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Project 6.1

Air Shock Pressure-Time Vs Distance

Pacific Proving Grounds

November 1952

Joint Task Force 132

April 1953

NOTICE

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

Air-pressure measurements on Operation Ivy were unique in two respects: Detonation of the first "superbomb" on Mike shot presented an opportunity to verify experimentally the applicability of the $W^{1/3}$ scaling law at larger yields than ever before; and on King shot it was possible to observe simultaneously the development of the shock waveform over land and over water.

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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

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ABSTRACT

Air-pressure measurements on Operation Ivy were unique in two respects: Detonation of the first "superbomb" on Mike shot presented an opportunity to verify experimentally the applicability of the $W^{1/3}$ scaling law at larger yields than ever before; and on King shot it was possible to observe simultaneously the development of the shock waveform over land and over water.

Measurements on Mike shot were successful, with the exception that no overpressure data were obtained at pressure levels greater than 20 psi. It is recommended that efforts to repeat these measurements be made at the earliest opportunity. Measurements on King shot were quite successful in that it was found that the waveform over water was nearly ideal, whereas that over land obviously was subject to some deterioration as a result of the thermal effect and precursor formation.

Analysis of the results made possible several significant conclusions, the most important of which were

1. The scaling law is apparently valid for radiochemical (RC) yields as great as 10 Mt.
2. Overpressures from Mike shot are evidently in agreement with the assumption that the overpressures to be expected from a yield, W, burst at the surface of a perfect reflector, are the same as would be observed from a yield of 2W, burst in free air.
3. Agreement of the results from both Mike and King shots with those predicted from the height-of-burst chart published in TM 23-200 justifies extension of this chart to yields of the order of 500 Kt. The correction applied in this chart for thermal effects also appears valid.

Appendix A to this report describes semiquantitative measurements of shock symmetry, and from all indications the shock wave was symmetrical along the two radii chosen for these measurements.

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ACKNOWLEDGMENTS

Shock-pressure measurements for Operation Ivy were planned by representatives of J-Division of the Los Alamos Scientific Laboratory and the Weapons Effects Department (5110) of Sandia Corporation. The author wishes to express his appreciation for the fine cooperation among the participating agencies and the personnel and contractors of the Pacific Proving Grounds.

Installation of the measuring equipment and field measurements were ably executed by personnel of the Pacific Proving Ground Division (5233) of the Field Test Organization of the Sandia Corporation. A list of all participating personnel is presented as Appendix B to this report.

The author wishes to acknowledge also the assistance of Miss Sally Langenstein in preparing this manuscript for issuance.

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AIR SHOCK PRESSURE-TIME VS DISTANCE

1 INTRODUCTION

Full-scale tests of atomic weapons at the AEC Pacific Proving Grounds on Eniwetok Atoll and the continental test site at the Nevada Proving Grounds have yielded valuable information[1–8] on the pressure-time-distance pattern for shock waves from air and tower bursts of weapons of various yields. Overpressures measured at or near the ground on three test series, Operations Greenhouse, Buster-Jangle, and Tumbler-Snapper, have been used to construct a height-of-burst chart based entirely on experimental data. Data on experimentally measured overpressures from nuclear bursts, used in conjunction with those from analogous bursts of small-scale HE charges, corroborate the well-known $W^{1/3}$ scaling law. Continued efforts in this direction are planned with the ultimate objective of gaining an understanding of blast-wave propagation that will take into account factors such as the effects of thermal radiation, mechanical disturbance of the surface soil, and variations in terrain.

2 OBJECTIVE AND SCOPE

The two shots of Operation Ivy presented an unparalleled opportunity to measure blast pressures and study the propagation of shock waves under conditions such that thermal and mechanical effects were essentially minimized. Mike shot was the first experimental burst of a "superbomb." Since it was only the second surface burst (the first was the Jangle Sugar shot) of a nuclear weapon, experimental data from this burst would have been expected to aid in fixing the zero intercepts of the experimental height-of-burst chart for nuclear weapons. The overpressures of interest occurred at comparatively great radial distances from ground zero, and the shock wave traveled a large percentage of its path over water to reach the majority of the measuring stations on the blast line, the locations of which were dictated by the geographical configuration of the island chain. Measurements on King shot were unique in that two blast lines were used, one entirely over water and the other predominantly over land. The only previous measurements of shock overpressures over water were those made on Bikini shot Able. The land line was intended to provide useful data for comparison not only with data from the blast line over water on King shot but with previously compiled blast data on shots at the Nevada Proving Grounds. It was hoped also that the results of these tests would provide supplementary information on optimum heights of burst.

Ordinarily, thermal effects from a surface burst over either land or water would be expected to be negligible because of the glancing angles of incidence. As a result of the size and thermal pulse duration of the fireball from a superbomb such as was used on Mike shot, however, some thermal energy might be incident upon the surface in the area in which the precursor is usually observed, causing a slight thermal effect upon the shock wave.

Thus it was believed that since the yield of Mike shot was considerably larger than that of any previous nuclear explosion, any attenuation of pressure (as compared with that predicted) or any appreciable deviation of the observed pressure-time-distance curve from the "ideal" could possibly be attributed to phenomena arising out of the size of the explosion.

Effects of ambient pressure and temperature gradients, such as are characteristic of the upper atmosphere of the earth, upon a passing shock wave are virtually unknown. After the shock wave has degenerated into a sound wave, its path may of course be calculated. Any existent theories regarding the effects of these temperature and pressure gradients on shock waves have as yet to be substantiated by reliable experimental observations. Available information does make possible some qualitative deductions[9,10] about the possible distortion of a spherical shock wave in a nonhomogeneous atmosphere which might explain a decrease in peak overpressure as measured at ground level, an attenuation which could conceivably become increasingly effective at greater distances from ground zero.

Since it is known that water is nearly an ideal reflecting surface, it was predicted that overpressures measured on the blast line over water on King shot would be nearer the ideal or estimated overpressures than those measured on the land blast line. Not only does water reflect a much greater percentage of the thermal energy incident upon it, but, in addition, any thermal energy absorbed by water is absorbed not just in the first fraction of an inch at the surface but over the entire path length of the refracted ray. As contrasted with observed behavior over land blast lines, one would expect to find no evidence, on bursts over a water surface, of precursor formation,[1,2,11] the thermal-mechanical effect in which the surface layer of soil is heated to the point of exploding or forming clouds of dust which move in the path of the shock wave. It would be virtually impossible to heat the huge mass of water involved to the vaporizing point under the conditions of this test.

Strictly speaking, the land blast line used on King shot differed somewhat in configuration from those used on similar tests at the Nevada Proving Grounds. Because it was necessary to place the measuring stations at different azimuths from the reference line passing through ground zero and because of the shape of the island on which stations were placed, some water was interspersed among the land areas; thus the paths traversed by the shock wave in reaching the various stations had different ratios of land to water. Nevertheless it was believed that conditions were similar enough to those in Nevada to warrant valid conclusions regarding the effects of different types of terrain on blast-wave propagation. It was hoped that comparison of measurements on the land blast line with those made at corresponding distances over water would give some indication of the degree to which pressures were attenuated as the shock wave passed over land areas and would serve as a semiquantitative measure of the deterioration of the pressure-time curves from the ideal waveforms as a result of thermal and terrain effects.

Inasmuch as the scaled height of burst on King shot was low — 178 ft — the results of these measurements are not particularly significant so far as supplying additional points for the experimental height-of-burst chart is concerned. Actually it would have been preferable to have made this burst at a greater height, i.e., a scaled height nearer the "knees" of the height-of-burst chart, had data on height of burst been a primary objective. Requirements for other measurements, however, necessitated the limitation on burst height.

3 PREDICTION OF OVERPRESSURES

The unprecedented size of the burst and the inherent uncertainty in predicting the yield posed some new problems in estimating blast overpressures and associated thermal effects from Mike shot. Since it was to be a surface burst over water, it was felt that a reflection factor of 2 could safely be assumed, i.e., that the blast wave would take the form of a hemisphere having peak pressures, waveforms, and radii equivalent to those of a yield of twice the size in free air.

The set ranges to be used for the pressure gauges, and consequently their locations, were directly dependent upon the anticipated overpressures; so it was necessary to formulate a more or less arbitrary method for predicting these overpressures. Because it was fairly certain that the yield of Mike shot would be at least 5 Mt, or the equivalent of a burst of 10 Mt in free air, a pressure-distance curve for 10 Mt, scaled directly from Greenhouse George and Easy shots,[12] seemed to be a feasible starting point. This 10-Mt curve from Greenhouse George and Easy shots is by no means a free-air curve. In fact, because of the comparatively low burst heights of these two shots, it might more properly have been considered as representative of surface burst conditions. Consequently, when allowance was made for variations in yield and for indeterminate factors causing variation in shock overpressure at great distances, this method of prognostication seemed as valid as any.

Prediction of overpressures on King shot was less uncertain, since the anticipated yield (500 Kt) was more nearly of the order of previously fired weapons. Not only could the yield be estimated more accurately, but set ranges for the gauges in the overpressure region of interest were derived from a pressure-distance curve scaled from experimental data on Greenhouse tower shots.[13] A factor of 20 per cent was added as a safety factor.

4 CONFIGURATION AND INSTRUMENTATION OF THE BLAST LINE

4.1 Mike Shot

The magnitude of the anticipated yield from Mike shot made it mandatory that pressure-measuring stations be placed at considerably greater distances from ground zero than on earlier tests at Eniwetok and the Nevada Proving Grounds (Table 1). Predicted overpressures at the eleven station locations (Fig. 1) ranged from a maximum of approximately 320 psi to a minimum of 0.8 psi, and spacing was such that the predicted overpressure at each station was approximately half that at the preceding station. Actually, factors such as suitable island locations and existing recording shelters had to be considered in choosing these locations, making it necessary in some instances to deviate slightly from the basic plan. One station was on a man-made island (Noah) between Bogon and Engebi. As pointed out earlier, the crescent-shaped configuration of the island chain made it impossible to align all stations of the blast line on a single radius from ground zero. The four closest stations, 614, 615.01, 615.02, and 610, were essentially on a radial line bearing northeast from the shot island, but the remaining stations were at variant azimuths from the reference line passing through ground zero. As will be seen from Fig. 1, the shock wave traveled a major portion of its path across water before reaching Stations 611.01, 611.02, 611.03, 613.01, 611.04, 613.02, and 612.01.

Table 1 — LOCATIONS OF MEASURING STATIONS FOR BLAST LINE ON MIKE SHOT

Island	Station No.	Azimuth (from north)	Distance from ground zero, ft	Type of mount* Line 1	Type of mount* Line 2	Shelter No. and recorder
Teiteir	614	72°11′51″	4,402	GB	GB	600(A)
Bogairikk	615.01	72°44′45″	5,900	GB	GB	600(A)
Bogon	615.02	73°01′08″	8,250	GB	GB	600(A)
Noah†	610	72°49′25″	11,490	SOB	SOB	600(B)
Engebi	611.01	93°16′38″	15,900	SOB	PS	601(A)
Muzin	611.02	105°51′31″	21,412	SOB	PS	602(A)
Bokon	611.03	111°18′50″	30,354	SOB	PS	603(A)
Aitsu	613.01	111°34′17″	36,708	SOB	SOB	603(B)
Aomon	611.04	109°55′37″	47,574	SOB	PS	604(A)
Runit	613.02	127°18′57″	74,884	SOB	SOB	605(A)
Parry	612.01	144°59′56″	114,240	SOB	PS	606(A)

*GB, ground baffle; SOB, side-on baffle; PS, pitot static tube.

†A pipe mount on the reef between Bogon and Engebi.

Dual installations of sensing instruments were made at all stations on the blast line for Mike shot.[14] Sensing elements were standard variable-reluctance Bourdon type gauges (Model 3PAD) manufactured by the Wiancko Engineering Company,[15] mounted either in standard ground and side-on baffles[3] or in pitot static tubes.[16] Pressures predicted for the first three stations, on Teiteir, Bogairikk, and Bogon, made it advisable to use Wiancko gauges mounted in ground baffles (Fig. 2). At Noah both installations were Wiancko gauges mounted in side-on baffles (Fig. 3). At the remaining seven stations one gauge at each location was mounted in a side-on baffle; at two stations the second gauge was also mounted in a side-on baffle, whereas at the remaining five locations the second gauge was mounted in a pitot static tube.

