PHOTOGRAPH THIS SHEET

AD A995156

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

WT-322

DOCUMENT IDENTIFICATION

15 Mar. 52

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☒
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
(15 Mar. 1952)		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

Released

DTIC COPY INSPECTED

UNANNOUNCED

DTIC
ELECTE
JUL 19 1982
S D
D

DATE ACCESSIONED

82 07 13 065

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

[redacted]

UNCLASSIFIED

WT-322

c43A Copy 43

Operation

BUSTER - JANGLE

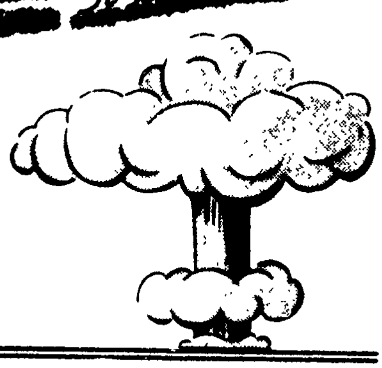
NEVADA PROVING GROUNDS
OCTOBER-NOVEMBER 1951

Project 7.6 (Buster)
Project 7.3 (Jangle)

#781
DWB
DOE 6/8

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF BUSTER AND JANGLE

[redacted]



ARMED FORCES SPECIAL WEAPONS PROJECT
WASHINGTON, D.C.

AD A995156

Statement A
Approved for public release;
Distribution unlimited

Not accountable to [redacted] JIADS

[redacted]

UNCLASSIFIED

[redacted]

[redacted]

Classification (Cancelled) (~~Changed to~~ ______

By Authority of ______

By ______ Date 24 Jun 72

[redacted]

[redacted]

UNCLASSIFIED

This document consists of 143 plus 4 pages (counting preliminary pages)
No. 43 of 279 copies, Series A

OPERATIONS BUSTER AND JANGLE

PROJECT 7.6 BUSTER AND PROJECT 7.3 JANGLE

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF OPERATIONS BUSTER AND JANGLE

by

G. B. OLMSTED

15 March 1952

Headquarters, U. S. Air Force
Office for Atomic Energy, DCS/O
AFOAT-1

[redacted]

UNCLASSIFIED

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

Measurements of the airborne low-frequency sound from the atomic explosions of Operations BUSTER and JANGLE (October and November, 1951) were made at ten locations covering a variety of directions and distances from the Nevada Test Site in order to determine the range and reliability of acoustic long-range detection equipment. The Surface test was detected at least to 2818 km (1520 naut. mi.); tests Baker, Charlie, Easy and the Underground test to 3670 km (1980 naut. mi.); and test Dog to 4400 km (2370 naut. mi.) from the Test Site. Transmission toward the east was better than toward the west, confirming expectations of seasonal effects in propagation. Results indicate the feasibility of acoustic techniques to detect and locate distant atomic explosions of various calibers detonated in the air, on the ground, or shallow underground. Further measurements during subsequent atomic tests are recommended.

[redacted]

1.0 OBJECTIVE

The primary objective of the remote acoustic measurements during Operations BUSTER and JANGLE was the determination of the range and reliability of acoustic detection equipment for continental explosions covering a wide range in yield. Additional important objectives were: (a) To study seasonal effects in long-range sound transmission by comparison of results with those obtained from GREENHOUSE; (b) To study the differences in long-range transmission of sound over land as compared with transmission over water (GREENHOUSE); (c) To obtain intercomparison data on the relative effectiveness of different types of acoustic detection equipment; (d) To provide additional information on the change of character of acoustic signal with distance and direction from the source and the correlation between long-range propagation from large explosions and short-range propagation from small explosions.

2.0 HISTORICAL BACKGROUND

The measurement of sound waves from large explosions goes back to the eruption of Krakatoa Volcano[1] (1883) where changes in barometric pressure believed due to the explosion were recorded for several passages of the sound waves around the earth. In 1908, the effects from the Great Siberian Meteor[2][3][4] were recorded on barographs as far away as the United States. Later, observations of acoustic propagation were made for the large TNT explosions conducted by the Explosives Safety Board at Arco, Idaho, in 1945 and 1946.[5][6][7][8] Similar measurements were made during the Helgoland Explosion,[9] 1947.

The first systematic effort to utilize acoustic equipment to detect atomic explosions at long range was made during Operation CROSSROADS,[10][11] 1946, with controversial results. During Operation SANDSTONE,[12][13][14][15] 1948, a comprehensive network of acoustic stations out to 1000 nautical miles from the explosions and a sparse network beyond this distance gave positive detection out to 1000 nautical miles for two of the three blasts and doubtful results at 2400 nautical miles for one blast.

During Operation GREENHOUSE (April and May of 1951), twelve acoustic stations were established at fairly uniform distance intervals out to 2400 nautical miles both to the east and to the west of the Eniwetok test site. Equipment having improved sensitivity and stability utilizing elaborate noise-reducing techniques detected every explosion at ranges of at least 2400 nautical miles.[16][17][18][19] Minor directional effects in propagation were observed.

[redacted]

3.0 INSTRUMENTATION

Each experimental acoustic station for Operations BUSTER and JANGLE consisted of at least three microphones so arranged as to permit an accurate determination of the azimuth and the apparent velocity of acoustic signals. In general, these microphones were capable of detecting a pressure change of a fraction of a dyne per square centimeter in the frequency range from 1.0 to 0.03 cycles per second. Each microphone was equipped with a special pressure-averaging pipe or hose array designed to reduce the noise background due to atmospheric turbulence. Signals were transmitted over wire lines from microphone outposts to a central recording station. Timing was accomplished by clocks and chronometers supplemented by radio checks with the National Bureau of Standards Station WWV.

