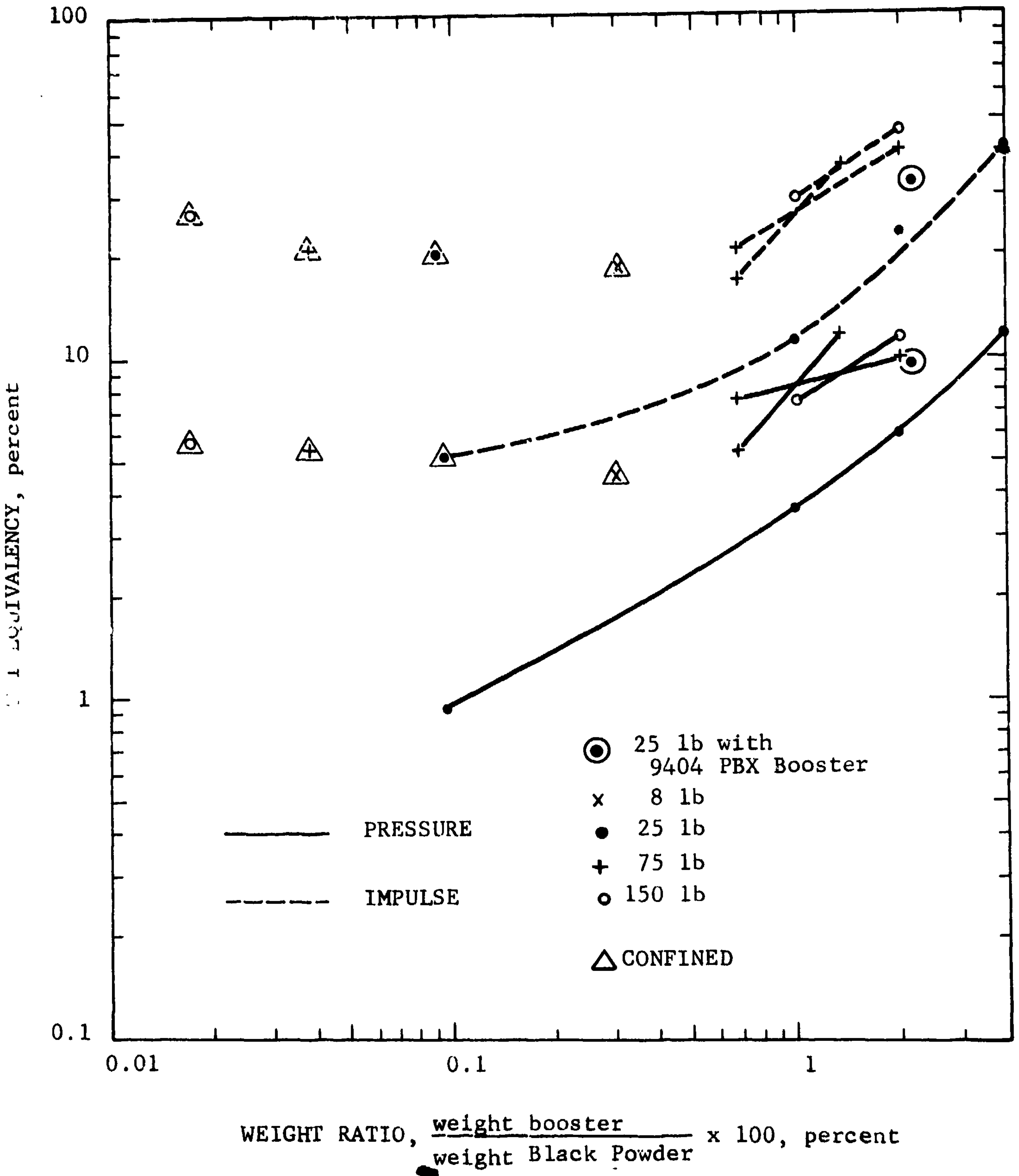


Figure 10 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS, SCALED DISTANCE λ=2

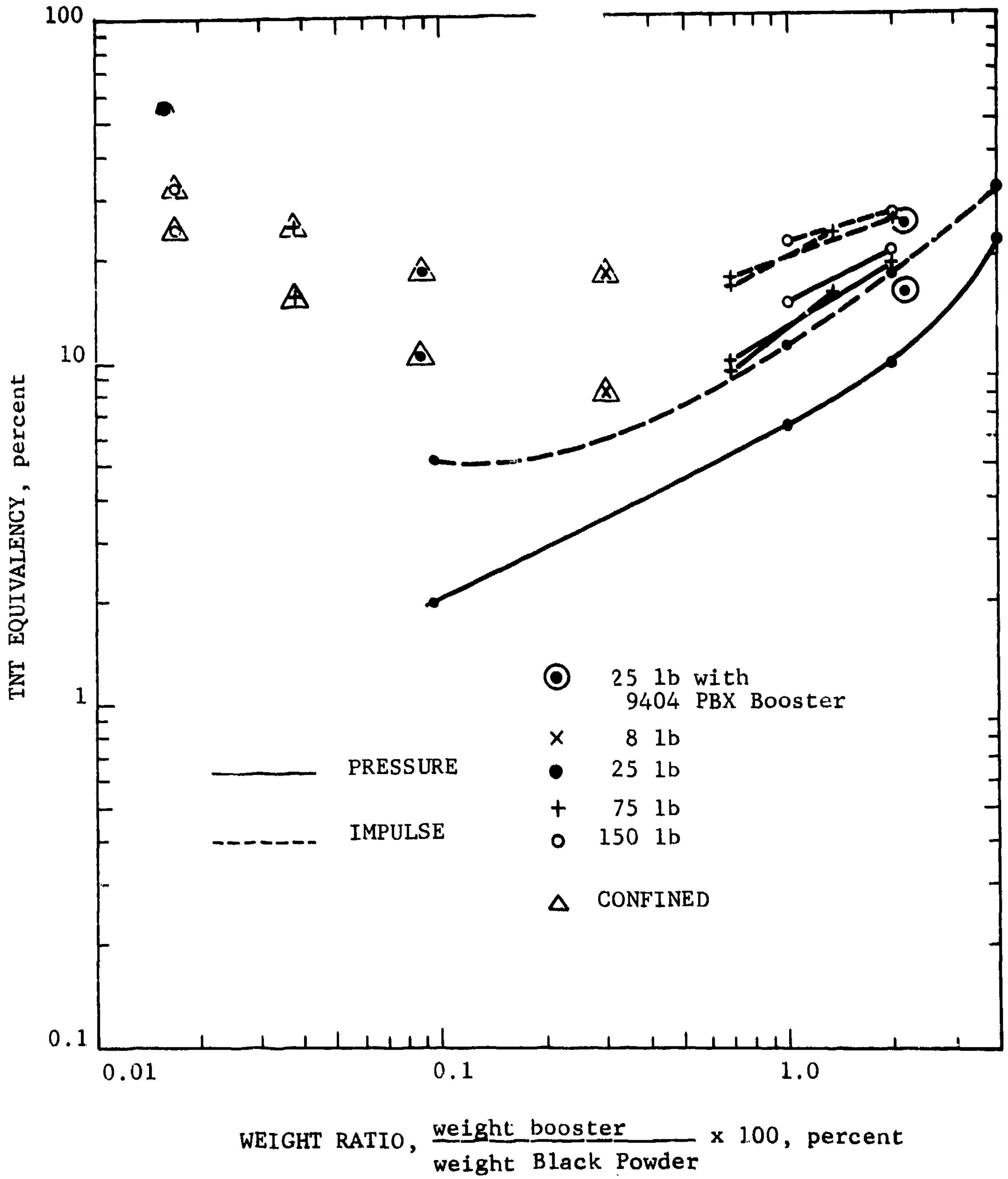


Figure 11 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS, SCALED DISTANCE $\lambda=5$

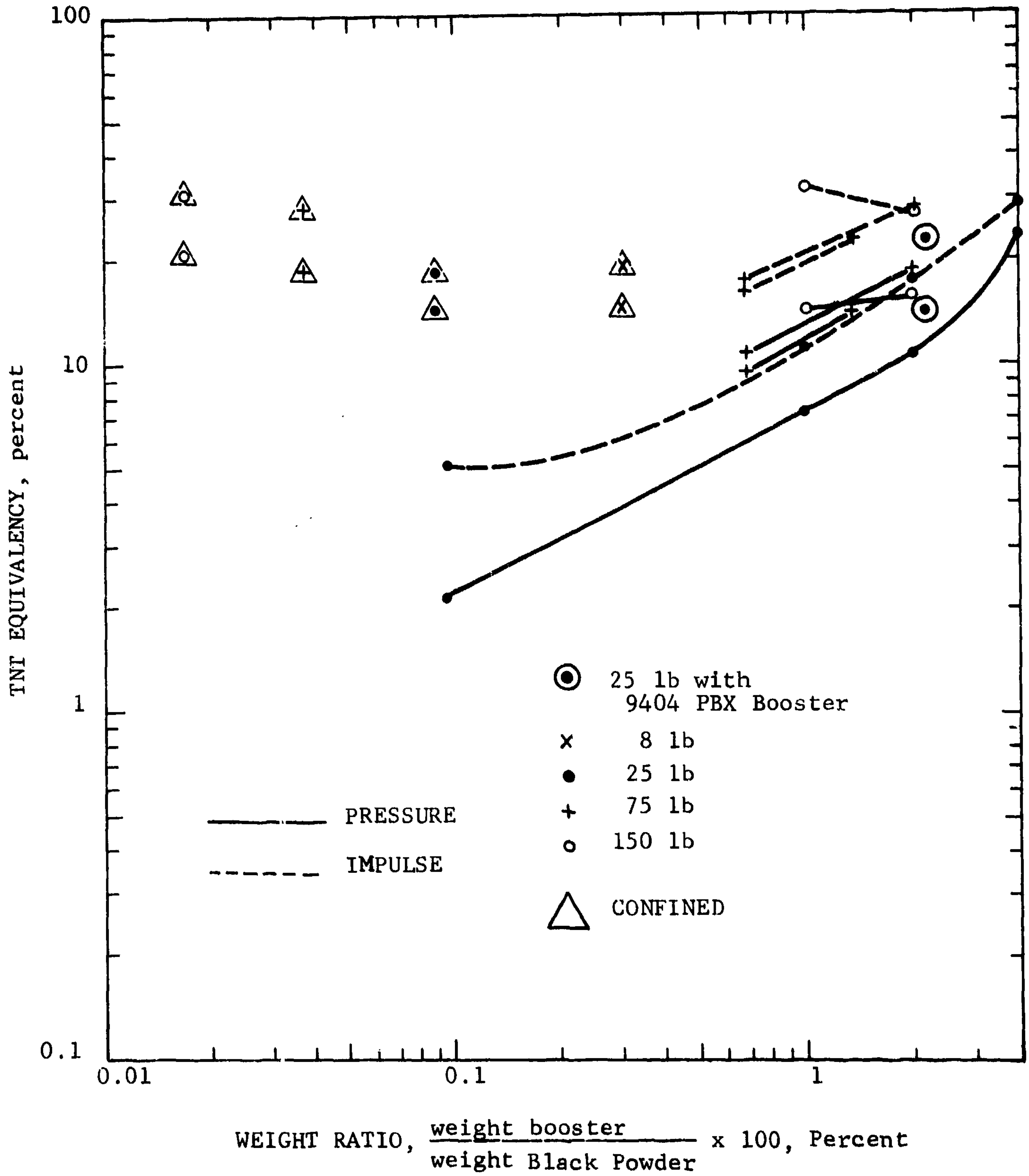


Figure 12 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS, SCALED DISTANCE $\lambda=10$

7. EFFECT OF VARIOUS PARAMETERS ON TNT EQUIVALENCY

In this section the effects that various test parameters have on the resulting Black Powder TNT equivalence are discussed. The factors that have an effect are the degree of confinement, the weight of the Black Powder charge, the weight of the explosive booster, and the type of explosive used for the booster. The explosive booster shape had no effect on equivalency for the two shapes evaluated. A limited number of tests were carried out on the jet milled material and comparisons were made with the behavior of the Black Powder.

Each subsection contains a discussion of the effect and the data are presented in graphical form. In a few instances a figure appears in more than one subsection. This was done for easier reading.

The notation used to identify each figure is as follows. Con 1, 2 (BP 8, 0.024) means tests Con 1 and Con 2 consisting of a confined 8 lb charge of Black Powder initiated with an 0.024 lb booster. If the initials SP follow the shot number it means the charge was placed on a steel plate. Thus BO 41, 42 SP (BP 150, 3.0) refers to tests BO 41 and BO 42; each test consisted of an unconfined 150 lb charge of Black Powder resting on a steel base plate and initiated with a 3.0 lb C-4 booster.

7.1 The Effect of Heavy Confinement on TNT Equivalency

One of the most significant findings is that the TNT equivalency is affected by the degree of confinement. Four levels of increasing confinement were evaluated:

a. No confinement; the sample was contained in a cardboard box placed 7 inches above the ground on a wood pedestal.

b. Light partial confinement; the sample was contained in a cardboard box placed on the ground, hence the bottom face is considered confined by the earth surface.

c. Heavy partial confinement; the sample was contained in a cardboard box placed on a steel plate which rested on ground.

d. Heavy confinement; the sample was contained in a steel box, having 1/4 inch wall thickness, placed on the ground.

It is clear from the results of a series of seven tests on 27 lbs of Black Powder initiated with a 0.024 lb booster that a confined charge has a higher blast output than unconfined Black Powder charge. This effect is emphasized in comparing the above results with three additional tests on 27 lb confined Black Powder charges where the charge was initiated with a DuPont S65 squib containing 0.2 grain of initiating mixture. Even with such a mild form of boostering, the TNT equivalency was greater for the confined squib-initiated charge than for unconfined Black Powder initiated by a 0.024 lb Tetryl booster.

Figures 13 and 14 are summaries of the effects of confinement for 27 lbs of Black Powder in terms of TNT equivalency. The raw data for this summary graph are found in the appendices (Volume II).

A more dramatic comparison is between shots Con 9 and 10, 140 lb charges initiated with 0.024 Tetryl booster and shot BO 40 an unconfined 150 lb sample initiated with a 1.5 lb booster. The TNT equivalencies are greater in the confined tests. When Con 9 and 10 are compared with unconfined 150 lb Black Powder initiated with a 3 lb booster, BO 41 and 42, the confined tests again yield higher pressure and impulse equivalencies except at scaled distances less than 3 ($\lambda < 3$). Thus it is clear that confinement is an important and sensitive parameter. These comparisons can be seen in Figures 15 and 16. Similar effects of confinement can be seen in Figures 17 and 18 for 75 lb charges.