The Wiancko gauges in side-on baffles were mounted 10 ft above the surface, either on single pipe stands (Fig. 4) or on goal-post type pipe stands (Fig. 5), depending on whether other types of instrumentation were to be mounted at the same locations. The pitot static tubes were mounted on the goal-post type stands in each instance.

Before the side-on type baffle was used on Operation Ivy, some extensive wind-tunnel tests were made to determine the influence of baffle orientation on the data obtained.[17] All side-on baffles were carefully aligned with ground zero in the belief that any error introduced by this orientation would be negligible and could safely be ignored.

Power to all gauges was supplied by a standard Consolidated Engineering Corporation 3-kc carrier system, and the outputs of the gauges were recorded on magnetic tape by a multichannel Ampex recording system.[14] Recording shelters were placed at convenient locations to serve all end instruments used; seven shelters (Table 1) were used on Mike shot, 602, 605, and 606 having one recorder each and the remainder having two recorders each.

4.2 King Shot

Since it was planned to install blast lines over both land and water on King shot, intended ground zero was fixed at a point off the north end of Runit (Fig. 6) to gain the advantage of a land blast line as long as possible. The land blast line comprised four stations, all on Runit, whereas the blast line over water had nine stations.

Eight of the stations for the blast line over water were placed on a coral reef along the northeast edge of Runit (Fig. 6), and the ninth was on the northern tip of Parry. All except the two most remote stations (617.08 and 612.02) were on a radial line from intended ground zero (Table 2). The station on Parry comprised two gauges, at the same locations as were used on Mike shot.

All stations on the land blast line were necessarily at different azimuths from the reference line passing through ground zero, and, although the blast line was predominantly over land, the shock wave had to traverse paths made up of varying percentages of land and water to reach the individual stations. Each of the land-line stations corresponded to one of the stations over water so far as its predicted overpressure and distance from intended ground zero were concerned (Table 2). The pattern followed in choosing station locations was the same as for Mike shot: it was attempted to choose locations such that overpressures would be halved at each successive measuring point.

Wiancko pressure gauges were again used for all air-pressure measurements on King shot. Those at the land-line stations were mounted in ground baffles (Fig. 2), and those over water in side-on baffles. The stations over water were single pipe stands mounted in concrete footings atop the coral reef (Fig. 7). The gauge in its baffle was thus effectively placed approximately 10 ft above the surface of the water, inasmuch as the footing was submerged the greater part of the time. Unfortunately, however, the movement of the tide caused the footings for some of the gauge installations to be exposed part or all of the time. Elevations of the footings for the various stations above the mean low water spring tide are presented in Table 3.

The carrier and recording systems for King shot were the same as those used for Mike shot. Outputs of all land-line gauges on Runit and all gauges over water near Runit were re-

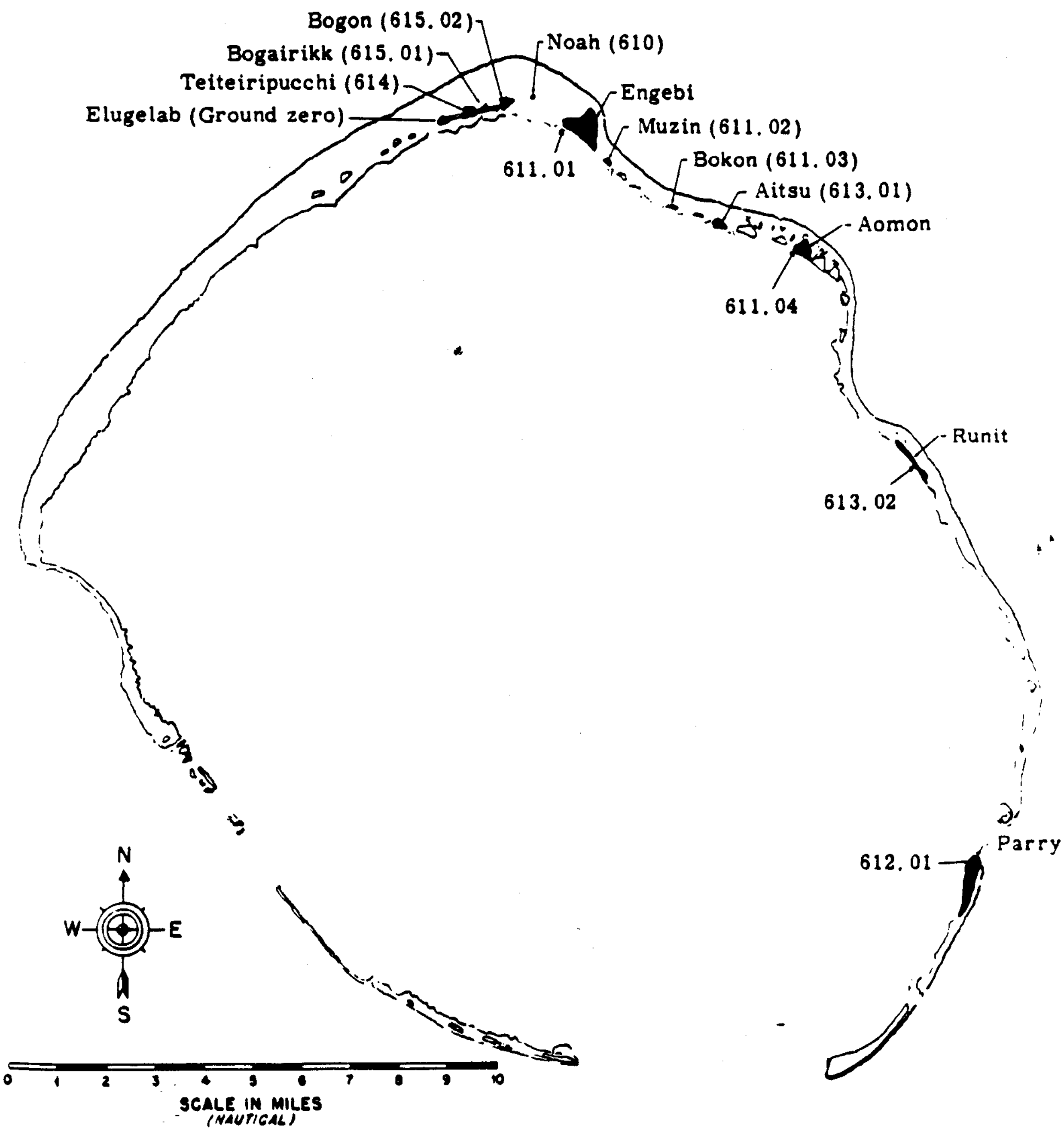

Fig. 1—Blast line for Mike shot.

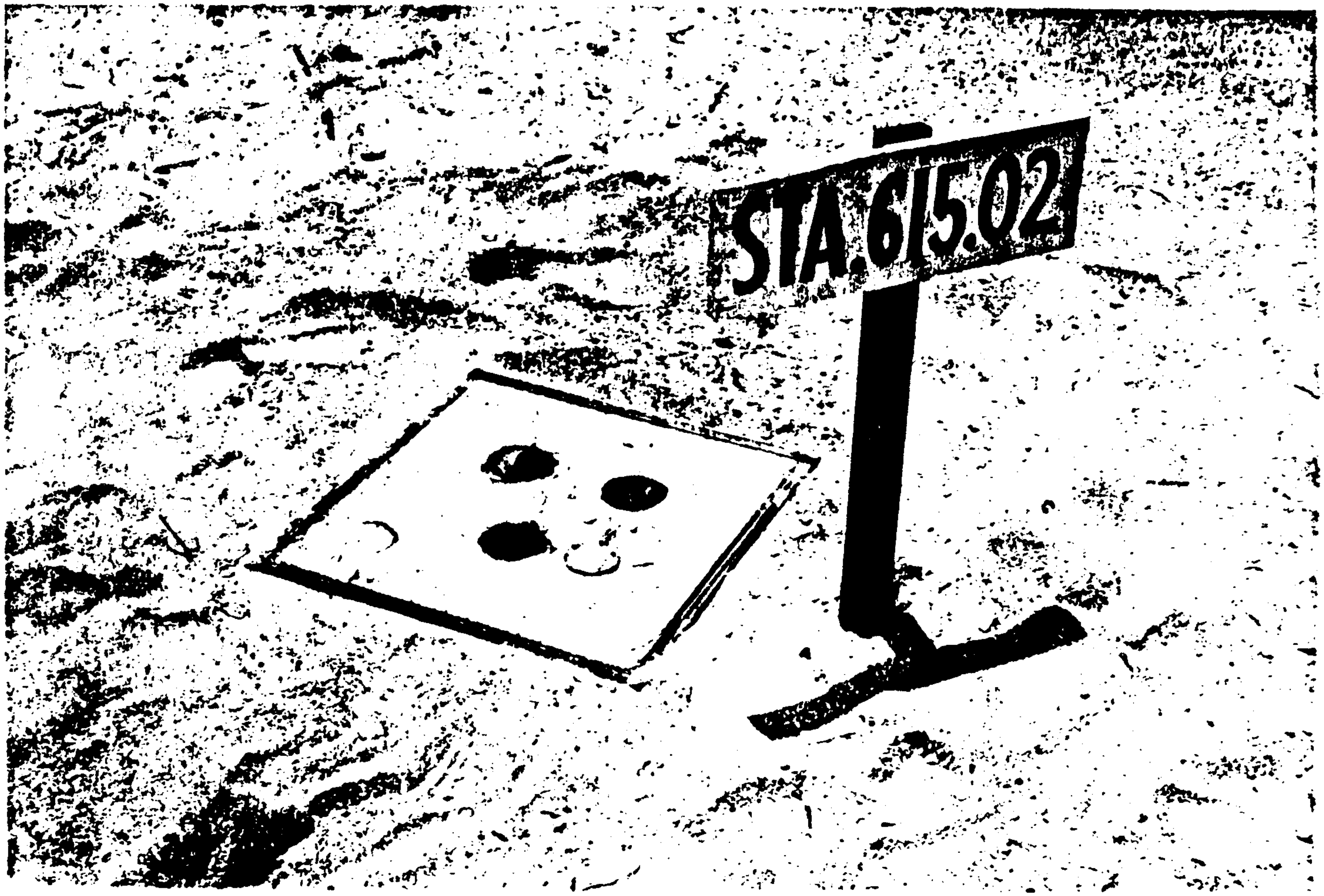

Fig. 2 — Wiancko gauges in ground baffle.

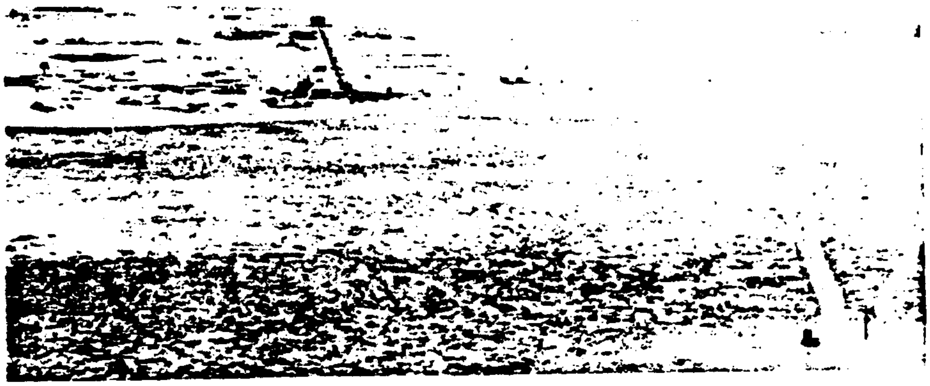

Fig. 3—Station Noah (lower right), showing Bogon in background.

