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(6) ~~REPORT TO THE TEST DIRECTOR~~

AIR SHOCK PRESSURE-TIME VS DISTANCE

(Project 19.1a)

(9) Rept. for Apr - June 52

~~by~~

(10) B. F. MURPHEY DIVISION 5111

(11) ~~date~~

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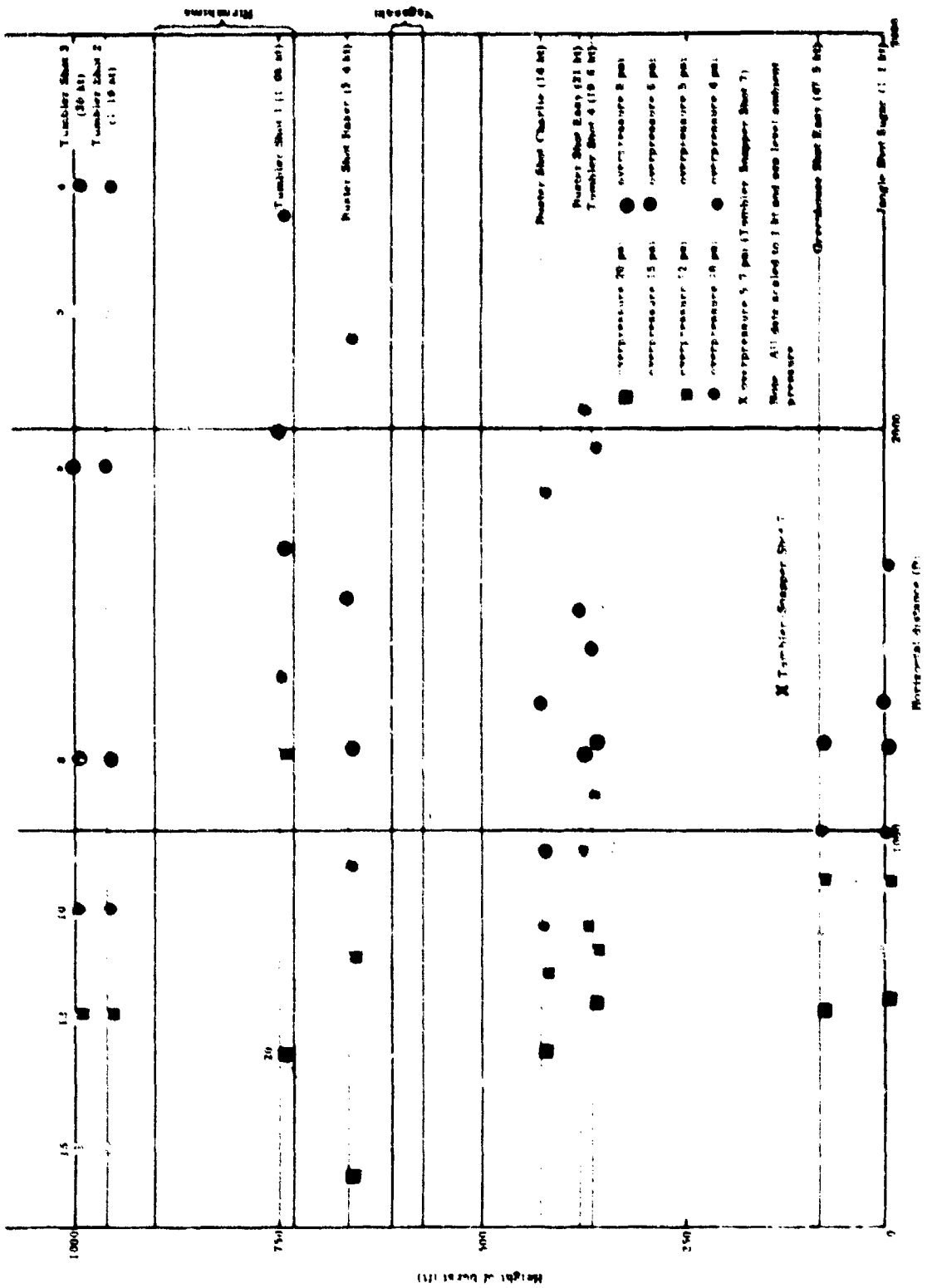

Frontispiece - Height-of-burst chart based on experimentally determined overpressures

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ABSTRACT

The Tumbler series [illegible] pressure measurements were useful in constructing an overall [illegible] to get a height-of-burst chart for atomic weapons. [illegible] pressures observed on Operation Buster were much lower than had been anticipated [illegible] by further tests was indicated.

Specifically the [illegible] was [illegible]:

(1) To provide pressure data from the burst of a 1.2-kt weapon at a height comparable to that of Buster Shot Baker [illegible] determine whether [illegible] pressure would [illegible] change [illegible] altitude.

(2) To provide pressure data from bursts of [illegible] and 41-kt weapons at nearly equal scaled heights, making it possible to establish whether the scaling law is applicable to this range of yields [illegible] burst height.

(3) To provide pressure-distance data from a greater scaled height of burst than had been [illegible] previously [illegible].

(4) To burst a weapon under [illegible] situations as nearly as possible those of the Buster Shot Charlie.

It was found that:

(1) A comparable scaled distance pressures measured on Operation Tumbler were somewhat higher than those from the Buster series although peak pressures were lower than would have been anticipated from predictions based on height-of-burst charts published [illegible] Operation [illegible].

(2) The scaling law appeared to be applicable at least for yields ranging from (+30)-kt at a scaled burst height of [illegible] feet (or higher).

(3) Data from Shot 4 produced [illegible] evidence of considerable deterioration of the shock wave from a nominal (20-kt) weapon burst at a low altitude.

Agreement of data from Tumbler Shot 4 with those from the Buster series tends to validate results of the Buster measurements, particularly since pressure-time measurements made by Sandia Laboratory were in close agreement with similar measurements made by the Stanford Research Institute and the Naval Ordnance Laboratory on Operation Tumbler.

Data from Operation Tumbler have contributed substantially to the construction of a new height-of-burst chart based on experimental data.

Measurements were also made of the variation in pressure with small altitudes at several stations on the blast line, the preshock ambient ground level pressures at several distances from ground zero, and the behavior of the pressure wave at comparatively large distances from ground zero. Some deductions are made from pressure-time data as to the decrease in positive impulse loading as a function of distance from ground zero. A comparison of pressures measured on Tumbler-Snapper Shots 7 and 8 (one on Shot 7 and two on Shot 8) with pressures measured at corresponding distances on Greenhouse Shot Easy shows that those measured on Tumbler-Snapper are smaller by several per cent.

ACKNOWLEDGMENT

Shock-pressure measurements for Operation Tumbler were planned by representatives of the Los Alamos Scientific Laboratory, the Armed Forces Special Weapons Project, the Stanford Research Institute, the Naval Ordnance Laboratory, the Ballistics Research Laboratory, and the Sandia Corporation. The operation was executed with a maximum of cooperation among the participating agencies and the personnel and contractors of the Nevada Proving Grounds.

Field measurements for Sandia Corporation were ably carried out by personnel of the Instrumentation Division of the Field Test Organization of the Corporation.

A list of all participating personnel and their specific assignments is presented in Appendix A to this report.

AIR SHOCK PRESSURE-TIME VS DISTANCE

Between the time of the first atomic weapon test (July 16, 1945) and Operation Greenhouse (1951), measurements of pressure-time vs distance for atomic weapon bursts were confined to one airburst and one underwater burst at Bikini Atoll* (1946) and three tower shots at Eniwetok† (1948). Observations made on Bikini Shot Able, plus experimental data from detonations of small high-explosive charges and from shock-tube studies, were used to construct height-of-burst charts‡ for airburst nuclear weapons. These charts were used extensively by the National Military Establishment (now Department of Defense) in planning optimum usage of the stockpile of atomic weapons; however, in this application it was impossible to take into account all stipulated reservations because confirmatory experimental data were lacking.

During the tower shots of atomic weapons on Operation Greenhouse the pressure-time measurements§ at stations close to ground zero indicated that the shape of the pressure wave

---

*Report of the Technical Director, Operation Crossroads, Vol I, Report No. XR-156, May 1947

†Hartmann, G. K., et al, Pressure-Time Measurements for Operation Sandstone, Technical Director's report on Operation Sandstone, Annex 5, Part III, (Sandstone report No. 22, LA-Q-25-22), June 2, 1948

‡Porzel, F. B., Reines, F., et al, Height of Burst for Atomic Bombs, Los Alamos report LA-743R, August 3, 1949; Pelsor, G. T., Overpressures Expected from an A-Bomb Burst over a Rigid Plane, Sandia Corporation report SC-1516(Tr), July 19, 1950

§Price, J. F., et al, Pressure-Time Measurements in the Mach Region, Technical Director's report on Operation Greenhouse, Annex 1.6, Part IV (to be published)

differed considerably from that postulated from the 'textbook' concept of the shock wave.* The question therefore arose whether similar differences might be observed for pressure waves from airburst weapons. Inasmuch as there was an obvious need for data from atomic bomb bursts which would check the accuracy of height-of-burst charts based upon small-scale high-explosive shots, a series of measurements was scheduled in conjunction with the program of airbursts known as Operation Buster. Measured pressures† from these three bursts varied considerably from those predicted from the published, admittedly optimistic, height-of-burst curves.‡

Buster shots were all at relatively low burst heights, however, and the only extensive pressure measurements were those made by Sandia Laboratory. It was at once apparent that it would be necessary at some future date to verify the results of the Buster measurements, using more extensive instrumentation, and to obtain pressure data from bursts at greater heights.§

Accordingly a series of four airbursts of atomic weapons, designated as Operation Tumbler, was carried out at the Nevada Proving Grounds in the spring of 1952. The following bursts were scheduled:

Shot 1. -- A 1.2-kt weapon to be burst at a height of 800 feet, scaled to be comparable to that for Buster Shot Baker; Shot 1 was burst over the Frenchman Flat area rather than over Area T-7 to determine whether the hard-packed terrain of Frenchman Flat, which had a considerably higher reflectivity for thermal

---

*The Effects of Atomic Weapons, prepared under the direction of the Los Alamos Scientific Laboratory, U.S. Government Printing Office, 1950, p 49 (Fig. 3.11)

†Results of the Sandia Laboratory pressure measurements on Operation Buster are described fully in Buster-Jangle reports WT-304, Air Over-Pressure vs Time vs Distance from Buster Airburst Bombs, March 4, 1952, by B. F. Murphey, and WT-305, Variation of Blast Pressure at Fixed Distances with Small Altitudes, April 3, 1952, by J. M. Harding.

‡Some revisions to the theoretical height-of-burst curves were made as a result of measurements on Operation Buster; these revised curves are published in Supplement 1 to TM 23-200, Capabilities of Atomic Weapons, July 1951, prepared for the Armed Forces Special Weapons Project by the Los Alamos Scientific Laboratory.

§Scaled heights or distances are obtained by dividing actual heights or distances by the cube root of the radiochemical energy of the weapon, expressed in kilotons of TNT. The energy equivalent of one kiloton of TNT is taken to be 10^{12} calories.

radiation and was decidedly more dust-free than Area T-7, would affect appreciably the pressures measured.

Shot 2. -- A 1.2-kt weapon to be burst at a height of 1,100 feet to obtain pressure-distance measurements from a greater scaled height than on any previously scheduled experimental burst.

Shot 3. -- A 30-kt weapon to be burst at a height of 3,450 feet; data from this shot were to be used in conjunction with those from Shot 2 to provide scaling data for this burst height. Shots 2 and 3 were to be fired over Area T-7, the same area used for Operation Buster.

Shot 4. -- A 20-kt weapon to be burst at 1,050 feet over Area T-7 under conditions simulating as nearly as possible the conditions for Buster Shot Charlie.

As a supplement to the nuclear tests of Operation Tumbler a series of test shots* of 250-lb spherical charges of high explosive was carried out at the Frenchman Flat and T-7 areas at the Nevada Proving Grounds and at the Coyote Canyon site near Albuquerque. These charges were detonated at three different heights above ground, and pressure-time measurements were made at various distances on each shot. The primary purpose of these tests was to determine whether mechanical effects† alone could account for the results observed on Operation Buster.

1.1 PRESSURE-TIME MEASUREMENTS

Sandia Laboratory had made the only extensive pressure measurements on Operation Buster. In recognition thereof Sandia was asked to provide a part of the pressure-time measurements on Operation Tumbler. Extensive pressure-time measurements on the Tumbler series were also made by the Stanford Research Institute and the Naval Ordnance Laboratory.

Pressure-time measurements made by Sandia Laboratory included reflected pressures at ground surface as follows:

---

*These tests are described in detail in memorandum report 5111(65), Pressure-Distance-Height Data for 250-lb HE Spheres - Operation Tumbler, Project 1.10, March 13, 1952, by B. F. Murphey; also published by the Armed Forces Special Weapons Project as a preliminary report of Operation Tumbler, Annex VIII, under the same title.

†The theories of thermal and mechanical effects on the shock wave have been discussed by F. B. Porzel in Los Alamos preliminary report LA-1406, Height of Burst for Atomic Bombs (to be published).

Table 1.1 -- SPACING OF GROUND BAFFLE GAUGES (TUMBLER SHOTS 1-4)

	Code[a]	Station No.	Distance from intended ground zero (ft)
Shot 1	1-0-P	201	250
	3-0-P	203	750
	5-0-P[b]	205	1,250
	7-0-P	207	1,750
	9-0-P	209	2,500
	11-0-P	211	4,000
Shots 2, 3, and 4	1-0-P	201	750
	3-0-P	203	2,250
	5-0-P[b]	205	3,750
	7-0-P	207	5,250
	9-0-P	209	7,500
	11-0-P	211	11,500

[a]The first number of the code designation refers to the station number, the second number to the height of the gauge above ground, and the final letter (P) indicates that the measurement is a pressure measurement.

[b]At Station 205 two gauges, designated by code as 5-0-P1 and 5-0-P2, were installed for all shots.

In addition to the pressure measurements at ground surface, measurements at heights of 2, 6, 20, and 35 feet above ground were made at the following stations:

Table 1.2 -- SPACING OF TOWER GAUGES (TUMBLER SHOTS 1-4)

	Code	Station No.	Distance from intended ground zero (ft)
Shot 1	2-2-P	202	500
	2-6-P	202	500
	2-20-P	202	500
	2-35-P	202	500
	6-2-P	206	1,500
	6-6-P	206	1,500

Table 1.2 --(cont)

	Code	Station No.	Distance from intended ground zero (ft)
Shot 1 (cont)	6-20-P	206	1,500
	6-35-P	206	1,500
Shots 2, 3, and 4	2-2-P	202	1,500
	2-6-P	202	1,500
	2-20-P	202	1,500
	2-35-P	202	1,500
	6-2-P	206	4,500
	6-6-P	206	4,500
	6-20-P	206	4,500
	6-35-P	206	4,500

Pressures at zero height (in a ground baffle) were measured by means of a Wiancko pressure gauge* mounted face up at the center of a concrete pad four feet square, the surface of which was flush with the surface of the ground (Figs. 1.1 and 1.2). This mount did not differ materially from that used on Operation Buster, wherein the gauge was placed at the center of an 18-in. square of concrete which was in turn placed at the center of a circle of macadam twenty feet in diameter.

The gauges at the 2-, 6-, 20-, and 35-ft levels were mounted flush with the surface of a circular steel plate 18 inches in diameter and one-half inch thick (Figs. 1.3 and 1.4), oriented vertically with its edge pointing toward intended ground zero. This mount differed from the horizontal circular-cross-section pipe used on Operation Buster† and is preferred because it is oriented to record pressures from any burst within the vertical plane passing through the

*This gauge is described fully in Operation Greenhouse report WT-1, Scientific Director's Report on Operation Greenhouse, Annex 3.4, Part I, Instrumentation of Structures Program, January 1951, by P. A. Northrop.

†On Operation Buster, where gauges were installed in horizontal pipes at the 15-ft height, it was not intended to measure the magnitudes of free-air pressures correctly; the main objective was to obtain comparative arrival times for the free-air and reflected pressure waves. Although free-air pressures were not measured correctly, the reflected pressures observed did check with those from the ground baffles.