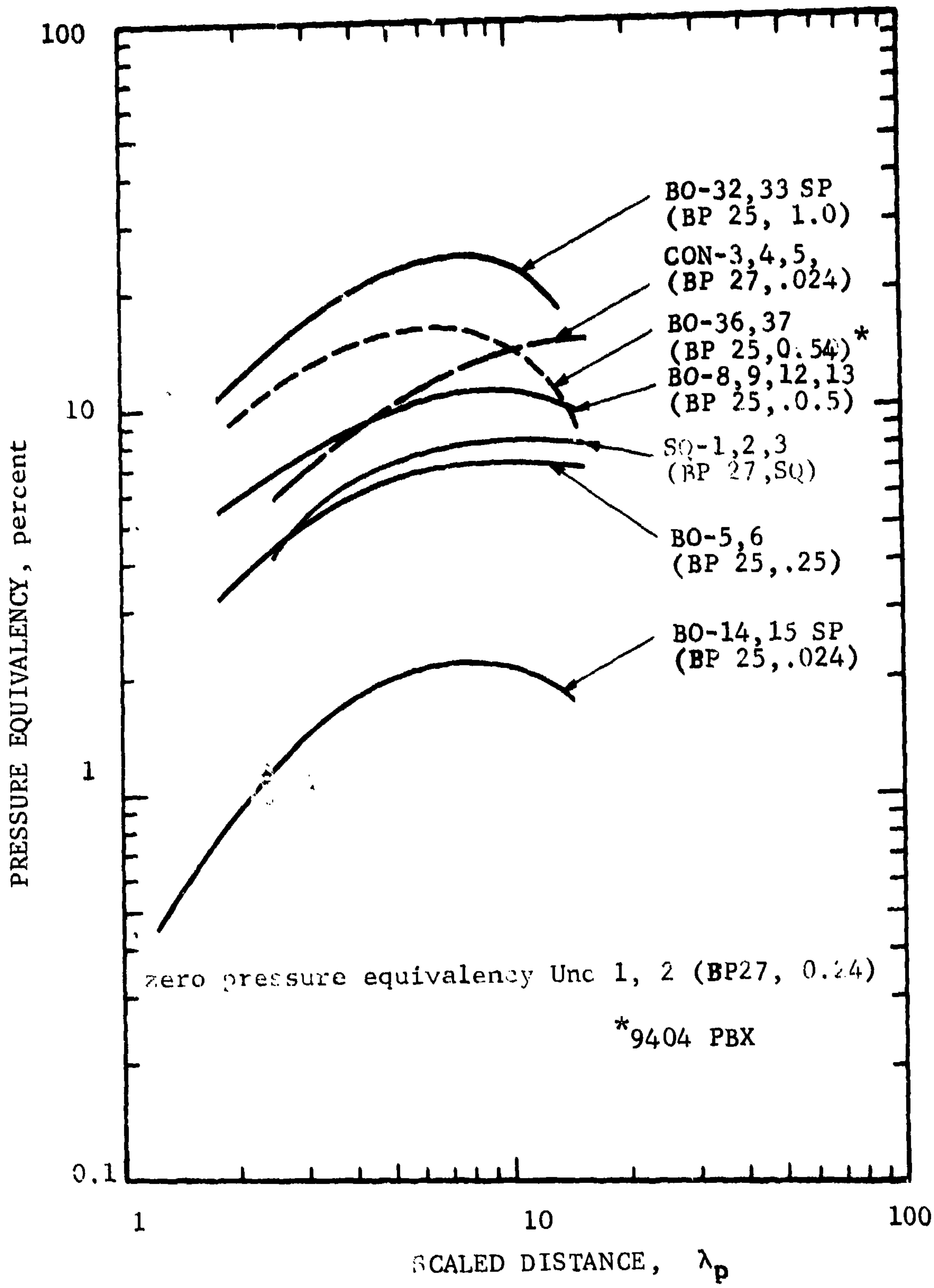


Figure 13 EFFECT OF CONFINEMENT AND BOOSTER WEIGHT ON TNT PRESSURE EQUIVALENCY, 25-27 LB BLACK POWDER

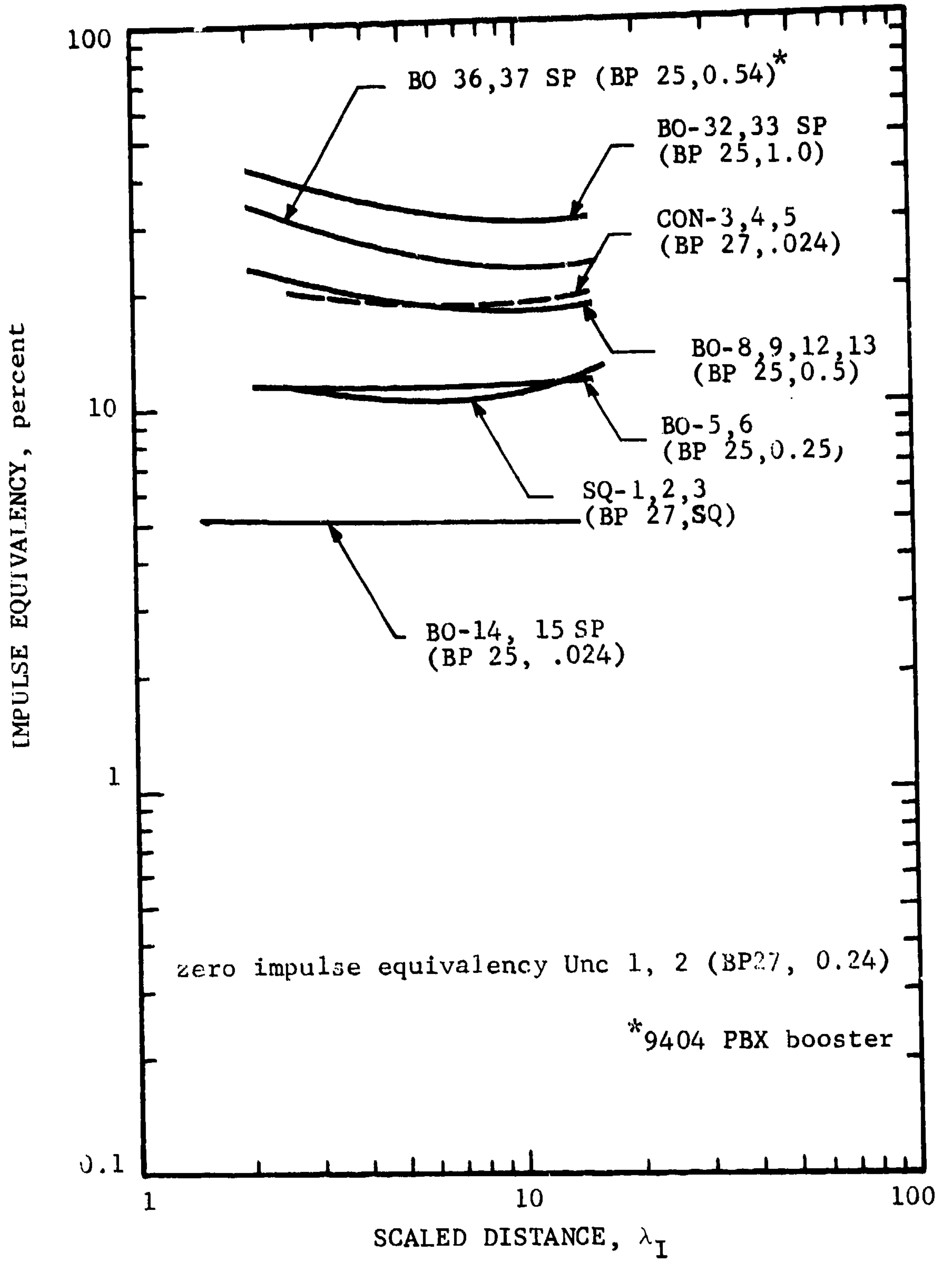


Figure 14 EFFECT OF CONFINEMENT AND BOOSTER WEIGHT ON TNT IMPULSE EQUIVALENCY, 25-27 LB BLACK POWDER

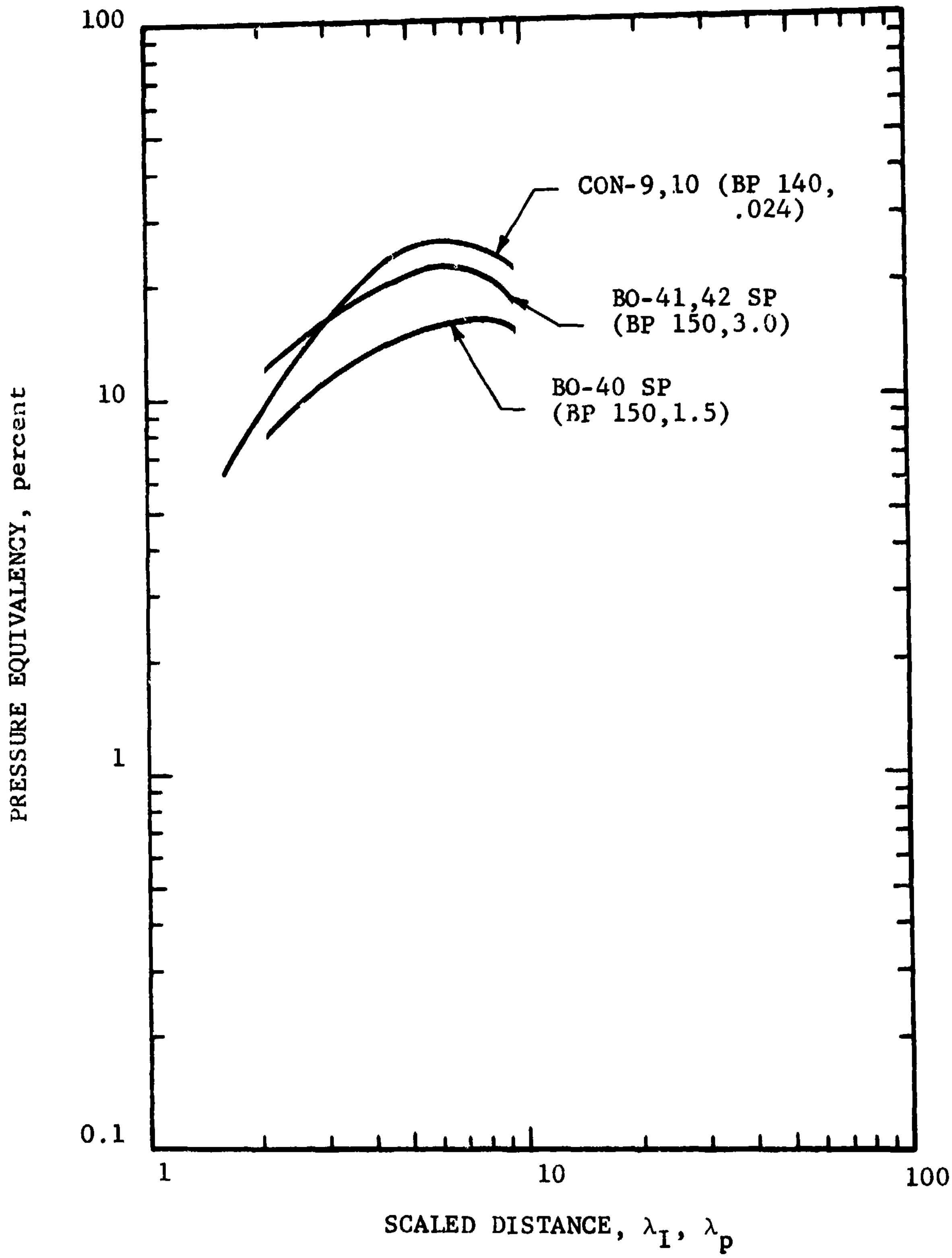


Figure 15 THE EFFECT OF BOOSTER WEIGHT AND CONFINEMENT ON TNT PRESSURE EQUIVALENCY, 140 AND 150 LB BLACK POWDER

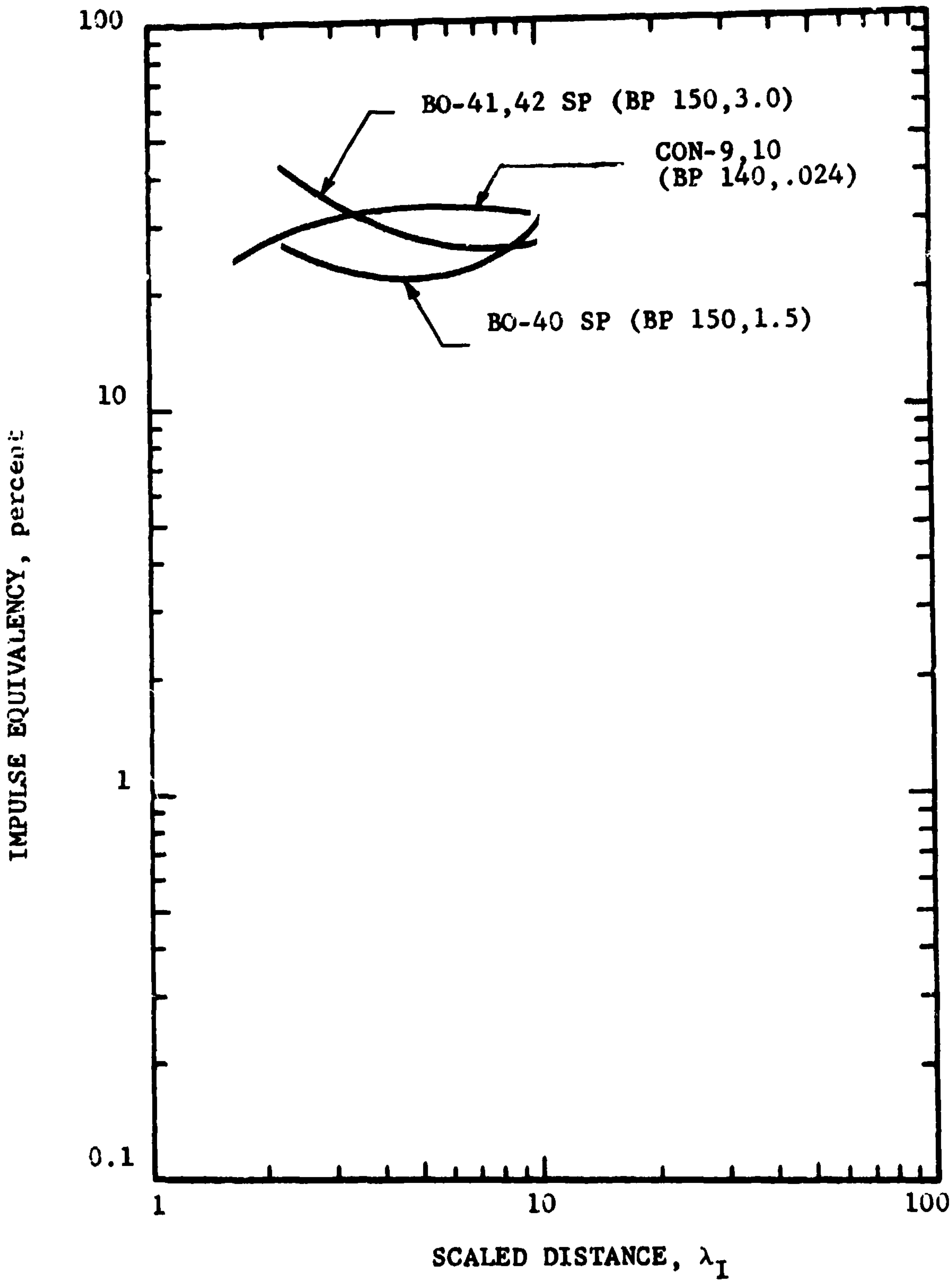


Figure 16 THE EFFECT OF BOOSTER WEIGHT AND CONFINEMENT ON TNT IMPULSE EQUIVALENCY, 140 AND 150 LB BLACK POWDER.

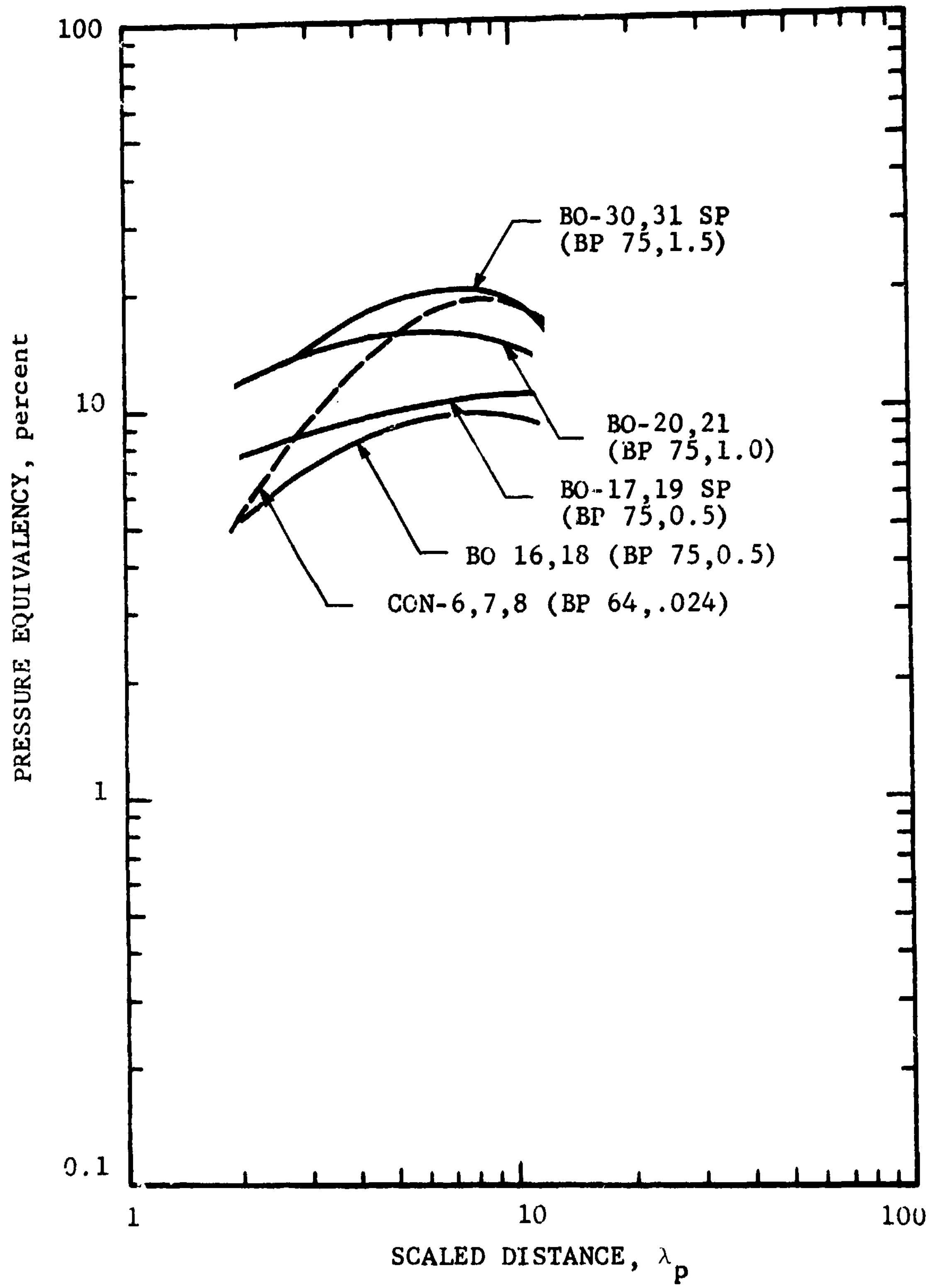


Figure 17 EFFECT OF BOOSTER WEIGHT AND CONFINEMENT ON TNT PRESSURE EQUIVALENCY, 64-75 LB BLACK POWDER

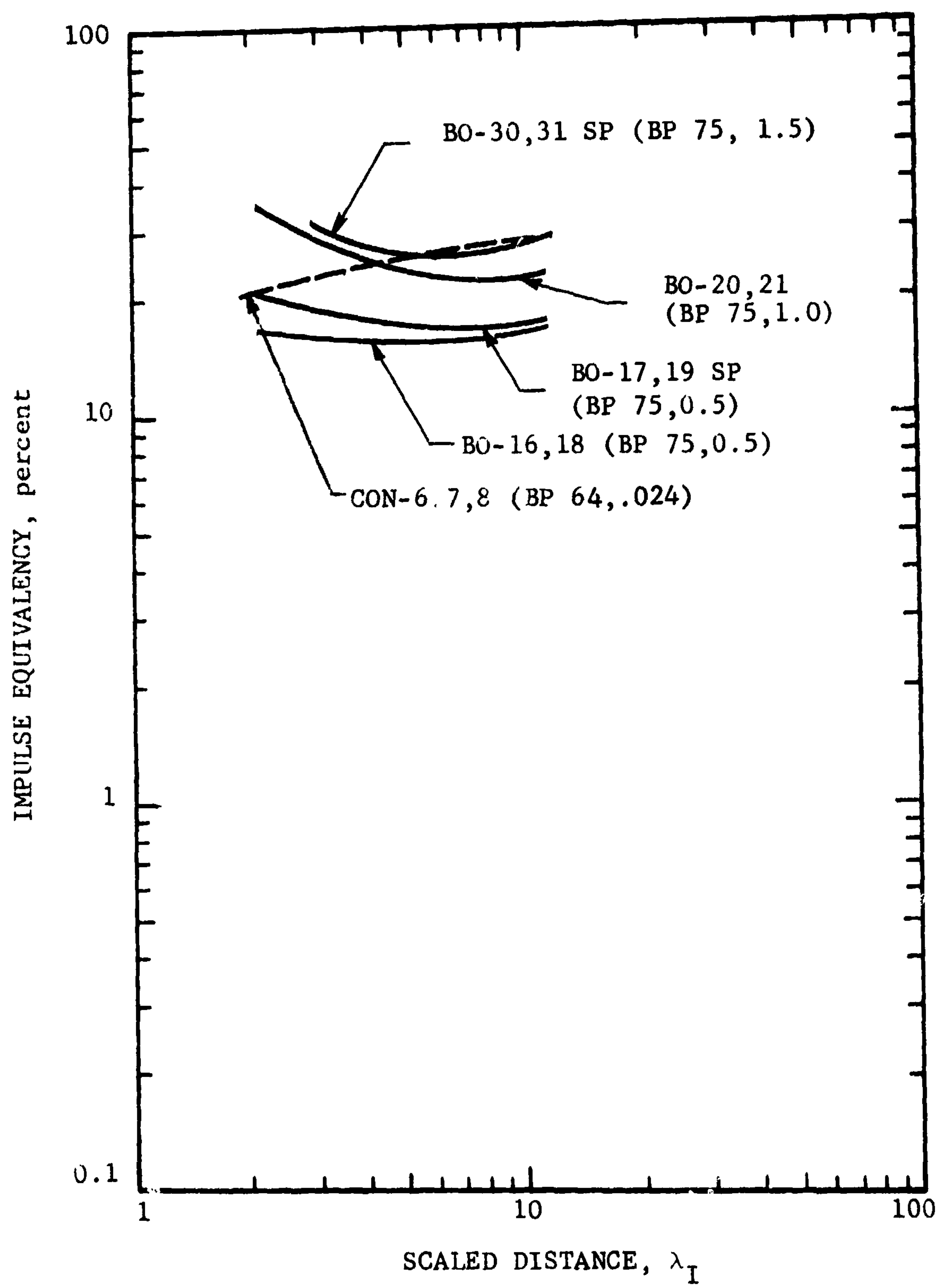


Figure 18 EFFECT OF BOOSTER WEIGHT AND CONFINEMENT ON TNT IMPULSE EQUIVALENCY, 64-75 LB BLACK POWDER

7.2 The Effect of a Steel Base Plate on TNT Equivalency

In an effort to maintain control of the surface on which the explosive sample is placed, a steel base plate was found to be necessary. This was considered especially important since some of the initial tests were carried out when the ground was frozen. Thus in the morning the charges would be placed on hard frozen ground, but by the end of the day the ground would not only be thawed, but it would be of a very loose texture after repeated testing. The effect of ground hardness on equivalency was not initially apparent, hence, many tests were carried out with the sample placed directly on the ground.