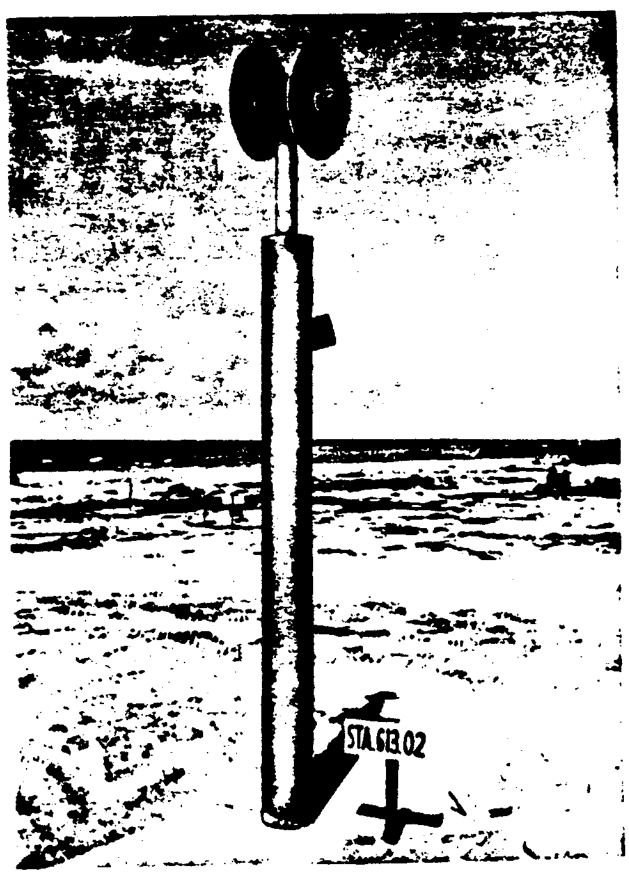

Fig. 4—Air baffles installed on single pipe stand.

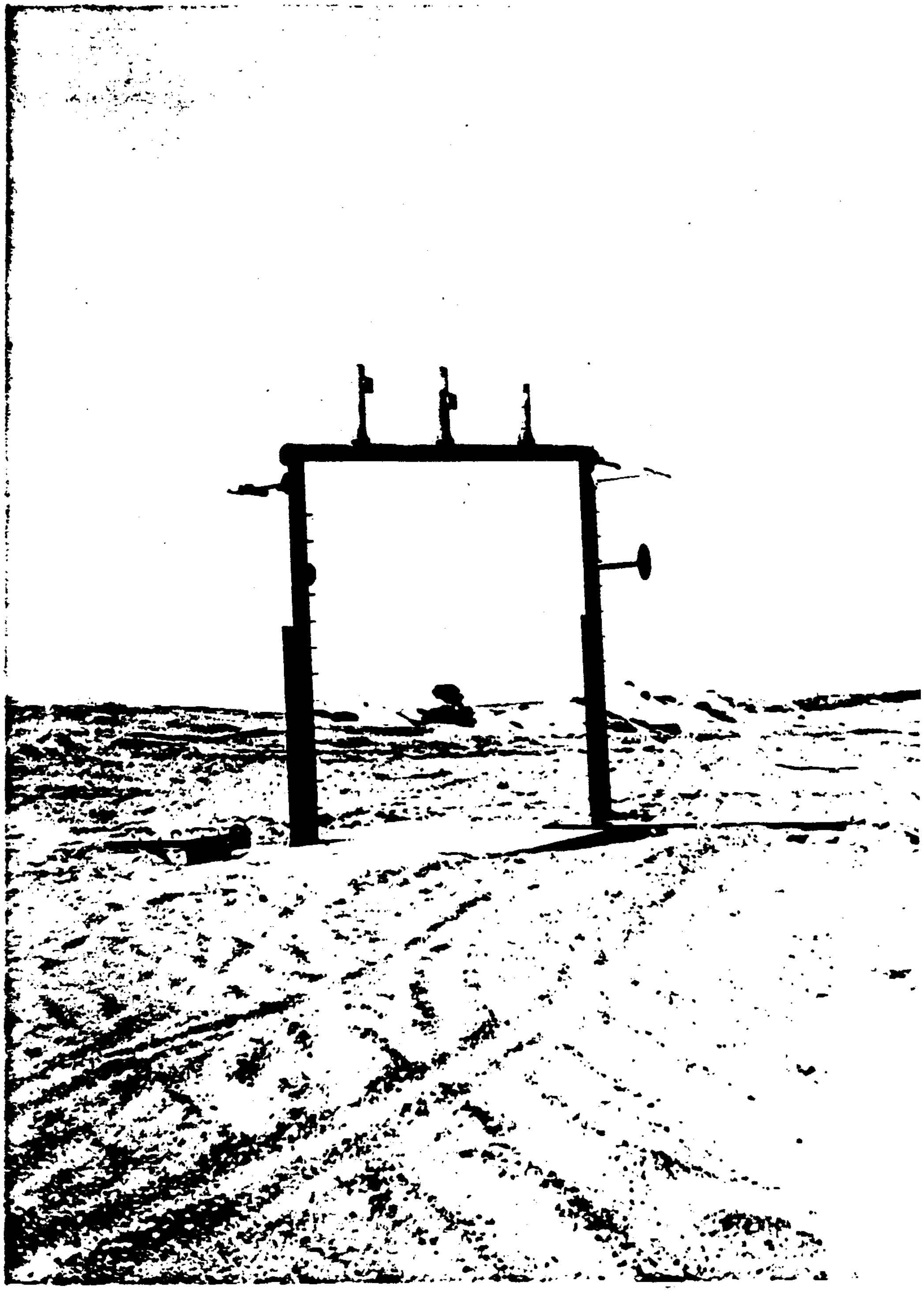

Fig. 5—Goal-post towers; side-on baffle and pitot static tube at right.

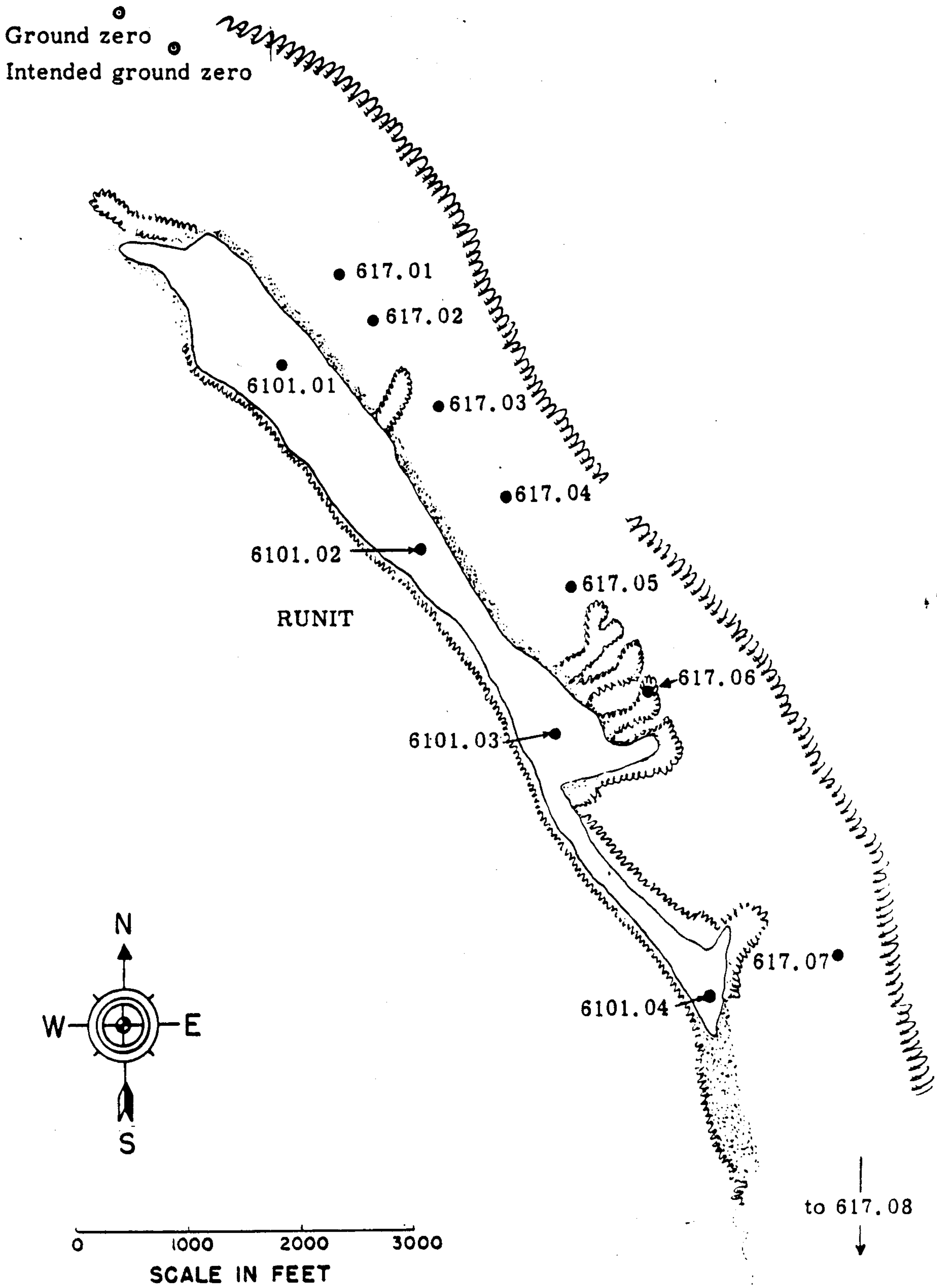

Fig. 6—Blast lines for King shot.

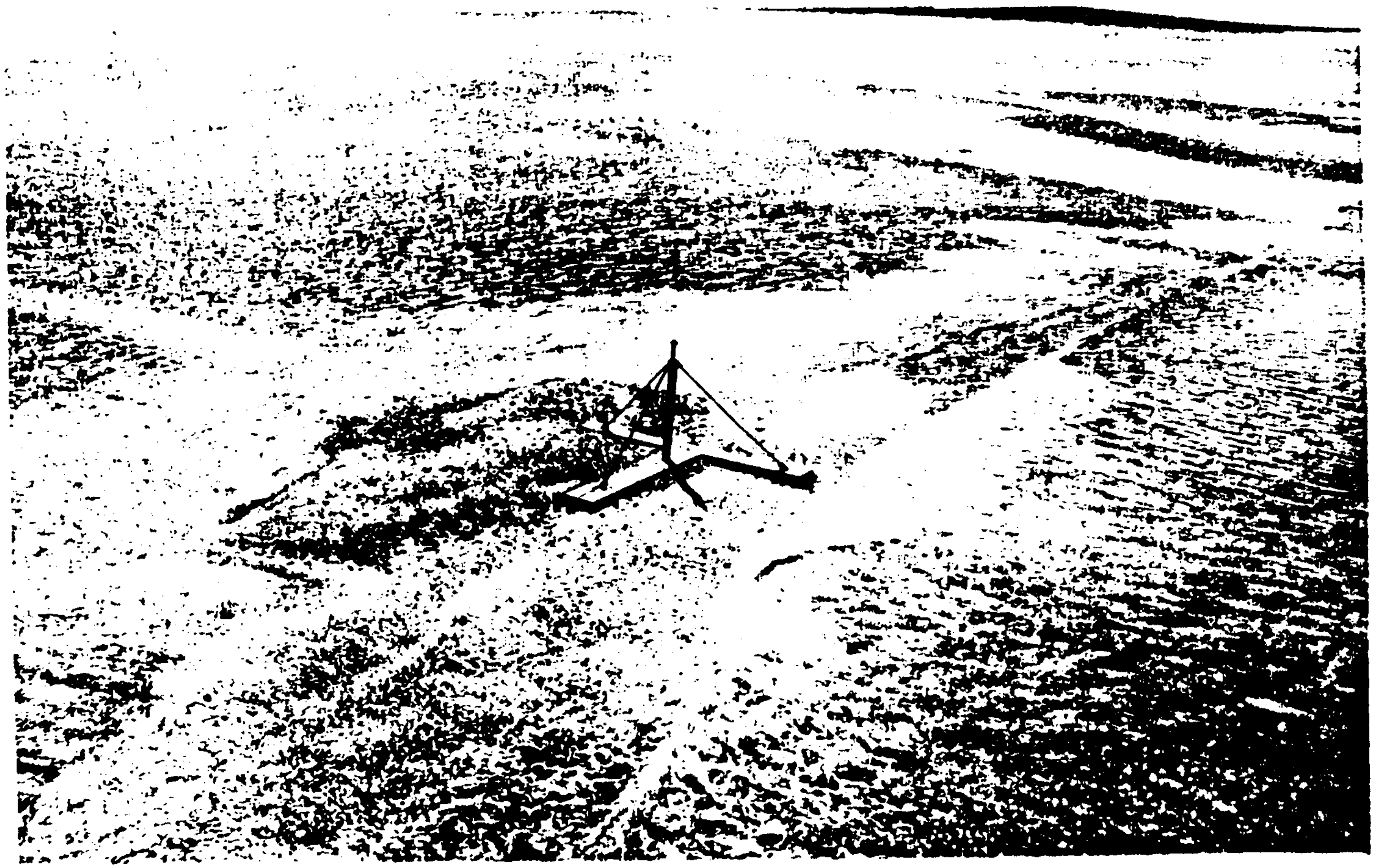

Fig. 7 — Water-line pipe stand before installation of side-on baffle.

corded at Shelter 605 on Runit; the gauges on Parry were served by the recorder at Shelter 606 on Parry.