Fig. 1.1 -- Wiancko pressure gauges installed in ground baffle at Station 205 (at this station two gauges, 5-0-P1 and 5-0-P2, were installed rather than just one, as at all other ground stations)

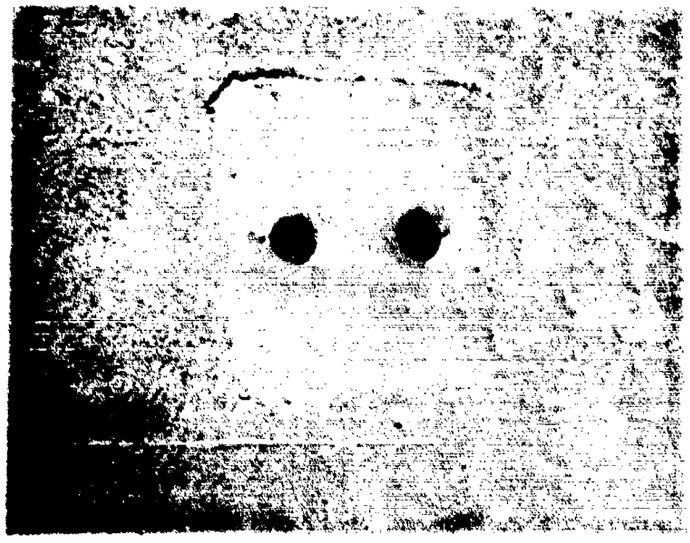

Fig. 1.2 -- Close-up of gauges in ground baffle at Station 205

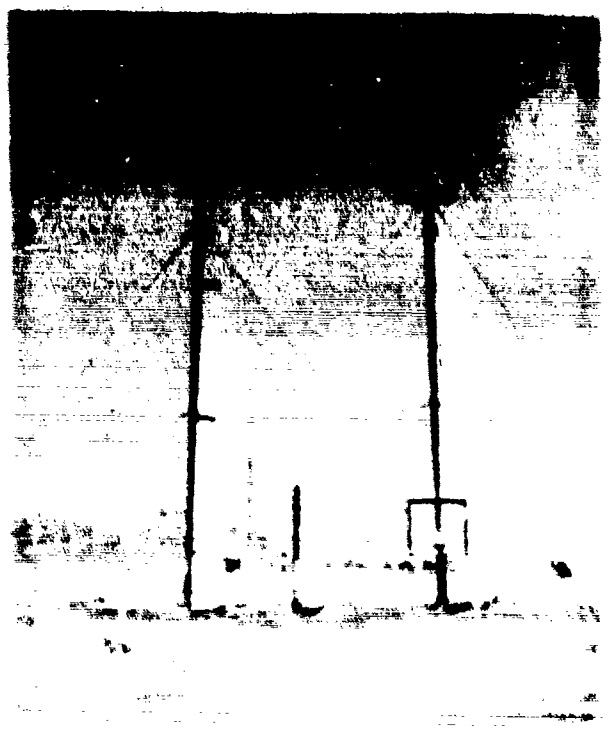

Fig. 1.3 -- Close-up of Wiancko pressure gauges installed in circular baffles on blast-line tower (the gauge on the right is not a Sandia Laboratory gauge)

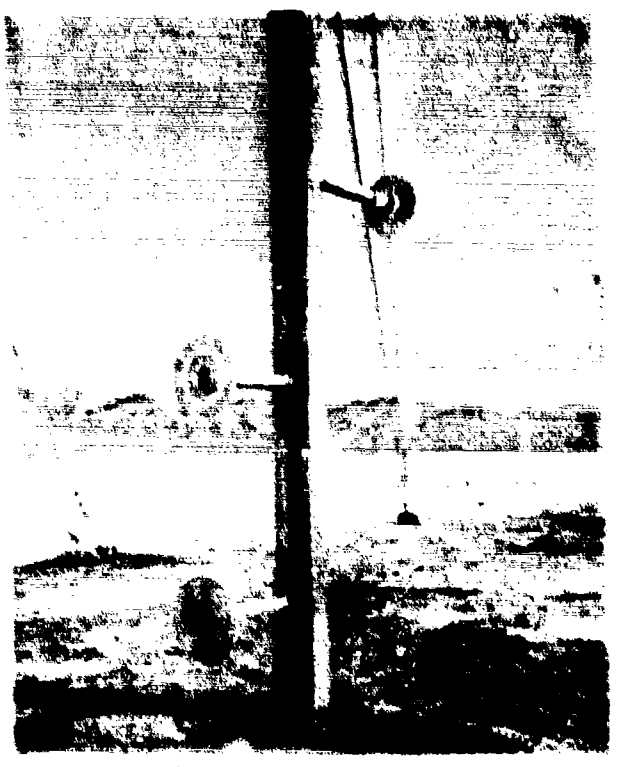

Fig. 1.4 -- View of blast line, looking toward ground zero. The 2-, 6-, and 35-ft pressure gauges are on the left-hand side of the tower on the right (the gauges on the right-hand side of this tower are not Sandia Laboratory gauges).

blast line. Any errors introduced by angles of incidence of 10° or less (as a result of the burst being off to either side of this plane) would be negligible.

The recording system used on Operation Tumbler was the same as that used on Operation Buster. The Wiancko gauge circuit is a balanced inductive bridge supplied by a 10-v, 3-kc carrier provided by the oscillator and power amplifier of the Consolidated Engineering Corporation Static-Dynamic Recording Measurement System D. After passing through the balancing network and attenuator, the output of the gauge is fed in turn to an amplifier, a demodulator, and finally to a recording galvanometer. All the equipment is operated on 110-v, 60-cps alternating current. The over-all response of the system, including the gauge, amplifier, demodulator, and galvanometer, is such that when a square wave pressure change is applied at the gauge, the galvanometer responds to within 95 per cent of its final output within 0.8-1.0 msec. Response of the system is therefore slightly faster than one msec. Stated another way, the system has a frequency response of 500 cps, and damping is approximately critical.

Calibration of the system consisted in applying three or four different static pressures to the gauge after it was installed in the field and recording the corresponding galvanometer displacements on photographic paper. On the first shot only one calibration was possible; on Shots 2, 3, and 4, however, all channels were recalibrated until successive calibrations varied by less than three per cent. The calibration standard was bourdon-type mechanical gauge which had been checked in the laboratory prior to use in the field.

The timing standard was a 500-cps signal from a crystal-controlled oscillator. When the frequency of this oscillator was checked following the Tumbler series of shots, it was found to be 0.6 per cent slow as compared with the 600-cps tone transmitted by radio WWV. All times recorded are the uncorrected times obtained from the oscillator.

A Telereader was used to convert recorded data to tabular form. Accuracy of the Telereader is considerably greater than that of the calibration procedure or the inherent accuracy of the over-all recording system. Recorded deflections may be read to an accuracy of 0.002 inch; maximum deflections, corresponding to peak pressures, were usually in the range of 0.5 to 1.0 inch.

It is doubtful whether the over-all accuracy of the field installation was greater than 5 per cent, but except for occasional obvious errors the accuracy of the measurements is believed to be within 10 per cent.

1.2 TEST RESULTS

Data from the four airbursts of Operation Tumbler have been summarized in Tables 1.3-1.6, compiled from plots of the Telereader tabulations. In addition to the peak pressures and arrival times, which are the quantities most accurately measured, positive and negative durations, positive and negative impulses, and maximum negative pressures are tabulated.

Figures 1.5-1.8* present composite data for all pressure measurements on Tumbler Shots 1-4. Note that the data obtained by Sandia Laboratory are essentially in agreement with those obtained by the Stanford Research Institute and the Naval Ordnance Laboratory. This agreement and the results observed on Tumbler Shot 4 have been interpreted as confirmatory evidence that the pressure measurements made on Operation Buster were valid.

Pressure-time curves for both the ground and tower gauges for Shots 1-4 are presented in Figs. 1.9-1.16. Figures 1.9 and 1.10 show rise times for the close-in stations on Shot 1 that may be slightly in excess of the time response of the system, which is one millisecond. The curves show some evidence of fluctuation at the peaks, the cause of which is not clearly understood. Other interesting features of these curves are the second positive pressure of small magnitude following the negative phase, and the peaking up of the pressure in the latter part of the negative phase (this peak, at the far-out stations, develops into a small second shock). As can be seen from Figs. 1.11 and 1.12, the curves for Tumbler Shot 2 are essentially the same as those for Shot 1; however, when comparing curves for corresponding stations and heights, bear in mind that the distances are not the same. The curves for Shot 3 (Figs. 1.13 and 1.14), which show only the positive phase of the pressure wave, do not differ appreciably from those for Shots 1 and 2.

Pressure waves observed on Shot 4 (Figs. 1.15 and 1.16), on the other hand, are similar to those found on Operation Buster. In their departure from the ideal they are the most entertaining of the lot. In Fig. 1.15 the pressure record labeled 1-0-P has been plotted from zero time to 1.4 seconds after zero time; the small initial wiggle immediately following zero time and decaying to zero at 10 msec is a transient electromagnetic signal, not a pressure, and is associated with the strong electromagnetic radiation at zero time. The gradual rise to about 7 psi at 0.12 second is independent of the shock wave and is discussed later in this report under Preshock Pressures. The first significant pressure increase takes place at 0.28 second

*These graphs have been taken from the Preliminary Report of Operation Tumbler, Part II - Preliminary Results and Analysis, TC-1952-0, prepared by the Armed Forces Special Weapons Project (no date).

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Table 1.3 -- **RESULTS OF TUMBLER SHOT 1 (APRIL 1, 1952)**
Radiochemical yield (as of June 10, 1952): 1.06 kt
Location of burst point: 67 ft E, 122 ft N from intended ground zero
Height of burst: 793 ft

Station	Distance[a] (ft)	Slant range[a] (ft)	Peak positive pressure (psi)	Duration of positive phase (msec)	Positive impulse (psi-sec)	Maximum negative pressure (psi)	Duration of negative phase (msec)	Negative impulse (psi-sec)	Time of arrival (sec)
0-0-P	177	813							
1-0-P	357	869	19.4	215	1.6	-3.0	920	-1.65	0.367
2-2-P	590	986.8	15.6	239	1.42	-2.2	900	-1.25	0.448
2-6-P		983.4	15	242	1.36	-2.3	890	-1.29	0.448
2-20-P		972.4	8.3[b]	252	0.8[b]	-1.3	840[b]	-0.7[b]	0.439
2-35-P		960.5	11.8	262	1.2	-1.85	857	-1.05	0.431
3-0-P	833	1,150	11.1	257	1.10	-1.9	866	-0.91	0.567
5-0-P1	1,328	1,546	9.7	274	0.80	-1.5	990	-0.90	0.879
5-0-P2			9.7	286	0.80	-1.3	985	-0.78	0.879
6-2-P	1,577	1,765	7.2	303	0.67	-1.1	944	-0.61	1.053
6-6-P			7.8	296	0.68	-1.25	951	-0.676	1.053
6-20-P			7.3	290	0.69	-1.3	960	-0.74	1.051
6-35-P			6.3	309	0.71	-1.2	935	-0.65	1.045
7-0-P	1,825	1,990	6.42	330	0.65	-0.92	940	-0.52	1.236
9-0-P	2,573	2,692	3.4	341	0.43	-0.70	1,100	-0.43	1.820
11-0-P	4,069	4,147	1.72	406	0.257	-0.36	1,030	-0.221	3.064

[a]These distances are actual distances, computed from the observed location of the burst point, which was determined to within ±20 feet.

[b]Obviously in error.

NOTE: In nearly every instance a small positive pressure of 0.2-0.5 psi follows the end of the negative phase by 1/4 second.

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Table 1.4 -- RESULTS OF TUMBLER SHOT 2 (APRIL 15, 1952)
Radiochemical yield (as of June 10, 1952): 1.19 kt
Location of burst point: 84 ft E, 143 ft S from intended ground zero
Height of burst: 1,100 ft

Station	Distance[a] (ft)	Slant range[a] (ft)	Peak positive pressure (psi)	Duration of positive phase (msec)	Positive impulse (psi-sec)	Maximum negative pressure (psi)	Duration of negative phase (msec)	Negative impulse (psi-sec)	Time of arrival (sec)
1-0-P	633	1,277	10.4	263	1.02	-1.94	1,320	-1.00	0.674
2-2-P	1,378	1,769	5.8	305	0.71	-1.3	909	-0.69	1.065
2-6-P			6.4	296	0.79	-1.3	1,030	-0.72	1.063
2-20-P			5.8	312	0.71	-1.2	1,165	-0.65	1.055
2-35-P			5.0	313	0.61	-1.2	1,394	-0.65	1.047
3-0-P	2,126	2,398	5.1	324	0.50	-0.92	1,600	-0.52	1.584
5-0-P1	3,625	3,791	2.6	366	0.32	-0.57	972	-0.32	2.774
5-0-P2			2.5	412	0.35	-0.42	1,090		2.774
6-2-P	4,375	4,514	1.98	408	0.26	-0.39	972	-0.23	3.400
6-6-P			1.83	401	0.26	-0.45	1,027	-0.25	3.400
6-20-P			1.83	430	0.25	-0.34	972	-0.19	3.400
6-35-P			2.01	419	0.28	-0.34	932		3.399
7-0-P	5,125	5,244	1.30	442	0.21	-0.31	914	-0.17	4.034
9-0-P	7,375	7,458	1.02	441	0.17	-0.28	1,065	-0.16	5.974
11-0-P	11,673	11,723	0.45	500	0.072	-0.13	1,213	-0.078	9.740

[a]These distances are actual distances, computed from the observed location of the burst point, which was determined to within ±20 feet.

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Table 1.5 -- RESULTS OF TUMBLER SHOT 3 (APRIL 22, 1952)
Radiochemical yield (as of June 10, 1952): 30 kt
Location of burst point: 80 ft S, 124 ft W from intended ground zero
Height of burst: 3,447 ft

Station	Distance[a] (ft)	Slant range[a] (ft)	Peak positive pressure (psi)	Duration of positive phase (msec)	Positive impulse (psi-sec)	Maximum negative pressure (psi)	Duration of negative phase (msec)	Negative impulse (psi-sec)	Time of arrival (sec)
1-0-P	659	3,509	11.0	751	3.12	-2.0	3,100	-3.6	1.749
2-2-P	1,404	3,722	9.6	809	2.81	-1.6	2,900	-2.67	1.916
2-6-P			10.3	811	3.02	-1.8	3,000	-3.00	1.914
2-20-P			8.5	840	2.62	-1.3	3,200	-2.31	1.903
2-35-P			10.3	820	3.10	-1.8	3,500	-3.22	1.894
3-0-P	2,153	4,064	9.6	900	3.26	-1.5	2,400	-2.18	2.187
5-0-P1	3,652	5,022	6.6	880	2.17	-1.28	3,200	-2.38	2.966
5-0-P2			6.25	936	2.05	-0.85	3,300	-1.65	2.966
6-2-P	4,401	5,591	5.7	909	1.83	-1.0	3,300	-1.82	3.434
6-6-P			5.7	916	1.88	-1.1	3,500	-2.01	3.432
6-20-P			6.4	940	2.05	-1.1	3,300	-2.09	3.425
6-35-P			6.4	882	1.97	-1.2	3,200	-2.02	3.418
7-0-P	5,151	6,139	6.1	960	1.93	-0.95	3,400	-1.70	3.939
9-0-P	7,401	8,164	4.2	1,000	1.22	-0.70	3,300	-1.33	5.598
11-0-P		12,198	2.1	1,200	0.69	-0.70			9.039

[a]These distances are actual distances, computed from the observed location of the burst point, which was determined to within ±20 feet.

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Table 1.6 -- RESULTS OF TUMBLER SHOT 4 (MAY 1, 1952)
Radiochemical yield (as of June 10, 1952): 19.6 kt
Location of burst point: 153 ft W, 140 ft S from intended ground zero
Height of burst: 1,040 ft

Station	Distance[a] (ft)	Slant range[a] (ft)	Peak positive pressure (psi)	Duration of positive phase (msec)	Positive impulse (psi-sec)	Maximum negative pressure (psi)	Duration of negative phase (msec)	Negative impulse (psi-sec)	Time of arrival (sec)
1-0-P	599	1,200	72	330	7.0	-6	1,040	-4.1	0.281
2-2-P	1,341	1,697	38						0.480
2-6-P			35						0.482
2-20-P			22						0.489
2-35-P			25						0.497
3-0-P	2,090	2,333	9.2	700	3.18	-2.2	3,200	-3.24	0.897
5-0-P1	3,587	3,735	6.2	817	1.98	-1.6	3,400	-1.95	1.957
5-0-P2			5.6	863	1.80	-1.0	3,450	-1.14	1.957
6-2-P	4,337	4,459	4.35	900	1.52	-1.0	3,600	-1.24	2.521
6-6-P			4.5	900	1.62	-1.1	3,400	-1.31	2.521
6-20-P			4.95	930	1.72	-1.04	3,250	-1.36	2.521
6-35-P			4.95	920	1.57	-1.0	3,000	-1.21	2.521
7-0-P	5,087	5,192	3.6	970	1.40	-0.98	3,400	-1.27	3.105
9-0-P	7,337	7,407	2.15	1,040	0.94	-0.8	3,800	-1.13	4.927
11-0-P	11,637	11,682	1.10	1,370	0.70	-0.35	3,200	-0.47	8.558

[a]These distances are actual distances, computed from the observed location of the burst point, which was determined to within ±20 feet.