The best direct comparison of the effect of the supporting base plate can be seen in tests on 75 lb Black Powder using a 0.5 lb C-4 booster, shots BO 16 and 18, that were placed on the ground, and shots BO 17 and 19 that were placed on a steel plate whose top face was flush with the ground. The TNT equivalencies were higher for BO 17 and 19. A summary figure showing the TNT equivalency of BO 16 and 18 compared with BO 17 and 19 can be seen in Figure 19.

Two additional sets of tests were carried to test the effect of the charge supporting surface on equivalency. These tests were on 27 lb Black Powder initiated with a 0.024 lb Tetryl booster. Tests BO 14 and 15 were carried out on a steel plate and shots Unc 3 and 5 were placed directly on the ground. However, we cannot make a quantitative comparison between these tests, since for both shots Unc 3 and 5 the gage system was overdriven resulting in measured values that are less than the actual values.

Similarly, Figures 20 and 21 summary curves for 75 lb charges show generally higher values of equivalency when steel base plates are used.

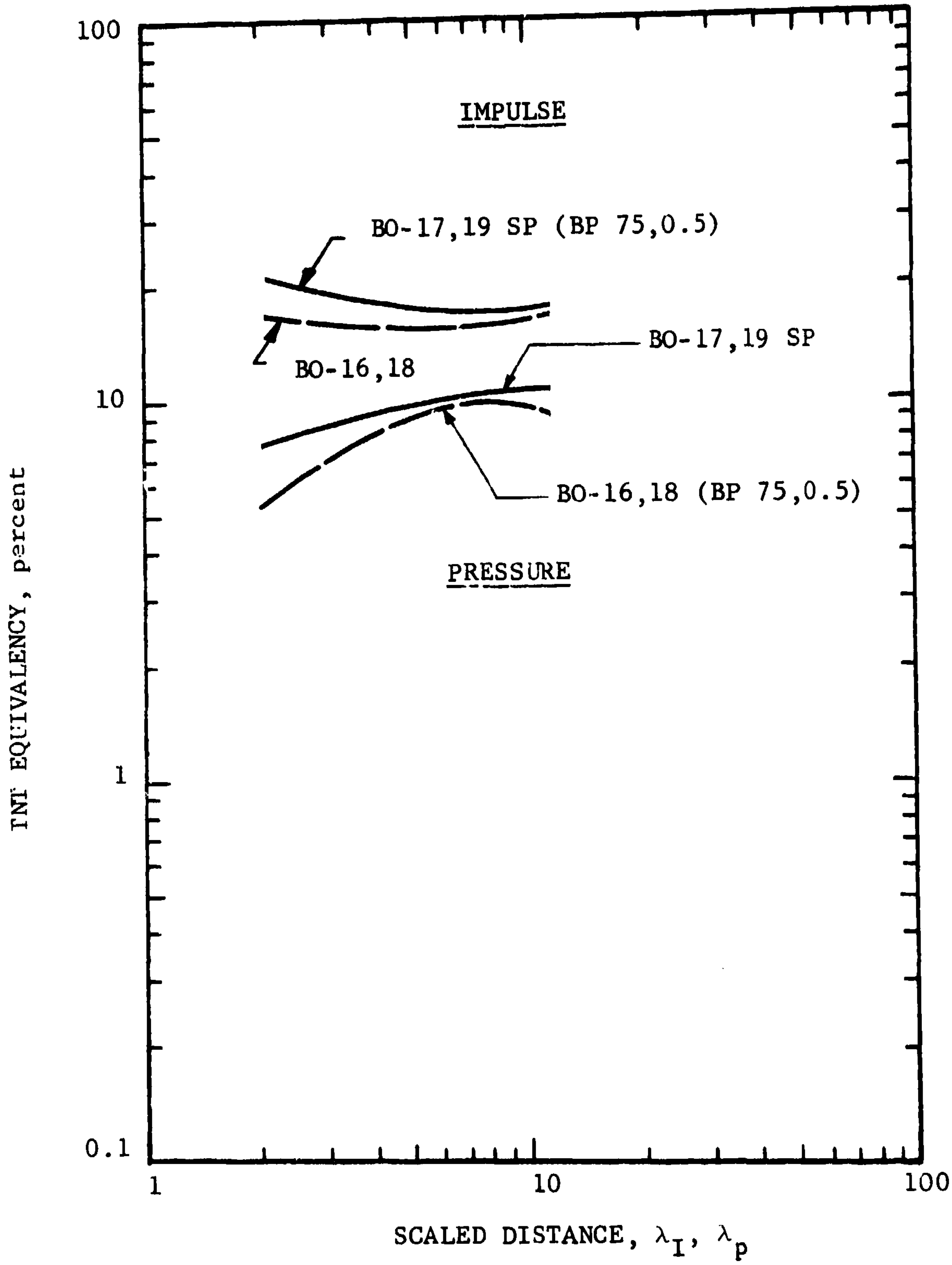


Figure 19 COMPARISON BETWEEN STEEL BASE PLATE AND GROUND SURFACE ON THE TNT EQUIVALENCY OF BLACK POWDER

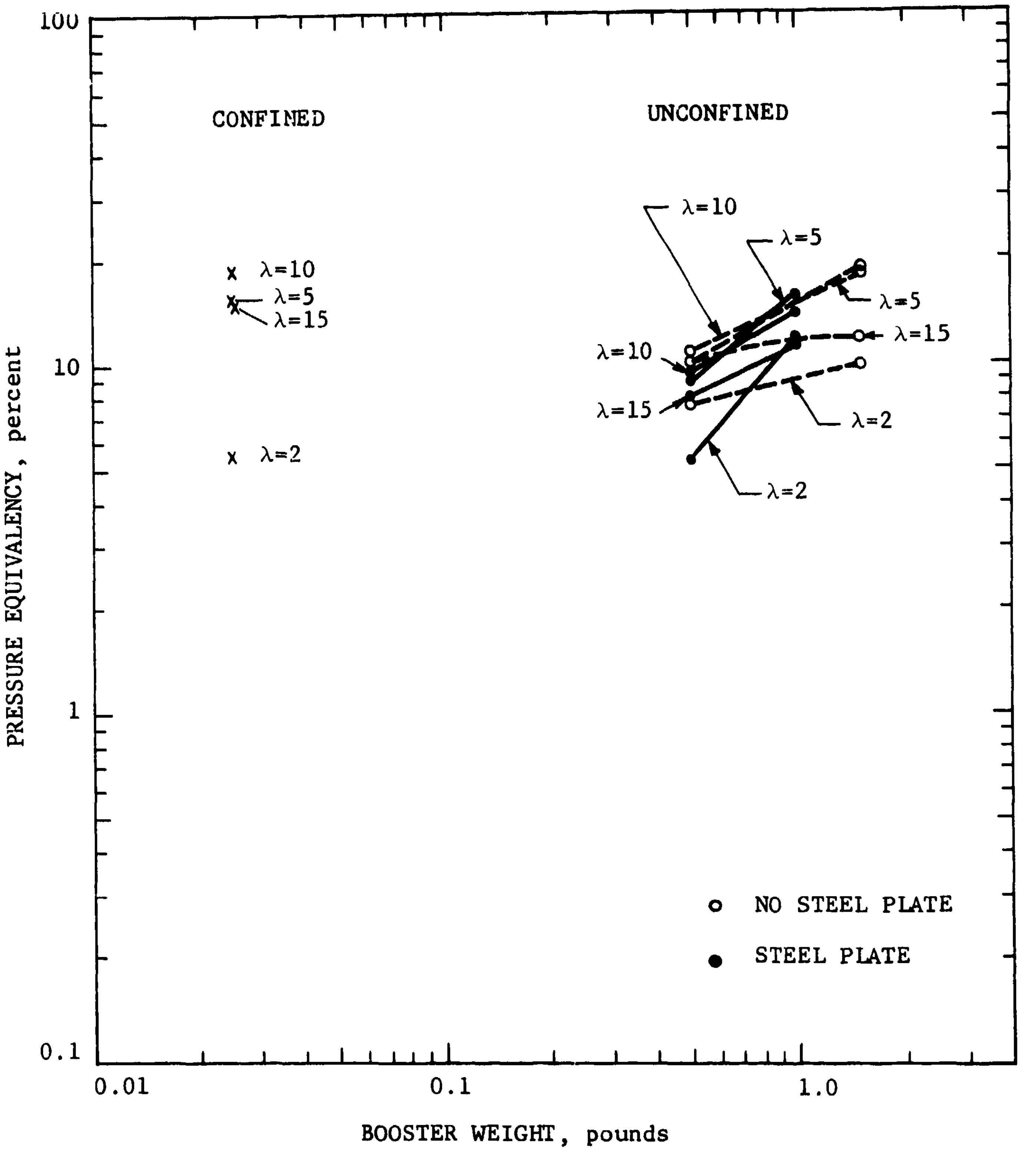


Figure 20 TNT PRESSURE EQUIVALENCY OF 75 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES

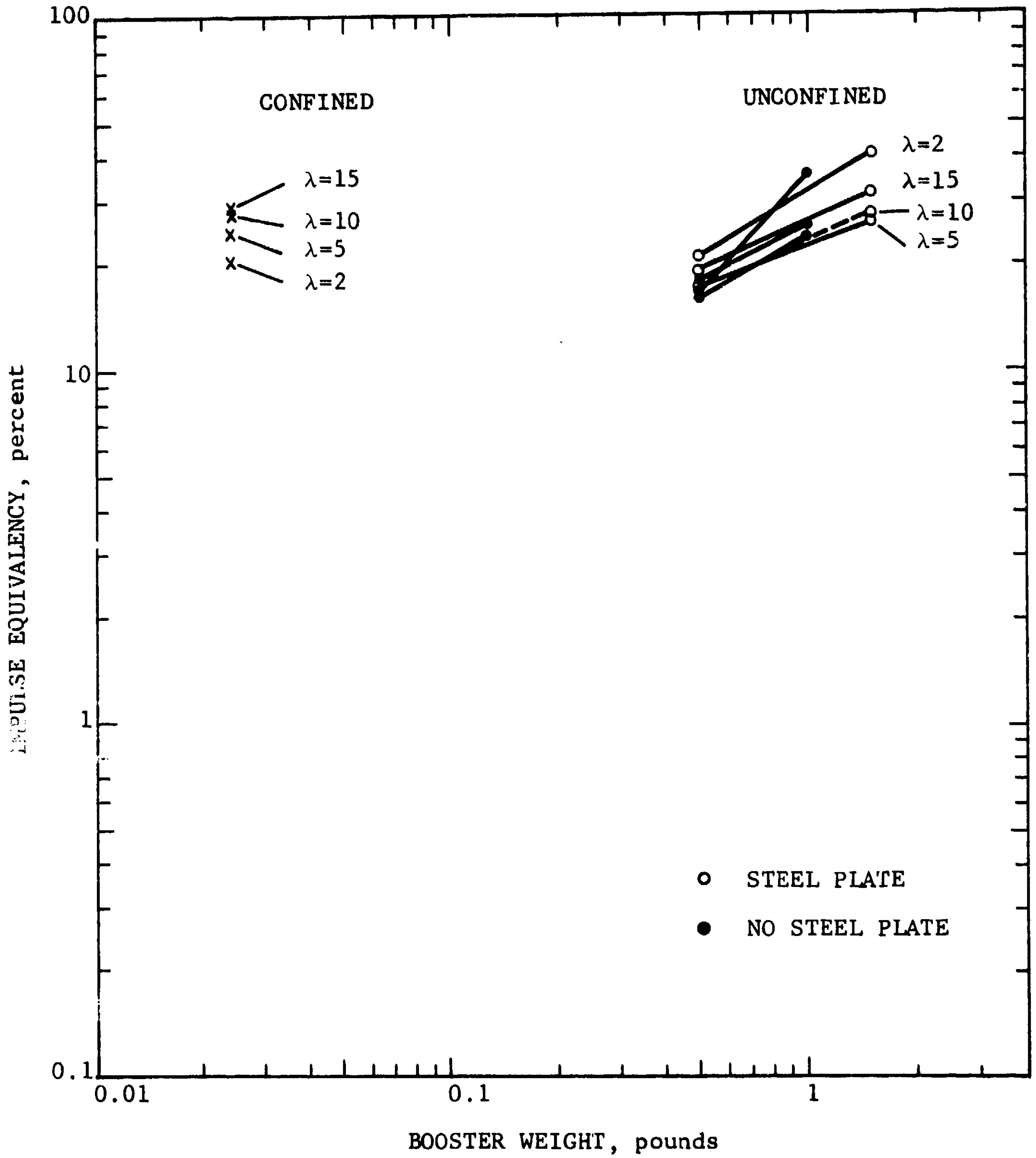


Figure 21 TNT IMPULSE EQUIVALENCY OF 75 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

7.3 The Effect of Small Standoff Distance Aboveground on TNT Equivalency

Three tests on Black Powder were carried out with the charge placed on a wood platform 7 inches above the ground. The reason for this elevation was so that comparisons could be made with work carried out elsewhere where the charges were placed at a height above the ground such that the standoff height to the centroid of the charge, was equal to one and one-half times the diameter of an equivalent weight of a spherical TNT charge. Since there was such a wide range of TNT equivalencies for Black Powder, depending upon the initial test conditions, it was not possible to predict with any degree of confidence in advance of testing what the appropriate height aboveground should be. Hence this approach was abandoned after three tests, Unc 1, 2 and 4. These tests resulted in essentially zero TNT equivalency. The results of tests Unc 1 and 2 can be compared with Unc 3 and 5 which were tests directly on the ground using the same charge weight and booster, 27 lb Black Powder and 0.024 lb Tetryl booster. The pressures and impulses were considerably greater for charges placed on the ground (Unc 3 and 5) although the exact values of the blast parameter for these tests are not known because the gage system for Unc 3 and 5 was overdriven, only that the actual pressures were higher than those measured. Thus it is clear that the blast output is very sensitive to the degree or extent of confinement.

7.4 The Effect of Black Powder Weight on TNT Equivalency

When the Black Powder is confined and the booster size is kept constant, the TNT equivalency increases with increase in charge weight. This effect is illustrated in Figure 22 and 23 curves showing the pressure and impulse equivalency, as a function of scaled distance. The data for 8 and 27 lb charges show that the pressure equivalency for 8 lb charges is much less than for 27 lbs up to a scaled distance $\lambda = 7$, at larger distances the values are essentially equal. The impulse equivalencies are approximately the same for 8 and 27 lb charges.