Table 2—LOCATIONS OF MEASURING STATIONS FOR BLAST LINES ON KING SHOT

		Land line		Overwater line	
Island	Distance from intended ground zero, ft	Station No.	Azimuth (from north)	Station No.	Azimuth (from north)
Runit	2,50C			617.01	143°30′00″
	3,000	6101.01	161°08′07″	617.02	143°30′00″
	4,000			617.03	143°30′00″
	5,000	6101.02	153°38′26″	617.04	143°30′00″
	6,000			617.05	143°30′00″
	7,000	6101.03	150°37′30″	617.06	143°30′00″
	9,686	6101.04	150°18′20″		
	10,000			617.07	143°30′00″
	15,000			617.08	151°45′00″
Parry*	54,754			612.02	170°20′27″

*Considered an overwater station because the major part of the path traveled by the shock wave was over water.

Table 3—ELEVATIONS OF FOOTINGS FOR STATIONS OVER WATER ABOVE MEAN LOW WATER SPRING TIDE

Station No.	Height of station, ft
617.01	1.63
617.02	0.18
617.03	2.06
617.04	2.30
617.05	1.39
617.06	4.75
617.07	2.02
617.08	1.43

5 RESULTS

5.1 Performance of Instrumentation and Recording System

Of the 22 air-pressure measurements attempted on Mike shot, 10 were completely successful and 3 partially so; on King shot, 9 of the 14 measurements attempted were entirely successful and the remaining 5 partially so. Consequently it is felt that enough satisfactory records were obtained to justify the conclusions reached in this report. It was necessary, however, in analyzing the data from both Mike and King shots, to exercise considerable personal judgment because of several unforeseeable failures of the recording and gauge systems.

On Mike shot three of the eleven recorders failed to start at all because the brakes on the tape transport system jammed. These brakes consisted of asbestos brake bands around soft iron brake drums; the extremely high moisture content of the air in the recording shelters prior to Mike shot apparently caused the brake bands to swell and the drums to rust, with the result that the mechanism was jammed prior to operation. The recorders so affected were the Able recorders on Bogon and Bokon and the Baker recorder on Aomon. None of the air-pressure gauges was connected to the Baker recorder on Aomon, but, since the primary air-pressure gauges at Stations 614, 615.01, 615.02, and 611.03 were connected to the first two recorders, no records were obtained from these gauges.

Three additional recorders on Mike shot ran properly only until the air shock front struck the shelter. One of these was the Baker recorder on Bogon, to which the gauges at Station 610 (Noah) were connected. Because this station was farther from ground zero than was the recorder shelter, the records from it were worthless. However, a low-range pressure gauge at Station 615.02 was also connected to this recorder and did provide information on arrival time since this station was nearer ground zero than was the shelter. At the time that the shock struck the shelter on Bokon, a small amount of slack developed in the tape on the Baker recorder, causing it to wind up on the capstan. Although the recorder continued to run for several seconds thereafter, the tape did not wind up on the take-up spool but became snarled inside the cover over the recorder. Although the speed at which the tape crossed the recorder head might have changed, information from the gauges at Aitsu, placed on the tape during this interval, apparently gave reliable arrival times and pressures which were only slightly reduced, if at all. When the shock struck the shelter on Muzin, it caused some tape "wow" or fluctuation of the speed at which the tape passed the heads of the recorder. Since this wow occurred as the pressure was decreasing in the positive phase, and since the speed had returned to normal before the crossover point into the negative phase was reached, the record was rather easily interpolated.

Determination of arrival times on the records from recorders at two of the shelters, those on Runit and Parry, was again a matter of judgment. The Blue Boxes at these locations failed, with the result that no signal was placed on the tape at zero time. Although the Blue Box on Bokon also failed, an electromagnetic signal at zero time appeared on the records at this shelter. A fairly accurate value for arrival time could be obtained from the other two records by counting from the start time of the tape at −15 sec.

On King shot all recorders ran properly, precautions having been taken to remove the brake bands and repair the brakes so that the recorders ran free. Actually, the brakes were not used during operation of the recorder (the Ampex recorder was designed for other applications in which it is desirable to start and stop the recording system quickly). Since the number of recorders required on King shot was not so great as on Mike shot, it was possible to take the added precaution of installing dual or backup recorders. Two of these dual installations were on Runit, and the other was on Parry. Both recorders at each dual installation ran during the test; thus, if one failed, a record was obtained on the other.

Perhaps the most serious difficulty experienced in obtaining intelligence from the air-pressure gauges on King shot was the tape wow which obscured all records from the recorders on Runit at about the time the air shock struck the shelter. Some records began in the middle of the wow, whereas others were in the crossover period from the positive to the negative phase. Fortunately some of the records—those from the first two gauges over water, which broke off, and those from two gauges considerably farther from ground zero than the shelter—were at balance during this period. Thus the signal that did appear on these channels during the period in question could be attributed solely to tape wow. The records that recorded the wow alone could be used as a standard for comparison in subtracting the wow from channels which did record gauge signals during this period. This procedure made it possible to obtain highly satisfactory records despite interference by tape wow, although on two records it was impossible to resolve either the shape of the pressure-time curve in the negative phase or the ending of the negative phase.

Several of the gauges over water failed completely or partially, but, even though those at Stations 617.01 and 617.02 broke off from their mounts, peak pressures and arrival times were obtained. The baffles for the gauges at Stations 617.03 and 617.04 rotated about 45° from the side-on position (presumably during the blast), but peak pressures could be read, and a fair approximation of a pressure-time curve could be obtained. Despite the fact that the cable to Station 617.06, which was on a sandspit, broke soon after the air shock reached the gauge, it was possible to obtain readings of peak pressure and arrival time. Failure of the gauges and cables did not cause the carrier voltage (monitored during the entire recording period) at the other gauges to decrease, and the remaining gauges on both blast lines operated properly throughout the test.

A possible source of error in the measurements made over water, for King shot, was the variation in the height of the tide. The elevations of the footings for some of the stations were above the mean low water spring tide (Table 3). The fact that the reef was exposed near the bases of some of the stations over water could conceivably have resulted in some distortion of the shock wave because of thermal effect, thus counteracting the advantage of the blast line over water. The height of the tide at the time of the shock wave on King shot was approximately 2 ft. However, the prevailing winds were in a direction such that they would tend to pile more water on top of the reef than would be indicated by the hydrographic charts. An examination of Table 3 reveals that Station 617.06 was the only one whose base was completely out of the water; others may have been awash. Results obtained from the measurements do not give evidence of any serious distortion of the shock wave, probably because at least 95 per cent of the reef on which the measuring stations were installed was awash or under water and because the hard rock of the reef was not overly subject to the type of superficial thermal explosion usually associated with distortions of this type.

An inherent and undesirable characteristic of the Ampex recording system as used for these tests was the tendency toward zero drift in the playback of the record. It was necessary to use a considerable amount of arbitrary judgment in establishing a base line for records from all gauges on both Mike and King shots, with the result that data on the negative phase—peak pressures, durations, and impulses—are subject to a potential error of significant magnitude.

5.2 Analysis of Results

(a) Mike Shot. Data from the air-pressure measurements on Mike shot are presented in Table 4. The arrival time at Station 615.02 was obtained from the low-range gauge connected to the Baker recorder on Bogon. It might also be noted that, since the arrival time on the USS Estes was determined by means of a stop watch, it is accurate only to within 1 sec (1 per cent).

From Table 4 and from the pressure profiles (Figs. 8 and 9) it can be seen that there is a sizable discrepancy between the peak pressures measured by the gauge in the side-on baffle and by that in the pitot static tube at Station 611.01; a similar discrepancy was observed between the readings for gauges of the same type at Station 612.01. The difference at Station 611.01 cannot be attributed simply to statistical variation;* it is possible that the lower reading from the gauge in the side-on baffle could have resulted from a leakage path across the terminals, caused by excessive moisture. Although the calibration steps for each gauge would have revealed any changes in system amplification, it would have been impossible to detect a leakage path in this manner. Too, evidence from wind and temperature measurements[18] leads to the belief that the higher reading of peak overpressure (20.5 psi) is the more reliable.

Each of these measurements—total head, dynamic pressure, and temperature—gave results consistent with those expected from a peak overpressure of 20 psi. The difference between pressures measured at Station 612.01 may be within the limit of statistical deviation, for, although the difference is comparatively great, the pressures being measured were rather

*The term "statistical variation" takes into account the accuracies of the system and instrumentation and is a means for expressing the differences in signal level observed when identical pulses act upon identical gauges.

Table 4—RESULTS OF MIKE SHOT (NOV. 1, 1952)*

Island	Station	Distance to ground zero, ft	Time of arrival, sec
Teiteir	614	4,402	
Bogairikk	615.01	5,900	
Bogon	615.02	8,250	1.379
Noah	610	11,490	
Engebi	611.01†	15,900	5.184
	611.01‡	15,900	5.183
Muzin	611.02†	21,412	8.713
	611.02‡	21,412	8.710
Bokon	611.03	30,354	
Aitsu	613.01(1)†	36,708	20.075
	613.01(2)†	36,708	20.076
Aomon	611.04†	47,574	28.867
	611.04‡	47,574	28.865
Runit	613.02(1)†	74,884	51.63§
	613.02(2)†	74,884	51.63§
Parry	612.01†	114,240	83.75§
	612.01‡	114,240	83.75§
USS Estes		185,500	145¶

*Fireball yield (as of Mar. 24, 1953): 10.5 ± 1.0 Mt.

†Side-on baffle.

‡Pitot static tube.

§Blue Box failed; time of arrival counted from −15-sec signal and corrected.

¶Time of arrival taken by stop watch by E. F. Cox.

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Table 5—RESULTS OF KING SHOT (NOV. 16, 1952)*

Island	Station	Distance to ground zero, ft	Slant range, ft	Time of arrival, sec
Runit	617.01	3,034	3,375	0.777
	617.02	3,533	3,830	0.965
	617.03	4,531	4,767	1.412
	617.04	5,531	5,725	1.934
	617.05	6,530	6,696	2.521
	617.06	7,529	7,674	3.153
	617.07	10,529	10,632	5.229
	617.08	15,494	15,564	8.992
Parry	612.02†	55,132	55,152	42.058
	612.02‡	55,132	55,152	42.060
Runit	6101.01	3,458	3,761	0.797
	6101.02	5,490	5,686	1.767
	6101.03	7,502	7,646	3.088
	6101.04	10,188	10,295	4.914

*Radiochemical yield (as of Mar. 24, 1953): 540 ± 10 Kt; location of burst point: 300 ft N, 480 ft W of intended ground zero; height of burst: 1480 ft.

†Side-on baffle.

‡Pitot static tube.

low. Also, the gauge used in the pitot static tube was a 10-psi (full-scale) gauge rather than a 1-psi gauge, as should have been used at this station. The 10-psi gauge had an absolute error of about 0.1 psi in addition to the system error of approximately 5 per cent. Kiel gauge measurements at this same station[18] gave the total head as approximately 0.51 psi. At this pressure the dynamic pressure is so low that the total head is almost the same as the static pressure.