Four main types of equipment were used for these tests; namely, Signal Corps Infrasonic System, M-2 (Modified); National Bureau of Standards Infrasonic Single-Microphone System; NBS Infrasonic Ring-Microphone System; and the Navy Electronics Laboratory Modified Rieber Microbarograph. The details of these equipments may be found in the laboratory reports attached as appendices to this report. A very brief description of each type is given below.

3.1 Signal Corps Infrasonic System, M-2 (Modified)

This system employed a condenser microphone, a resistance-capacitance bridge, an amplifier, and a synchronous detector at the remote locations with the low-frequency electrical signals being transmitted over wire lines to the recording center where the signals were amplified and recorded on an Esterline-Angus Recording Milliammeter. Dry batteries supplied power at the microphone and 60-cycle, AC, commercial power was used at the recording center.

3.2 NBS Single-Microphone System

This system employed a condenser microphone to frequency-modulate a carrier. The modulated carrier signal was transmitted over wire lines to a recording center where it was amplified, demodulated, and recorded on an Esterline-Angus Recording Milliammeter. Where possible, power was supplied to the remote locations over wire lines from a central supply. In some cases, separate AC power-supplies were installed at the remote locations and only the signal transmitted by wire.

3.3 NBS Ring-Microphone System

This system utilized four condenser microphones connected together into a single circuit frequency-modulating a carrier. In this case, each microphone in the "ring" was placed in a straight line with 500 ft separation between microphones. Wire lines carried the FM signal from the "ring" to a recording center where the signal was demodulated, amplified and recorded.

3.4 NEL Modified Rieber Microbarograph

This system employed a vibrating-string type microphone utilizing a "Rieber Vibratron" to frequency-modulate a carrier. The FM signal was transmitted over wire lines to a recording center where it was amplified, demodulated with a second vibratron, and recorded on a Brush six-channel recorder. Dry batteries supplied power at the remote locations and 60-cycle AC was used at the recording center.

4.0 OPERATIONS

4.1 Participating Agencies

This experiment was conducted jointly by the Navy Electronics Laboratory, the Signal Corps Engineering Laboratories, and the National Bureau of Standards under the sponsorship of Headquarters USAF (AFOAT-1). The Office of Naval Research (Code 418) coordinated the Navy effort and the Office of the Chief Signal Officer (SIGGG-S) coordinated the Army effort. Each laboratory assumed full responsibility for supplying equipment, installing, operating, and maintaining it at the locations shown in Figure 1. Each laboratory analyzed its own data and submitted a report which appears as an appendix to this report.

4.2 Station List

The primary network of stations established for Operations BUSTER and JANGLE are listed as the first seven stations in Table 1. Three additional stations which were either already existing or were established under other research programs are also included in Table 1. Note that the most complete coverage was to the east of the Test Site.

At Hawaii, all three laboratories cooperated in the operation of a station designed to intercompare equipments.