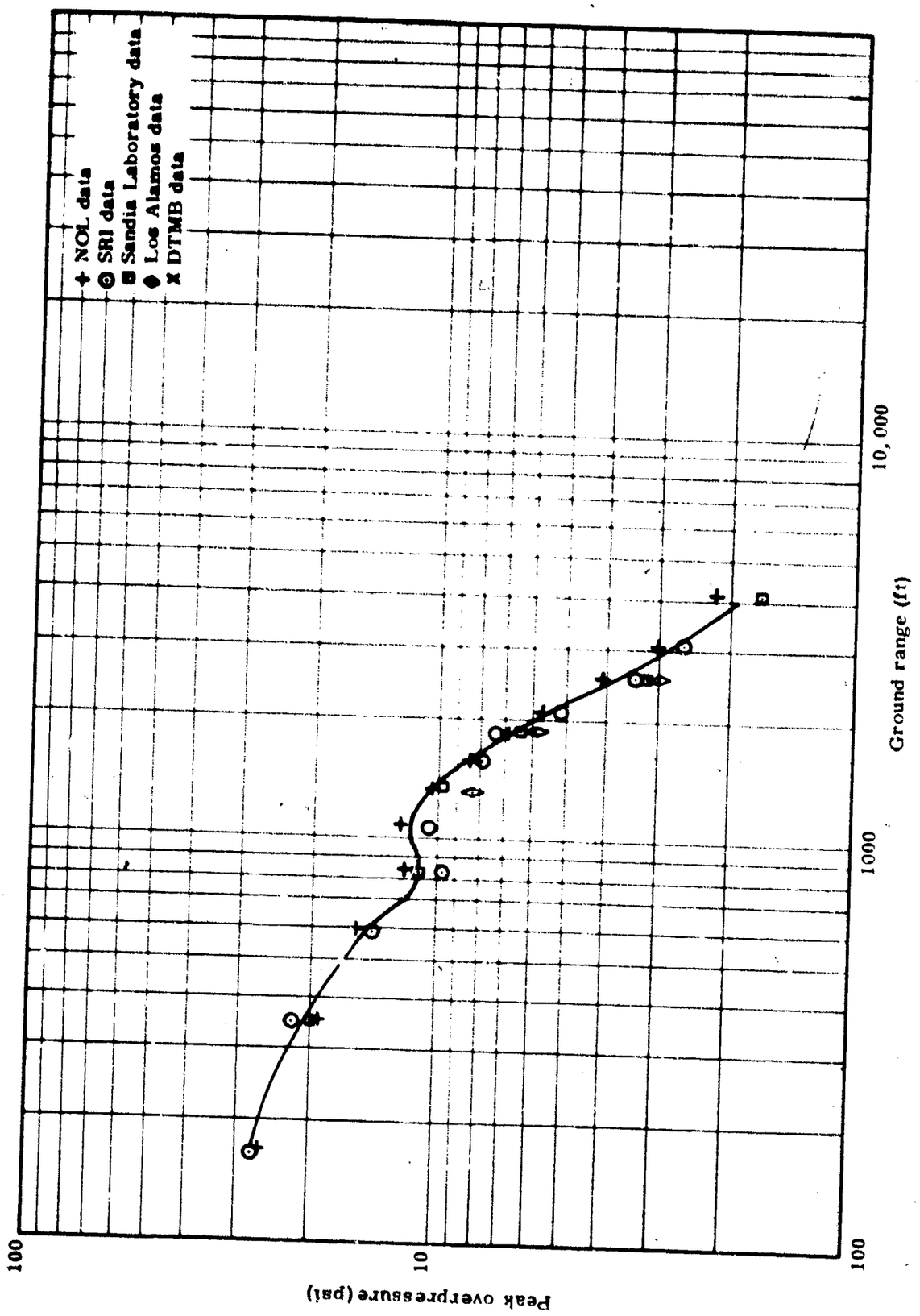

Fig. 1.5 -- Composite pressure-distance curve for Tumbler Shot 1 presenting data from all participating organizations

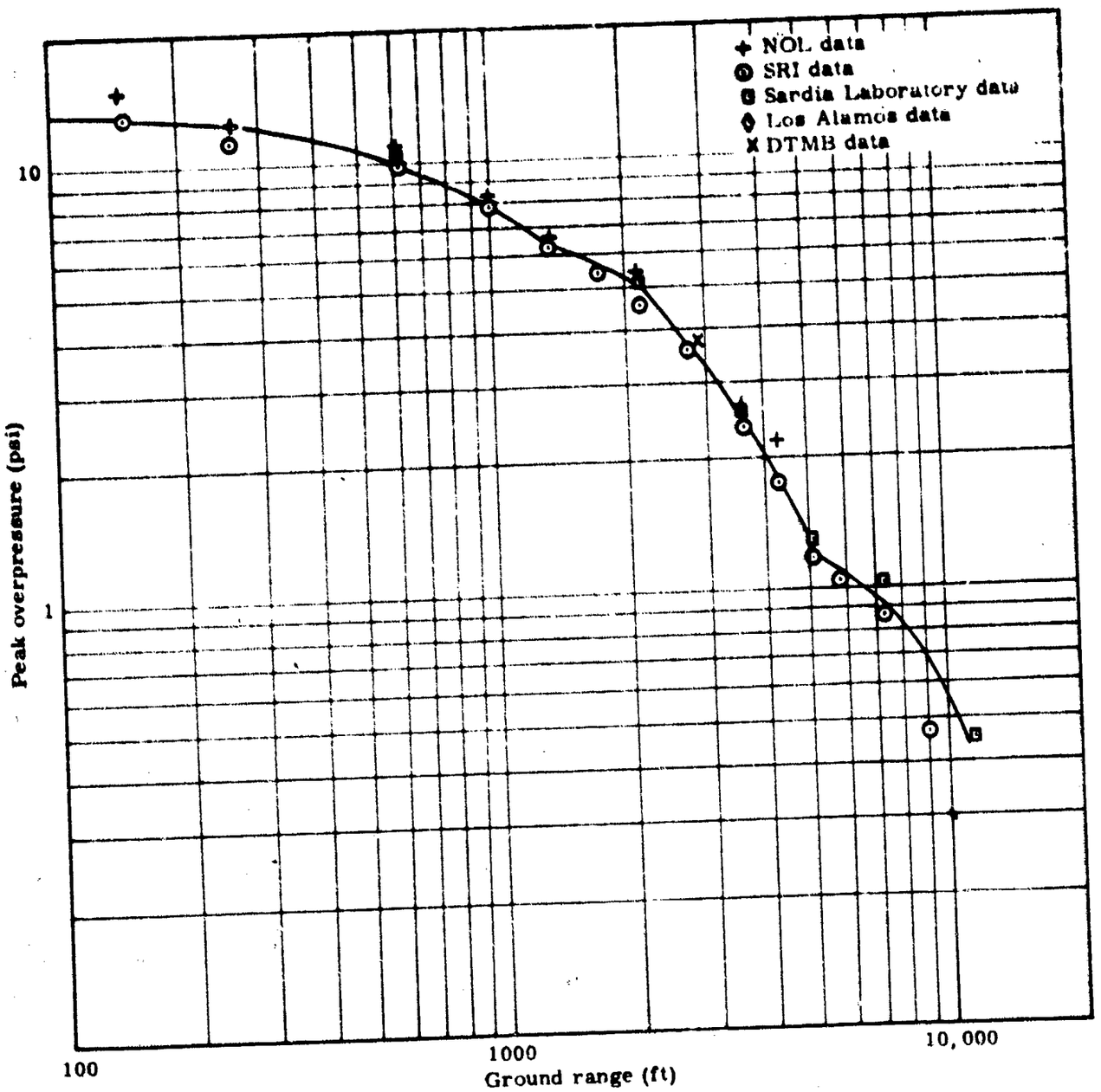

Fig. 1.6 -- Composite pressure-distance curve for Tumbler Shot 2 presenting data from all participating organizations

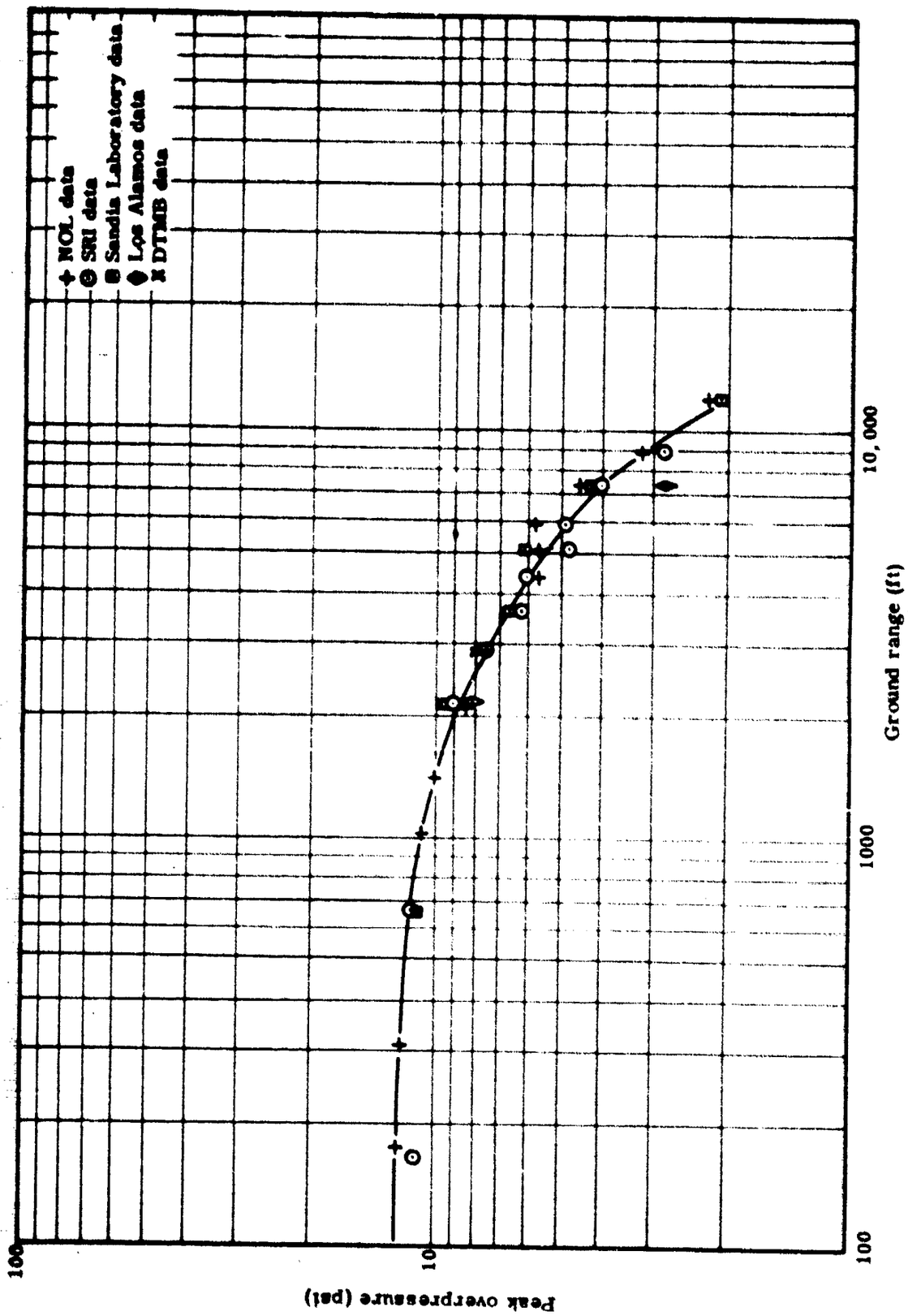

Fig. 1.7 -- Composite pressure-distance curve for Tumbler Shot 3 presenting data from all participating organizations

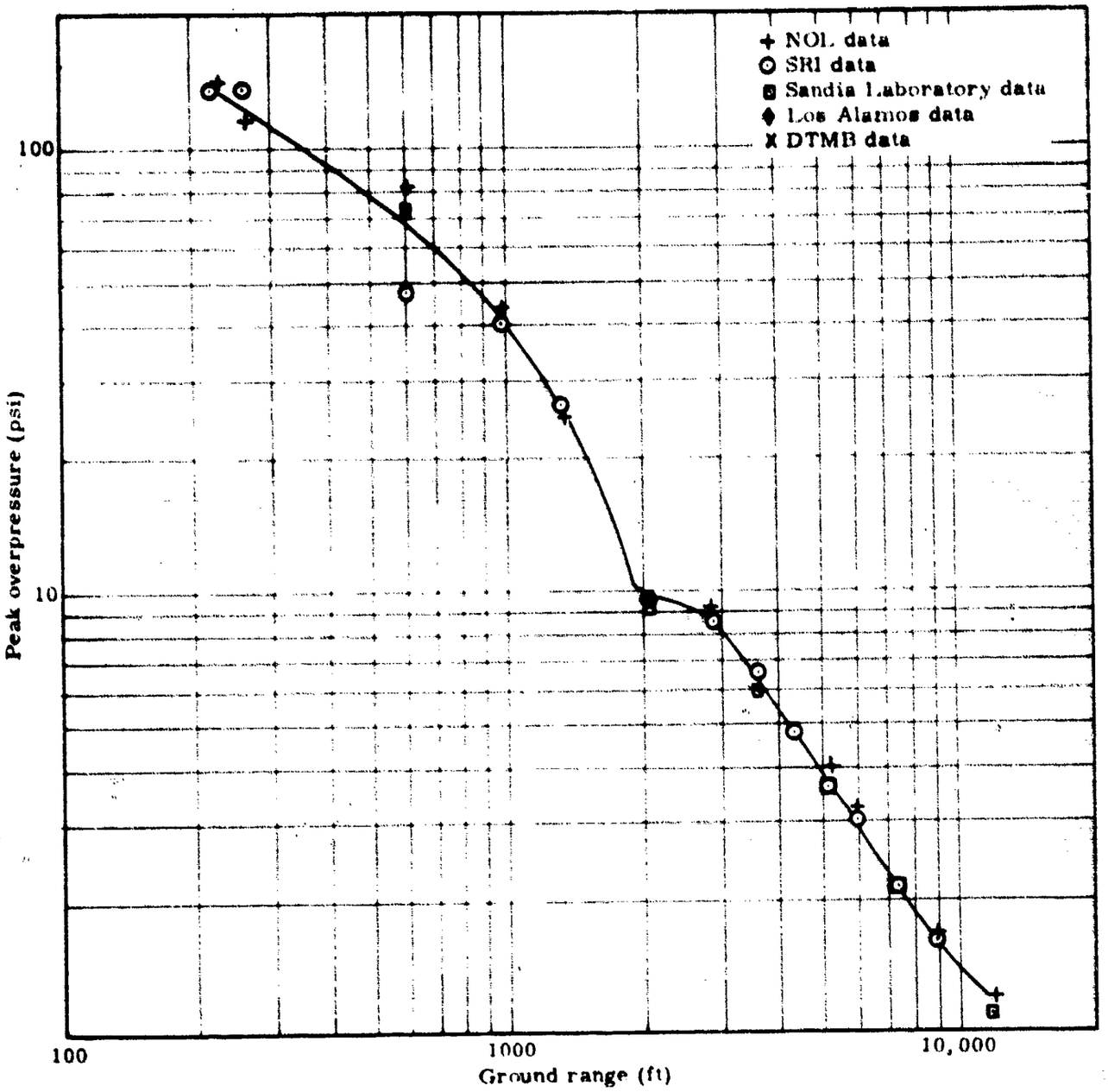

Fig. 1.8 -- Composite pressure-distance curve for Tumbler Shot 4 presenting data from all participating organizations

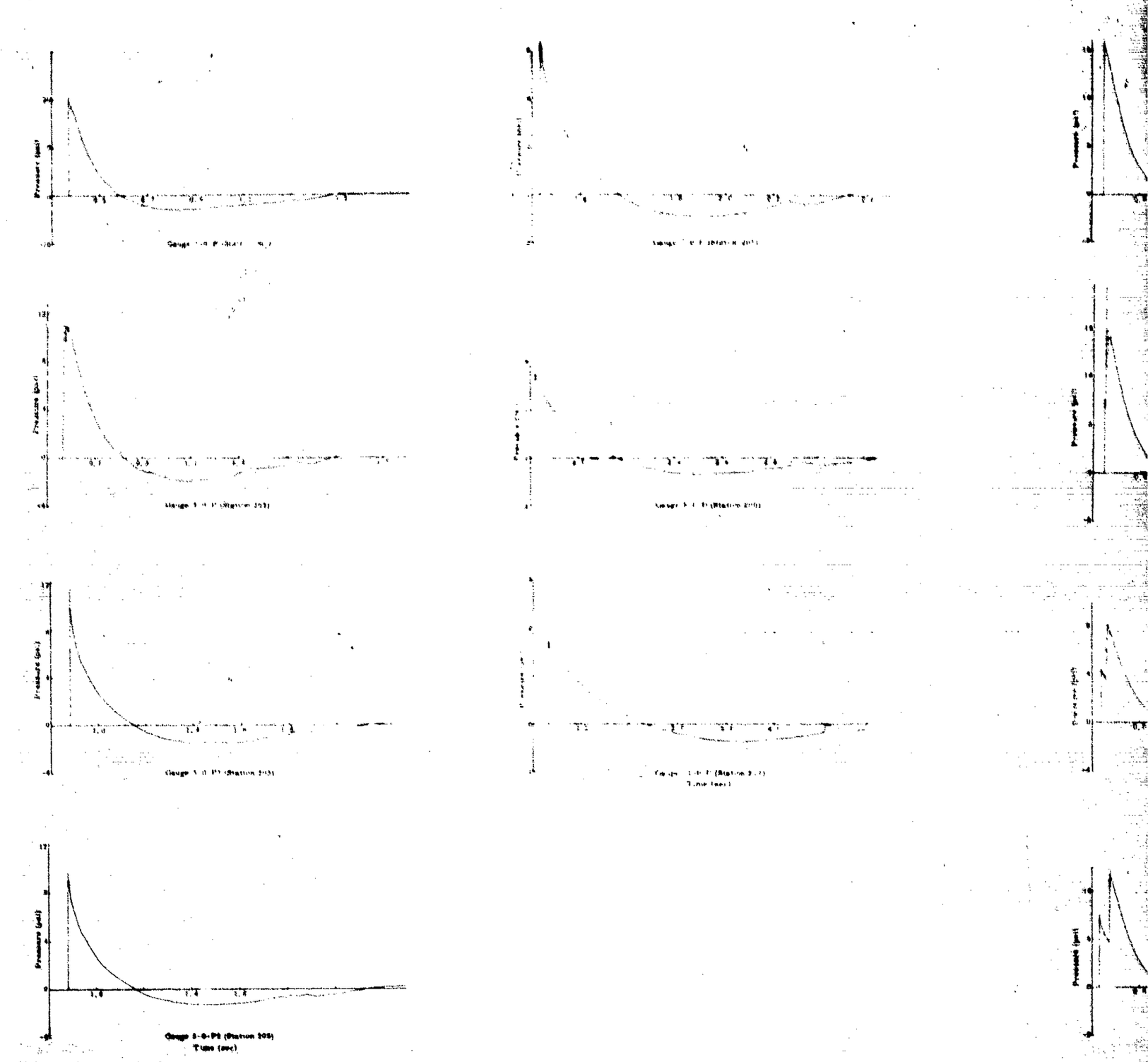

Fig. 1.9 -- Pressure-time curves for ground-baffle gauges on Tumbler Shot 1 (April 1, 1952)