The pressure-time profiles for the various stations (Figs. 8 and 9) are not unusual except that at large distances and low pressures there is a rounding off of the peaks.

The tabulated data from Mike shot are presented graphically in Figs. 10 to 16. In the curve of arrival time vs distance (Fig. 10), only a single data point is plotted for each station, since arrival times at the two gauges were almost identical. In the curves showing variation of peak positive pressure, positive-phase duration, positive impulse, peak negative pressure, negative-phase duration, and negative impulse with horizontal distance from ground zero, the values for each gauge are plotted, using appropriate identifying symbols. No attempt was made to draw the curves through every point; the curves were fitted visually and merely give a general indication of how the function in question varied with horizontal distance from ground zero.

(b) King Shot. Data from the air-pressure measurements on King shot are presented in Table 5. Absence of data on the negative phase from Stations 617.03 and 6101.01 is a result of inability to make the correction for tape wow.

As will be seen from a comparison of Tables 2 and 5, distances of the various stations from ground zero differed considerably from those intended; by the same token the distances from ground zero to the corresponding stations over land and water were quite different. Consequently, in constructing pressure-time profiles (Figs. 17 to 19) for the corresponding stations on the land and water lines (6101.01-617.02, 6101.02-617.04, 6101.03-617.06, and 6101.04-617.07), it was necessary to correct arrival times at the stations over water for comparison with those at the land-line stations. The only really serious discrepancy was between Stations 617.07 and 6101.04, for which the intended distances from ground zero had not been the same.

The pronounced dips in the pressure-time profiles for the gauges at Stations 617.03 and 617.04 are attributed to rotation of the gauges. There was a strong temptation to draw a smooth curve from the peak to the crossover point, but it was thought preferable to show the actual shape of the curve.

A comparison of the profiles for the gauges over water with those for the land-line gauges emphasizes the fact that the blast wave traveling over water exhibited a sharp rise time and a well-defined peak, decaying smoothly to zero; in fact, it was almost a perfect "textbook" waveform. That traveling over land, on the other hand, was obviously affected by thermal radiation. Only the first station on the land line (6101.01) actually recorded any definite evidence of a precursor; if there was a precursor at the second station (6101.02), its magnitude was such that it was all but indistinguishable from the background noise. The main shock wave appeared to have a slow rise time and a peculiar double peak. At two stations farther out along the blast line there was definite evidence of recovery from the thermal effect, i.e., a sharp rise to within 80 to 90 per cent of the peak pressure and a rounding off of the peak.

An interesting phenomenon observable from the data on King shot was the second shock at the very beginning of the negative phase (Figs. 17 to 19). Data on this second shock are presented in Table 6; the peak overpressures tabulated are the actual rises measured, considering the pressure at the time of arrival of the second shock as ambient. It is unlikely that this shock could be attributable to a shocking up of the negative phase, since such a shock would occur at the end rather than at the beginning of the negative phase. Such a second shock has been noted before,[1,2] but at the end of the positive phase or nearer the crossover point. Although no second shock was seen by the gauges as far from ground zero as those on Parry, it is probable that its magnitude at this distance would have been such (~0.03 psi) that it would have been lost in the background noise.

Positive-phase durations (Table 5) for stations on the land line were taken from the point at which the pressure first began to rise to the crossover point; no attempt was made to com-

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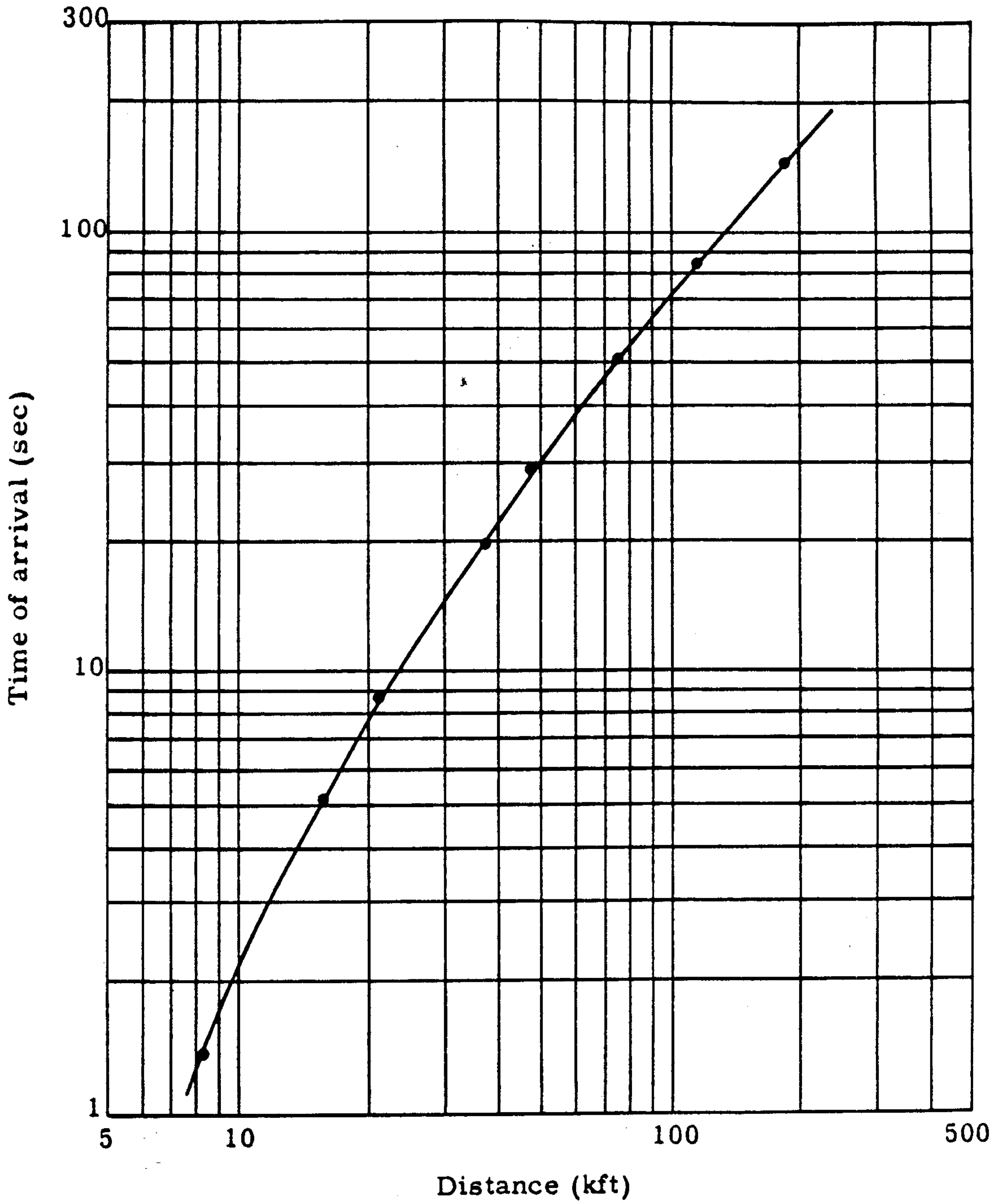

Fig. 10—Time of arrival vs distance from ground zero (Mike shot).

pensate for the duration of the precursor. Likewise the peak positive pressures and positive impulses were those actually read from the pressure-time curves with no correction for the precursor or other factors. Negative impulses were not corrected for the effect of the second shock.

Table 6—DATA ON SECOND SHOCK (KING SHOT)

Station No.	Arrival time, sec	Peak positive pressure, psi
Blast Line over Water		
617.01		
617.02		
617.03		
617.04	4.108	
617.05	4.885	
617.06		
617.07	8.353	
617.08	12.684	
612.02		
Blast Line over Land		
6101.01		
6101.02	4.048	
6101.03	5.601	
6101.04	7.948	

Tabulated data from King shot (Table 5) are presented graphically in Figs. 20 to 29. In Figs. 20 and 21, arrival times are plotted against both slant range and horizontal distance from ground zero. It is readily seen that there is no significant difference in the shapes of the two curves, and consequently the other parameters are plotted against horizontal distance only. The fact that in every instance the shock wave arrived at the land-line stations sooner than at those over water may be attributed to formation of the precursor, which of course traveled faster than the main shock.

Peak pressures measured at the stations over water decayed smoothly with distance from ground zero (Fig. 22), and there was considerably less scatter in the data than in those measured on Mike shot. Peak pressures measured over land exhibited the attenuation believed characteristic when the precursor forms; since the precursor was just beginning to be well formed at the first station on the blast line, this attenuation was actually not observable until the shock wave had reached the second and third stations on the land blast line. At the fourth station the peak pressures had apparently recovered. The dip in peak pressures was not as marked on this test as under similar circumstances in tests at the Nevada Proving Grounds, probably because the sector of land over which the precursor formed was quite narrow and the sharp waveforms over the adjacent large areas of water tended to aid in maintaining the shape of the shock front.

Despite the scatter of the data it would appear that the positive-phase durations (Fig. 23) as measured on the land blast line were longer than those measured over water, as would have been expected in view of precursor formation. On the other hand, precursor formation apparently did not decrease the positive impulse (Fig. 24). The increased length of the positive phase over land thus compensated for the diminution of peak positive pressure.

Although there was considerable scatter in the data from the negative phase (Figs. 25 to

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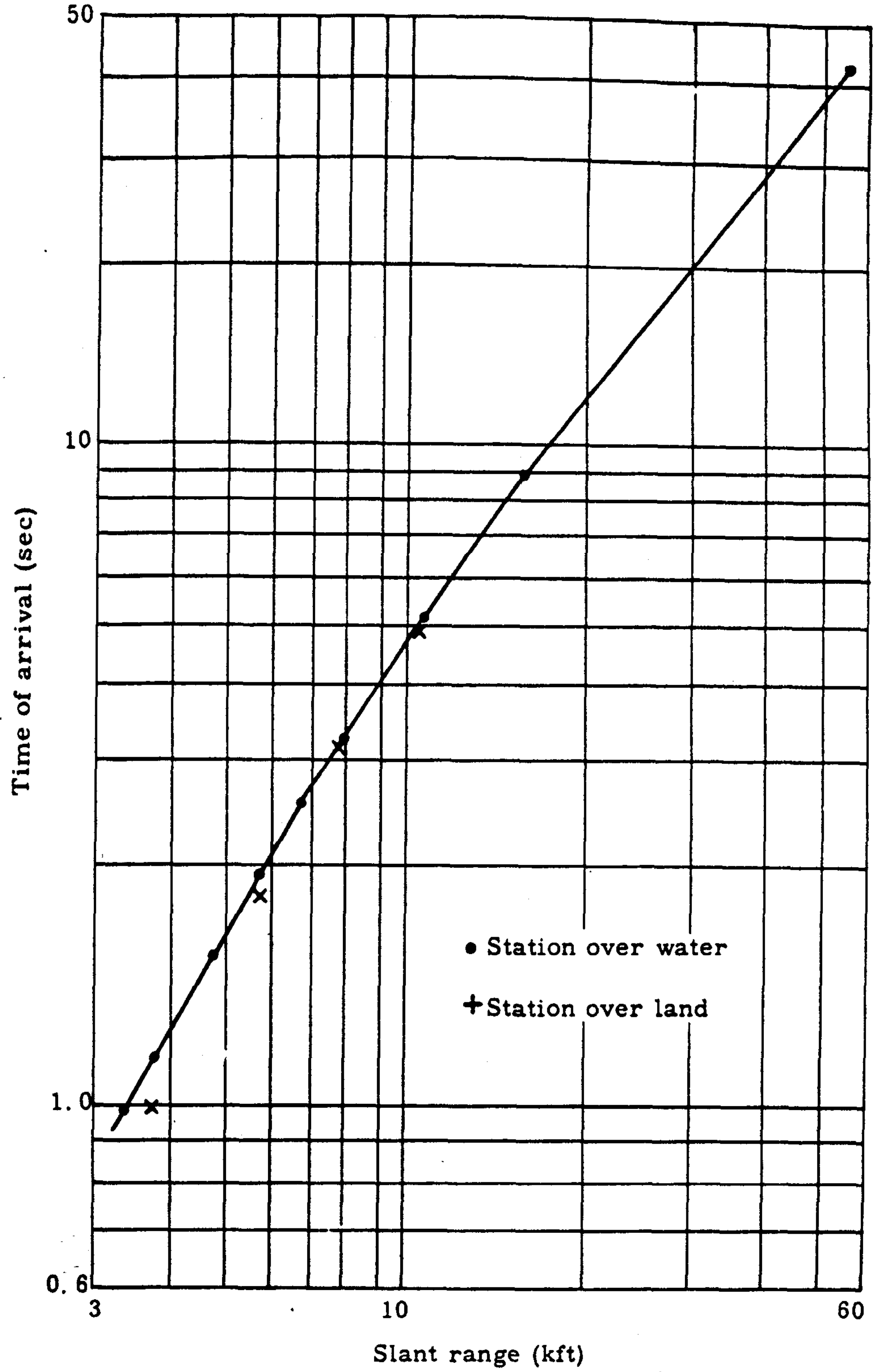

Fig. 20 — Time of arrival vs slant range (King shot).