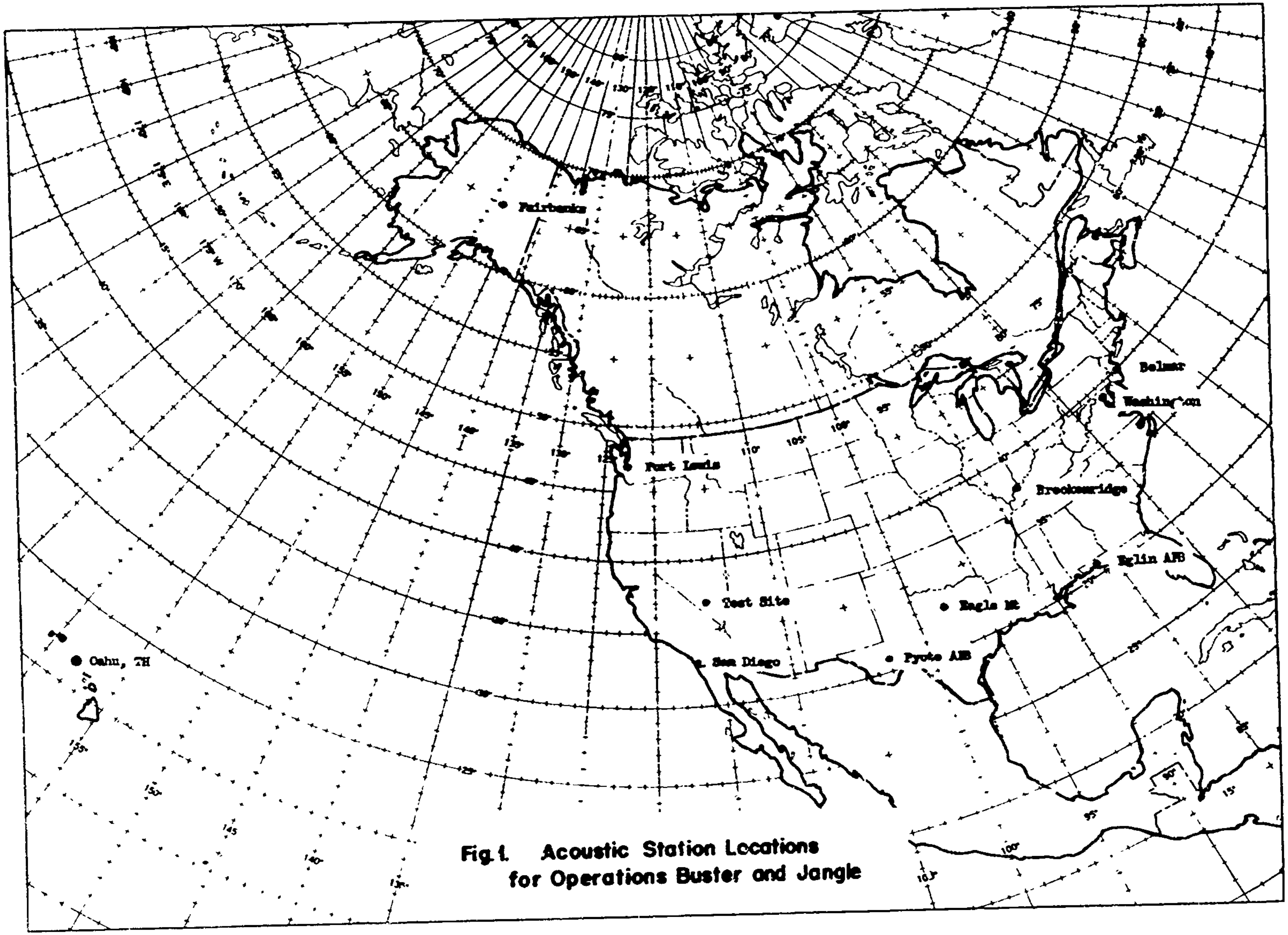


Fig. 1. Acoustic Station Locations for Operations Buster and Jangle

TABLE 1

BUSTER-JANGLE Acoustic Station List

Station	Responsible Laboratory	Location N Lat.	Location W Long.	Distance from Test Site (km)	Azimuth from Station to Test Site
Pyote AFB, Tex.	SCEL[1]	31°	103°	1330	301° 48'
Ft. Lewis, Wash.	NBS[2]	47° 05'	122° 35'	1237	151° 08'
Eagle Mt Lake, Tex.	NEL[3]	32° 59'	97° 30'	1755	290° 02'
Eglin AFB, Fla.	NEL	30° 30'	86° 35'	2818	292° 52'
Belmar, N.J.	SCEL	40°	74°	3670	278° 24'
Fairbanks, Alaska	SCEL	65°	148°	3705	130°
Oahu, T.H.	SCEL	21°	158°	4400	57° 06'
San Diego, Calif.	NEL	32° 42'	117° 15'	502	12° 43'
Breckenridge, Ky.	SCEL	38°	88°	2460	277° 48'
Washington, D.C.	NBS	38° 56'	77° 05'	3397	276° 30'

1. Signal Corps Engineering Laboratories.
2. National Bureau of Standards.
3. U.S. Navy Electronics Laboratory.

5.0 RESULTS

The results may be obtained in detail from the laboratory reports, Appendices A, B, and C. The more important data are summarized in Tables 2 through 7. Values for time of first arrival, average speed of travel from source to station for first arrivals, duration of detectable signal, maximum peak-to-peak signal pressure amplitude, average peak-to-peak noise amplitude, significant signal periods, signal azimuth, and apparent velocity are presented for each BUSTER and each JANGLE test except BUSTER Able. All results on Test Able were negative. The data presented here were obtained by visual analysis of the records. Appendix C presents the first results of machine analysis of magnetic tape recordings and points out some of the difficulties involved in the visual technique.

6.0 DISCUSSION

6.1 Detection Range

None of the stations detected Test Able.

To the east of the Test Site, Tests Baker, Charlie, Easy, and the Surface Test[1] were detected at every station, the most distant being Belmar, 3670 km (1980 nautical miles). Signal levels were sufficient to indicate that detection should have been possible at considerably greater distances if suitable locations for checking this had been available. Test D was detected at 3397 km (1830 nautical miles) but not at 3670 km (1980 nautical miles) where the noise level was very high - 58 dynes/cm^2. Test S was detected at 2818 km (1520 nautical miles) but not at 3397 km nor at 3670 km where the noise levels were 13 and 49 dynes/cm^2, respectively. It should be noted that the noise-reducing arrays at 3670 km (Belmar, N.J.) were not of optimum design.

To the northwest of the Test Site, only two stations were available - Ft. Lewis at 1237 km (675 nautical miles) and Fairbanks at 3705 km (2000 nautical miles). All of the tests except A were detected at Ft. Lewis but none were detected at Fairbanks. Signal levels at Ft. Lewis were low, considering the short distance from the source.

To the west, the only available station, Hawaii at 4400 km (2375 nautical miles), probably detected Test D. Results for other tests were negative. Noise levels during these tests ranged from 5 to 12 dynes/cm^2.

---

[1] Hereafter tests will be referred to as A, B, C, D, E, S, and U.

TABLE 2

Acoustic Data for BUSTER Test Baker
(Source Time: 281520 Oct. GMT)

Station	DTG First Arrival (GMT)	Travel Speed meters/sec	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity meters/sec
San Diego, Cal.	281549	288	9	5	2	3-10 15,25	-	-
Pyote AFB, Tex.	281624	346	18	32	2.5	5,6,7,8 10,15,16	304.0°	327-382
Ft. Lewis, Wash.	281639	261	13	5	2	15,30,50	153.6°	363
Eagle Mt Lake, Tex.	281653	314	3.5	2	3	5	292.5°	326
Breckenridge, Ky.	281732	310	9	18	3	6,7 8,9,10	273.8°	351-383
Eglin AFB, Fla.	281752	308	8	4	1	7	294°	371
Washington, D.C.	281820	315	18	8.5	2.5	7,13	282°	358
Belmar, N.J.	281837	310	7	6	4	7,10 11,12	277.4°	356-389
Fairbanks, Alaska	Negative	-	-	-		-	-	-
Oahu, T.H.	Negative	-	-	-	12	-	-	-

TABLE 3

Acoustic Data for BUSTER Test Charlie
(Source Time: 301500 Oct. GMT)