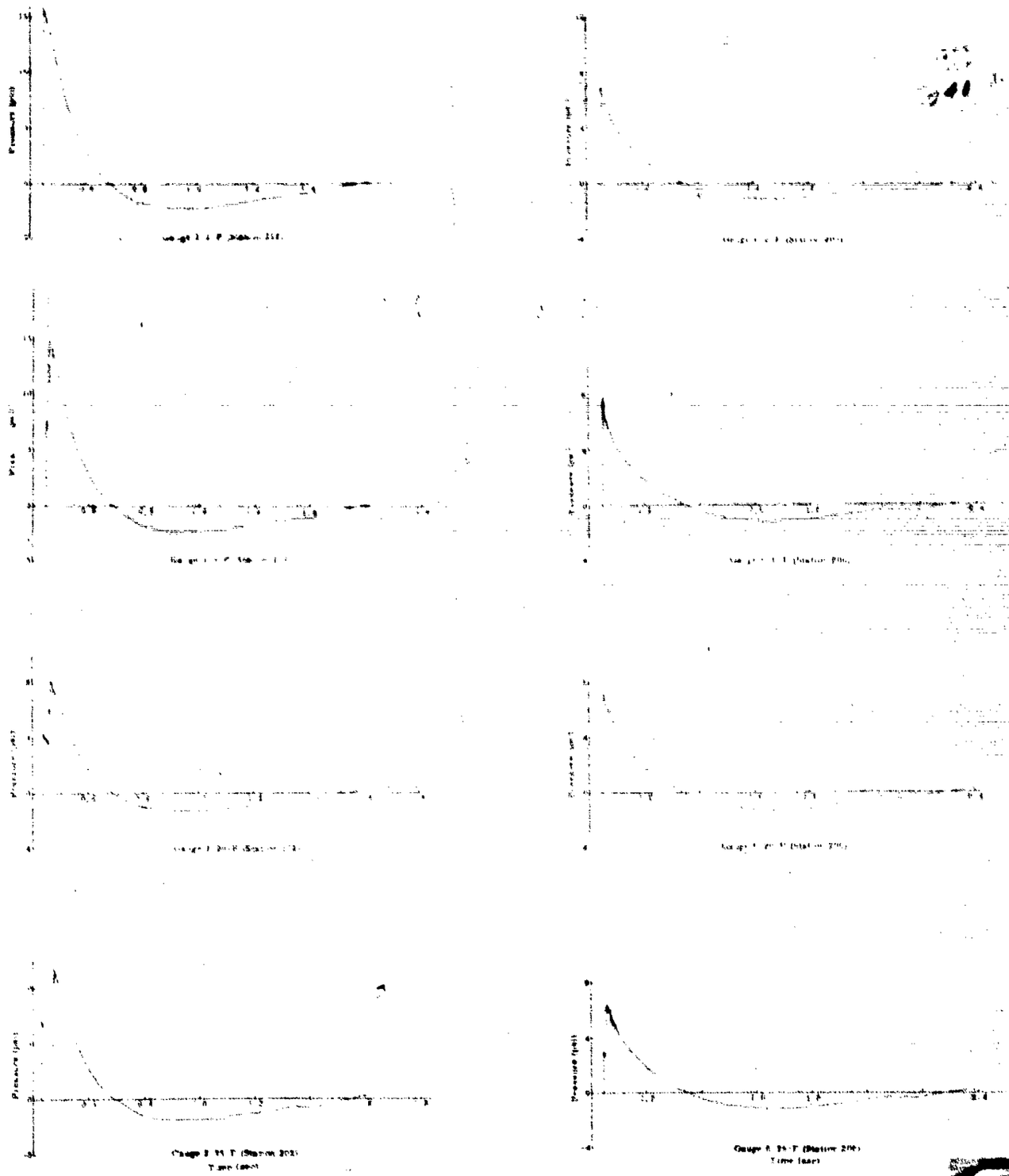

Fig. 1.10 -- Pressure-time curves for tower gauges on Tumbler Sh 1 (April 1, 1952)

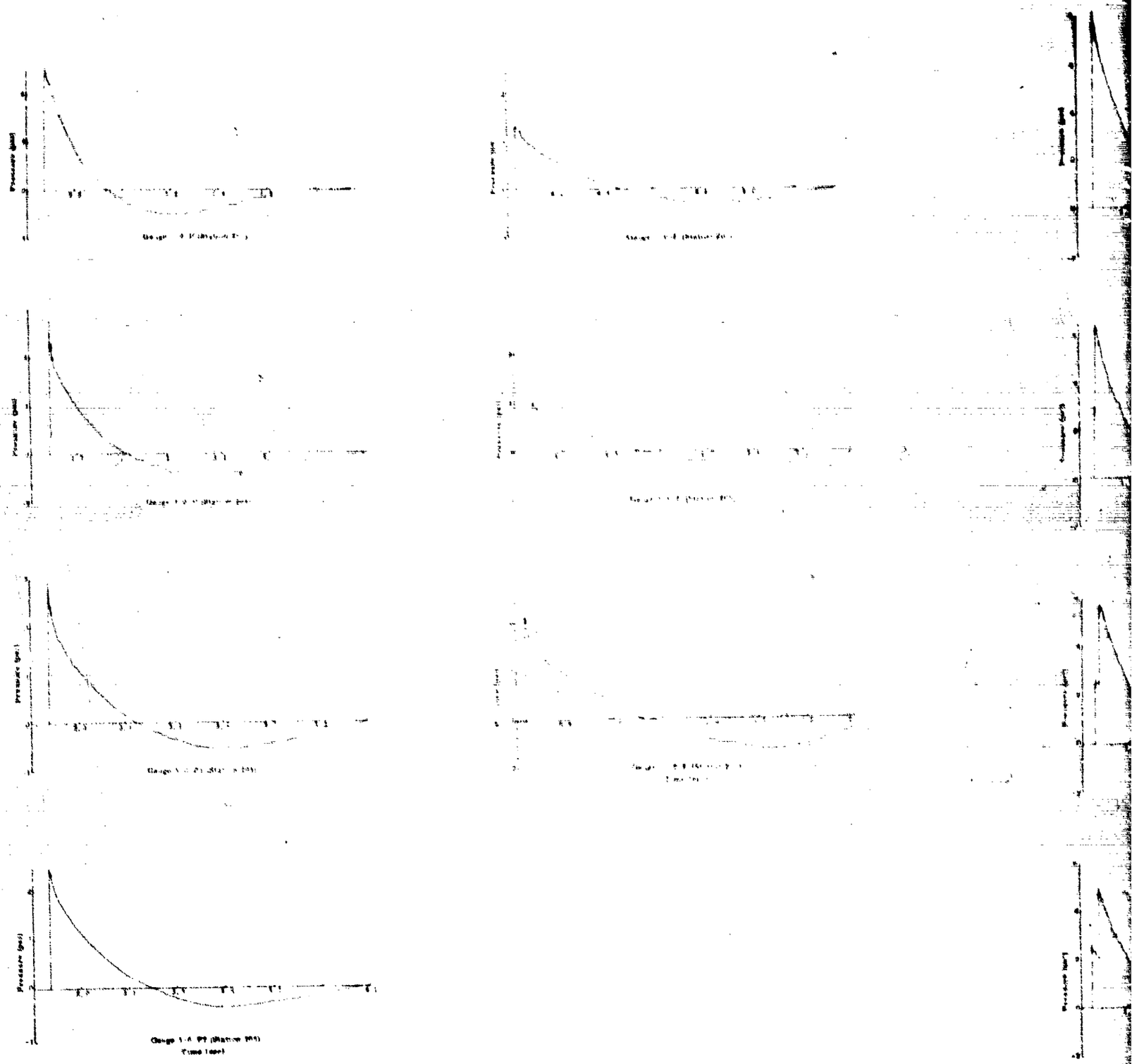

Fig. 1.11 -- Pressure-time curves for ground-baffle gauges on Tumbler Shot 2 (April 15, 1952)

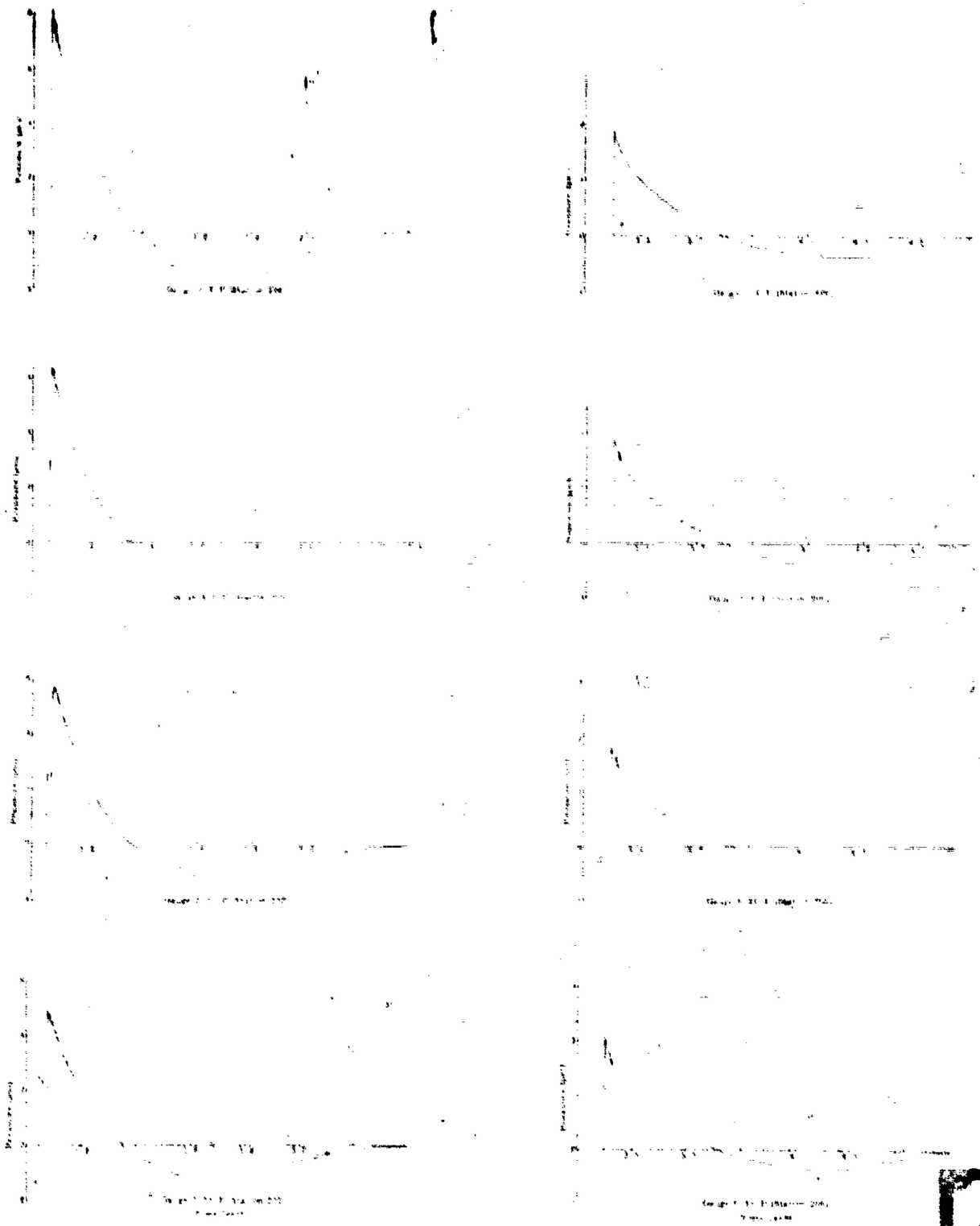

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Fig. 1.12 -- Pressure-time curves for tower gauges on Tumbler Shot 2 (April 15, 1952)

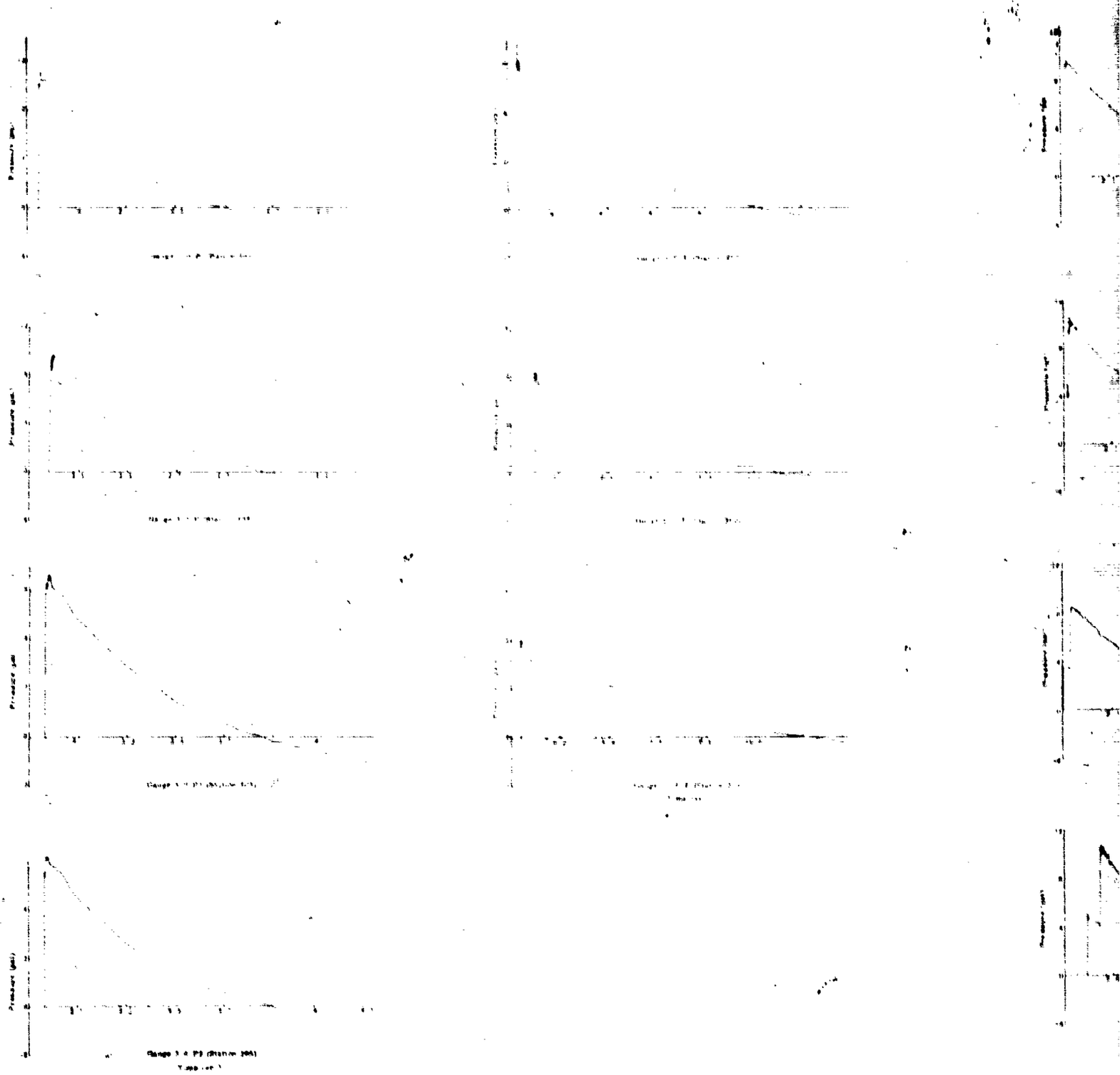

Fig. 1.13 -- Pressure-time curves for ground-baffle gauges on Tumbler Shot 2 (April 22, 1952)

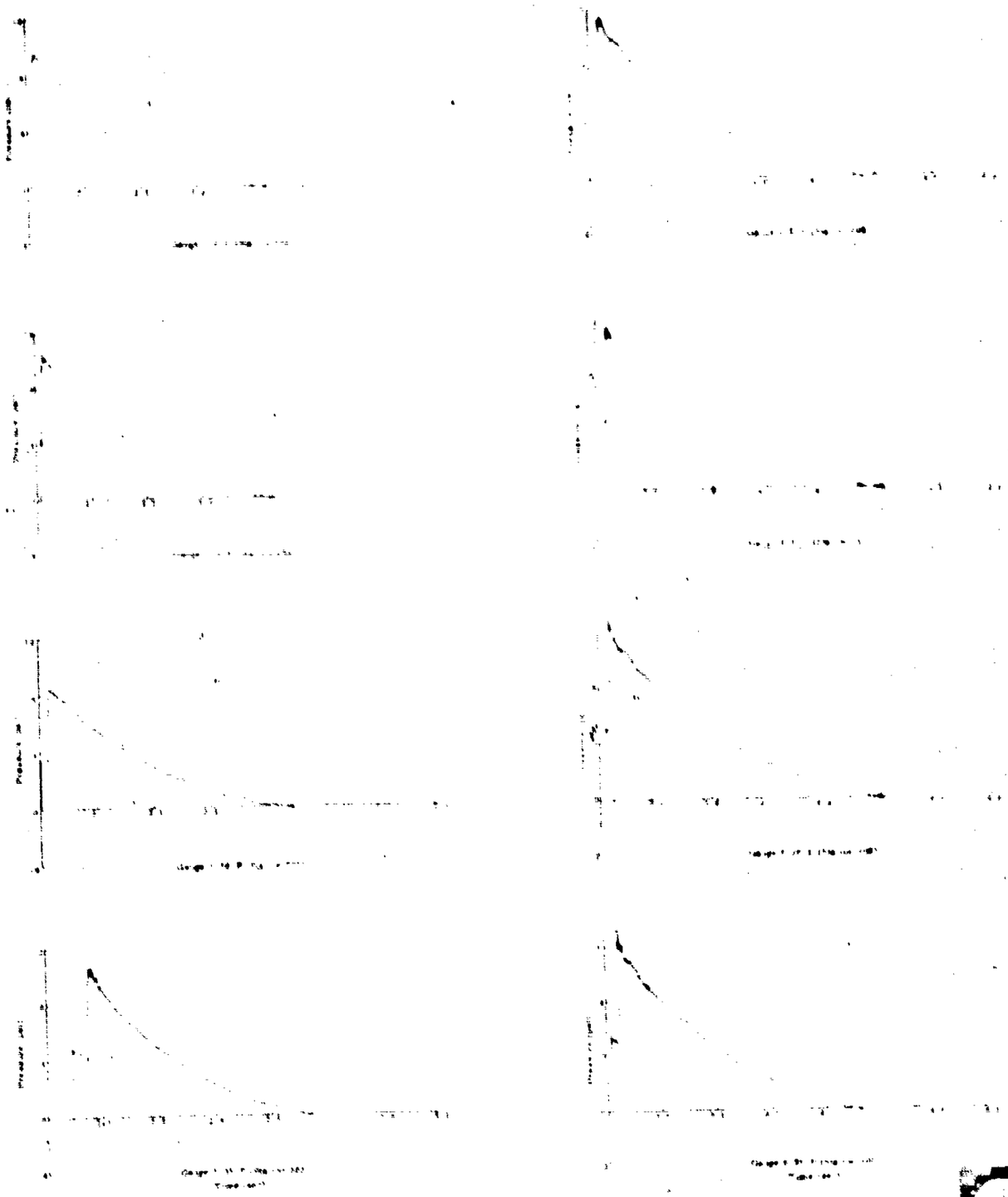

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Fig. 1.14 -- Pressure-time curves for tower gauges on Tumbler Shot 3 (April 22, 1952)