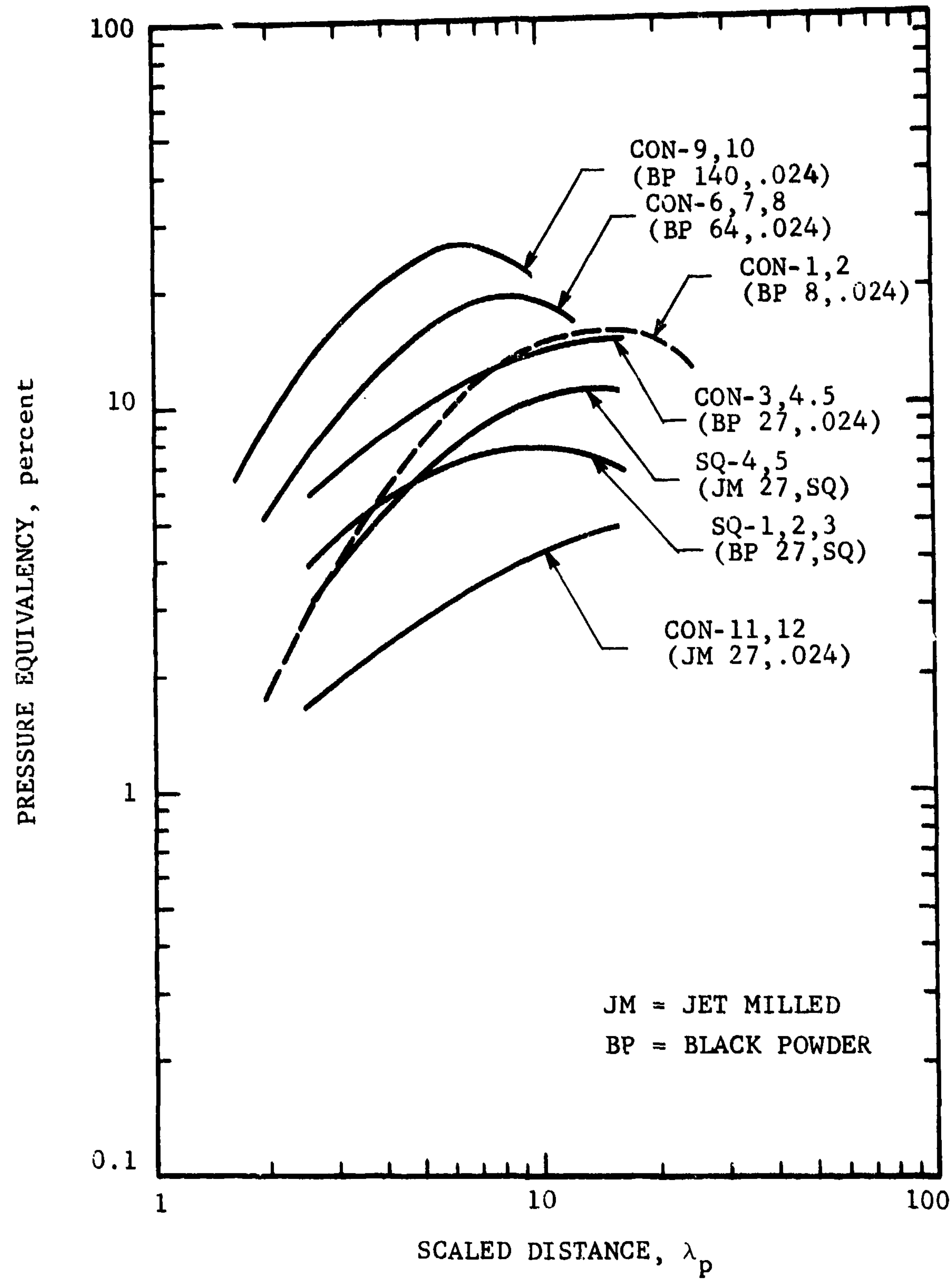


Figure 22 EFFECT OF CHARGE WT ON TNT PRESSURE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

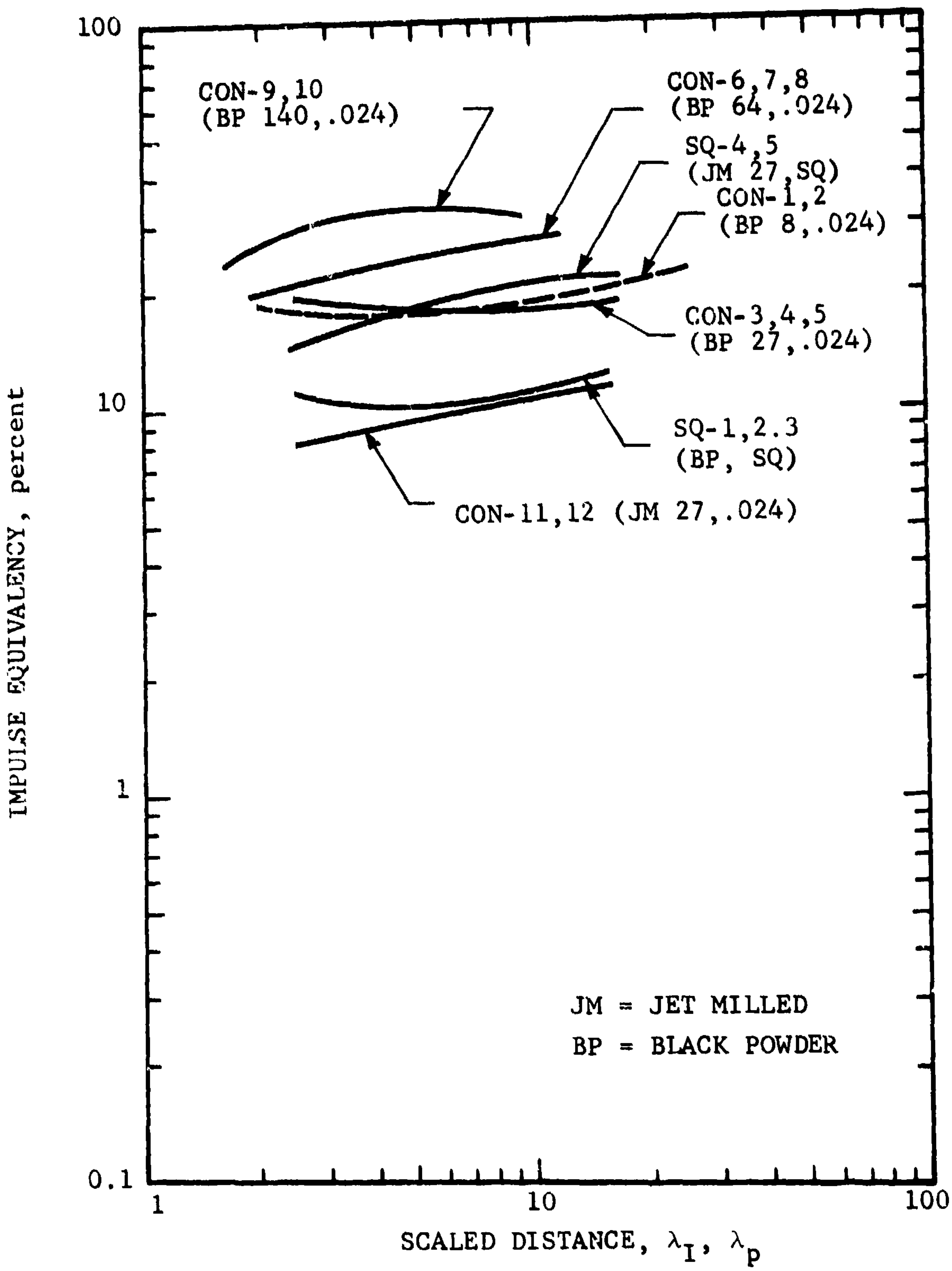


Figure 23 EFFECT OF CHARGE WT ON TNT IMPULSE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

The data for unconfined charges, on the other hand, show the opposite effect, when equivalencies are compared on the basis of constant booster weight. The larger unconfined charges required larger size boosters. Apparently, unless sufficiently boostered the reaction does not grow. The heat generated is lost to the environment faster than it is produced by the explosion. Figures 24 and 25 show the comparisons between 25 lb charges and 75 lb charges initiated with a 0.5 lb booster. Figures 26 and 27 illustrate these effects for charges initiated with 1.0 and 1.5 lb boosters, respectively.

The combined effects of charge weight, booster weight, and degree of confinement is illustrated in the six summary curves in Section 6, Figures 7 through 12. Although it is clear that unconfined charges have been underboostered, all of the data do fall within the envelope shown in Figures 7 through 9 and the equivalencies seem to level off. Then the weight ratio is increased, i.e., booster weight divided by Black Powder weight, the equivalency increases, as expected.