Station	DTG First Arrival (GMT)	Travel Speed meters/sec	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity meters/sec
San Diego, Cal.	301529	286	10	40	6	2-8 13	-	-
Pyote AFB, Tex.	301603	352	14	54	3	5,6,9 10,13,15	306.8°	346-398
Ft. Lewis, Wash.	301618	265	22	8	2	5-19,16	145.2°	322
Eagle Mt Lake, Tex.	301634	312	3	>25	11	9-15	294°	368
Breckenridge, Ky.	301705	329	15	26	2	6,7,8,9,10 15,16,18,19	280.2°	330-410
Eglin AFB, Fla.	301729	315	6	>20	2-4	7-16	295°	340
Washington, D.C.	301755	324	19	9	1	11,20	232°	374
Belmar, N.J.	301807	320	12	24	5	10,11,12 14,18,20	276.4°	363-415
Fairbanks, Alaska	Negative	-	-	-		-	-	-
Oahu, T.H.	Negative	-	-	-	5	-	-	-

TABLE 4

Acoustic Data for BUSTER Test Dog
(Source Time: 011530 Nov. GMT)

Station	DTG, First Arrival (GMT)	Travel Speed meters/sec	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity meters/sec
San Diego, Cal.	011555	335	42	60	12	1-8,5	-	-
Pyote AFB, Tex.	011632	359	15	102	8	7,8,10 11,12,15	305.2°	356-417
Ft. Lewis, Wash.	011645	275	23	10	2	7-23	145.3°	352
Eagle Mt Lake, Tex.	011702	318	1.5	10	3	12	300°	406
Breckenridge, Ky.	011734	331	11	46	11	9,10,11 12,13,18	279.1°	337-382
Eglin AFB, Fla.	011755	324	3	14	2	9	-	-
Washington, D.C.	011826	322	9	10	3	10,13,30	282°	404
Belmar, N.J.	Negative	-	-	-	58	-	-	-
Fairbanks, Alaska	Negative	-	-	-		-	-	-
Oahu, T.H.	012018	256	11	10	7	20,25,30 45,50	062.3°	346-360

TABLE 5

Acoustic Data for BUSTER Test Easy
(Source Time: 051630 Nov. GMT)

Station	DTG First Arrival (GMT)	Travel Speed meters/sec	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity meters/sec
San Diego, Cal.	051658	298	30	95	5	1-35,12	-	-
Pyote AFB, Tex.	051735	342	10	100	25	6,7,9,10 11,13,18	302.9°	342-378
Ft. Lewis, Wash.	051745	275	35	10	1	5-40	148.2°	356
Eagle Mt Lake, Tex.	051751	361	16	120	2	3-10,15	290°	332
Breckenridge, Ky.	051838	322	11	>24	3	7,10,12,14 15,16,23	275.3°	321-383
Eglin AFB, Fla.	051848	340	27	20	3	7-20,15	295°	383
Washington, D.C.	051929	316	16	30	5	5,15,45	280°	368
Belmar, N.J.	051939	317	10	52	12	9,11,13 15,18,19	276.3°	334-375
Fairbanks, Alaska	Negative	-	-	-		-	-	-
Oahu, T.H.	Negative	-	-	-	12	-	-	-

TABLE 6

Acoustic Data for JANGLE Surface Test
(Source Time: 191700 Nov. GMT)

Station	DTG First Arrival (GMT)	Travel Speed meters/sec	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity meters/sec
San Diego, Cal.	191730	284	8	17	4	1.5-6	-	-
Pycte AFB, Tex.	191810	316	10	31	4	4,5,6 8,11	301.0°	346-381
Ft. Lewis, Wash.	191821	255	8	5	2	15-40	149.3°	374
Eagle Mt Lake, Tex.	191834	312	10	12	3	3,5,7,10	290°	354
Breckenridge, Ky.	191916	302	6	15	6	5,6,7,8	271.8°	324-366
Eglin AFB, Fla.	191930	340	4.5	5	3	3-8.5	287°	365
Washington, D.C.	Negative	-	-	-	13	-	-	-
Belmar, N.J.	Negative	-	-	-	49	-	-	-
Fairbanks, Alaska	Negative	-	-	-		-	-	-
Oahu, T.H.	Negative	-	-	-	16	-	-	-

TABLE 7

Acoustic Data for JANGLE Underground Test
(Source Time: 292000 Nov. GMT)

Station	DTG First Arrival (GMT)	Travel Speed (meters per sec)	Duration (Min)	Max. P-P Signal Amplitude (dynes/cm^2)	Avg. P-P Noise (dynes/cm^2)	Signal Periods (Secs)	Measured Azimuth	Apparent Velocity (meters per sec)
San Diego, Cal.	Negative	-	-	-	-	-	-	-
Pyote AFB, Tex.	292104	346	17	23	6	3,4,5,6	302.0°	342-400
Ft. Lewis, Wash.	292120	258	3	6	3	15-40	145.4°	334
Eagle Mt Lake, Tex.	292135	308	5.5	13	2	3-6	290°	360
Breckenridge, Ky.	292208	322	17	10	5	3,4,6,9	277.9°	312-383
Eglin AFB, Fla.	292233	307	10	10	3	4-7,5	288°	364
Washington, D.C.	292302	312	16	2.5	1	2.5,4,10	280°	388
Belmar, N.J.	292314	306	14	12	8	4,5,6,7	284.2°	331-348
Fairbanks, Alaska	Negative	-	-	-	2	-	-	-
Oahu, T.H.	Negative	-	-	-	24	-	-	-

To the southwest, the only available station was a makeshift setup at San Diego. All tests except A and U were detected there, the distance being approximately 500 km (270 nautical miles).