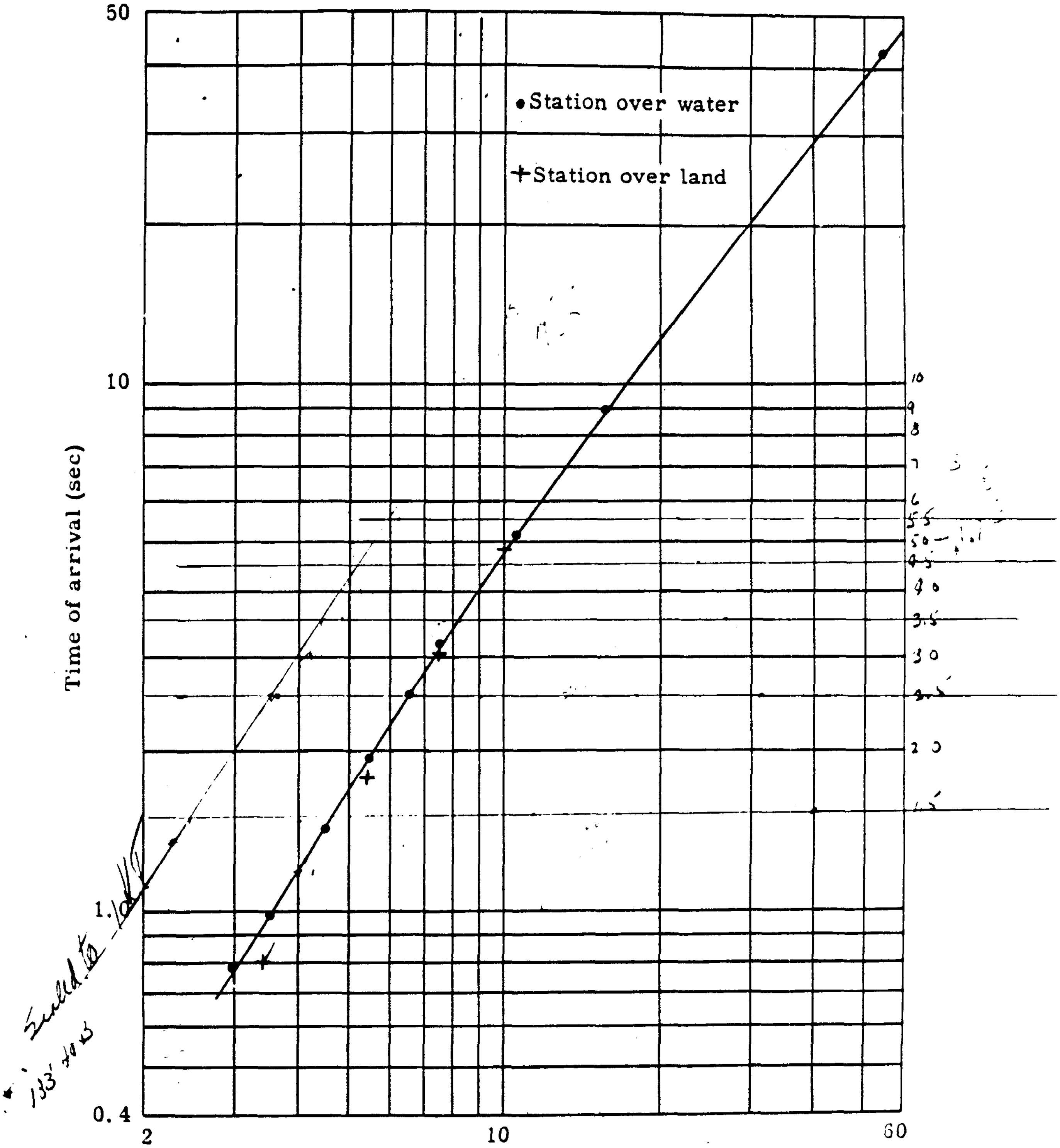

Fig. 21 —Time of arrival vs horizontal distance from ground zero (King shot).

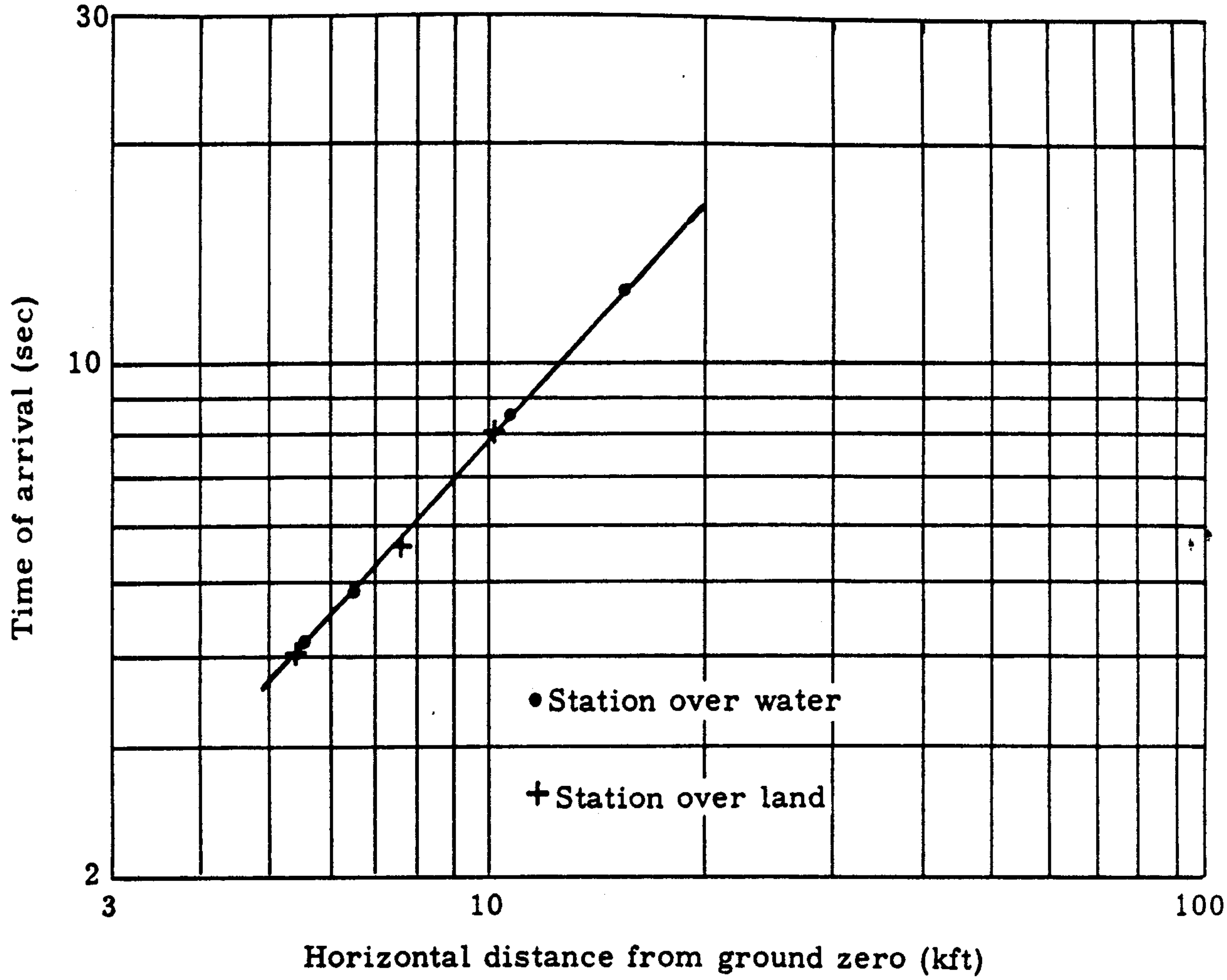

Fig. 28—Time of arrival of the second shock vs horizontal distance from ground zero (King shot).

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27), it would seem that formation of the precursor has little effect on the measured parameters.

Little attempt was made at a thorough analysis of the measured data on the second shock (Figs. 28 and 29). Its formation is apparently unrelated either to formation of the precursor or to the type of surface over which the shock wave travels. It was noted that the peak pressures in the second shock dropped off much more rapidly than in the initial shock.

6 RESULTS SCALED TO 1 KT AT SEA LEVEL

Measured parameters on Mike and King shots have been scaled to 1 Kt (RC) at sea level; significant characteristics of the two shots and the scaling factors used are listed in Table 7. It was desired to compare scaled data on time of arrival and peak pressure vs distance with the composite curves prepared by the Naval Ordnance Laboratory (NOL) for Tumbler shots 1 to 4, in which these parameters were scaled[2] to 1 and 2 Kt. Thus it was necessary also to scale the data on time of arrival to 20°C, the temperature used by NOL in preparing these reference curves. Because no scaled data on positive-phase duration and positive impulse were available, however, it was necessary to draw comparisons with scaled curves for 1- and 2-Kt bursts as derived[19] from the IBM problem M for these parameters. Measured peak overpressures are also compared with the height-of-burst curves for nuclear explosions published in TM 23-200.[20]

6.1 Mike Shot

Scaled values of the various parameters are presented in Table 8. This shot was a surface burst. Therefore, if none of the energy normally going into blast was lost to the surface, the scaled values would be those obtained from a burst of a 2-Kt bomb in free air, i.e., from a bomb of twice the yield.

As can be seen from Fig. 30, scaled arrival times correspond closely with those indicated by the composite curve for a 2-Kt bomb (evidently the scaled times of arrival fit the 2-Kt reference curve within the accuracy to which the yield is known). Because NOL did not make measurements of time of arrival at scaled distances greater than 1400 ft, however, it was necessary to extend the reference curves for 1 and 2 Kt by tying in curves based on measured results[1] from Tumbler shot 2. This application of data obtained by another group was deemed valid in view of the fact that beyond this scaled distance the shock velocities are essentially sonic velocities.

Peak positive overpressures, plotted against scaled distances from zero (Fig. 31), are compared with the corresponding curves for 1 and 2 Kt as derived from Tumbler data at overpressure levels ranging from 30 to 5 psi. At the lower overpressure levels the reference curves are essentially the Stoner-Bleakney curves as reproduced in SC-1827(Tr).[21] Because the Stoner-Bleakney curves did not match exactly those published in WT-513 but were parallel to them, the curve for the lower overpressure levels was moved to the right far enough to obtain a continuous curve. Measured overpressures from Mike shot seem to fall on the 2-Kt curve in the higher overpressure range (12 to 20 psi) and follow a smooth transition toward the 1-Kt curve in the lower overpressure regions. It is believed that the point at 3.6 psi may be low because of faulty measurements. The fact that in the lower overpressure regions the measured points fall away from the 2-Kt curve is attributed to the effects of a nonhomogeneous atmosphere or atmospheric refraction. It is unfortunate that no pressures in excess of 20 psi were measured, for it would be interesting to see whether they fell on the 2-Kt curve.