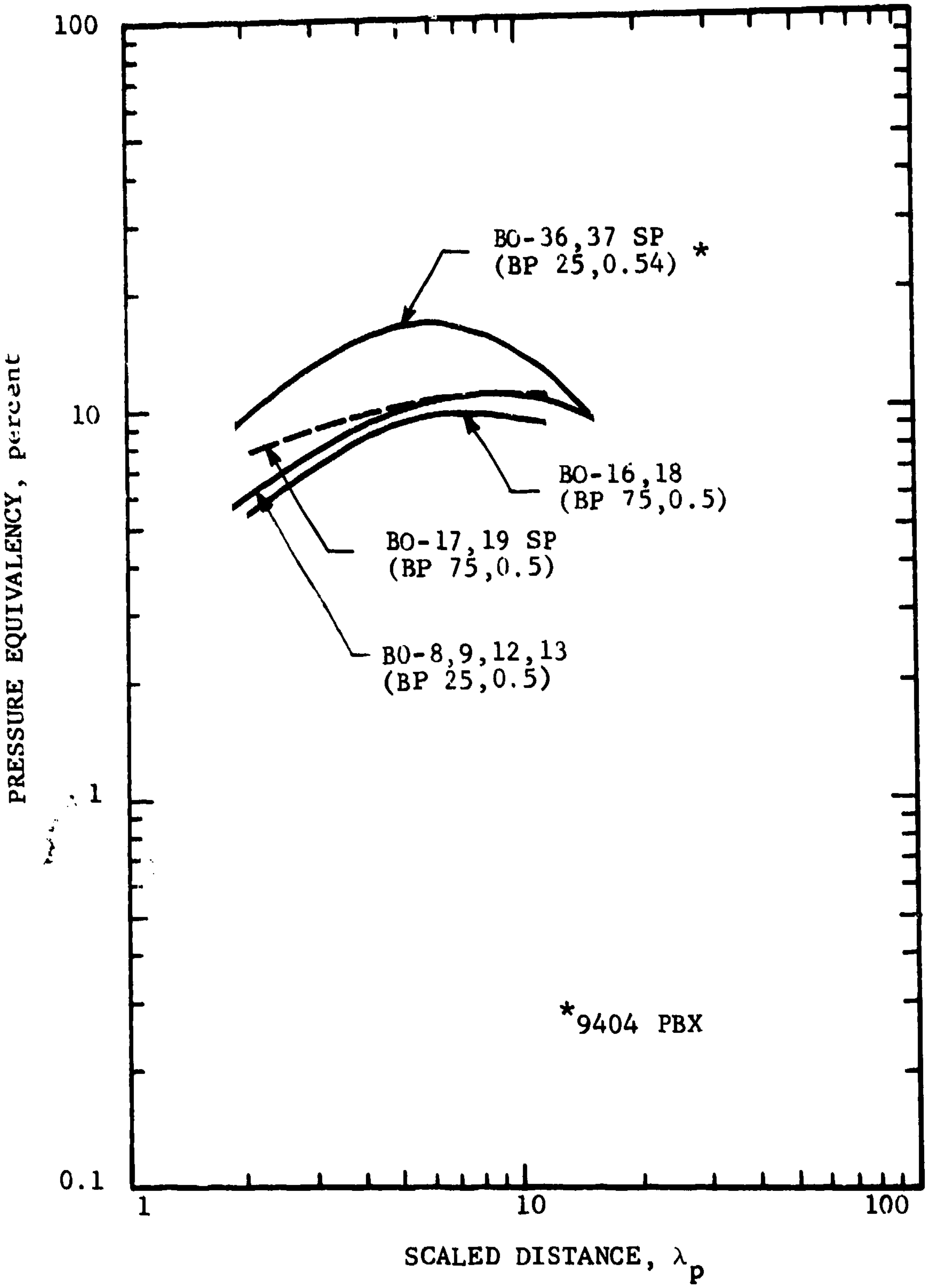


Figure 24 THE EFFECT OF BLACK POWDER WEIGHT ON TNT PRESSURE EQUIVALENCY FOR ALL TESTS USING 0.5 LB BOOSTERS

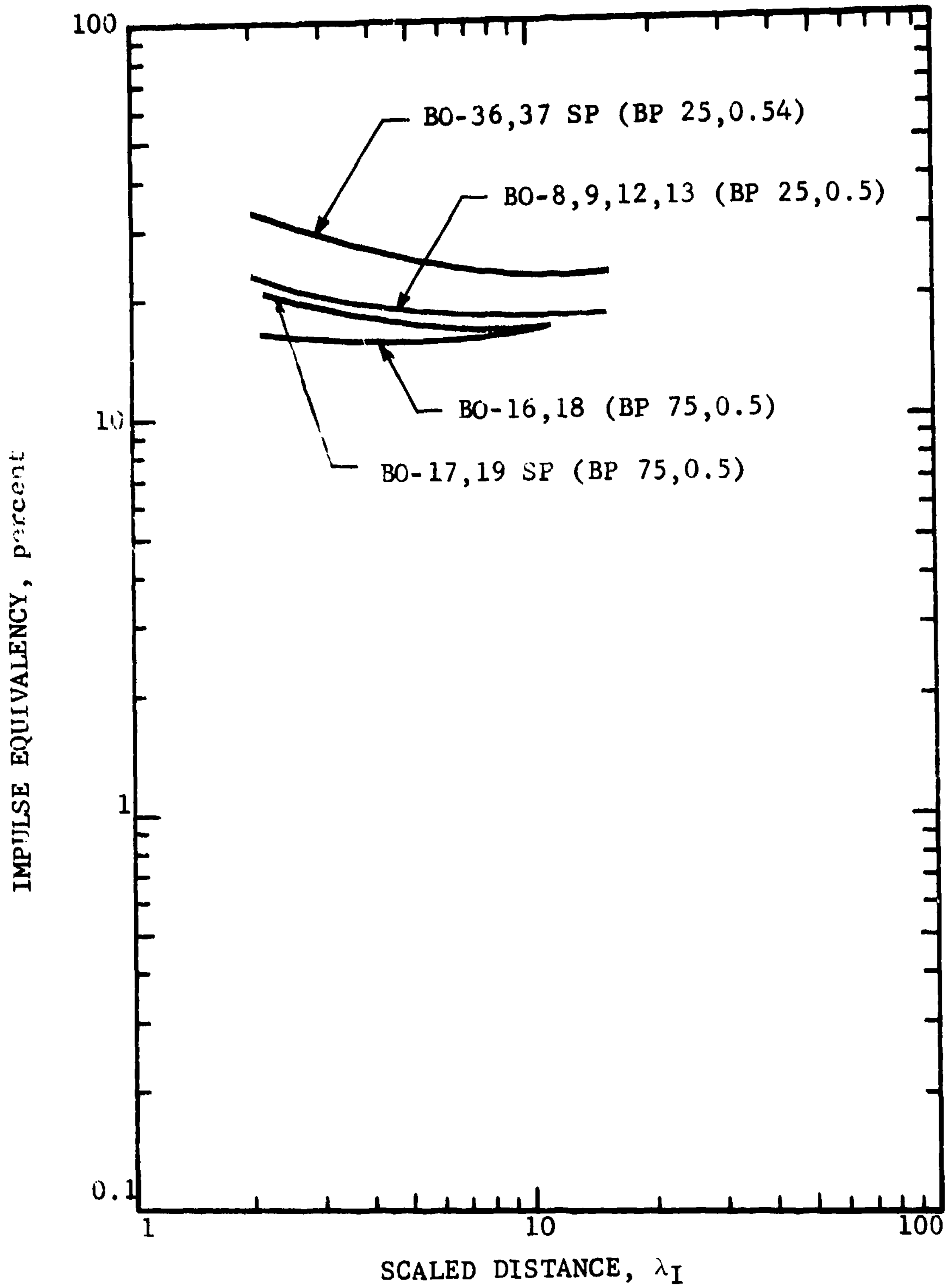


Figure 25 THE EFFECT OF BLACK POWDER WEIGHT ON TNT IMPULSE EQUIVALENCY FOR ALL TESTS USING 0.5 LB BOOSTERS

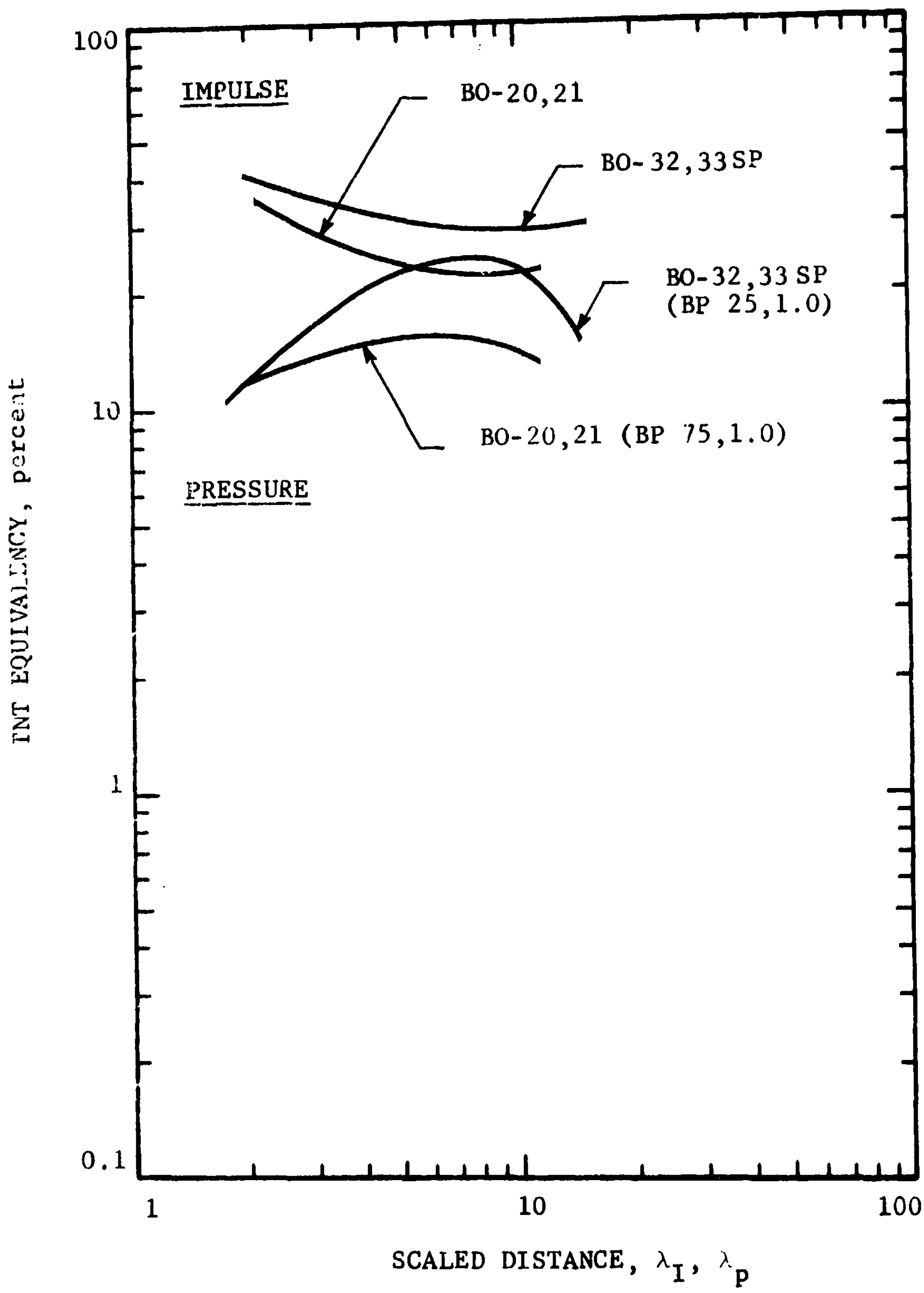


Figure 26 THE EFFECT OF BLACK POWDER WEIGHT ON TNT EQUIVALENCY FOR ALL TESTS USING 1.0 LB BOOSTERS

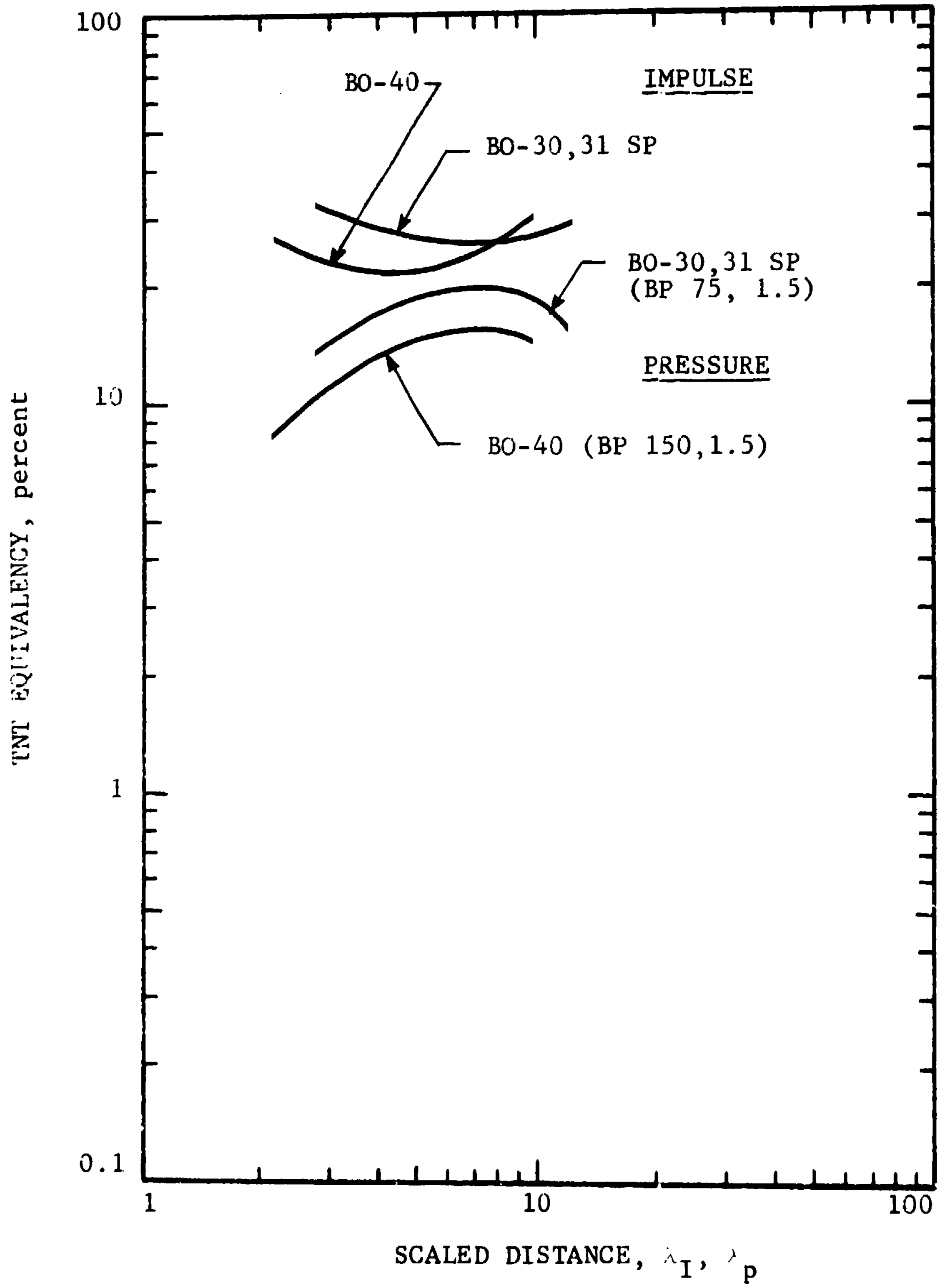


Figure 27 THE EFFECT OF BLACK POWDER WEIGHT ON TNT EQUIVALENCY FOR ALL TESTS USING 1.5 LB BOOSTER

7.5 The Effect of Booster Weight on TNT Equivalency

For unconfined Black Powder charges, it was found that an increase in booster weight resulted in an increase in TNT equivalency. This was also true in confined charges, where only squib and 11 gm (0.024 lb) boosters were used. For the confined tests the equivalencies were comparable to that of unconfined charges using boosters that were almost 10 times heavier in weight. These effects are summarized in Figures 28 and 29 for 25 lb charges, Figures 30 and 31 for 75 lb charges, and Figure 32 for 150 lb charges.

The figures reflect the complexity of the behavior of Black Powder, and indicate that there are interactions between booster weight, scaled distances λ, and degree of confinement (which is illustrated in the figures for tests on 75 lb quantities). If one does not wish to use maximum values for design and quantity-distance purposes, then the value of equivalency associated with a given weight and confinement level, for protection at a required distance, can be determined from the data presented in this report.

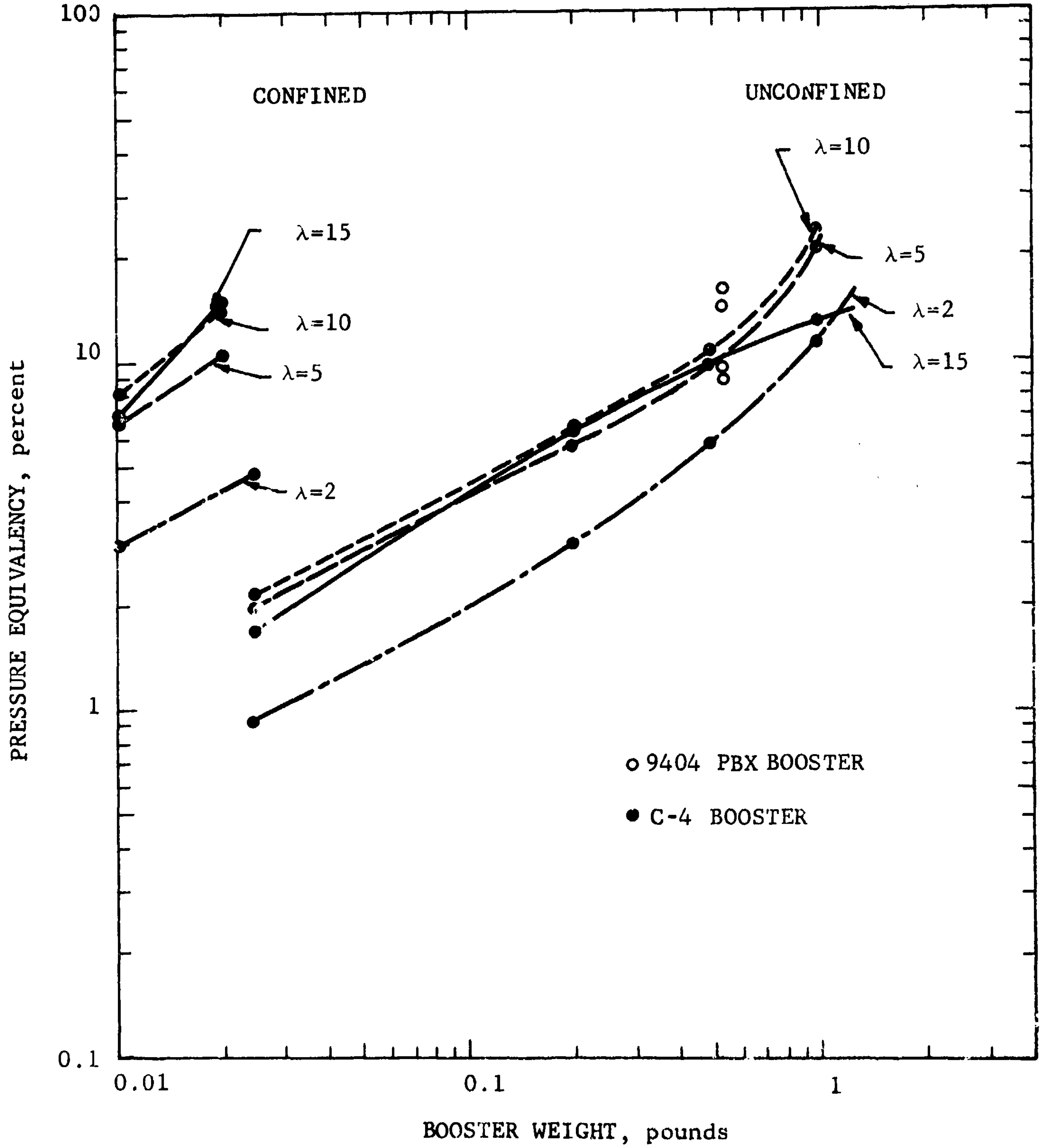


Figure 28 TNT PRESSURE EQUIVALENCY OF 25 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

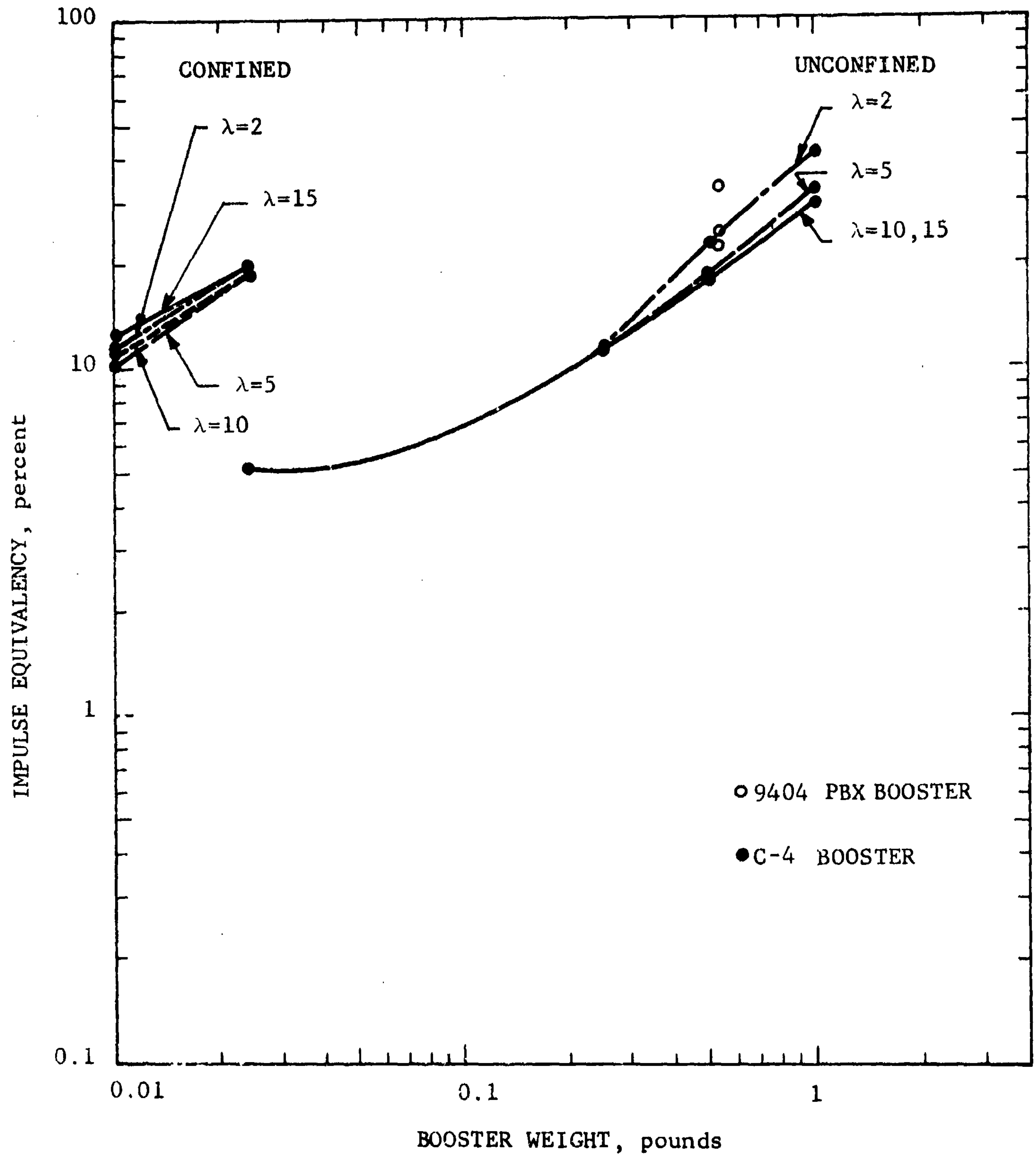


Figure 29 IMPULSE EQUIVALENCY OF 25 AND 27 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES λ

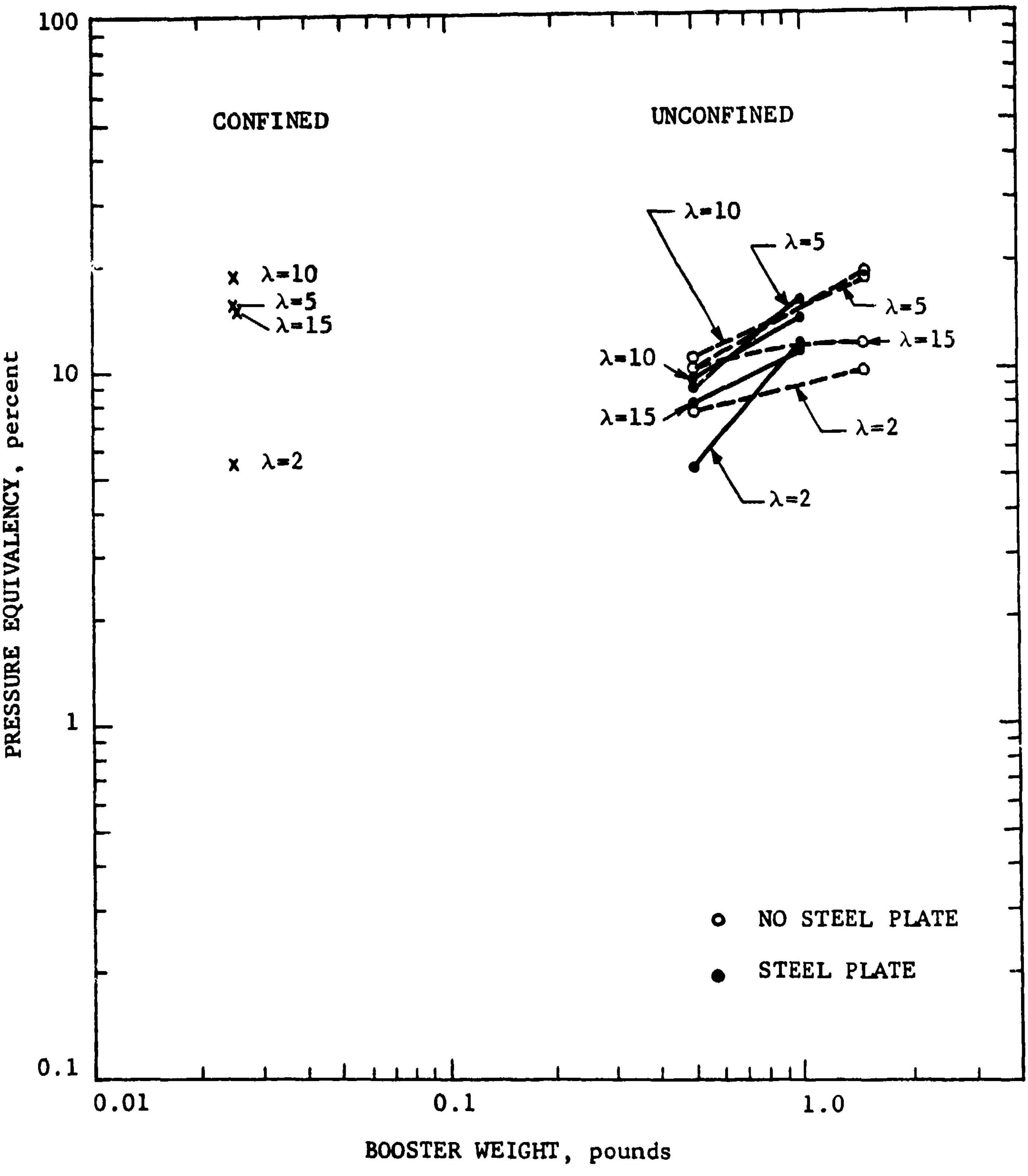


Figure 30 TNT PRESSURE EQUIVALENCY OF 75 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES

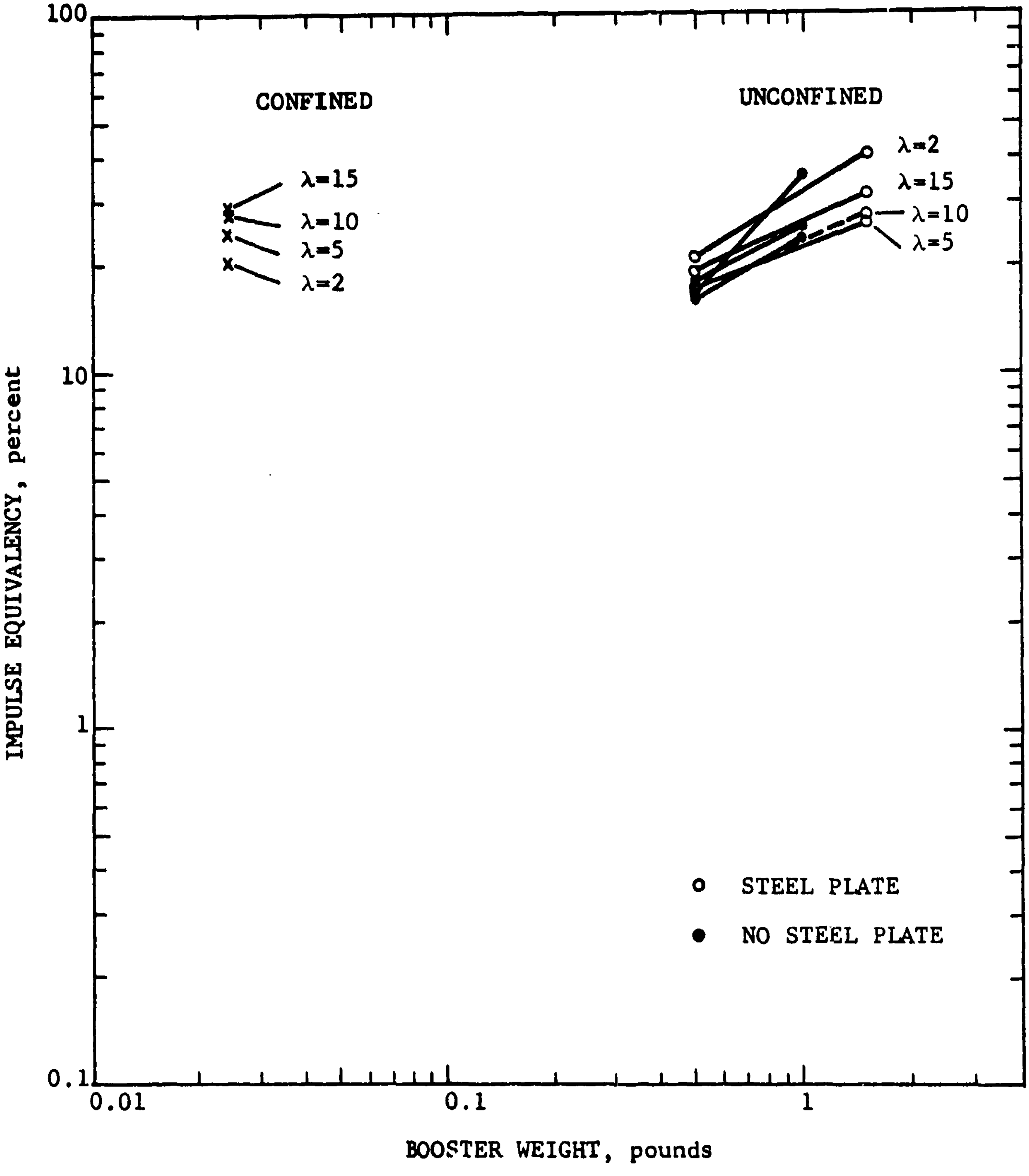


Figure 31 TNT IMPULSE EQUIVALENCY OF 75 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

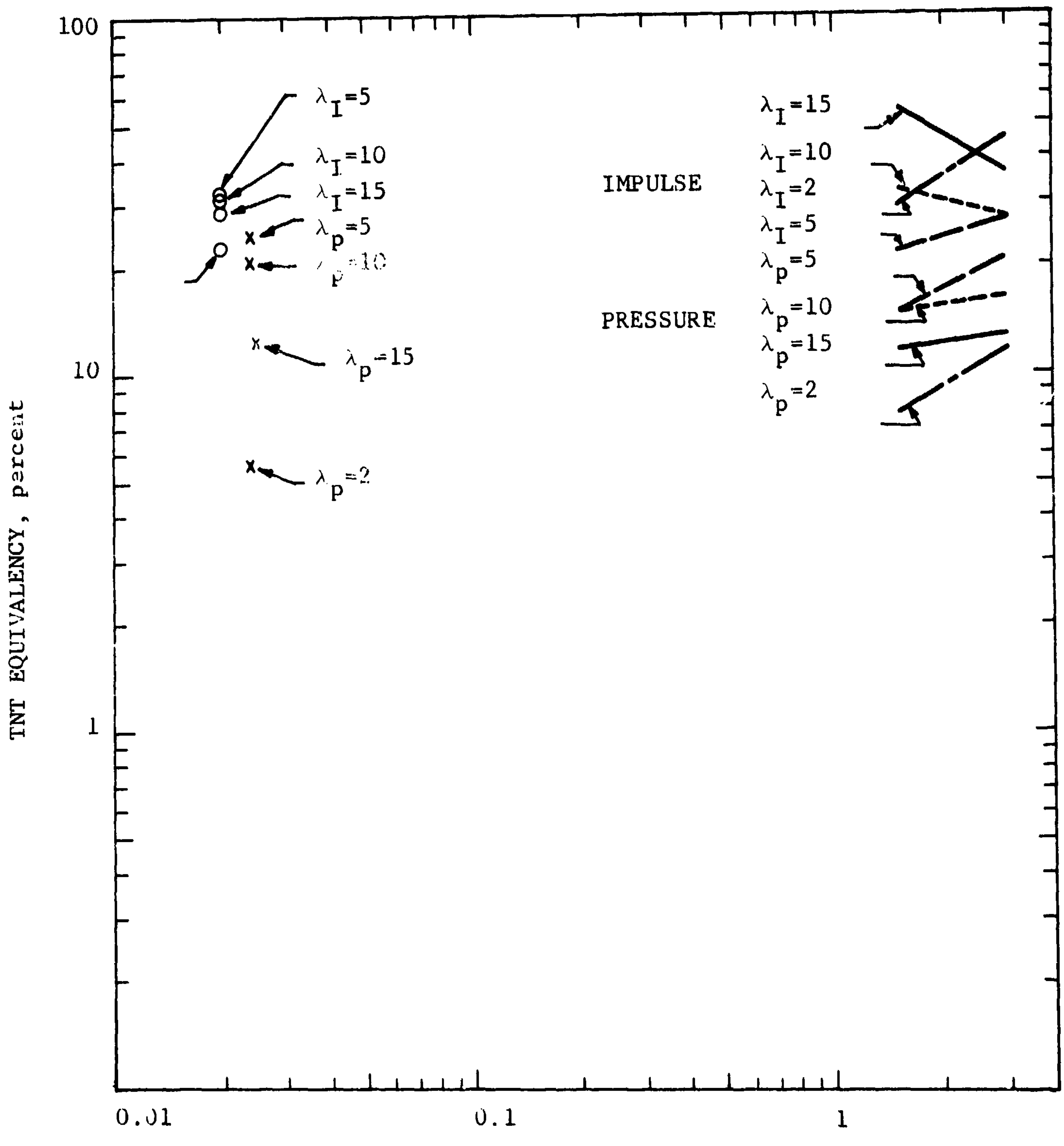


Figure 32 TNT EQUIVALENCY OF 140 AND 150 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

7.6 The Effect of Booster Geometry on TNT Equivalency

No differences in pressure or impulse were found when cone shaped or cylindrical boosters were evaluated. The weight of each shaped booster was the same. The aspect ratio, L/D, of the cylinder was such that the surface area of the cylinder in contact with the Black Powder was the same as the area of the flat face of the cone which was in contact with the Black Powder. The reason for considering these two shapes is that work carried out by other investigators* showed that the conical boosters give a very high initiating effect relative to their weight, for boosters that are placed externally with the end surface in contact with the acceptor charge. They found that the factors that affect initiation of the acceptor charge are peak pressure of the booster, duration of the boosters pressure pulse, and the surface area of the booster in contact with the charge. The surface area and duration are interrelated since they both depend upon the weight of the booster. The referenced study did not compare initiating effectiveness between booster charges placed inside the acceptor with those placed on the outside. Thus tests were carried out using cone shaped boosters placed in contact with the bottom surface of the Black Powder and cylinder shaped boosters placed internally.

The effects of booster geometry were evaluated using 25 lb unconfined Black Powder charges initiated with 0.5 lb boosters of C-4. Shots BO 8 and 9 used cone shaped boosters. Shots BO 12 and 13 utilized cylindrical shaped boosters. A summary of the TNT equivalency data for pressure and impulse can be seen in Figure 33.

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* Johansson, C. H. and Persson, P. A., "Detonics of High Explosives" Academic Press, 1970.

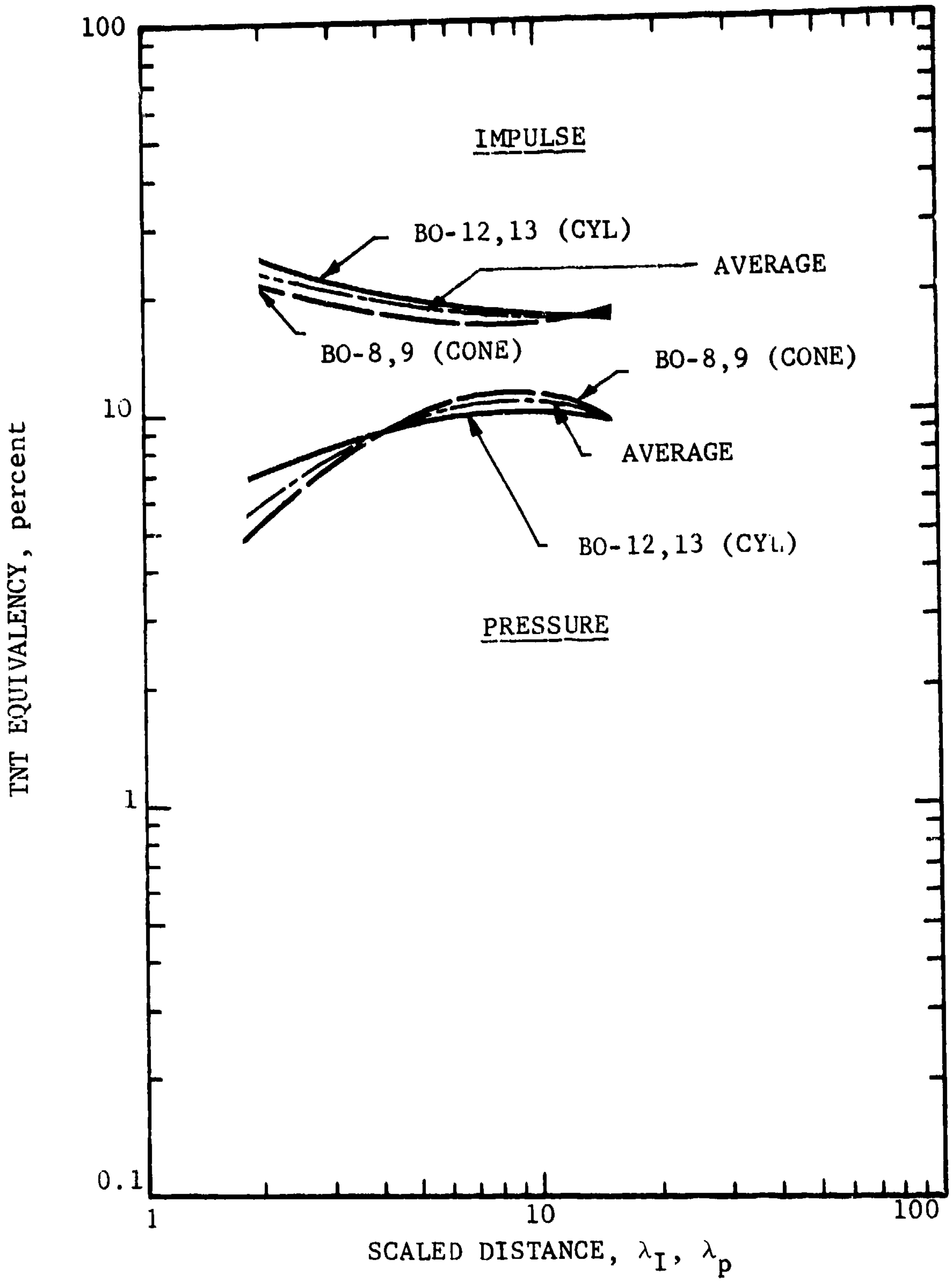

Figure 33 THE EFFECT OF BOOSTER GEOMETRY ON TNT EQUIVALENCY OF BLACK POWDER

7.7 Effect of Type of Explosive Used For Boosters, on Equivalency

To determine the effect of type of booster explosive on output of Black Powder, unconfined 25 lb Black Powder charges were initiated with C-4 (BO 12 and 13) and 9404 PBX (BO 36 and 37) boosters weighing 0.5 lb and 0.54 lb respectively. The tests using 9404 PBX boosters, also used steel base plates, whereas the tests charges using C-4 boosters were placed on bare ground. Thus this comparison involves the interaction of both booster type and steel plate. Other comparisons on steel plate effects alone shot BO 16, 18, and BO 17, 19, Figure 19 showed that there is an increase in pressure and impulse equivalency when steel plates are used. However, the effect of using 9404 PBX booster is much greater than that attributed to use of steel plate alone. This can be seen in Figures 34, 35, and 36 where the TNT equivalency is plotted as a function of weight ratio, i.e., the ratio of booster weight to Black Powder weight. Each of the three figures is for a different scaled distance. In these curves no distinction is made between those tests using a steel plate and those tests fired on the ground. Clearly the 9404 PBX data fall above the other 25 lb charge data. Similar effects can be seen in Figures 37 and 38, which are plots of equivalency as a function of booster weight, at selected scaled distances for 25 lb Black Powder. The data points for 9404 PBX boosters fall above the curves for C-4 boosters.

Although the higher detonation pressures from 9404 PBX boosters results in an enhancement of the initiating effects of Black Powder, as compared with C-4 boosters of the same weight, it is not suggested that 9404 be used for future investigations since the cost of the PBX explosive is prohibitive for routine use, and the same results can be obtained by using a larger booster of C-4 explosive.

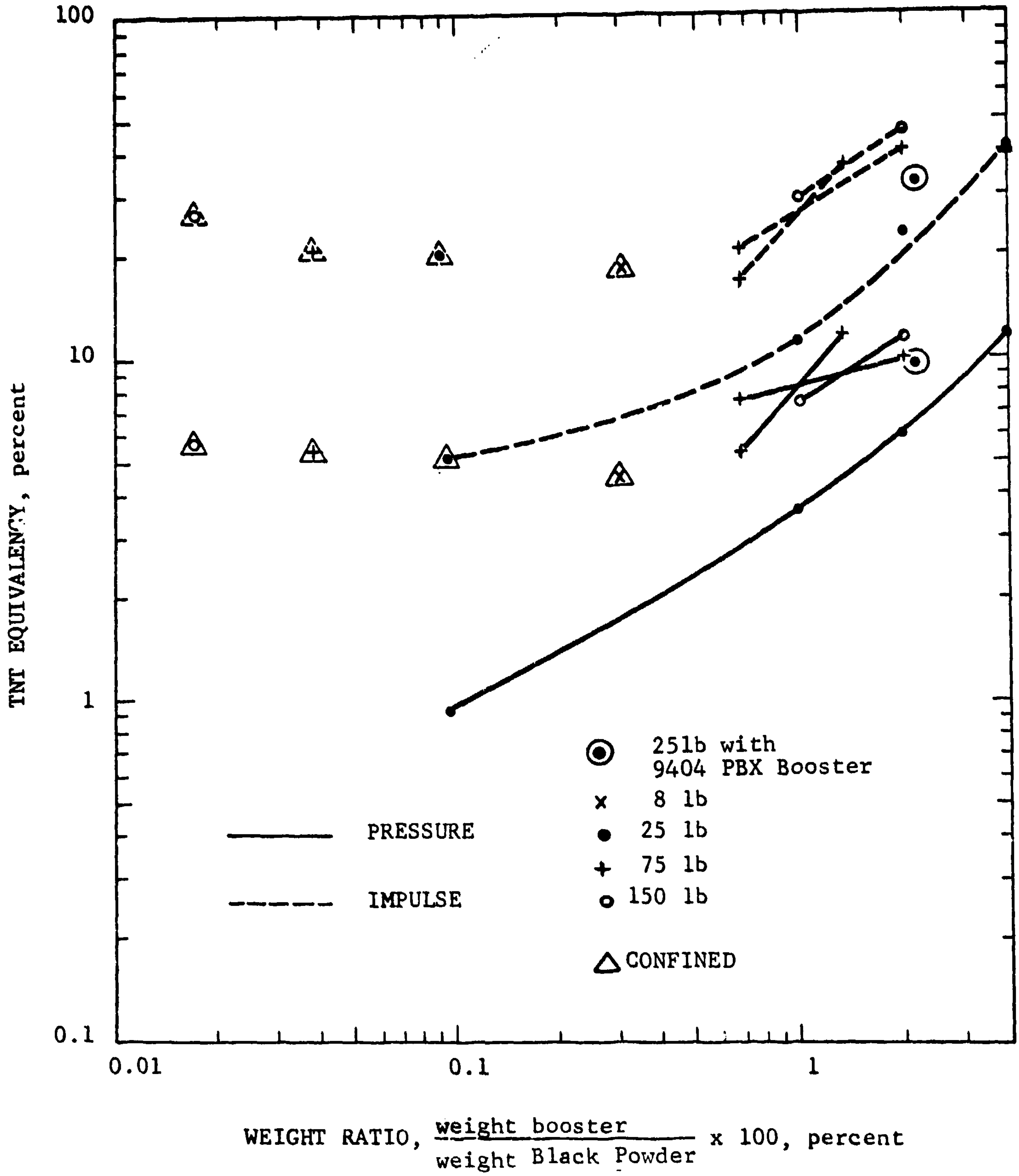

Figure 34 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS, SCALED DISTANCE $\lambda=2$