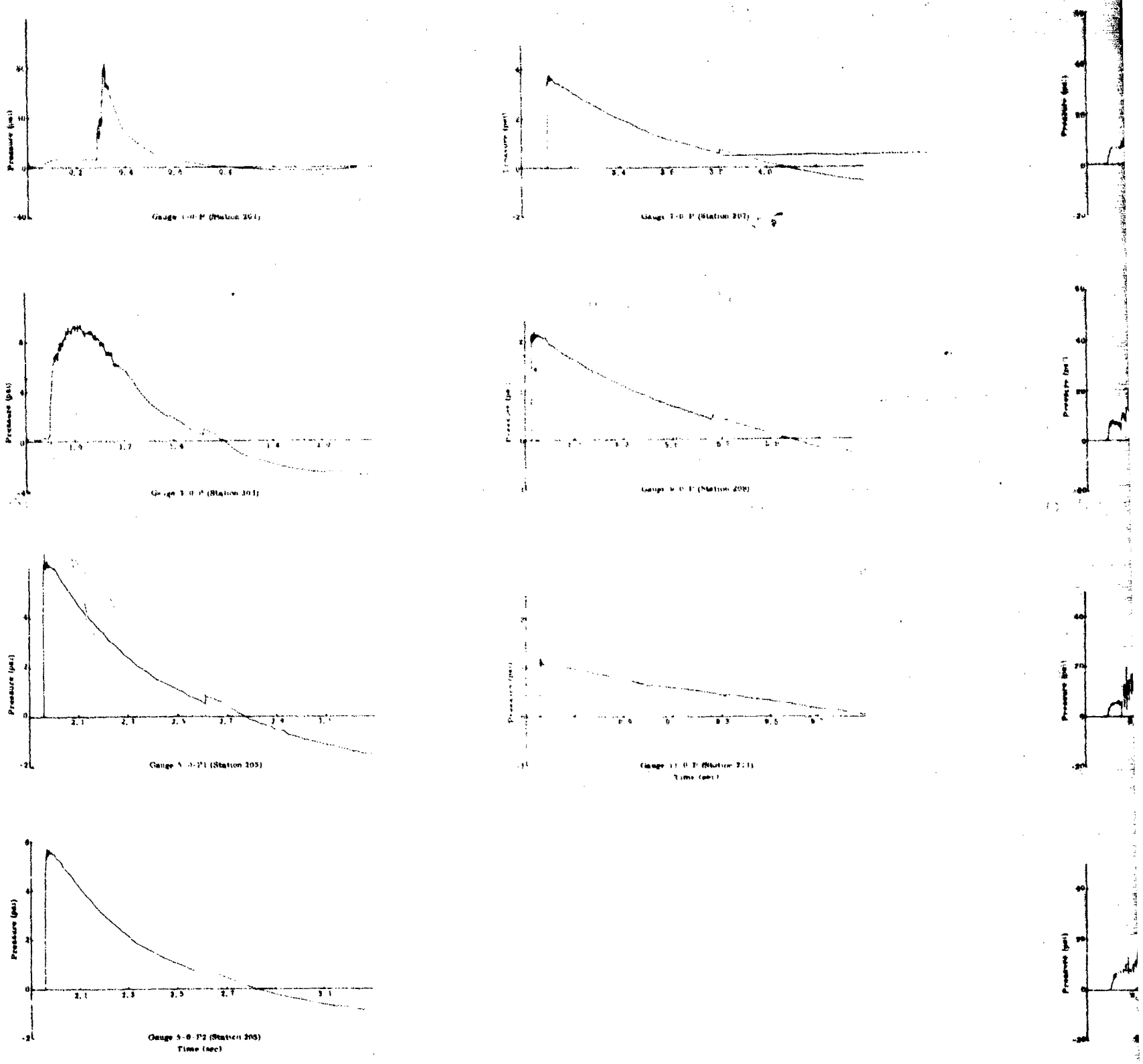

Fig. 1.15 -- Pressure-time curves for ground-baffle gauges on Tumbler Shot 4 (May 1, 1952)

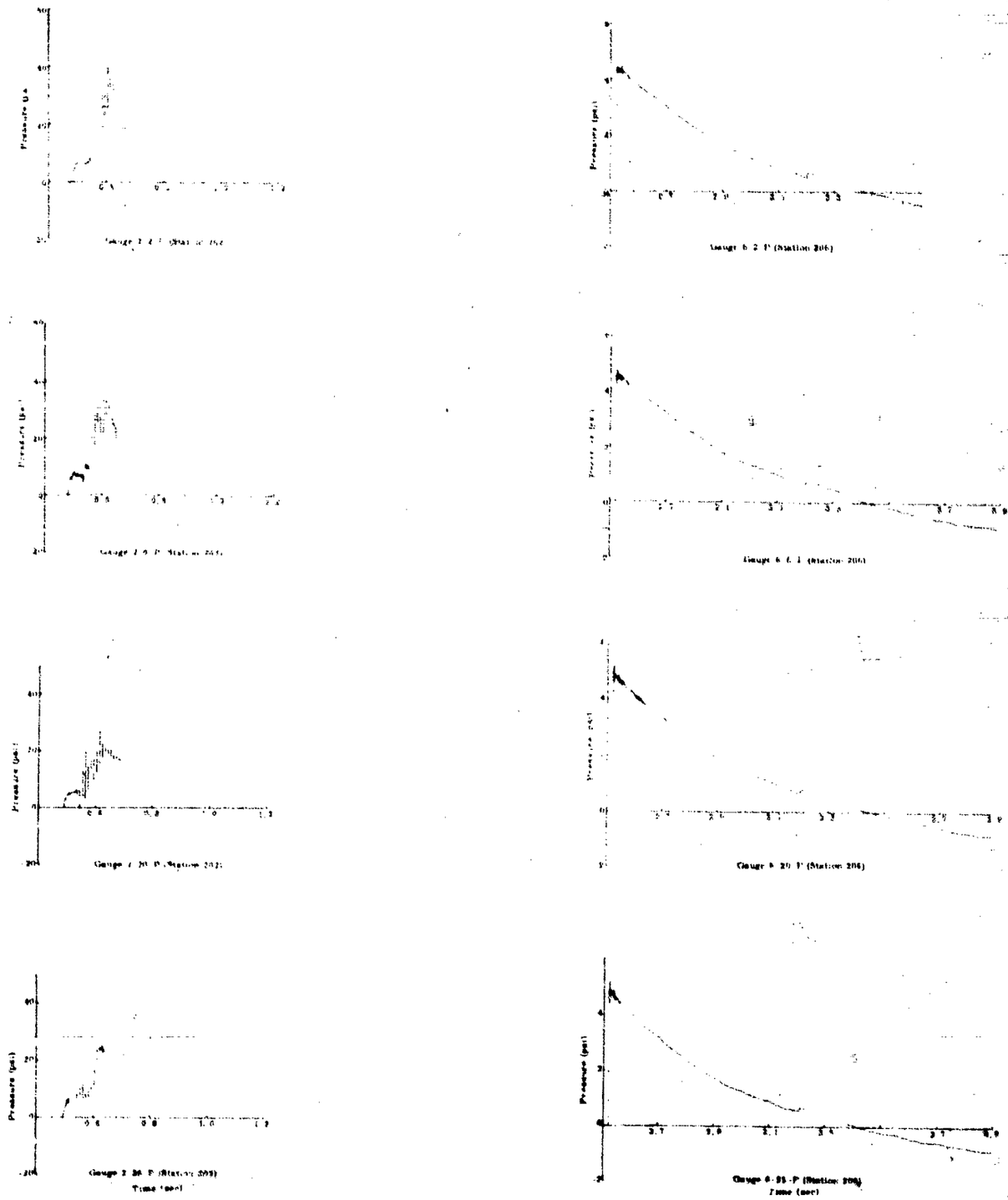

Fig. 1.16 -- Pressure-time curves for tower gauges on Tumbler Shot 4 (May 1, 1952)

and may be identified with the so-called 'precursor' (Fig. 1.17) observed in photographs at stations as close as in Station 202.

This precursor, a forerunner of the main pressure rise associated with the primary pressure wave, has a slower rise time and smaller amplitude than the main shock wave and is absorbed into the main shock front at a distance of approximately 2000 feet from ground zero. Formation of a precursor was also observed on Buster Shot Charlie; pressure-time records indicated that it formed at some point beyond 400 feet* from ground zero and was absorbed into the main shock wave in the vicinity of 2000 feet from ground zero. Re-examination of photographs of Buster Shot Charlie seems to corroborate the evidence of the pressure-time records; photographs also seem to show formation of a precursor wave on Buster Shot Dog and do show the dust pedestal associated with the presumed precursor on Shot Easy.

A suggested mechanism for the formation of the precursor is the absorption of thermal energy by the ground and release of water of crystallization by the constituents of the earth's crust, causing a sudden evolution of a relatively large amount of heated material.† The presence of this heated material throughout the region above ground level is presumed to affect substantially the progress of the shock wave through it; it becomes a region of velocity dispersion. Since the postulated temperatures are high, this effect is a strong one, and a forerunner is clearly possible.

Ordinarily (except in the region where the Mach stem exceeds 50 feet) at stations where pressure measurements are made at levels above ground level, increases are observed first at the highest level and last at the level nearest the ground. On Tumbler Shot 4, however, arrival of the precursor at the various levels causes the order of arrival to be reversed; for instance data on time of arrival at Station 202 (Table 1.6) indicate that the precursor arrives at the 35-ft level 17 milliseconds after it arrives at the 2-ft level. This 'toeing out' of the

*Results obtained by the Stanford Research Institute on Tumbler Shot 4 from gauges OB (ground range 233 feet) and 2B (ground range 260 feet) were similar to those from Buster Shot Charlie in that the precursor is not evident at the stations close to ground zero; these results are presented in Preliminary Report - Operation Tumbler Project 1.2 - Air Pressure vs Time, Stanford Research Institute report SU-Q-12, May 9, 1952, by E. B. Doll.

†Bates, J. J., et al, The Thermal and Optical Characteristics of Nevada Sand, Material Laboratory, New York Naval Shipyard, report No. ND-Q-63, May 12, 1952; see also Bleakney W., Interaction of a Shock Wave with a Thermal Boundary Layer, Princeton University Shock Wave Laboratory memorandum report, January 11, 1952; Porzel, F. B., Height of Burst for Atomic Bombs, Los Alamos Scientific Laboratory preliminary report LA-1406 (to be published).

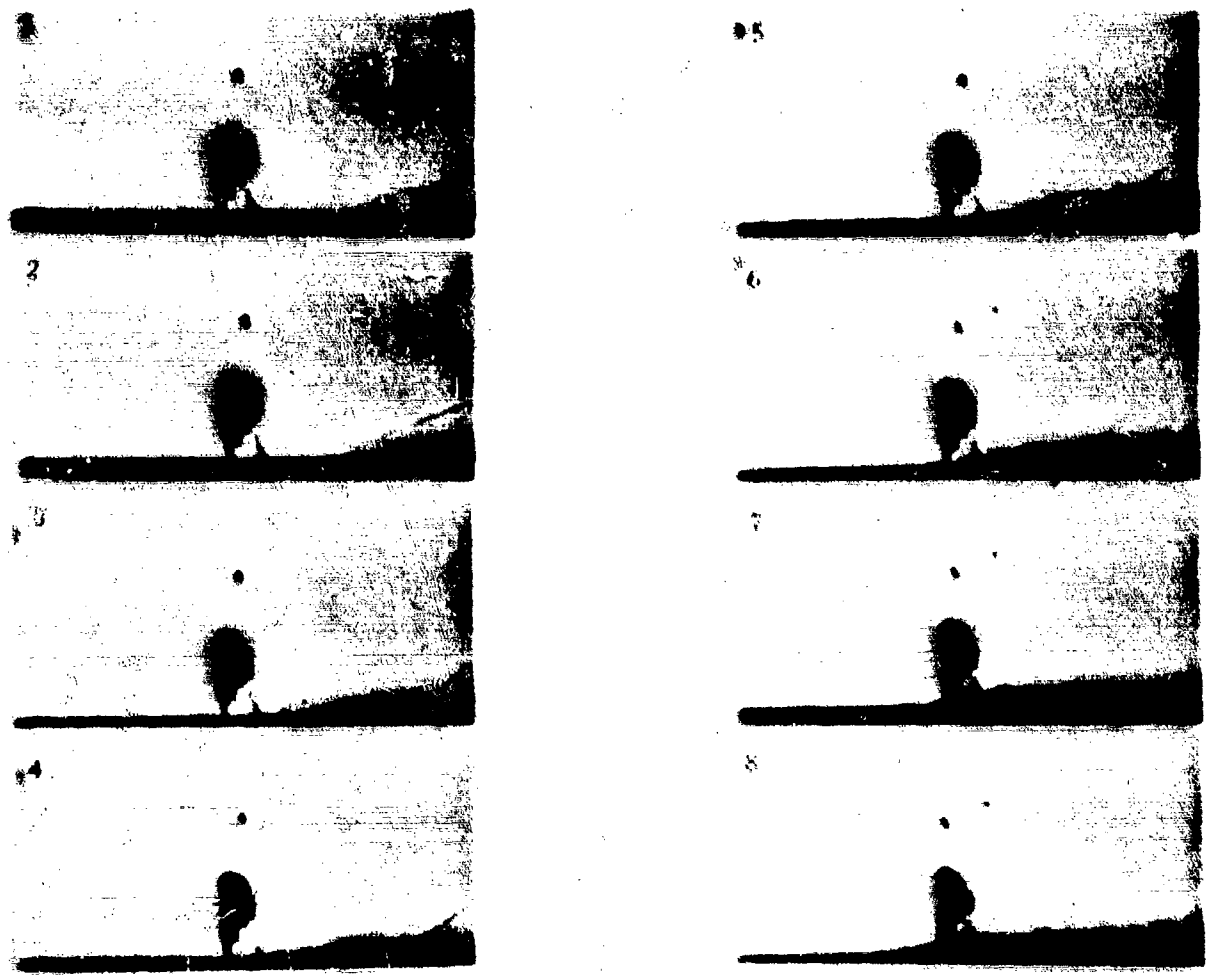

Fig. 1.17 -- Stills from motion picture of shock wave, photographed at Station 202 on Tumbler Shot 4 by Edgerton, Germeshausen and Grier for the Los Alamos Scientific Laboratory project for mass motion photography. These stills are spaced at 8-frame intervals; in frame 1 the precursor is entering at the lower right, and in frame 3 the reflected pressure wave appears at the lower right. In frame 6 the precursor appears to pass through the top of the 50-ft tower and extends just beyond the base of the JATO smoke cloud; the incident wave has just passed the smoke puff immediately above the JATO cloud, and its intersection with the reflected wave is barely visible. In frame 8 the incident wave has flattened the top right side of the JATO cloud. Note the dust rising above the ground following the precursor and preceding the arrival of the incident and reflected shock waves.

precursor wave is clearly evident in motion pictures taken at Station 202 on Shot 4. The tower on which the gauges were mounted was blown down by the blast (Fig. 1.18), and the record (Fig. 1.16) terminates at 0.69 second. The pressure wave exhibits violent oscillations (indicated by plotting maxima and minima for 10-msec intervals) which may be attributable in part to the presumably violent motion of the tower as well as to turbulence within the heavily dust-laden pressure wave. Figure 1.15 is of interest mainly because it illustrates the recovery of the shock wave, beyond Station 205 the shock wave has a normal appearance.

Thus all shock waves for Tumbler Shots 1, 2, and 3 are of conventional appearance except for some chopping of the peaks and somewhat slow rise times at some stations near ground zero. Tumbler Shot 4, on the other hand, produced a pressure wave that differs markedly in the overpressure region of 8-60 psi from those of the other shots of the series and resembled more closely those observed on the Greenhouse and Buster shots.