Although it would have been preferable to have been able to evaluate scaled values of positive-phase duration and positive impulse against measured values of the same parameters as derived from data on other tests, lack of such data made it infeasible in this instance. However, when peak pressures and arrival times computed from the IBM problem M were compared with those obtained by Hartmann et al., they were found to be in agreement within rea-

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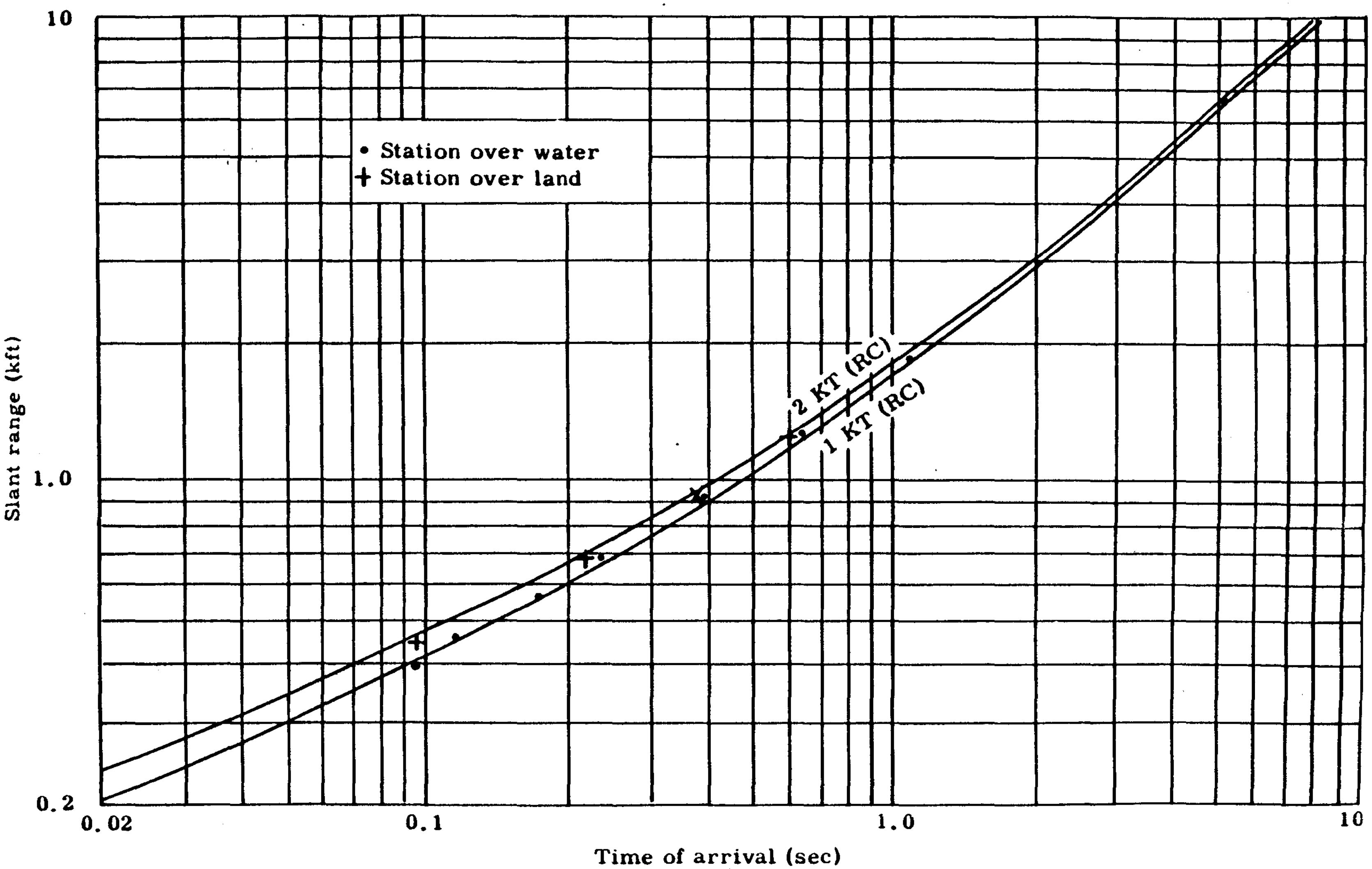

Fig. 30—Time of arrival vs distance from ground zero (Mike shot); data reduced to 1 Kt (RC) at sea level. Reference curves are composite free-air curves from data on Tumbler shots 1 to 4 (from WT-513) at scaled distances out to 1400 ft; at greater distances they were obtained from data on Tumbler shot 2 (from WT-501).

sonable limits of error. Thus it was felt that no appreciable error was introduced by using the results of such a computation as a standard for comparison, and the 1- and 2-Kt reference curves of Fig. 32 for positive-phase duration were derived in this manner. The data from the reference curves derived from the IBM run were thus scaled down to 1 Kt. The scaled durations from Mike shot were found to be considerably longer than would have been anticipated from a burst of a 2-Kt bomb in free air. Positive impulses, on the other hand, were somewhat nearer those expected from a 2-Kt burst (Fig. 33) and of an order of magnitude that would indicate that the decrease in peak pressure coupled with the increase in positive-phase duration to maintain the impulse at a balance.

Table 7 — CHARACTERISTICS OF IVY SHOTS

Characteristic	Symbol	Mike	King
Time of shot		0715 local, Nov. 1, 1952	1130 local, Nov. 16, 1952
Nominal ground zero, on Eniwetok grid	IGZ	N 147,750 E 67,790	N 108,150 E 124,130
Actual ground zero	GZ		N 108,450 ± 30 E 123,650 ± 30
Actual height, ft	h		1480 ± 20
Yield, Kt	W_{RC}	10,500 ± 1,000	540 ± 5
Preshot pressure on ground	P_{0g}	1,007.4 mb 14.61 psi	1011 mb 14.66 psi
Preshot pressure at burst height	P_0	1,007.4 mb 14.61 psi	960 mb 13.92 psi
Preshot temperature on ground	T_{0g}	83.75°F 28.7°C	85.5°F 29.7°C
Preshot temperature at burst height	T_0	28.7°C	25.6°C
Factor used to correct pressure to sea level	$S_P = \frac{14.7}{P_0}$	1.005	1.055
Factor used to correct distance to 1 Kt at sea level	$S_D = \left(\frac{P_0}{14.7\, W_{RC}}\right)^{1/3}$	0.04558	0.1206
Factor used to correct time to 1 Kt at sea level	$S_T = \left(\frac{T_0+273}{293}\right)^{1/2}\left(\frac{P_0}{14.7}\right)^{1/3}\left(\frac{1}{W_{RC}}\right)^{1/3}$	0.04625	0.1217
Factor used to correct impulse to 1 Kt at sea level	$S_I = S_T S_P = \left(\frac{T_0+273}{293}\right)^{1/2}\left(\frac{14.7}{P_0}\right)^{2/3}\left(\frac{1}{W_{RC}}\right)^{1/3}$	0.04648	0.1284
Reduced height, ft	$H = \frac{h}{(W_{RC})^{1/3}}\left(\frac{P_0}{14.7}\right)^{1/3}$		178

6.2 King Shot

Scaled data from King shot are presented in Table 9. Scaled arrival times are compared with the 1- and 2-Kt curves from Tumbler in Fig. 34. Inasmuch as this shot was neither a surface burst nor a burst in free air, the scaled arrival times at comparatively small scaled dis-

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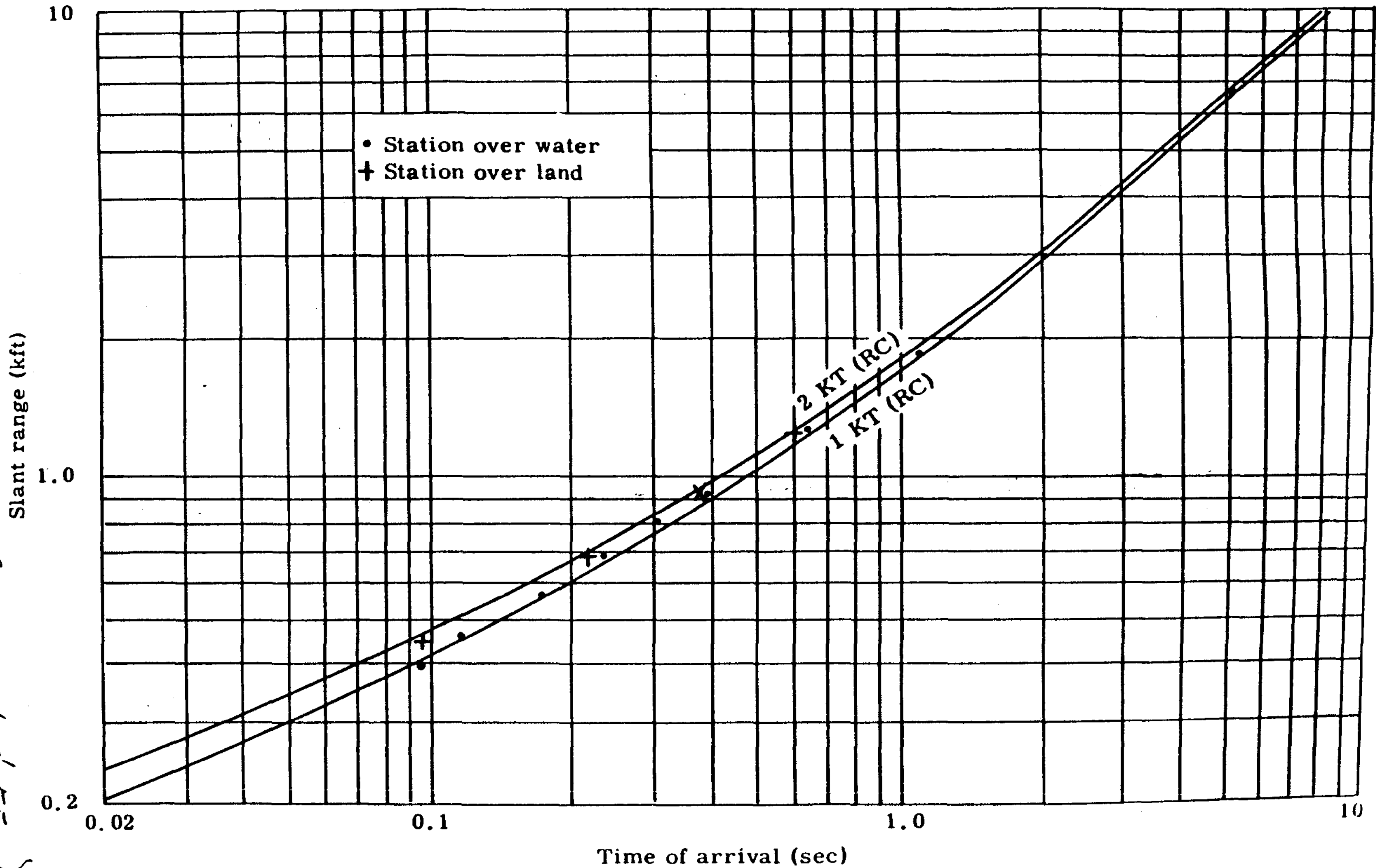

Fig. 34—Time of arrival vs slant range (King shot); data reduced to 1 Kt (RC) at sea level. Reference curves are composite free-air curves from data on Tumbler shots 1 to 4 (from WT-513) at scaled distances out to 1400 ft; at greater distances they were obtained from data on Tumbler shot 2 (from WT-501).

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tances, i.e., in the region where Mach reflection had just started, should coincide rather closely with those for the 1-Kt curve. At greater distances one would expect a smooth transition toward the 2-Kt curve as the Mach stem grows until it covers the entire hemisphere. It is interesting to note that scaled arrival times derived from measurements over water behave in exactly this fashion. No attempt was made to compare the curve of peak positive overpressure vs scaled distance on King shot with a reference standard, since no data were available from another shot having the same scaled height of burst. The only alternative was a comparison with a height-of-burst chart. As on Mike shot, scaled values of positive-phase duration were compared with free-air curves for 1 and 2 Kt (Fig. 35). It was difficult to predict how these values should have compared, but again it was found that scaled durations were a little longer than would have been expected from a burst of a 2-Kt bomb in free air, although not so long as on Mike shot. Positive impulses (Fig. 36) were found to be close to those expected from a 2-Kt burst.