6.2 Azimuth Errors

The differences between measured azimuths and actual azimuths are presented in Table 8. An "E" is used to show that the measured azimuth indicates a source to the east of the real source, an "N" to indicate measured source north of real source, etc. The mean error for eastern stations was 2.7°; the maximum error was 10°. The mean error for the northwestern station was 4.1° and the maximum error was 5.9°. Errors include reading and correlation errors and errors caused by upper atmospheric winds and horizontal gradients in winds and temperatures. Reading and correlation errors were estimated to be less than 1°; hence, the major errors were due to atmospheric effects.

The consistent deviation of azimuths toward the east at the northwestern station is believed due to westerly winds ordinarily expected in the stratosphere during winter months.

6.3 Travel Speeds

The speed of travel from source to recording point for first sound arrivals ranged from 255 to 361 meters/sec. Average speed to the east of the source was 322 m/s; the maximum was 361 m/s and the minimum was 302 m/s. Average speed to the northwest was 265 m/s, with a maximum of 275 m/s and a minimum of 255 m/s. For the one test detected to the west (Test D at Hawaii), the speed was 256 m/s.

It should be noted that visual determination of first signal arrival is dependent upon the noise level at the recording site and upon the individual interpretation of the record. Appendix B discusses this problem in greater detail and points out that travel speeds for the maximum arrival may yield more consistent results in some cases. Nevertheless, the marked difference in speed for first arrivals to the east compared with speeds to the northwest and west is significant. These results are consistent with results from the Navy Electronics Laboratory experiments with small explosions[22] which showed that, in winter, propagation to the west was considerably slower than toward the east. This is believed due to westerly winds in the stratosphere which assist eastward transmission. The slow westward speeds may be due to bucking the west wind or to a transmission path via the 100 km layer or both.

TABLE 8

Azimuth Errors

Station/Test	BUSTER				JANGLE	
	Baker	Charlie	Dog	Easy	Surface	Under-ground
Pyote AFB, Tex.	2.2°N	5.0°N	3.4°N	1.1°N	0.8°S	0.2°N
Ft. Lewis, Wash.	2.6°W	5.9°E	5.8°E	2.9°E	1.8°E	5.7°E
Eagle Mt Lake, Tex.	2.5°N	4.0°N	10.0°N	0.0°	0.0°	0.0°
Breckinridge, Ky.	4.0°S	2.4°N	1.3°N	2.5°S	6.0°S	0.1°N
Eglin AFB, Fla.	1.1°N	2.1°N	-	2.1°N	5.9°S	4.9°S
Washington, D.C.	5.5°N	5.5°N	5.5°N	3.5°N	-	3.5°N
Belmar, N.J.	1.0°S	2.0°S	-	2.1°S	-	5.8°N
Fairbanks, Alaska	-	-	-	-	-	-
Oahu, T.H.	-	-	5.2°S	-	-	-

6.4 Seasonal Effects

The strong directional effects in propagation noted in Sections 6.1, 6.2, and 6.3 were not observed during Operation GREENHOUSE (April and May of 1951). This confirms expected seasonal changes in propagation believed due to winds in the stratosphere. Westerly winds are expected in winter and easterly winds in summer. In spring and fall, lower wind speeds and variable wind direction are expected. Recent studies of sound propagation through the atmosphere to short distances from small explosions conducted by the Air Force Cambridge Research Center,[20] by Denver University,[21] and by the Navy Electronics Laboratory[22] all support these expectations.

6.5 Over-water vs. Over-land Propagation

Comparison of BUSTER and JANGLE results with results from GREENHOUSE indicate that long-range transmission of sound over land areas is just as effective as transmission over water areas.

6.6 Intercomparison of Equipments

All equipments were effective in detecting signals.

6.7 Signal Characteristics

6.7.1 Amplitude

At distances greater than 3300 km (1780 nautical miles) the maximum peak-to-peak signal amplitudes ranged from 2.5 to 52 dynes/cm^2. In general, the signal amplitude decreased with distance. Generally, amplitudes were smallest for Tests B, S, and U and largest for Test E. Signals to the east were considerably stronger at equal distances from the source than were signals to the northwest.

6.7.2 Duration

Visual analysis gave signal durations ranging from 1.5 to 42 minutes, the average being 13 minutes. Analysis of magnetic tape recordings made at Ft. Lewis (See Appendix C) indicate that actual signal persistence may be several times these values. The explanation of such large durations at relatively close ranges is unknown. Ordinary explanations of multiple paths of transmission appear inadequate.

6.7.3 Frequency

The existence of true periodicity in the signals is open to serious question. Data presented here are pseudo-periods obtained by visual analysis of pen-and-ink traces and are subject to considerable interpretational variations. However, the general trend toward longer periods from Tests S and U through B, C, D, and E for eastern stations is believed to be real. In addition, longer periods toward the west are consistent with the findings of the Navy Electronics Laboratory(22) for small explosions and indicate possible transmission via the region of second temperature inversion (approximately 100 km altitude) for westward propagation in winter.

Detailed investigation of the signal power vs. frequency is possible by convenient audio techniques when magnetic tape recordings are available. First results of such an investigation are presented in Appendix C. These results appear to be interesting, but considerable additional study is required before the full meaning of these data and their application to the problem of acoustic long-range detection is apparent.

6.7.4 Apparent Velocity

This quantity is variously called "trace velocity", "horizontal phase velocity", and "apparent velocity" in Appendices A, B, and C. It is a measure of the speed with which a sound wave moves across a horizontal array of detectors. Apparent velocities for these tests ranged from 312 to 417 meters per second.