1.3 HEIGHT-OF-BURST CHART

The Tumbler-Snapper series of test shots has contributed more than half the data for an experimentally-determined height-of-burst chart. These data were combined with those from Buster measurements, the Greenhouse Easy Shot, and the Jangle surface shot* to construct the chart presented as the frontispiece to this report. All points represent experimentally determined pressures from actual bursts of atomic weapons, to which altitude corrections have been applied. Distances have been scaled for both altitude and yield.†

Fig. 1.18 -- Post-shot view of gauge tower at Station 202 on Tumbler Shot 4, which was blown down by the blast. Note the broken baffle plate in the foreground; it is not certain whether this is a Sandia gauge, but in all probability it was blown in from another station.

Empirical or theoretical height-of-burst curves, such as those based on measurements

*Howard, W. J., and Jones, R. D., Free Air Pressure Measurements for Operation Jangle by Project 1.4, Sandia Corporation report SC-2261(Tr), February 19, 1952

†Sachs, R. G., The Dependence of Blast on Ambient Pressure and Temperature, Ballistic Research Laboratory report BRL-466, May 15, 1944

from experimental high-explosive shots and presented in LA-743R and SC-1516(Tr), have been deliberately omitted as being prejudicial. Thus the new height-of-burst chart presents information based only on data from nuclear explosions.

There are still no experimental data for scaled heights of burst greater than 1000 feet. As can be seen from the chart, these data are needed to establish the burst heights which will give areas of maximum radius for overpressures of 4-8 psi. In particular, a burst at a scaled height of 1,250 feet would provide valuable supplementary information on the shapes of the isobars for 4-8 and perhaps 10-12 psi.

Tumbler Shots 2 (1.19 kt) and 3 (30 kt) produced strong evidence regarding pressures at scaled heights of approximately 1000 feet since measured pressures for these two shots were essentially the same at equal scaled distances. This agreement leads one to conclude that it is valid to scale pressure-distance curves over the range of 1 to 30 kt for bursts at a 1000-ft scaled height.

On the other hand, although the scaled height of burst for Tumbler Shot 1 (1.06 kt) was selected to be the same as that for Buster Shot Baker (3.4 kt), pressures for Buster Baker were considerably lower than for Tumbler Shot 1 at equal scaled distances from ground zero. Similarly, although pressures measured for bursts at a 400-ft scaled height (Tumbler Shot 4 and Buster Shots Charlie and Easy, 14-31 kt) are somewhat scattered, they lie well below those anticipated prior to Operation Buster. It is currently conjectured that these discrepancies in measured pressures are at least partially caused by the thermal effects associated with the formation of the precursor found on shots of large yield at low elevations.

On all shots of the Buster and Tumbler series at scaled heights greater than 600 feet the thermal energy has been less than 90 cal/cm^2 at ground zero, compared with a thermal energy in excess of 300 cal/cm^2 for shots at scaled heights in the vicinity of 400 feet. The thermal energy at ground zero was quite small for Tumbler Shot 1 and Buster Shot Baker, being approximately 55 cal/cm^2 for Tumbler Shot 1 and presumably 70 cal/cm^2 on Buster Baker. The superficial ground surfaces over which these particular shots were burst were quite different: Tumbler Shot 1 was over an almost white surface that was relatively less dusty than that for Buster Baker, which was very dusty and of darker color. Whether the difference in dust and reflectivity would, per se, account for the marked differences in pressure is extremely questionable. Pressure-time records from Buster Baker and Tumbler Shot 1 are similar in that both are almost 'ideal' shock waves and neither shows any evidence of a precursor such as that observed on Tumbler Shot 4 and Buster Shots Charlie and Easy. Discrepancies between the pressures measured on these two series of shots are therefore as yet unexplained.

The complexity of the phenomena observed on the Buster and Tumbler series seems to indicate that additional data for bombs of various size burst at intermediate heights are necessary if any valid explanation of these anomalies is to be made. It would be interesting to observe experimentally the effect of thermal energy on the behavior of pressure waves by bursting a 1-kt weapon at a height of 400 feet and a 15-kt weapon at a scaled height of 600 feet. The approximate thermal energy at ground zero from a 1-kt yield at a burst height of 400 feet would be 220 cal/cm^2 and that from a 15-kt yield at a scaled burst height of 600 feet would be 180 cal/cm^2.

The answers to questions posed by these observed anomalies may prove significant in the interests of the Department of Defense. Evaluation of war damage as a function of distance from atomic explosions is currently possible only on the basis of the Hiroshima and Nagasaki bursts. Neither the yields nor the burst heights for these weapons are precisely known. Measurements and estimates indicated that the radiochemical yield of the Hiroshima weapon was between 11 and 15 kt and its burst height between 1,800 and 2000 feet. Similarly, the yield of the Nagasaki weapon was between 22 and 23.8 kt and its burst height between 1,650 and 1,700 feet. Scaled burst heights for these two war weapons were thus 575-610 feet for the Nagasaki burst and 730-900 feet for the Hiroshima burst. As the height-of-burst chart (frontispiece) shows, scaled heights for these weapons, from which we have the only evaluation of military damage, fall in the region where indeterminacy of pressures is most pronounced.

1.4 AUXILIARY PRESSURE MEASUREMENTS

An opportunity was presented in conjunction with the pressure-time measurements on Operation Tumbler to make some auxiliary pressure measurements that would provide experimental data on related problems, for example

1. Variation of pressure with small altitudes at several stations on the blast line.

2. Preshock ambient ground-level pressures at several distances from ground zero.

3. Decrease in positive impulse loading as a function of distance from ground zero.

4. Behavior of the pressure wave at comparatively large distances from ground zero.

1.41 Pressure-Altitude Measurements

Pressures observed at four altitudes (2, 6, 20, and 35 feet) above the surface of the ground have been plotted to an expanded time scale in Figs. 1.19-1.23. These pressure-altitude measurements have permitted some interesting observations; for instance, from these plots the height of the Mach stem has been computed graphically at two distances (stations 202 and 206) on each of Shots 1-4; these computed heights are presented in Table 1.7.

Table 1.7 -- COMPUTED HEIGHTS OF MACH STEM

	Station	Distance from ground zero (ft)	Height of Mach stem (graphical) (ft)
Shot 1	202	590	4.5
	206	1,577	14.5
Shot 2	202	1,378	2.2
	206	4,375	>35
Shot 3	202	1,404	0
	206	4,401	0
Shot 4	202	Rise was too slow to determine height of Mach stem	
	206		>35

In the two instances in which the height of the Mach stem exceeded 35 feet the Mach wave arrived simultaneously (within 1 msec) at the four heights and could therefore be assumed to be vertical to 35 feet.

It is also possible, when both the free-air* and reflected pressure waves are observed, to compute a reflection coefficient and compare this with that deduced from the theory† for regular reflection. Table 1.8 presents the results of this comparison.

Note that the observed reflection coefficients correspond within 10 per cent to the theoretical values. It is difficult to determine, in view of the paucity of data, whether the fact that

*Free-air pressures are taken from the initial rise portion of the pressure-time records for the various stations.

†Polachek, H., and Seeger, R. J., Regular Reflection of Shocks in Ideal Gases, Navy Bureau of Ordnance Explosives Research report No. 13 (BuO-ER-13), February 12, 1944

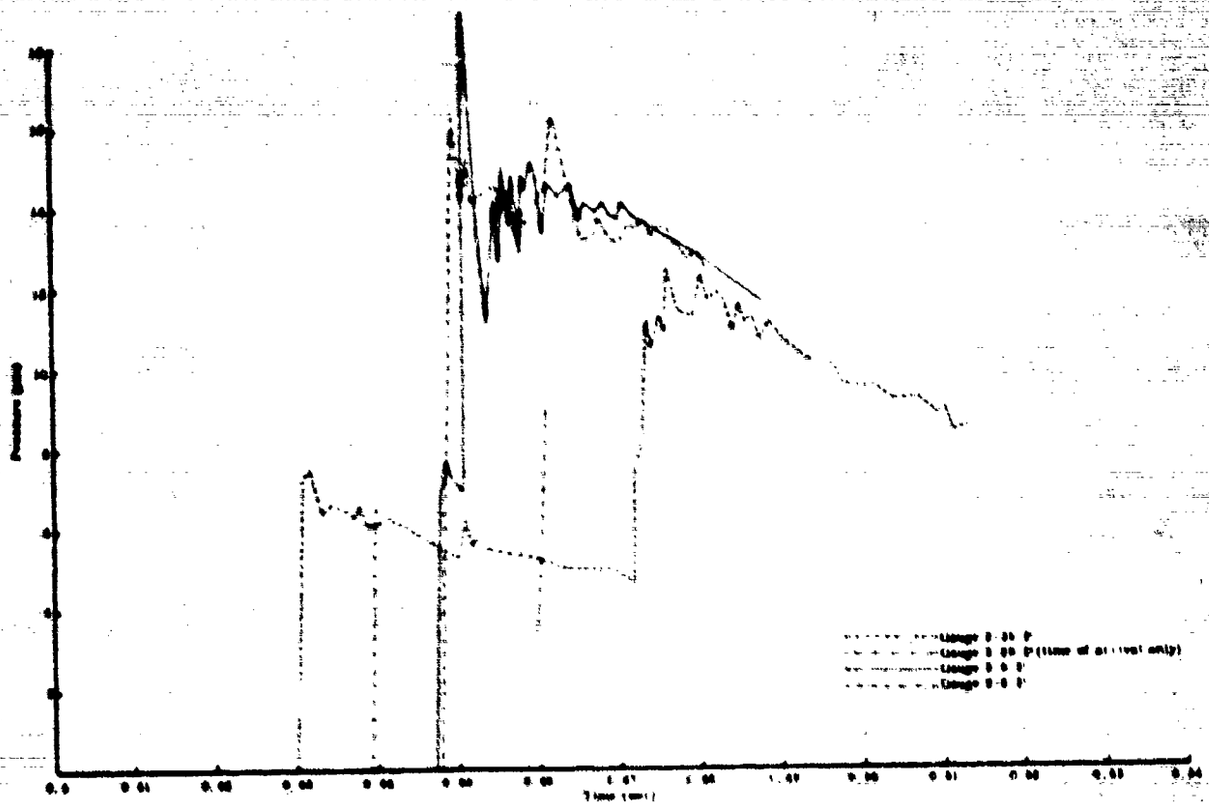

Fig. 1.19 -- Pressure-time curves for gauges at various heights at Station 202 on Tumbler Shot 1 (April 1, 1952)

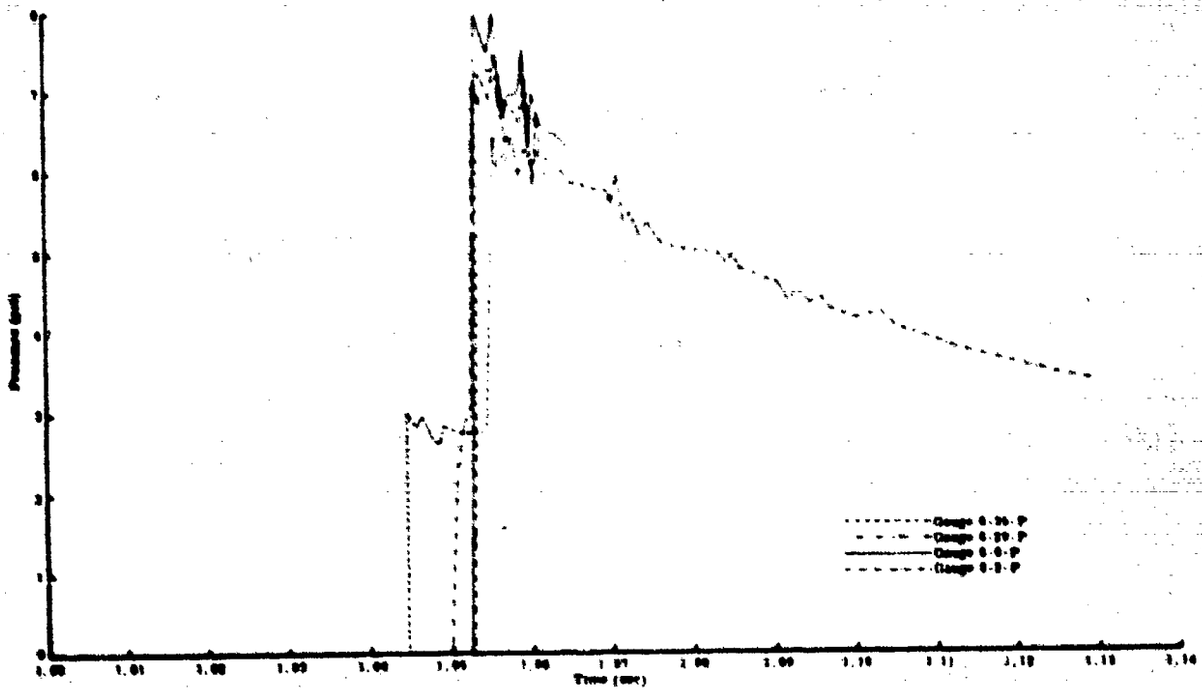

Fig. 1.20 -- Pressure-time curves for gauges at various heights at Station 206 on Tumbler Shot 1 (April 1, 1952)

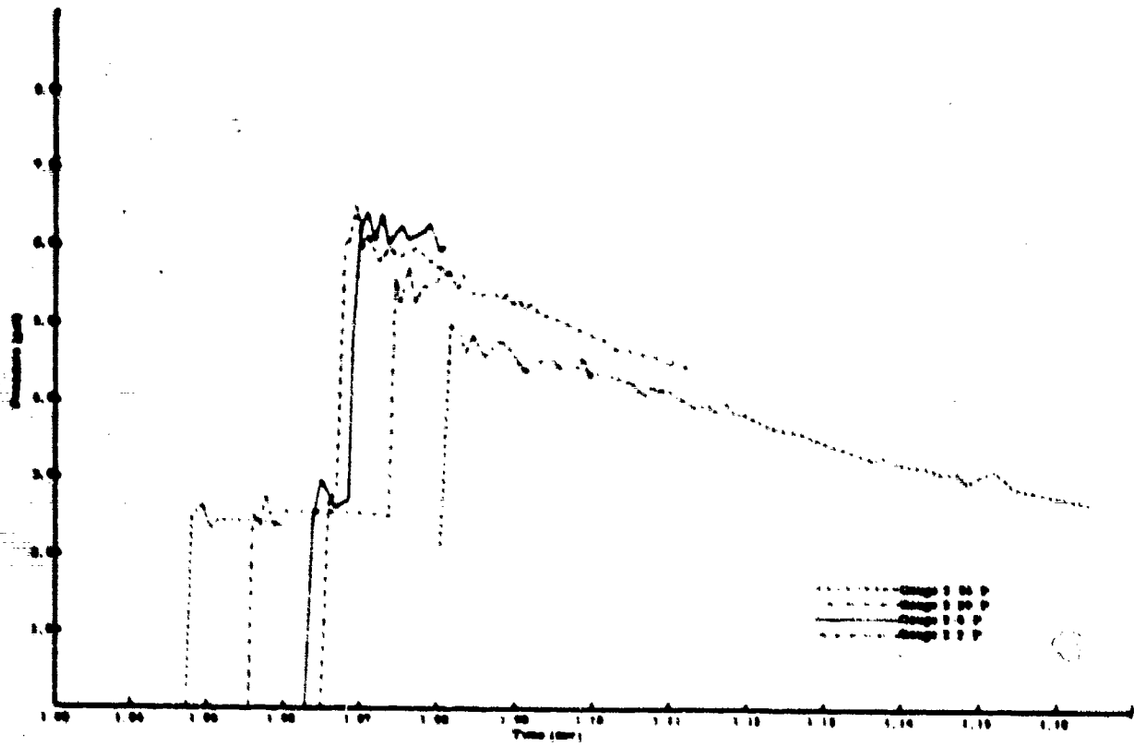

Fig. 1.21 -- Pressure-time curves for gauges at various heights at Station 202 on Tumbler Shot 2 (April 15, 1952)

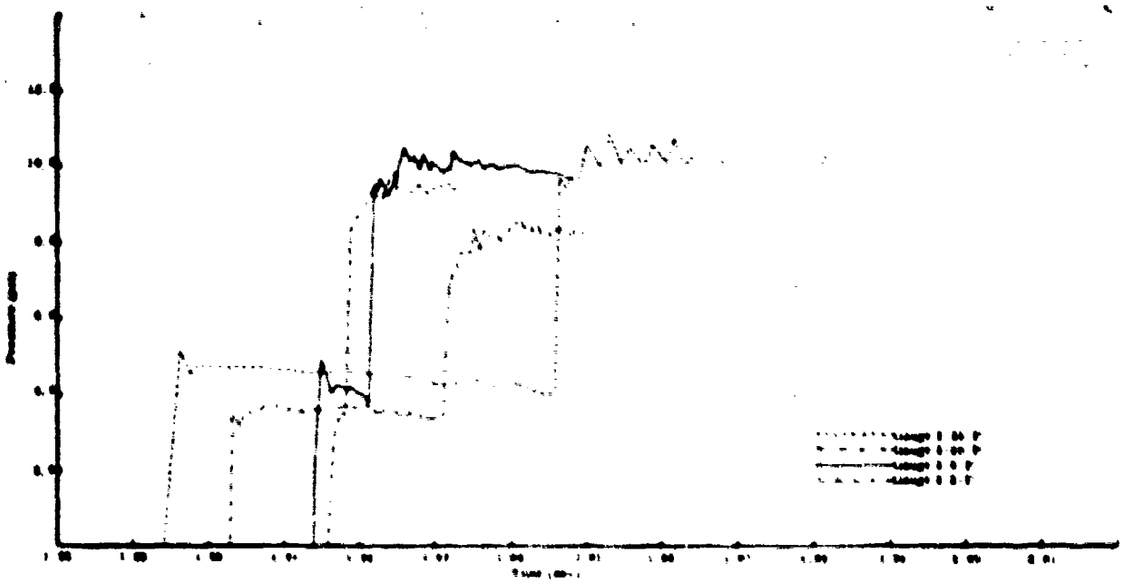

Fig. 1.22 -- Pressure-time curves for gauges at various heights at Station 202 on Tumbler Shot 3 (April 22, 1952)