Table 8—RESULTS OF MIKE SHOT REDUCED TO 1 KT (RC) AT SEA LEVEL

Station No.	Distance to ground zero, ft	Time of arrival, sec
615.02	376.0	0.0638
611.01*	724.7	0.240
611.01†	724.7	0.240
611.02*	976.0	0.403
611.02†	976.0	0.403
613.01*	1673	0.928
613.01*	1673	0.929
611.04*	2168	1.335
611.04†	2168	1.335
613.02*	3413	2.388
613.02*	3413	2.388
612.01*	5207	3.873
612.01†	5207	3.873
USS Estes	8455	6.71

*Side-on baffle.
†Pitot static tube.

6.3 Height-of-burst Chart

The scaled distances at which the various peak overpressures occurred on Mike and King shots have been indicated on the height-of-burst chart[20] published in TM 23-200 (Fig. 37) by means of appropriate symbols. It will be noted that, for pressure levels of 4 psi and greater on Mike shot, the scaled distances from the overpressure level of interest to ground zero are greater than would be indicated by the isobars; at lower overpressure levels the effects of atmospheric refraction cause the converse to be true. This observation would seem to indicate that perhaps the zero intercepts of the height-of-burst chart should be revised and that some of the curves should toe out more than they do. Overpressures measured over water on King shot seem to corroborate in general the findings on Mike shot, whereas those measured on the land blast line fall very near the isobars, an indication that the correction applied for thermal effect in constructing the height-of-burst chart had been a valid one.

Table 9—RESULTS OF KING SHOT REDUCED TO 1 KT (RC) AT SEA LEVEL

Station No.	Distance to ground zero, ft		Slant range, ft	Time of arrival, sec
617.01	365.9	122	407.0	0.095
617.02	426.1	142	461.9	0.117
617.03	546.4	182	574.9	0.172
617.04	667.0	222	690.4	0.235
617.05	787.5	262	807.5	0.307
617.06	908.0	303	925.5	0.384
617.07	1270	423	1282	0.636
617.08	1869	623	1877	1.094
612.02*	6649	2216	6651	5.118
612.02†	6649	2216	6651	5.119
6101.01	417.0	139	453.6	0.097
6101.02	662.1	221	685.7	0.215
6101.03	904.7	301	922.1	0.376
6101.04	1229	400	1242	0.598

*Side-on baffle.
†Pitot static tube.

7 CONCLUSIONS AND RECOMMENDATIONS

Aside from the fact that no data were obtained at pressure levels greater than 20 psi on Mike shot, gauge and recorder failures did not pose any insurmountable problem so far as the over-all objectives of the program to measure air-blast pressures on Operation Ivy were concerned. As it turned out, the sensitivity of the Ampex recording system to acceleration did not seriously hamper analysis of the data received. Some of the difficulties were resolved between shots, and others are in the process of being corrected. Especial care should be exercised to eliminate the zero-drift characteristics of the Ampex recording system if it is to be used on future measurements of this type.

Analysis of the data from Mike and King shots led to the following conclusions:

1. Use of the cube root scaling law to scale distances and times of arrival appears to be valid for radiochemical yields as great as 10 Mt.

2. Overpressures from Mike shot are evidently in agreement with the assumption that the overpressures to be expected from a yield, W, burst at the surface of a perfect reflector, are the same as would be observed from a yield of 2W, burst in free air.

3. Pressures at distances equivalent to the height of the atmosphere are apparently attenuated considerably as a result of the effects of a nonhomogeneous atmosphere.

4. Agreement of the pressures from Mike and King shots with the isobars on the height-of-burst chart published in TM 23-200 is considered ample justification for extending the applicability of this chart to yields of the order of 500 Kt. The correction factor used in constructing the original isobars to take into account the thermal effect would seem to be quite valid as corroborated by the results obtained on the land blast line for King shot.

5. Although there was no evidence of the thermal effect on Mike shot, it is possible that a thermal effect would have been noted had the burst been entirely over land. On King shot a thermal effect was definitely observed in measurements made on the land line, but sharp rise times were obtained over water.

6. Findings regarding attenuation of positive impulse over land more or less substantiated

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those on Tumbler shots 1 to 4 in that there was little or no decrease in positive impulse despite a sizable attenuation of peak pressures. On Tumbler shots 1 to 4 it was found that the decrease in positive impulse (10 per cent) was considerably less than would have been expected as a result of the decrease in peak pressure.

To augment the data compiled on surface bursts of atomic weapons, it would be highly desirable to instrument a surface burst of operational size over land so that the blast line is entirely over land. If no continental test site were available for a surface burst of this size, it could be performed at Eniwetok on Engebi. Increased interest in contact fuzing is a strong argument in favor of a burst of this type.

Measurements of the type made on Mike shot should be repeated at the earliest opportunity on a detonation of a superbomb to test the validity of the assumption that a surface burst has the same effectiveness as a bomb of twice the yield burst in free air. It would not be necessary to extend the blast line to the low-pressure regions instrumented on Mike shot except as indicated to explore the effect of atmospheric nonhomogeneities. It is desirable, however, to measure overpressures from the higher-overpressure regions (100 psi) to those overlapping the higher pressure levels instrumented on Operation Ivy. Measurements of this sort are currently planned for Operation Castle.

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APPENDIX A

SHOCK SYMMETRY MEASUREMENTS

Copper indenter gauges[1,2] were used to determine whether there were any gross asymmetries of the divergent air shock wave on Mike shot. Groups of 10 gauges were placed at each of two locations at equal radial distances from ground zero; the angle between the radii was 142°36′. Table A.1 presents pertinent information on gauge locations.

Table A.1 — LOCATIONS OF GAUGES

Island	Station No.	Distance from ground zero, ft	Azimuth angle
Bogallua	6104	18,568	240°39′
Engebi	6103	18,568	98°03′

The assembled gauges were mounted flush with the ground surface on steel stake mounts. No attempt was made to baffle the gauges, inasmuch as this series of measurements was to be semiquantitative only in that data from one set of gauges were to be compared with those from another set. It was recognized, of course, that had these gauges been used for quantitative measurements of peak pressure it would have been necessary to provide a suitable baffle arrangement as well as to damp the gauges.[1,3] As used here the gauges in effect probably integrated the pressure-time curve for the first small fraction of a second. Since the duration of the positive phase at the distance of these gauges is approximately $5\frac{1}{2}$ sec, the peak pressure could not have decayed appreciably in this fraction of a second. Thus it can be assumed that the gauges did read a fair approximation of peak pressure.

Nineteen of the twenty gauges were recovered, and the pertinent data obtained from analysis of the gauge indentations are presented in Table A.2. Peak pressure is proportional to the area of the indentation in the copper disk of the gauge. But, since the ultimate objective was merely the comparison of the two sets of data, it was unnecessary to find the area; the square of the diameter was sufficient. Using X_i to represent the square of the diameter for one statistical set (the readings from the group of gauges on Bogallua), the formula for the standard deviation of the mean can be written

$$\sigma_{\bar{X}} = \sqrt{\frac{\sum \Delta_X^2}{N_X(N_X - 1)}}$$

From Table A.2

$$N_X = 10$$
$$X_i = 32.76 \times 10^{-4}$$
$$\overline{X} = \frac{\sum X_i}{N_X} = 3.28 \times 10^{-4}$$
$$\Delta_X^2 = 7.15 \times 10^{-8}$$

Thus $\sigma_{\overline{X}} = 0.28 \times 10$

Table A.2—DATA FROM INDENTER GAUGES

Island	Gauge No.	Diameter, in.	Diameter² (X_i) $(\times 10^4)$	$\Delta_X = X_i - \overline{X}$ $(\times 10^4)$	Δ_X^2 $(\times 10^8)$
Bogallua	1	0.0171	2.92	−0.36	0.13
	2	0.0129	1.66	−1.62	2.62
	3	0.0179	3.20	−0.08	0.01
	4	0.0206	4.24	0.96	0.92
	5	0.0170	2.89	−0.36	0.15
	7	0.0208	4.33	1.05	1.10
	8	0.0205	4.20	0.92	0.85
	9	0.0199	3.96	0.68	0.46
	10	0.0173	2.99	−0.29	0.08
	21	0.0154	2.37	−0.91	0.83
			(Y_i) $(\times 10^4)$	$\Delta_Y = Y_i - \overline{Y}$ $(\times 10^4)$	Δ_Y^2 $(\times 10^8)$
Engebi	11	0.0145	2.10	−1.15	1.32
	12	0.0182	2.31	−0.94	0.88
	13	0.0214	4.58	1.33	1.77
	14	0.0214	4.58	1.33	1.77
	15	0.0189	3.57	0.32	0.10
	16	0.0180	3.24	−0.01	0.00
	17	0.0166	2.76	−0.49	0.24
	18	0.0175	3.06	−0.19	0.04
	20	0.0174	3.03	−0.22	0.05

Likewise, using Y_i to represent the square of the diameter for the other statistical set (readings from the gauges on Engebi), the standard deviation from the mean becomes

$$\sigma_{\overline{Y}} = \sqrt{\frac{\sum \Delta_Y^2}{N_Y(N_Y - 1)}} = 0.29 \times 10^{-4}$$

Therefore

$$\overline{X} = (3.28 \pm 0.28) \times 10^{-4}$$

and

$$\overline{Y} = (3.25 \pm 0.29) \times 10^{-4}$$

$\overline{Y}$ can then be subtracted from $\overline{X}$ to determine whether there is any significant difference between the two quantities:

$$\overline{X} - \overline{Y} = [3.28 - 3.25 \pm \sqrt{(0.28)^2 + (0.29)^2}] \times 10^{-4} = (0.03 \pm 0.40) \times 10^{-4}$$

Since this difference is considerably less than the standard error, it can be assumed that, within the accuracy of the measurements and the measuring instruments, there was no significant difference in the peak pressure measured at equidistant points along two different azimuths from ground zero. Therefore it can be concluded that along these two radii the shock wave exhibited marked symmetry.

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2. P. E. Shafer and E. R. Walthall, A Copper Indenter Gauge for the Measurement of Air Blast Peak Pressures, Naval Ordnance Laboratory Report, NavOrd-2192, July 1951.
3. R. R. Caforek, Evaluation of Copper-Disc Indenter Gauge in Measurement of Peak Pressure and Pressure Ratio of Small Charges, Naval Ordnance Laboratory Report, NavOrd-2170, September 1951.

APPENDIX B

PERSONNEL

Personnel of the Sandia Corporation Field Test Organization, under the direction of G. A. Fowler, performed the field installation and calibration of the pressure gauges and auxiliary instrumentation for these measurements. H. E. Lenander of the Proving Ground Department served as Project Officer of Project 6.1. Other members of the Sandia personnel force were

R. S. Millican, Division Supervisor of the Pacific Proving Ground Division

J. H. Scott, Project Engineer

Bell, H. E.	Looney, T. C.	Spilker, R. E.
Beyeler, J. A.	Mesnard, J. M.	Swartzbaugh, H. S.
Bolinger, N. C.	Minck, J. L.	Thompson, R. H.
Bunker, R. B.	Morrison, J. H.	Thornbrough, A. D.
Covington, M. B., Jr.	Neil, B. D.	Valentine, J. W.
Csinnjinni, C.	Pritchett, R. E.	Wistor, J. W.
Gross, W.	Reis, G. E.	Witt, L. J.
Hampson, E. P.	Richardson, H. M.	Wood, E. E.
Landes, G. N.	Shannon, E. V.	Yearout, R. M.
List, D. B.	Smith, J. W., II	

The following military personnel were assigned temporarily to the Field Test Organization for assistance on Operation Ivy:

Bonham, W. D.	Greenleaf, D. E.	Meinert, R. E.
Daniel, V. H., Jr.	Kelso, C. J.	Payne, W. C.
Gobble, D. E.	Korbe, A. J.	Vaughn, J. F.
Green, J. R.	Mandrell, W. L.	

E. F. Cox, M. Cowan, Jr., and G. W. Rollosson of the Weapons Effects Department of Sandia Corporation participated in the field operations. Cox also served as Co-Director, with F. Porzel, Los Alamos Scientific Laboratory, of Scientific Program 6 of Operation Ivy. Under his direction the following personnel from the Weapons Effects Department assisted in the analysis of the data obtained on these measurements:

M. Cowan, Jr.	G. W. Rollosson
B. F. Murphey	J. D. Shreve, Jr.

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