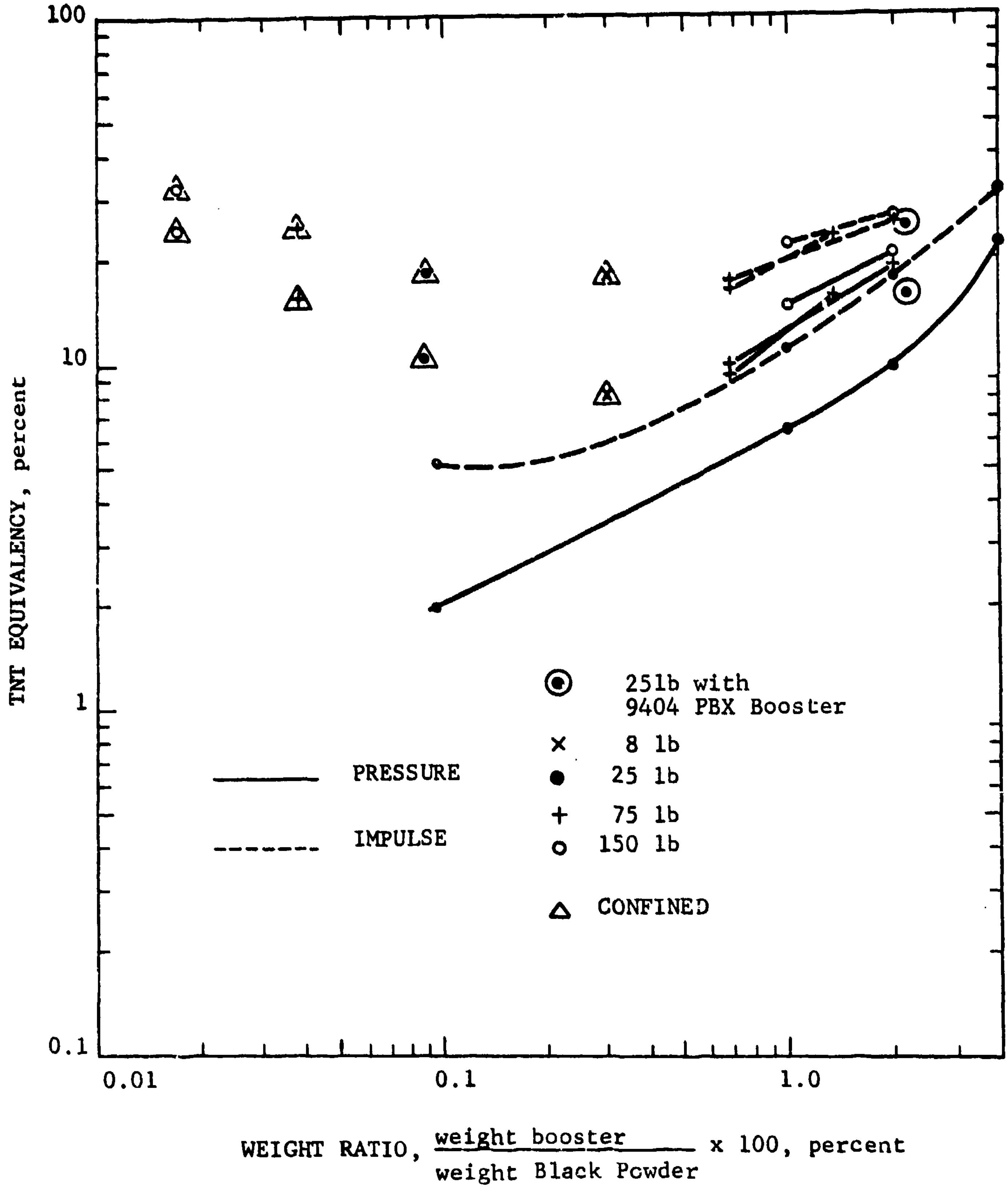

Figure 35 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS SCALED DISTANCE λ=5

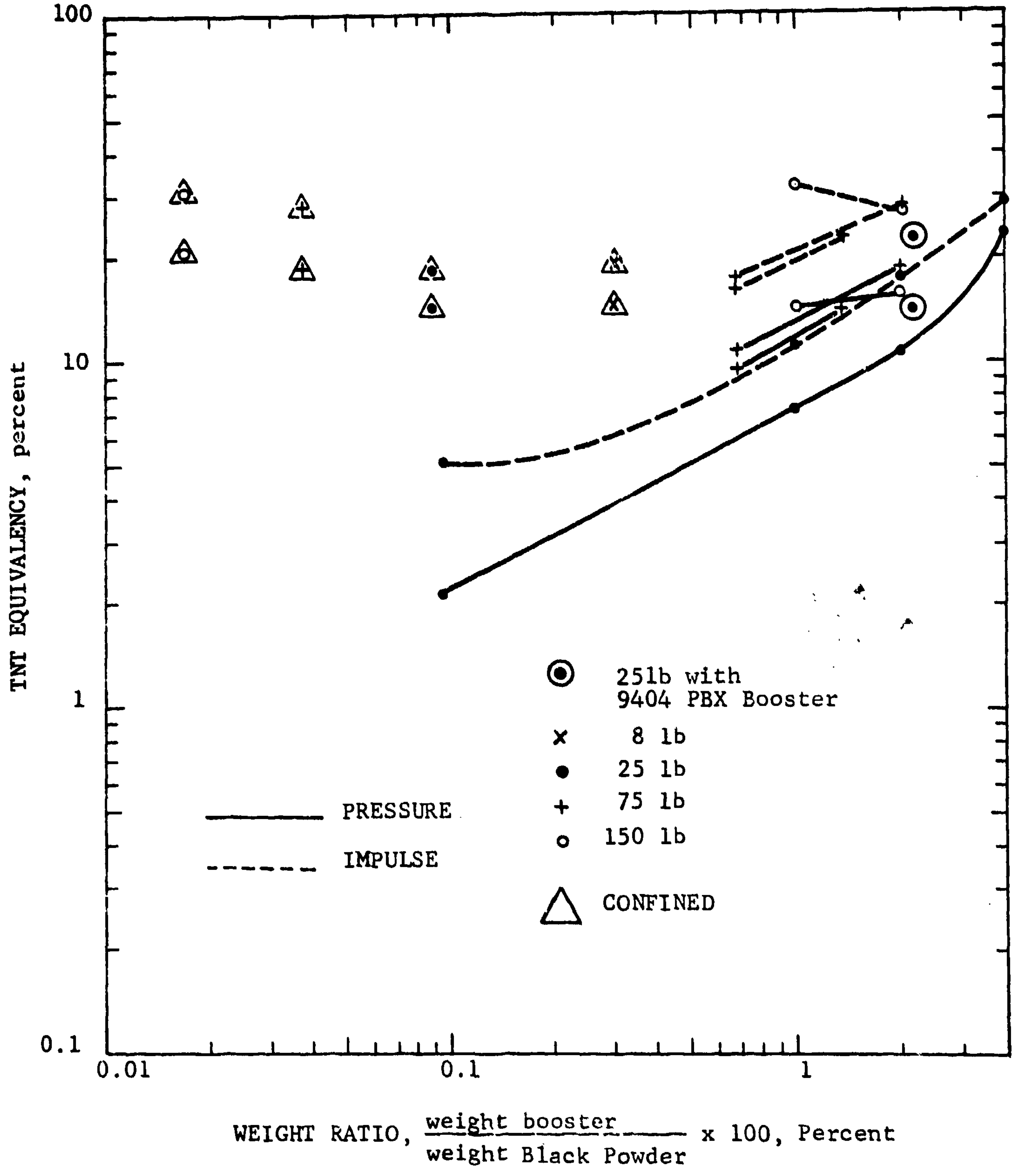

Figure 36 PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF WEIGHT RATIO, FOR ALL TESTS, SCALED DISTANCE $\lambda=10$

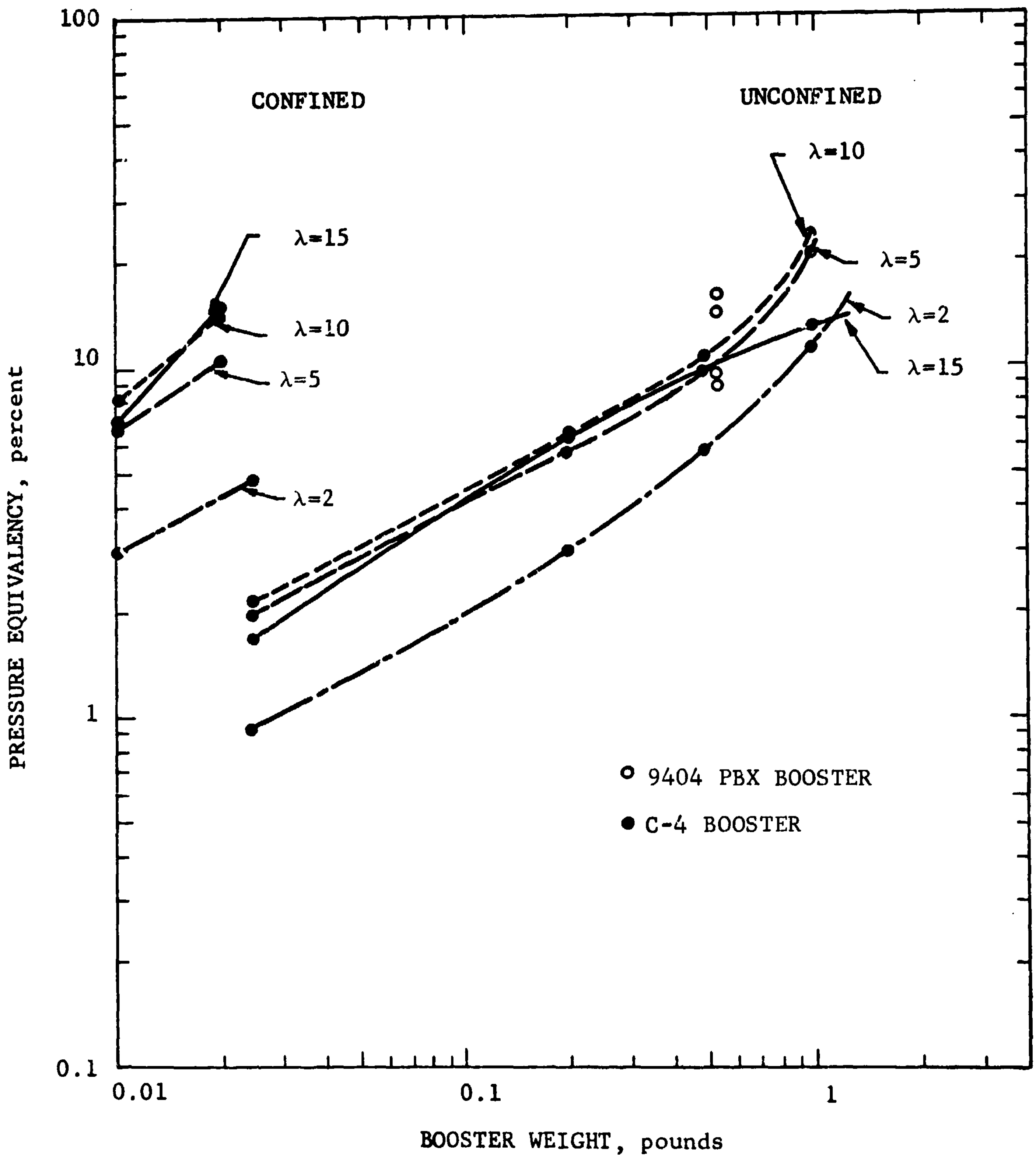

Figure 37 TNT PRESSURE EQUIVALENCY OF 25 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES, λ

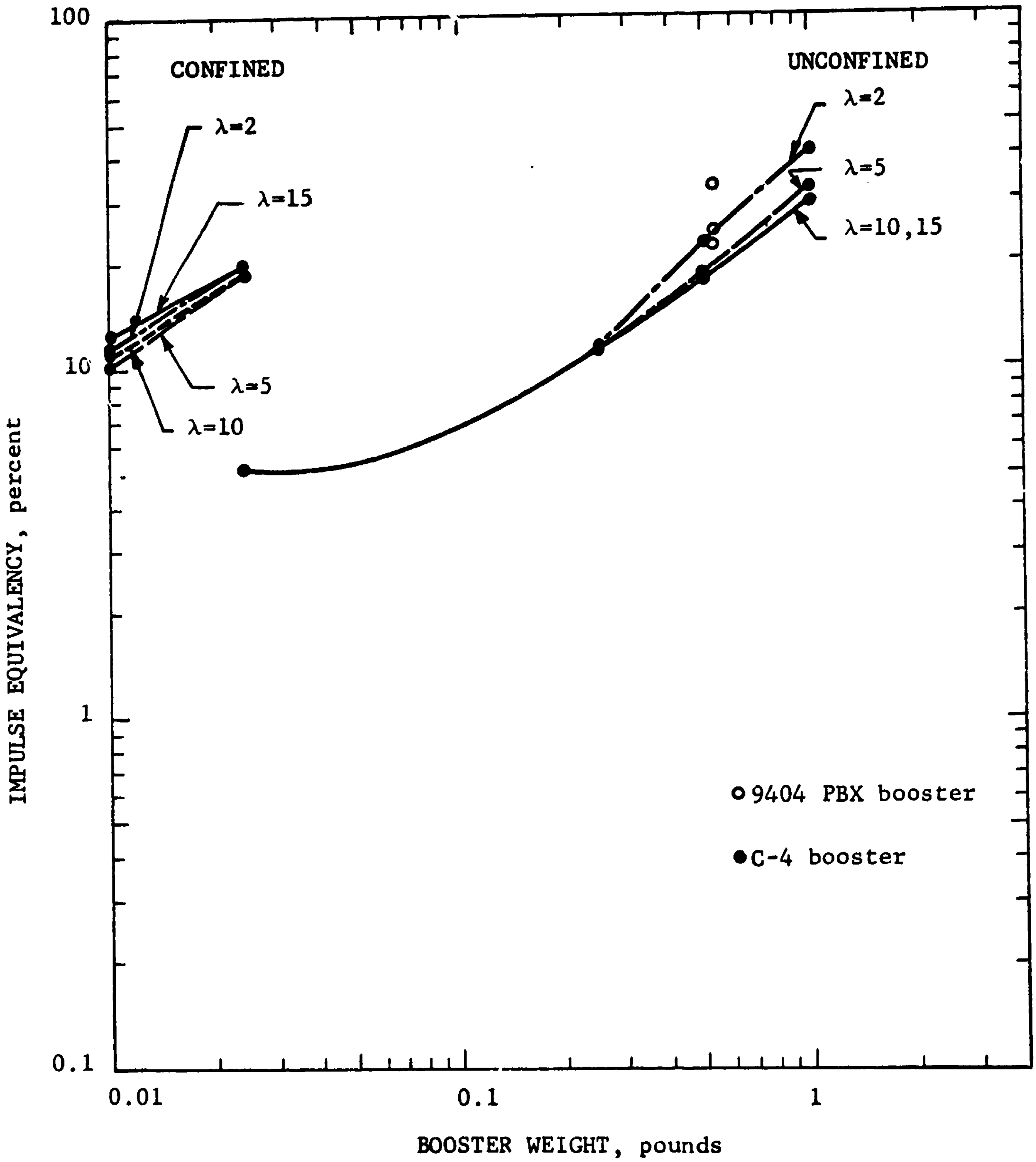

Figure 38 IMPULSE EQUIVALENCY OF 25 AND 27 LB BLACK POWDER AS A FUNCTION OF BOOSTER WEIGHT, FOR SELECTED SCALED DISTANCES λ

There are several factors that affect the initiation of Black Powder (or any acceptor material) by a shock wave. They are: the peak pressure of the disturbance; its duration; and the surface area of the initiation source that has a direct action on the acceptor. The shock wave need not be produced by a high explosive booster. It can be produced by impact of a foil or a thick plate. If the foil and plate are of the same material and velocity then the pressure at the acceptor face is the same, but the duration is much smaller for the foil than it is for the thick plate. Similarly, we can increase the duration of the pulse by increasing the weight of the booster explosive--in tests where the booster is in contact with the acceptor material. It has been shown for three different explosive materials, using test results of a number of investigators, that the shock sensitivity of an explosive can be characterized by two values; peak pressure and duration of pulse. Thus in the work reported here the peak pressure of the donor charge was constant (C-4 boosters were used in the majority of the tests). The duration, or pulse widths, were increased by using booster weights ranging from 0.024 to 3 lbs. The tests using 9404 PBX, which has a higher detonation pressure than C-4, gave the same results as tests using a larger weight C-4 booster.

The same results could be obtained by using a booster with a lower peak pressure, but longer pulse duration. By using lower pressure boosters (e.g., low density Tetryl or nitroguanidine), or impact of flyer plates we would still be able to map out the possible reaction intensity levels that the Black Powder could achieve, and this would be the same as already achieved with C-4 boosters.

7.8 Comparison of the TNT Equivalency of the Jet Mill Product and Black Powder

A total of six tests were carried out on 27 lb charges of the jet milled product. The output of the jet milled product is lower than Black Powder both for confined and unconfined test conditions, when charges are initiated with 0.024 lb (11 gm) Tetryl boosters. These effects are illustrated in Figures 39 and 40. However when these materials are initiated by a squib (DuPont S65 squib consisting of 0.2 grain initiating mix), the jet milled material has a much higher impulse equivalency and a higher pressure equivalency for scaled distances $\lambda \geqslant 5$. Figures 41 and 42 illustrate this effect. The only squib tests were for confined charges. When Black Powder was squib initiated, shots SQ 1, 2, 3, the blast output was lower than when initiated with an 0.024 lb Tetryl booster, as expected. One explanation for the unusual behavior of the jet milled material is that the squib caused a deflagration reaction in the material. Upon reflection of the deflagration pressure wave from the steel confining surfaces an increase of pressure of high enough intensity caused retonation; a detonation propagates back into the already heated and disturbed jet milled product. Whereas the Black Powder was promptly initiated to a low order detonation reaction. It is believed that higher reaction intensity levels can be achieved in preheated Black Powder and its in-process forms.