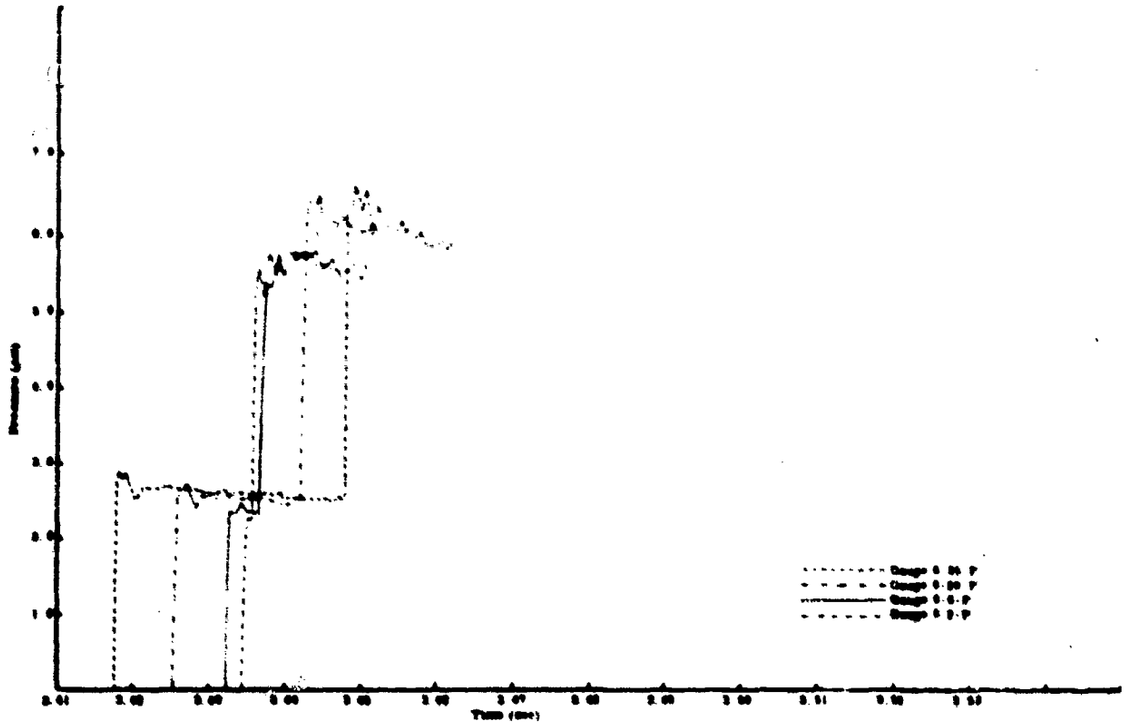

Fig. 1.23 -- Pressure-time curves for gauges at various heights at Station 206 on Tumbler Shot 3 (April 22, 1952)

observed reflection coefficients are in general high on Shot 3 and low on Shots 1 and 2 has any real significance.

Table 1.8 -- COMPARISON OF OBSERVED AND COMPUTED REFLECTION COEFFICIENTS

	Gauge	P_F	P_R	P_R/P_F	Average observed P_R/P_F	P_R/P_F for a given P_F (from theory)
Shot 1	2-35-P	4.9	11.8	2.40		
	2-20-P	-	-	-	2.18	2.3
	2-6-P	7.2	14	1.95		
	2-2-P	-	14.8	-		
	6-35-P	2.75	6.3	2.28		
	6-20-P	2.9	7.0	2.42	2.35	2.55
	6-6-P	-	7.5	-		
	6-2-P	-	7.2	-		
Shot 2	2-35-P	2.2	4.8	2.18		
	2-20-P	2.[illegible]	5.5	2.19	2.25	2.3
	2-6-P	2.7	6.25	2.31		
	2-2-P	2.7	6.25	2.31		
Shot 3	2-35-P	4.1	10.3	2.52		
	2-20-P	3.4	8.3	2.45	2.55	2.2
	2-6-P	4.0	10.2	2.55		
	2-2-P	3.5	9.4	2.68		
	6-35-P	2.5	6.4	2.55		
	6-20-P	2.45	6.4	2.61	2.55	2.3
	6-6-P	2.35	5.8	2.47		
	6-2-P	2.25	5.8	2.57		

1.42 Preshock Pressures

On each of the four Tumbler shots a pressure gauge was placed in a ground baffle at each of Stations 200, 204, and 207 to measure any large changes in ambient pressure that might take place between zero time and the time of arrival of the shock wave. Because of an

'electromagnetic transient' at zero time these gauges were actually not operative until about zero time plus 10 milliseconds. Table 1.9 lists the maximum gauge pressures observed at these stations during the time interval prior to arrival of the shock wave. These pressures are the recorded departures from ambient (ie, atmospheric) pressures. The pressure gauge at Station 201 on Shot 4 also recorded an excursion to 7 psi (Fig. 1.15) prior to arrival of the shock.

Table 1.9 -- MAXIMUM PRESHOCK GAUGE PRESSURES[a]

	Station 200 (psi)	Station 204 (psi)	Station 207 (psi)
Shot 1	-0.3	-0.01	0.03
Shot 2	0.35	-0.01	-0.01
Shot 3	-0.4	0.03	0.03
Shot 4	1.2	0.07	0.04

[a]The fact that these pressures may not be actual pressures is discussed in the text.

There was some question whether the excursions listed in Table 1.9 represent actual pressure changes or whether they are attributable, at least in part, to some other factor. The most obvious possibility is that the bourdon tube in the Wiancko pressure gauge might be sensitive to the large incident thermal flux and possibly to steady-state changes in temperature at temperatures as high as 180°F. It is conceivable that the high intensity of thermal radiation and the resulting large temperature gradient between the inside and outside walls of the bourdon tube might cause it to twist in some manner.

Upon recovery of some of the gauges used on Shot 4 the glass fiber with which the bourdon tube was filled was partially scorched and fuzed, indicating that the intial transient temperatures were significantly high and that the gauges used on the Tumbler shots should be subjected to a control test in which the transient thermal conditions were simulated. These tests were performed in the laboratory; a thermal flux computed to be approximately 2-3 cal/sec was attained by focusing sunlight through a lens 4 inches in diameter, and when this radiation was allowed to fall upon the exposed wall of the bourdon tube, transient deflections were noted. The magnitudes of these deflections were even greater than the measured pressures listed in Table 1.9 -- in fact, deflections were as great as 20 per cent of gauge range. The deflections observed on all but one gauge were negative; this gauge was a 10-psi gauge (not used on the Tumbler tests) in which the acoustical damping material was undamaged, and both positive and

negative deflections of 0.05 psi were obtained. Moreover, it was found that the deflections caused by thermal radiation were transient signals of one second or longer. Thus it has been found that thermal radiation can cause what appears to be a 'pressure' change as read on the Wiancko pressure gauges, and although it can not be definitely established that the positive deflections noted in the field, particularly those of 1, 2 and 7 psi, were attributable to thermal radiation, neither can it be asserted that these deflections were caused by actual pressure changes.

The gauges used to measure preshock pressures were, of course, considerably more sensitive than those used to measure shock pressures. Therefore it would appear that except for the deflections of 1, 2 and 7 psi the deflections observed in the field would constitute so small a percentage of measured shock pressures as to make negligible any error in shock pressure readings. Moreover, the side-on gauges used to measure shock pressures are placed at right angles to the incident thermal flux and would not be appreciably affected by thermal radiation. In similar future measurements the sensing element should obviously be so oriented as to preclude any interference from thermal radiation.

1.43 Positive Impulse

The question has been raised, regarding Tumbler Shot 4 and Buster Shots Baker and Charlie, whether positive impulse as a function of distance is decreased to the same extent as are the corresponding pressures. It has been found that when a reduction in pressure resulting from a chopping off of the peak pressure is observed, the duration of the positive phase is likely to be relatively greater than that corresponding to the same pressure for an idealistic shock wave.

According to the scaling law, at distances corresponding to a given pressure for varying yield the impulses will be in the ratio of these distances, ie, in the ratio of the cube roots of the charge weights. Since scaling of pressures over the range of yields for Tumbler Shots 2 and 3 appears to be valid as based on measurements of peak pressure, the scaling of impulses computed from experimental data should likewise be valid. The pressure-distance curves gave a pressure reading of 10 psi at 1,350 feet from ground zero on Tumbler Shot 2 and 3,750 feet from ground zero on Tumbler Shot 3; corresponding impulses at these distances were computed to be 0.96 and 3.0±0.3 psi-sec. Thus

$$\frac{3,750}{1,350} \times 0.96 = 2.8 \text{ psi-sec}$$

and

$$\left\{\frac{31}{1.25}\right\}^{1/3} \times 0.96 = 2.8 \text{ psi-sec}$$

Apparently within the limits of accuracy possible in determining impulse this kind of scaling from Tumbler Shot 2 to Tumbler Shot 3 is valid.

When impulses are plotted against slant range on log-log paper (Fig. 1.24), the scaled values of impulse [illegible] along a 45° line on which W-values correspond to $\sqrt{2} \times W^{1/3}$. The impulses, as scaled from observed impulses for 1.25 kt* (Tumbler Shots 1 and 2), are plotted and labeled with the assumed yield used in scaling.

Values of positive impulse obtained by measuring the total area under the pressure-time curve (positive phase) using a planimeter have also been plotted for Tumbler Shots 3 and 4 and Buster Shots Baker and Charlie. It will be noted that the measured impulses are lower than those determined from the scaled curves, particularly at small distances from ground zero. However, a comparison of impulses and corresponding pressures reveals that the decrease in impulse is not so great as that in pressure. This fact may be illustrated by plotting pressure vs impulse as observed on Tumbler Shot 4 and pressure vs impulse $\times \left(\frac{1.20}{1.25}\right)^{1/3}$ as obtained from data on Tumbler Shot 1 (Fig. 1.25). As can be seen from this plot, impulses observed from corresponding pressures are higher by as much as 50 per cent than those which are scaled. Stated another way, the impulses for corresponding pressures were not reduced below the scaled impulses by as much as were the pressures themselves simply because of the longer durations. On Shot 1 a pressure of 10 psi is observed at a scaled distance of 12,000 feet, but on Shot 4 the observed pressure is 8 psi at the corresponding scaled distance, 1,150 feet. The impulse at this distance, as scaled from Shot 1, was 2.5 psi-sec but was observed to be 2.2 psi-sec. Thus actual pressure is less than scaled pressure by 20 per cent, but impulse is less by only 10 per cent.

From the point of view of military damage this relatively higher impulse for a given pressure and yield offsets to some extent the reduction in peak pressure, provided total impulse is as valid a criterion of damage as peak pressure. However, a detailed study would be necessary to determine to what extent a relatively larger impulse offsets the loss in peak pressure. Figure 1.24 shows that observed impulses are lower than those predicted from scaling so that it is certain that there is some reduction in the effectiveness of the pressure wave even if the impulse criterion were assumed to be more valid than the peak pressure criterion for damage.

1.44 Pressure Measurements at the Control Point in Yucca Pass

Observers viewing nuclear explosions from distances of approximately 10 miles, ie, at the Control Point Building at the Nevada Proving Grounds, on several occasions have heard

*The calculations for impulse scaling were made on the basis of the yields used by the Armed Forces Special Weapons Project in preparing the Preliminary Report of Operation Tumbler, TC-1052-0.

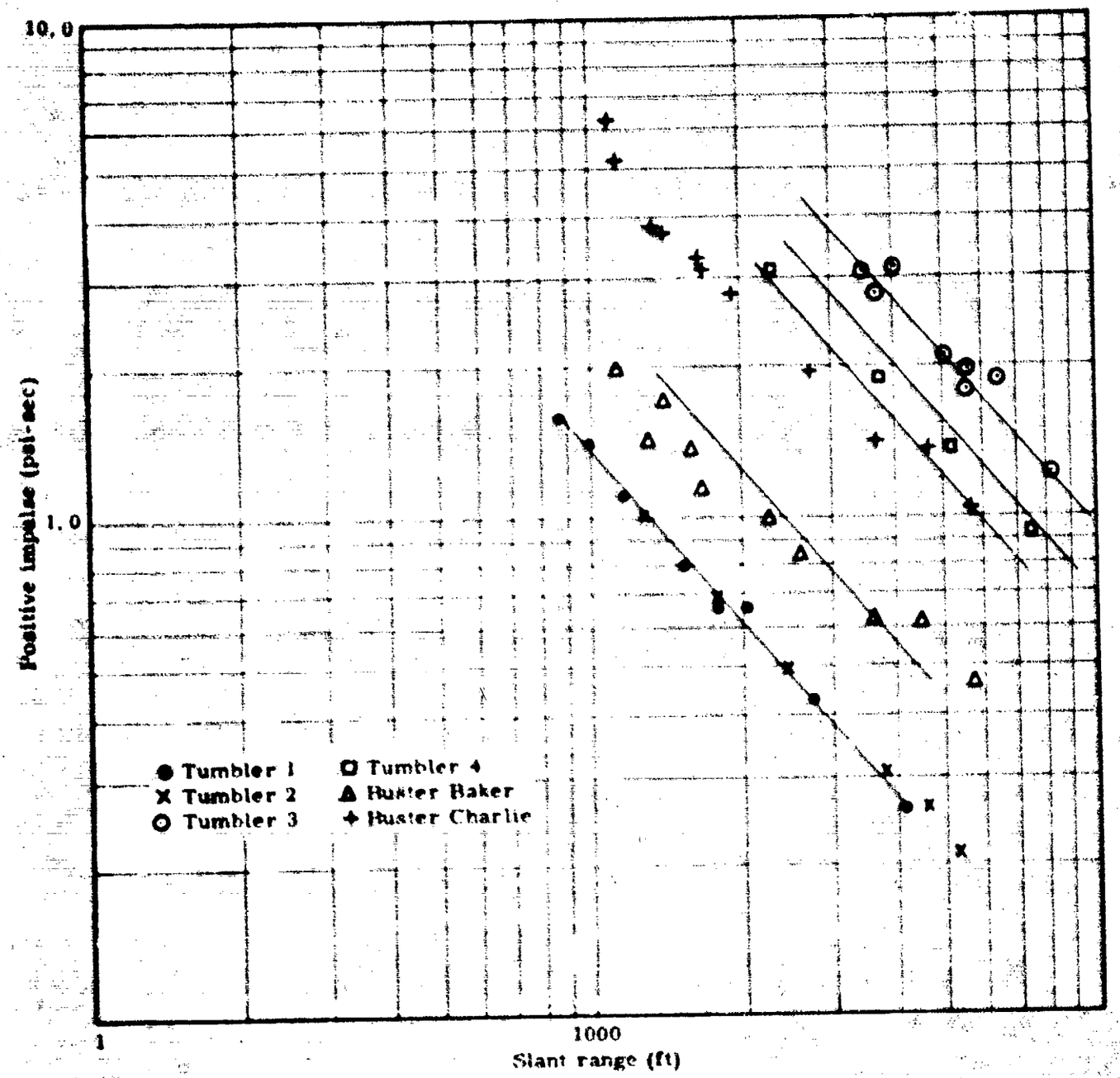

Fig. 1.24 -- Positive impulse vs slant range

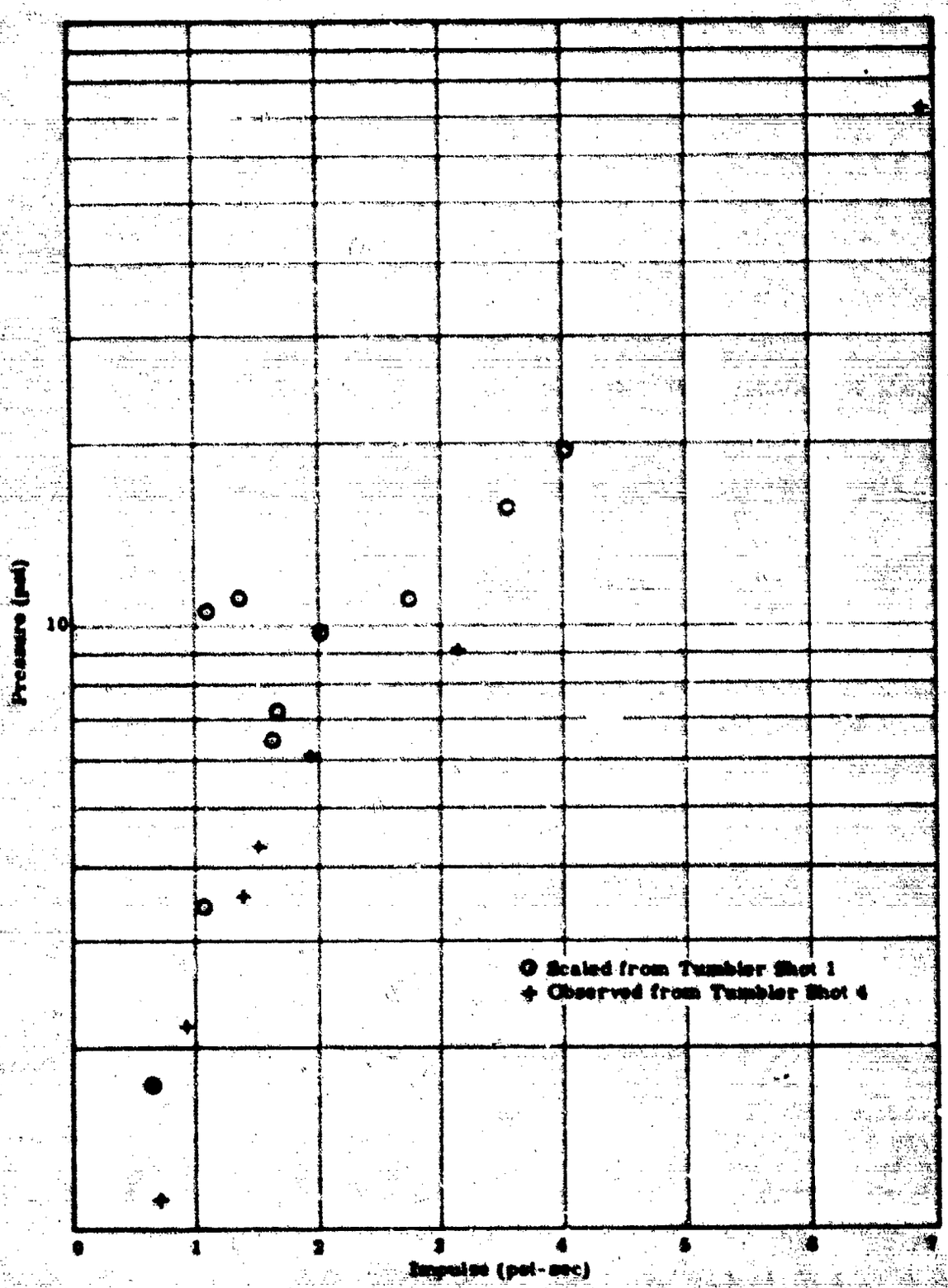

Fig. 1.25 -- Overpressure vs impulse

at least three shocks. Because these multiple shocks are not readily explainable without recourse to an accurate record of the pressure-time wave*, pressures at the Control Point were recorded for each of the shots of the Tumbler-Snapper series by means of a Wiancko pressure gauge mounted face up near the front edge of the roof of the Control Point Building. Its output was recorded on a Brush pen recorder.