6.8 Correlation Between Long-range and Short-range Propagation

Results show a strong qualitative resemblance between long-range transmission from atomic bombs and short-range transmission from 1200 lbs of TNT.

7.0 CONCLUSIONS

It is concluded that acoustic techniques continue to show the capability of detecting and locating air, surface, and shallow underground atomic explosions of various calibers at long range under a variety of weather conditions and for explosions over either land or water.

8.0 RECOMMENDATIONS

It is recommended that additional remote acoustic measurements be made during future atomic tests in order to establish the limits of detection capabilities due to variability of the atmosphere. Particular emphasis should be placed on measurements during summer and fall test periods and during tests having unusual test conditions.

REFERENCES

(1) "The Eruption of Krakatoa and Subsequent Phenomena" Report of the Krakatoa Committee of the Royal Society of London (1888) (Londons Printed by Harrison and Sons, St. Martins' Lane, W.C., and published by Trubner and Co., 57 and 59, Landgate Hill, 1888) (Unclassified)
An exhaustive report of air waves recorded by world-wide barographs. Includes an extensive bibliography.

(2) "Meteorite on 30 June 1908 in Central Siberia" by I. S. Astopovitch. Q. Jour. Roy. Met. Soc. 60:493-501. (Uncl)
A complete review of acoustic and seismic records obtained throughout the world from the Siberian Meteor.

(3) "On Phenomena Related to Great Siberian Meteor" by F. J. Whipple. Q. Jour. Roy. Met. Soc. 60:505-516. (Uncl)
A review of microbarograph results to distances of 8910 kilometers. Gives arrival time, travel velocity and amplitude of acoustic signals. Estimates energy of explosions to be 2×10^{21} ergs.

(4) "The Great Siberian Meteor and the Waves, Seismic and Aerial Produced by It" by F. J. Whipple. Q. Jour. Roy. Met. Soc. 56:287-301 (1930) (Unclassified)
An early report of acoustic data.

(5) Technical Paper No. 3, "Igloo Tests, Naval Proving Ground, Arco, Idaho, 1945". Army-Navy Explosives Safety Board (Unclassified)
Reports on-site blast measurements and briefly presents results of acoustic observations at considerable distance from two $62\frac{1}{2}$-ton and six 125-ton blasts in igloos and revetments. Arrival times only for two Benioff barographs located at approximately 50 and 100 miles from one 125-ton blast are given.

(6) Technical Paper No. 5, "Igloo and Revetment Tests, Naval Proving Ground, Arco, Idaho, October, 1946", by Army-Navy Explosives Safety Board. (Unclassified)
Reports results of on-site blast measurements from two 125-ton and three 250-ton blasts in igloos and revetments. Brief summary of remote acoustic measurements.

(7) "Microbarometric Pressures from Large High Explosive Blasts," by Everett F. Cox, Naval Ordnance Laboratory J. Acoust. Soc. Am., v19, n5, 1947, p832. (Unclassified) Reports acoustic signals recorded by eight single-microphone stations scattered in distance from 12 to 872 kilometers from the Arco blasts of October, 1946. Data beyond 300 kilometers are questionable.

(8) Tab D to Volume VI, "Report of Operation FITZWILLIAM", Evans Signal Laboratory, Project BIRTHROOT (1949) (Secret) Reports acoustic signals recorded by a three-microphone station at Green River, Wyoming, (337 kilometers) from one of the 125-ton Arco (1946) blasts. No complete reports of Signal Corps participation at Arco have been written.

(9) NOLR 1070, "Microbarometric Waves from the Helgoland 'Big Bang'," Naval Ordnance Laboratory (1947) (Unclassified).

(10) Tab D to Volume VI, "Report of Operation FITZWILLIAM," Evans Signal Laboratory (Secret) Reports possible acoustic signals at San Francisco and Ft. Monmouth from the Bikini Able blast. These signals have been the source of considerable controversy since it is impossible to state whether they are actually due to the Bikini blast.

(11) Crossroads Technical Instrumentation Report, "Remote Microbarometric Measurements (Inductiphone, Kwajalein, Washington, D.C.)" Project No. II-28. Naval Ordnance Laboratory (Classification ?) Reports acoustic signals at Kwajalein during Bikini tests.

(12) Tab A to Volume VI, "Report of Operation FITZWILLIAM," Naval Ordnance Laboratory, Project TENSOR (Secret) Lists amplitude, frequency, and duration of acoustic waves at Pacific Atolls within 3200 kilometers of Eniwetok for three atomic blasts. Practically all of the significant data was taken along a line extending southeast of Eniwetok to a distance of 1245 kilometers.

(13) Tab B to Volume VI, "Report of Operation FITZWILLIAM," Navy Electronics Laboratory (Secret) Lists amplitude, frequency, and duration of acoustic waves at Guam during the Eniwetok tests of 1948. The most reliable data obtained at a distance (1916 km) from Eniwetok. A large difference in maximum signal strength, unrelated to blast energy, was the most interesting anomaly reported.

(14) Tab D to Volume VI, "Report of Operation FITZWILLIAM," Evans Signal Laboratory, Project BIRTHROOT. (Secret)
Reports unsuccessful attempts to detect acoustic waves at very large distances (over 4000 kilometers) from Eniwetok.

(15) Part I to Annex V, Report of Technical Director, Operation SANDSTONE by Dr. G. K. Hartmann and others. (Top Secret Restricted Data)
An exhaustive report of blast pressure and impulse measurements made in the immediate vicinity of Eniwetok during Operation SANDSTONE.