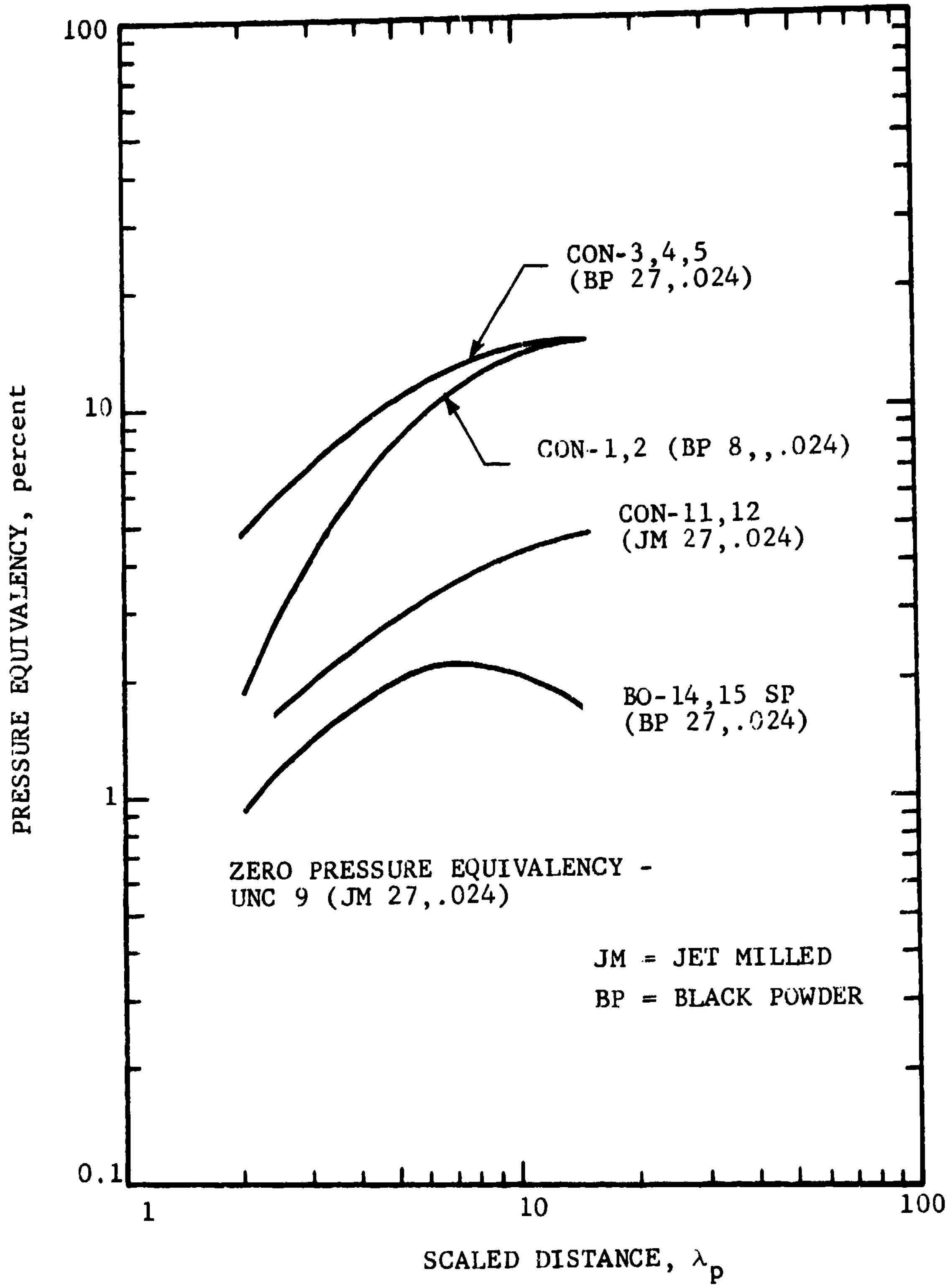

Figure 39 COMPARISON BETWEEN THE BEHAVIOR OF BLACK POWDER AND THE JET MILLED MATERIAL AND THE EFFECT OF CONFINEMENT ON PRESSURE EQUIVALENCY FOR 8 AND 27 LB CHARGES, .024 LB BOOSTER

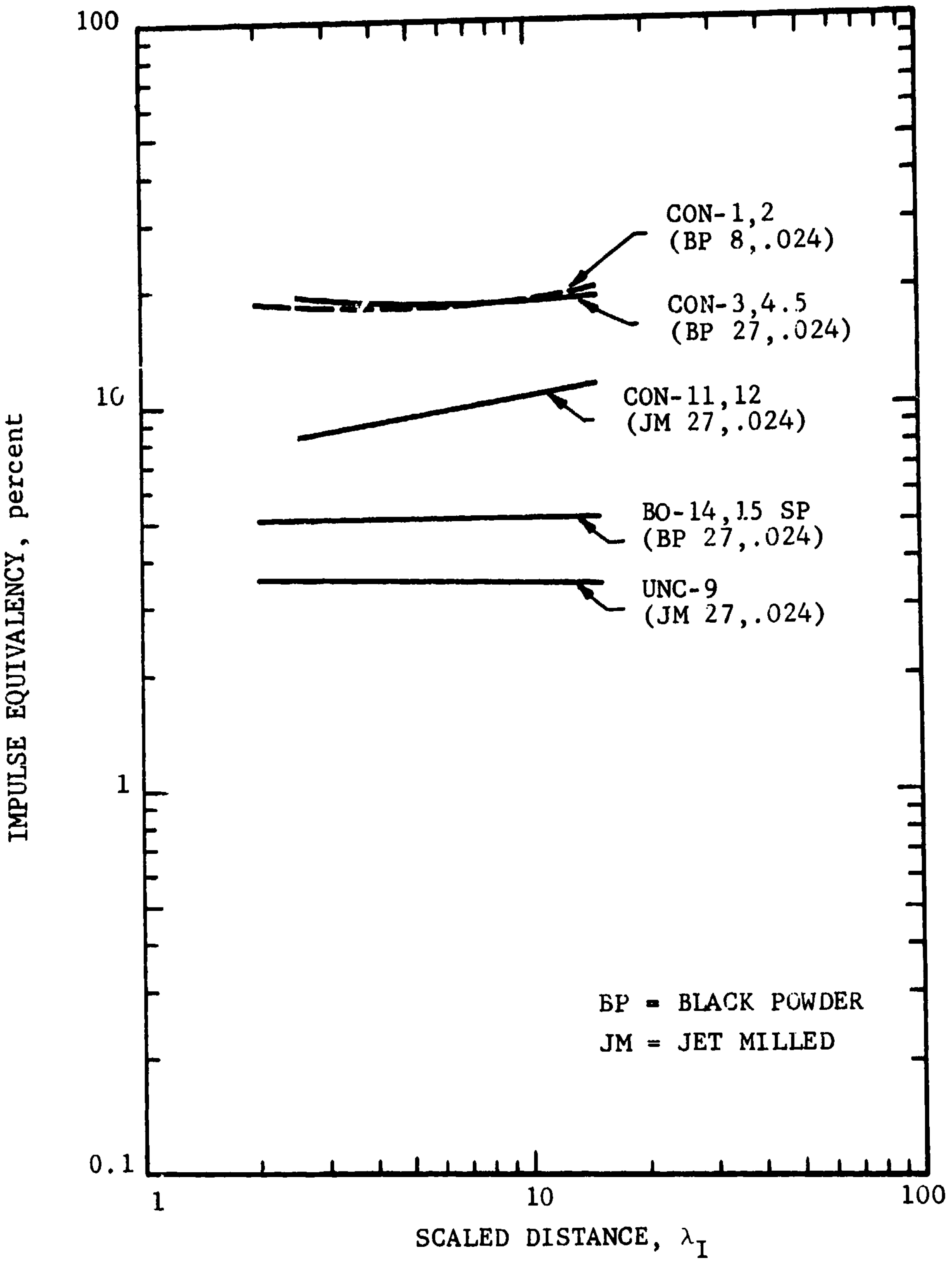

Figure 40 COMPARISON BETWEEN THE BEHAVIOR OF BLACK POWDER AND THE JET MILLED MATERIAL AND THE EFFECT OF CONFINEMENT ON IMPULSE-EQUIVALENCY FOR 8 AND 27 LB CHARGES, 0.024 LB BOOSTER

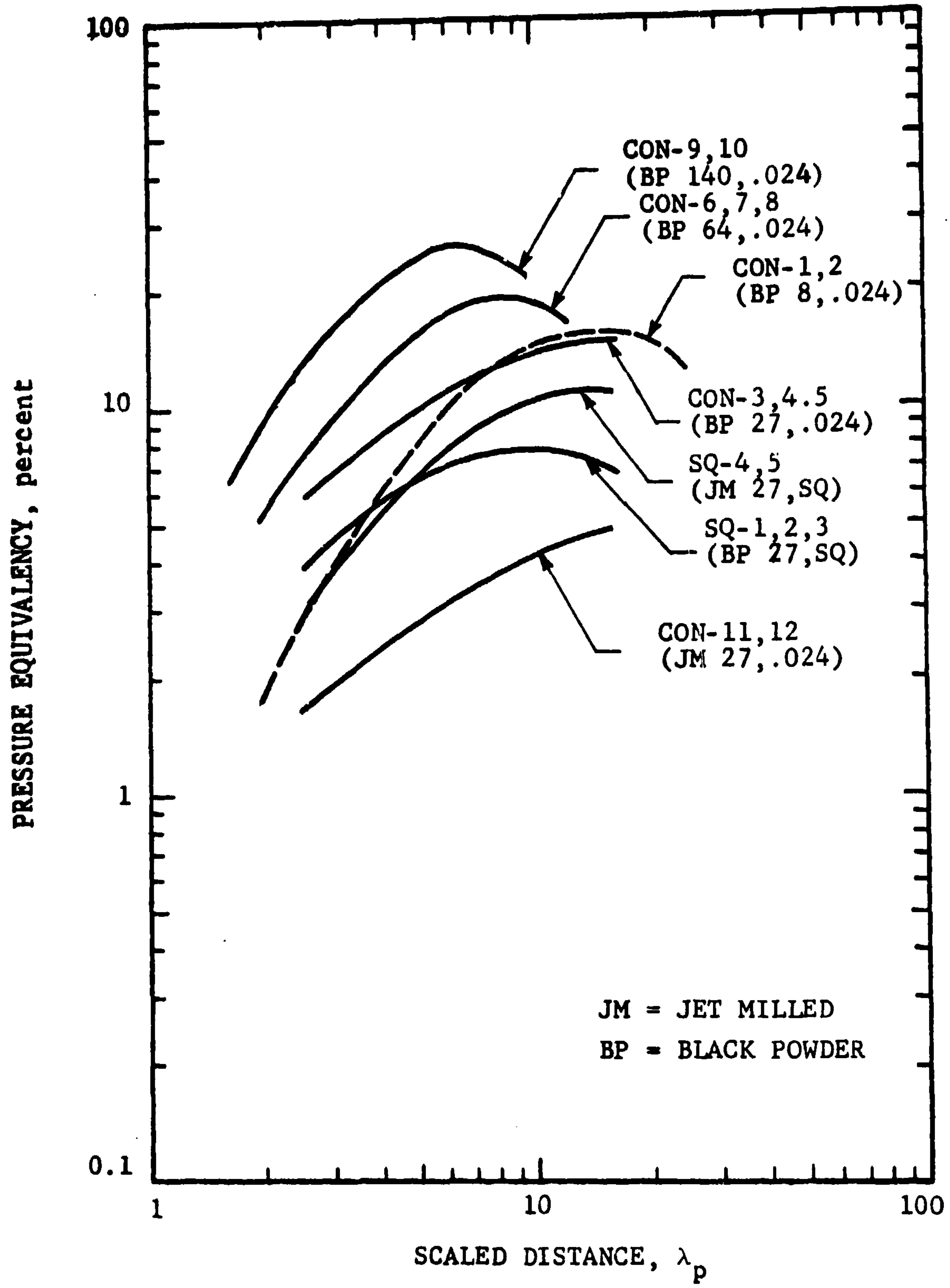

Figure 41 EFFECT OF CHARGE WT ON TNT PRESSURE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

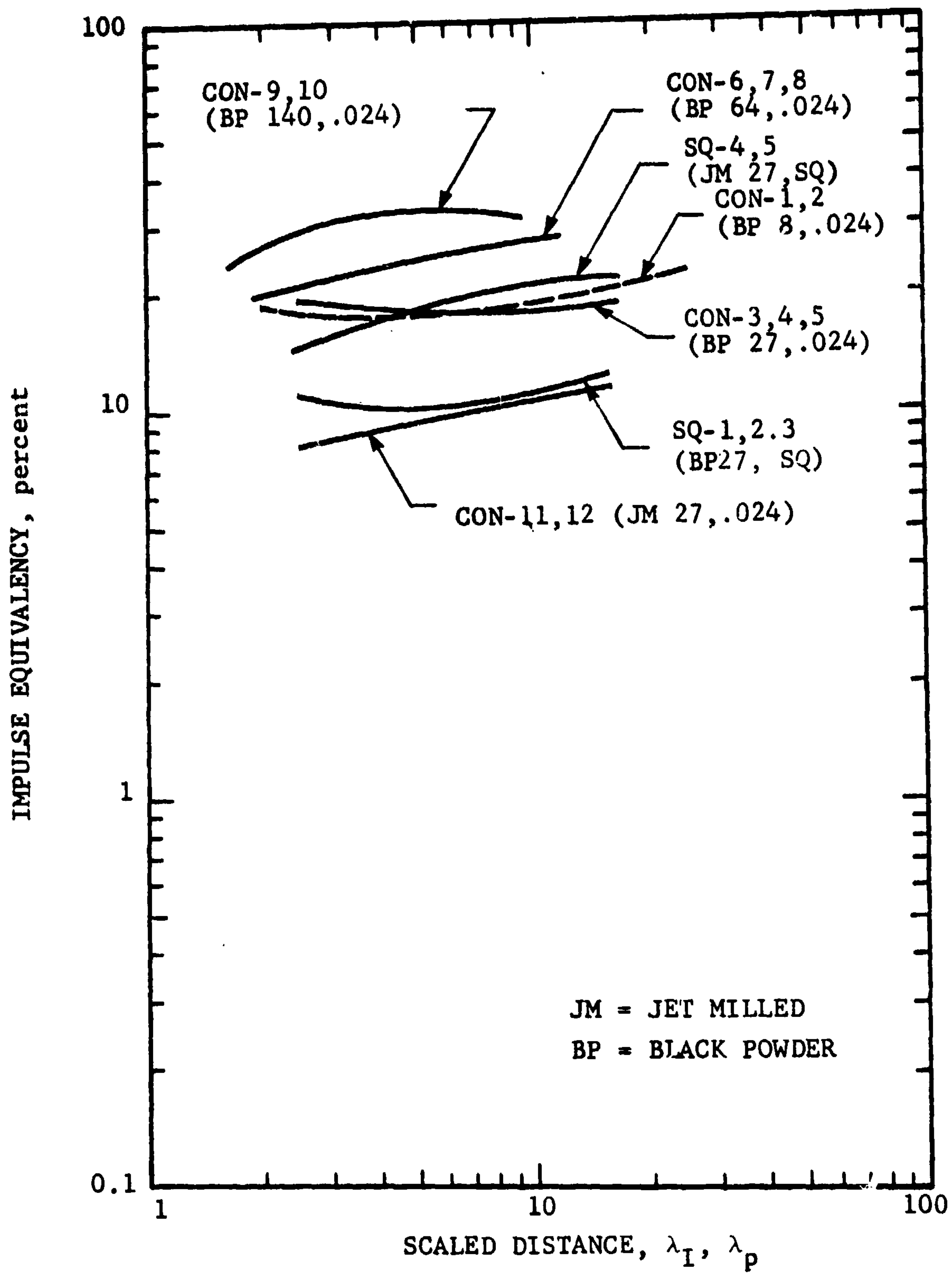

Figure 42 EFFECT OF CHARGE WT ON TNT IMPULSE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

7.9 The Significance of the Convex Shape of the Pressure Equivalency Distance Curves and the Effect of Errors in Measurements on the Computed Values of Equivalency

The pressure equivalency of Black Powder varies with distance. The pressure-distance equivalency curves are generally convex in shape. They reach their maximum at a scaled distance of between 7 and 10 $ft/lb^{1/3}$. This effect can be traced back to the shapes of the pressure-distance curves for TNT and Black Powder. The TNT pressure curve is concave in shape, whereas the Black Powder curves are generally opposite, or convex, in shape. This effect of pressure equivalency varying with distance has also been observed for solid rocket propellants,* and may be due to the slower rate of reaction of Black Powder or propellants, as compared with TNT. The impulse equivalency on the other hand does not vary substantially with distance. It is essentially constant, since the impulse-distance curve for Black Powder is parallel to the impulse-distance curve for TNT.

It must be recognized that since the computations of equivalency involve cubing the ratio of two scaled distances, an error in a Black Powder measurement would result in an error of three times that magnitude in the equivalency value. Hence, if we assume a 5 percent error in λ, resulting from a 10 percent error in measuring pressure, then the computed equivalency value may be in error by as much as 15 percent. Thus, if the TNT equivalency was computed to be 30 percent it could, assuming a 5 percent error in λ, be between 25.5 and 34.5 percent equivalency.

The error or uncertainty was minimized by each test condition being carried out in duplicate or triplicate. The pressure (or impulse) for each distance was averaged and a first or second order polynomial curve was fitted through the averaged points. The deviations of the fitted curve from a measured average value of pressure or impulse, was maintained at less than 10 percent.

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*Petes, J., "Watch Your Equivalent Weight," Minutes of the 12th Explosives Safety Seminar, August 1970.

If the deviation was greater, that point was eliminated as being an invalid measurement. Typically the error was of the order of 3 to 4 percent in pressure (because of the relatively steep slope 60 to 70 deg of the pressure curve, an error in λ is one-half the error in P). <u>It is thus believed that errors in λ are much less than 3 percent and hence errors in equivalency reported herein are expected to be much less than 10 percent</u>.

8. RESULTS OF TESTS ON SAND AS AN INERT SIMULANT

Calibration-type tests were carried out using sand as an inert simulant for Black Powder. The purpose of the inert simulant tests was to determine the contribution of the booster explosive to the airblast parameters. Initially it was believed that an adequate approximation to account for booster effects was to subtract the pressure (or impulse) obtained in the tests on sand from the values of pressure (or impulse) obtained on the tests with Black Powder, using the same booster size. Although it was recognized that blast wave addition is a nonlinear process, it was thought that the effect of subtracting the booster-sand pressures and impulses would be small. Although this is true, a more correct method for accounting for the booster was derived; the iterative process described in Appendix B. Comparisons were made in the equivalency values obtained by subtracting the sand test booster effect and those equivalencies obtained by the more accurate method of Appendix B. The difference in the results were small, it was therefore decided that the more correct iterative method should be used in this report and in all future work. Therefore, in the final interpretation of the Black Powder data the sand test results are not used. The raw data on pressure and impulse for the series using sand can be found in Appendix A (Volume II).