The pressure-time curves are presented in Fig. 1.26. Two definite shocks (or sharp cracks as heard by an observer) was the greatest number observed on any one shot (Shot 4). The pressure-time curve for this shot shows two abrupt transitions in pressure, one at the beginning of the shock wave and the other in the negative phase. During these two transitions enough high-frequency components were present to be definitely audible. Nearly all the other records show low-frequency components following the initial pressure rise.

Large initial spikes were observed on Shots 5, 6, and 7; the curve for Shot 8 shows an oscillation during the first portion of the shock wave which suggests the development of an acoustic signal. It is interesting to note that this oscillation takes place at a pressure amplitude seven times that of the smallest signal recorded, which was 0.004 psi on Shot 2.

In Fig. 1.27 observed peak pressures are plotted against distance/$W^{1/3}$. The only valid conclusion to be drawn from this curve is that a straight line drawn through four of the points will indicate maximum pressures to be anticipated for various scaled distances beyond 17,000 feet. The maximum pressure to which the Control Point was exposed, 0.17 psi on Shot 7, was of short duration and dropped to 0.06 psi in approximately 30 milliseconds. The maximum positive impulse was observed on Shot 3.

These measurements might conceivably have practical application to the design of additional structures in the Control Point area since pressure loadings are not so high as had been anticipated when the original structures were built.

1.45 Pressure Measurements on Tumbler-Snapper Shots 7 and 8

In connection with the pressure measurements and feasibility tests on wind instruments†

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*Pressures intermediate between the blast line and the Control Point are discussed by M. L. Merritt in another report of the Tumbler-Snapper series, Air Shock Pressures as Affected by Hills and Dales, WT-502 (to be published)

†Perret, W. R., Earth Pressures and Earth Strains, Tumbler-Snapper report WT-503 (to be published); Cook, T. B., Jr., Sandia Laboratory Shock-Gauge Evaluation Tests, Tumbler-Snapper report WT-505 (to be published)

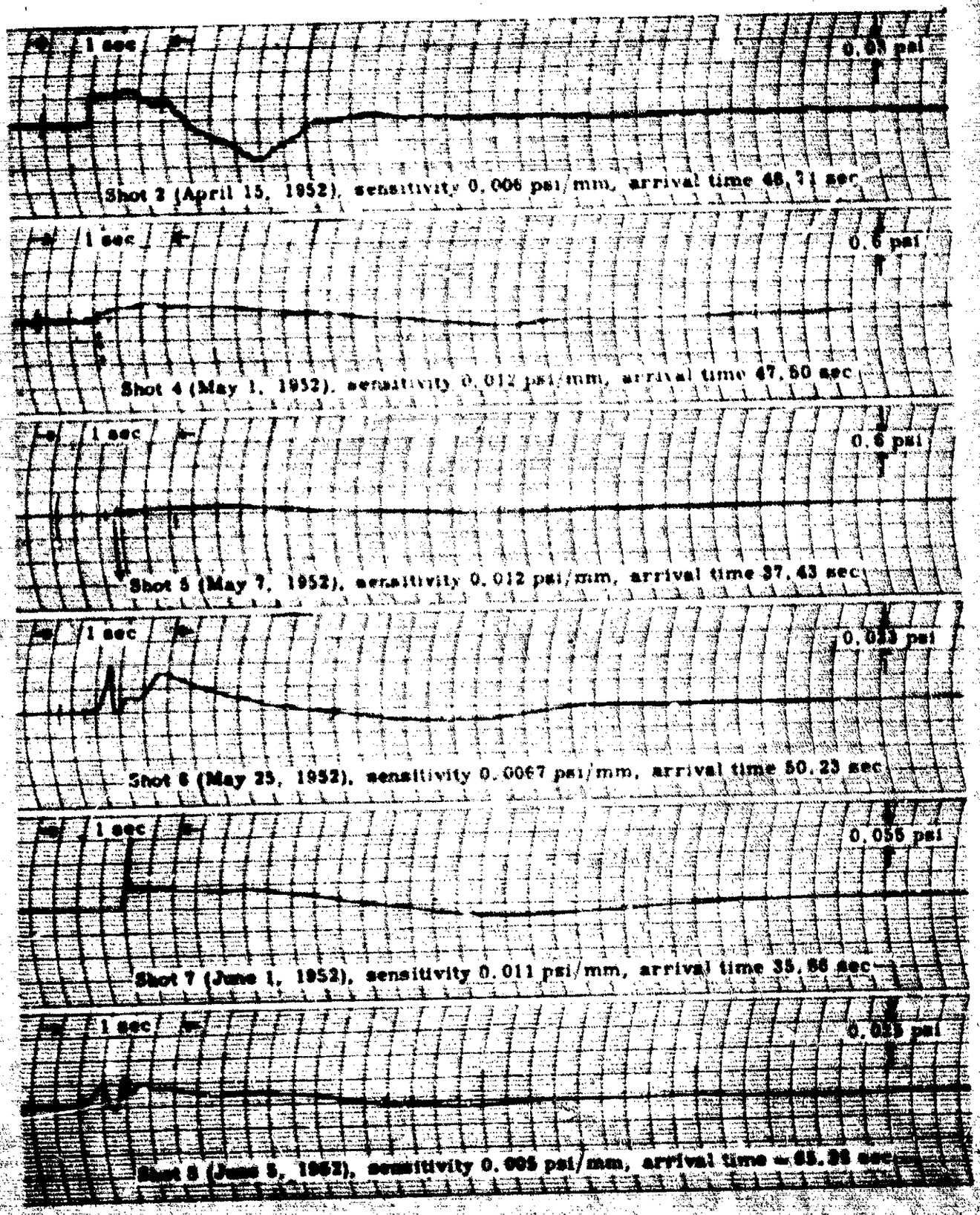

Fig. 1.28 -- Pressure-time records from Control Point

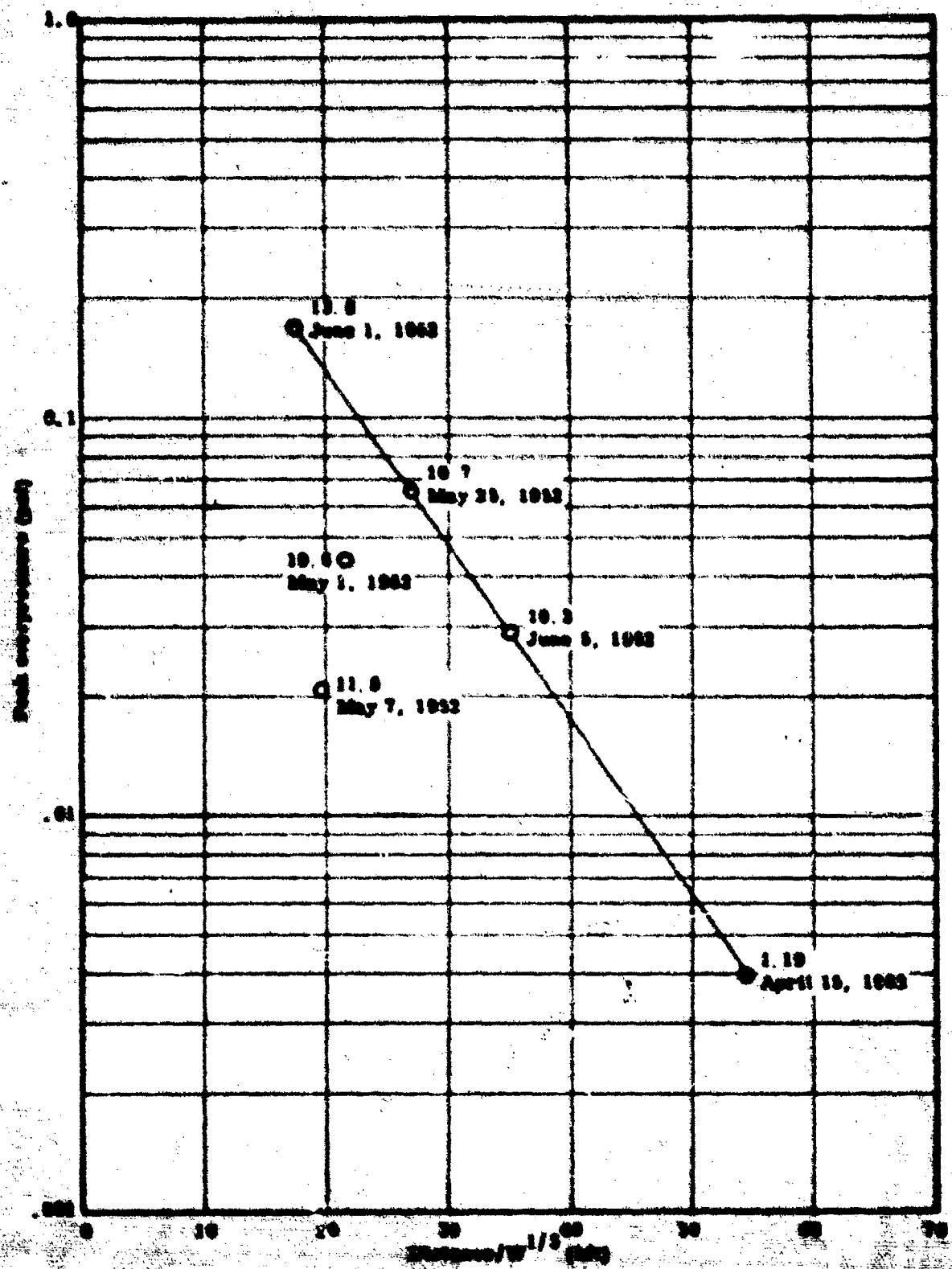

Fig. 1.27 -- Peak overpressure vs distance/$W^{1/3}$

a few observations of pressure were made on Tumbler-Snapper Shots 7 and 8. In predicting the pressure level direct scaling from Greenhouse observations was employed.

The following table shows the observed pressures compared with the pressures from corresponding scaled distances at Greenhouse. Observed peak pressures for Tumbler-Snapper have been multiplied by $\frac{14.7}{12.7}$ to provide an altitude correction; the distance of the peak pressure observed at Greenhouse has been scaled by the yield ratio $(14/47^{1/3})$ to provide the scaled distances for the pressures listed.

Table 1.10 -- COMPARATIVE PRESSURES FROM TUMBLER-SNAPPER SHOTS 7 AND 8 AND GREENHOUSE SHOT EASY

Shot	Yield (kt)	Pressure at 1,550 ft (psi)	Pressure at 3,100 ft (psi)
T-7	13.8	15.2	7.0
T-8	14		6.1
Greenhouse Easy	47	18	7.2

It is interesting to note that the close-in pressure exhibited a rise time of the order of 50 msec. These measurements are hardly extensive enough to compare percentage of yield going into blast.

CONCLUSIONS AND RECOMMENDATIONS

Pressure-time data obtained by Sandia Laboratory on Operation Tumbler were not only in essential agreement with those obtained by other agencies from the same series of tests but tended, in general, to corroborate similar data obtained on Operation Buster. It has therefore been concluded that pressure measurements on Operation Buster were valid and that data from these two series of tests can legitimately be used to construct a height-of-burst chart based on these and other experimentally determined pressures.

Discovery of the precursor in photographs of the shock waves from Tumbler Shot 4 and what appears to be a precursor in photographs of Buster Shots Charlie and Dog has provided a clue which, when used in conjunction with thermal and pressure measurements, may explain the anomalous pressures observed on these shots. Observations such as these have made it clear that a height-of-burst chart for nuclear weapons, to be dependably accurate, must be based on experimentally determined pressures from nuclear weapons.

It is interesting to review a statement* made five years ago by W. G. Penney and K. Fuchs:

"The bombs [Hiroshima and Nagasaki] were placed in such positions that they could not have done more damage by any alternative bursting point in either city.

"The heights of burst were correctly chosen with regard to the type of destruction it was desired to cause. The extent of the blast damage was exactly that predicted."

Evidently the accuracy of determination of overpressures and target damage considered sufficient a few years ago (at least by the above authors) does not satisfy present requirements, which must clearly be considerably more stringent.

To predict overpressures and choose appropriate burst heights from the height-of-burst chart, it is important that this chart be complete. Although considerable information has been acquired recently, it would appear desirable to complete the task of ascertaining pressure-distance-height data by carrying out some additional tests:

1. A burst at a scaled height of 1,250 feet to establish the 'knees' in the height-of-burst curves for overpressures of 4-8 psi. Apparently, since Tumbler Shots 2 and 3 scaled satisfactorily, any yield in the range of 1-50 kt would be suitable.

2. A burst having a yield of 15-50 kt at a scaled height of approximately 700 feet to determine whether the deleterious effects observed on Tumbler Shot 4 are observed at this scaled height when the bomb yield is large.

3. A burst of a 1-kt weapon at a scaled height of approximately 300 feet to determine the extent to which these deleterious effects are observed for this low yield and low burst height. Presumably no thermal effect would be observed for a burst of a 1-kt weapon at a height of approximately 450 feet.

These last two tests should provide needed corroboratory data for that range of scaled burst heights in which blast effects are not so precisely predictable as for greater scaled heights.

*Blast Wave (edited by H. A. Bethe), Los Alamos report LA-1022, Vol. VII, Part III, August 15, 1947, p XIII

It has also been noted that positive impulses are somewhat smaller when peak pressures are less than ideal although the percentage decrease is not so large when it is considered that the pressures are of longer duration. However, it is reiterated that the extent to which the comparatively lesser decrease in impulse offsets the loss in peak pressure can only be determined from a detailed study of the relative merits of peak pressure and positive impulse as damage criteria.

APPENDIX A

The following personnel of the Weapons Effects Instrumentation Division of the Proving Grounds Department, under the direction of Mr. H. E. Lenander, performed the field installation and calibration of the pressure gauges and auxiliary instrumentation used for these measurements:

Baca, J. M., assisted with installation and calibration of gauges
Bolinger, N. C., in charge of installation and checkout of recording equipment, Operation Snapper
Cainnjinni, C., assisted with installation and checkout of recording equipment
Finchum, W. A., in charge of installation and calibration of gauges, Operation Tumbler
Hampson, P., liaison with contractors
Korbe, A. J., ET1(C), in charge of installation and checkout of recording equipment, Operation Tumbler
List, D. H., SFC, assisted with installation of timing equipment and cables from shelters to instruments
Meinert, R., T/Sgt, assisted with installation and calibration of gauges
Millican, R. S., Division Supervisor in charge of administration for Operation Tumbler-Snapper
Myers, V. V., in charge of installation of cables from gauges to recording equipment for Operation Tumbler-Snapper
Payne, W. C., RD1, assisted with installation and checkout of recording equipment
Pritchett, R. E., in charge of installation of cables from gauges to recording equipment, Operation Snapper
Reis, G. E., assisted with installation and calibration of gauges
Scott, J. H., project engineer, Operation Tumbler
Schwartzbaugh, S., liaison with contractors
Thompson, F. E., project engineer, Operation Snapper
Thompson, R. H., in charge of installation and calibration of gauges, Operation Snapper
Vaughn, J., EM1, assisted with installation of timing equipment and cables from shelters to instruments
Whitlow, E. L., photography and processing of film records, Operation Tumbler-Snapper
Witt, L. J., assisted with installation of timing equipment and cables from shelters to instruments
Yearout, R., installation of motor generator

The following personnel from the Weapons Effects Department under the direction of Dr. E. F. Cox assisted in the analysis of the data obtained on these measurements:

T. B. Cook
B. F. Murphey
H. A. Richardson
J. D. Shreve, Jr.
J. Todd, Jr.

All data were reduced by the Mathematical Services Division, 5242, of Sandia Corporation.

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