(16) NAVORD Report 2153, "Report on Microbarometric Data Taken During Project GREENHOUSE," dated 17 August 1951, by Ellingson, Pomerantz, Opland, and Coate, Naval Ordnance Laboratory. NOL data from Majuro, Truk, Palau, and Ponape. (Secret)

(17) NEL Final Report B/53/A/ONR/NEL, (NEL Problem 1A8), "Air-borne Low-Frequency Sound at Bikini, Kwajalein, and Guam from Atomic Explosions of Operation GREENHOUSE," dated 30 September 1951, by Hale, McLoughlin, and Pickens, Navy Electronics Laboratory. (Secret)

(18)-(19) Signal Corps and National Bureau of Standards Reports on GREENHOUSE (Not yet received). (Secret)

(20) Geophysical Research Paper No. 5, "Investigation of Stratosphere Winds and Temperatures from Acoustical Propagation Studies," dated June, 1950, by A. P. Crary, Air Force Cambridge Research Laboratories. (Unclassified)

(21) Quarterly Progress Report No. 3 (Air Force Contract AF19(122)-252), "Determination of Atmospheric Winds and Temperatures in the 30 to 60 Kilometer Region by Acoustic Means," dated 27 April 1951, by J. M. Richardson and U. C. Huffsmith, Institute of Industrial Research, Denver University. (Unclassified)

(22) Final Report on AFOAT-1 Project Authorization B/10/A/ONR/NEL, "Experimental Study of Acoustic Waves Propagated in the Atmosphere from Small Explosions," dated 30 Sept. 1951, by C. T. Johnson, F. E. Hale, and A. B. Focke, U.S. Navy Electronics Laboratory. (Confidential)

OPERATIONS BUSTER AND JANGLE

PROJECT 7.6 BUSTER AND PROJECT 7.3 JANGLE

APPENDIX A

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF OPERATIONS BUSTER AND JANGLE - U.S. NAVY ELECTRONICS LABORATORY PARTICIPATION

by

R. C. McLOUGHLIN

and

C. T. JOHNSON
Consulting Staff

29 December 1951

U.S. Navy Electronics Laboratory, San Diego, California

ACKNOWLEDGMENTS

NEL personnel operating the field stations were A. B. Focke and J. R. Chiles at Oahu, T.H., C. P. Wiedow and D. D. Crowell at Eglin AFB, Florida, and D. E. Holcomb, J. E. Rusconi, and A. J. Bloom at Eagle Mountain Lake, Texas.

PRECEDING PAGE BLANK-NOT FILMED

ABSTRACT

In accordance with AFOAT-1 SECRET Project Authorization B/90/W/ONR/NEL, dated 22 March 1951, and SECRET Amendment Number 1 dated 19 June 1951, NEL monitored low-frequency sound from the atomic explosions of Operations BUSTER and JANGLE. Several microbarographs were set up and operated at each of four sites to detect low-frequency sound waves from atomic explosions. Operating sites were on the island of Oahu, T.H., at Eglin AFB, Florida, at Eagle Mountain Lake, Texas, and at San Diego, California. Harmonic analysis has been performed on a small amount of the records. No signals were received at the Oahu, T.H., station. Signals were received at all three continental stations for all shots except the first, which was a dud, and the last, which the San Diego station failed to receive. Further study of smaller noise-reducing arrays to supplement or replace the 1000-foot arrays is felt to be warranted. In case of further tests, location of all equipment and wire lines within a fenced area is much to be desired.

A.1.0 OBJECTIVE

In accordance with AFOAT-1 SECRET Project Authorization B/90/W/ONR/NEL dated 22 March 1951, and SECRET Amendment Number 1 dated 19 June 1951, NEL monitored low-frequency sound from Operations BUSTER and JANGLE at recording stations on Oahu, T.H., at Eglin AFB, Florida, at Eagle Mountain Lake National Guard Base, Newark, Texas, and (unofficially) at NEL, San Diego, California.

A.2.0 OPERATIONS

Four low-frequency Rieber microphones connected to 1000-foot, Signal Corps type, tapered pipe arrays were used at the Texas and Florida recording stations. The arrays were arranged at the corners of a quadrilateral at each station. Also, the arrays were laid on the ground in a 110° - 290° direction. Recording was made on six-channel Brush pen recorders, with WWV timing marks along the side of each tape.

At the Florida station, in addition to the pipe arrays, a single microphone was operated on a hose array of four 50-foot legs on all tests. A similar set-up was used at the Texas station on a few tests.

The recording at NEL was done on an unofficial basis. Only two microphones were available for use, so no determinations of azimuth or characteristic velocity could be made. One mike was operated on a 50-foot, four-leg hose array; the other mike was simply operated in a closed barracks building, with the building itself acting as the noise-reducing array.

NEL and NBS were guests of SCEL at the Oahu, T.H., recording site. There were four 1000-foot pipe, noise-reducing arrays, and each laboratory attached its own microbarometric recorder to each array.

The locations of the NEL recording stations (other than the one on Oahu) and the aximuths from the firing point to the recording station are given in Table A.1.

NOTE: A, B, C, D, E, S, and U are used to refer to Tests Able, Baker, Charlie, Dog, Easy, and the Surface, and the Underground Tests.

TABLE A.1

List of NEL Stations

Location	Longitude	Latitude	Azimuth(1)	Distance (km)
San Diego, Cal.	117° 15'W	32° 42'N	12° 43'	502(2)
Eagle Mt Lake, Tex.	97° 30'W	32° 59'N	290° 2'	1755
Eglin AFB, Fla.	86° 35'W	30° 30'N	292° 52'	2818

(1) At the receiving station.
(2) Slightly greater for last two shots.

Figure A.1 is a map of the United States showing the firing point and receiving stations. Figures A.2, A.3, and A.4 are drawings of the microphone layout at each recording station.

A.3.0 RESULTS

A.3.1 NEL recordings at the Oahu Station showed no apparent signals from 22 October 1951 through 19 November 1951. (NEL station did not operate after the latter date.) Evans Signal Laboratory will report the final analysis of these records.

A.3.2 In the first tests, sensitivities were set rather high on most channels, resulting in a large percentage of off-scale records. Later, sensitivities were reduced and signals were more often on-scale.

A.3.3 As proposed in the B/53/A/ONR/NEL Final Report, a microphone (termed the 1A8b mike) covering the frequency range from 0.005 to 0.13 cycles per second was tested (periods from 200 to 7.7 seconds per cycle). The signal-to-noise ratio for signals of 10- to 15-second periods was found to be about the same as for the standard 1A8 mike, which has a passband of from 0.05 to 1.3 cps (20 to 0.77 seconds per cycle). The 1A8b mike, however, had a long-period drift (about 3 minutes period) of large amplitude, which made it almost unusable. Further tests of this microphone will be made later to see if perhaps the conditions under which it was used were particularly unfavorable.

A.3.4 A new microphone with leaks of such size as to yield a narrow passband, from 0.033 to 0.19 cps (30 to 5.3 seconds per cycle), was used in Texas for S and U shots. Its signal-to-noise ratio was found to be the same as that of the regular 1A8 microphone, but its sensitivity was only half as great. High-frequency components of less than two-second periods were lacking on the record from this unit.

A.3.5 A harmonic analysis was conducted for sections of the Texas tape of 19 November 1951. Channels 1 and 2 were used. These were identified with heads A and A_1 whose passbands were 0.8- to 20-second periods and 5- to 30-second periods, respectively. Eighty amplitude measurements were made in a 2-minute interval for each, beginning at approximately 1035:30. Then, each minute of the two aforementioned minutes was divided into 80 parts and amplitude measurements were then treated by conventional Fourier analysis. The apparent duplication of effort was made because the exact expected frequencies were not known and the half-minute fundamental period 80-ordinate analysis would possibly detect frequencies two and four times those found by the 1- and 2-minute fundamental period 80-ordinate analyses, respectively. Conversely, the longer period fundamentals (1 and 2 minutes) would find the longer period signals more readily. Furthermore, a given frequency might be present with large amplitude for a short time only, in which case analysis of a short length of record might reveal a frequency that would not be detectable over a longer section. The results of the analysis are shown in Table A.2.

A.3.6 Figures A.5, A.6, and A.7 show plots of arrival times for various shots at different locations. The lengths of the horizontal lines indicate relative amplitudes for any particular shot. The longest line is unit magnitude. Amplitudes of different shots should not be compared on these graphs. For Shot E, signals whose travel times correspond to those expected of direct waves arrived at both Texas and Florida stations. This condition is probably related in some way to the storm that was centered over northern Texas at the time.

A.3.7 On several shots, it was observed that, after the coherent signal had ceased, the background noise level was higher than it had been before the arrival of the signal. Several minutes

TABLE A.2

Component Periods Found by Harmonic Analysis, Eagle Mountain Lake, Texas, 19 November 1951 (Surface Test)

Channel 1, Head A, 1A8 leaks, passband 0.77 to 20 seconds			
Fundamental (sec)	Times	Major Period Range (sec)	Predominant Periods (sec)
30	1st half minute	2.5 to 30	7.5
30	2nd half minute	2.0 to 30	7.5
60	1st minute (includes 2 above)	2.5 to 20	7.5
60	2nd minute	2.4 to 30	6.0
120	Entire 2 minutes (includes 2 above)	3.3 to 24	3.3,[1] 4.8, 6.7, 7.1, 9.2, 24
Channel 2, Head A, 1A8b front leak, 1A8 back leak, passband 5 to 30 seconds.			
Fundamental (sec)	Times	Major Period Range (sec)	Predominant Periods (sec)
60	1st minute	6.7 to 20	20
60	2nd minute	6.0 to 60	15
120	Entire 2 minutes (includes 2 above)	6.7 to 120	24, 120[2]

(1) Periods previously reported by observers making mere visual inspection were 3, 5, 7 and 10 seconds.
(2) The 120-second period shown by the analysis is probably not signal but rather a pressure change caused by a temperature change, e.g., in the pipe array.

were required for the noise level to drop to that observed before the arrival of the signal. It is thought that this effect may be a reverberation similar to that observed with underwater sound. This effect was less evident on the microphones attached to the 50-foot hose arrays than on those with the long pipe arrays.

A.3.8 The 1000-foot pipe arrays were found to become very noisy when temperature changes were taking place. Patches of clouds moving across the sky gave some trouble, and intermittent showers and sunshine made operations almost impossible.

A.3.9 Difficulties were encountered at the Florida site in keeping wire lines intact. The microphones there were on an unfenced section of the reservation, deer season was open, and hunters were abundant.

A.3.10 The results for the NEL continental stations on each test are summarized in Tables A.3, through A.9. The determination of the "prominent periods" has been done simply by eye and a time scale. The measurements are subjective, and may not seem the same to different observers, or even to the same observer at different times.

TABLE A.3

Results for Shot Able
22 October 1951, 0600 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	502	1755	2818
Noise	--	10-mph wind	1dpsc

(No signals received at any NEL station)

TABLE A.4

Results for Shot Baker
28 October 1951, 0721 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	502	1755	2818
Start of signal (PST)	0749:00	0853:30	0952
Signal duration (min)	9	3.5	8
Signal double amp. (dpsc)	5	2	4
Prominent periods (sec)	3 to 10 1 of 15 1 of 25	5	7
Noise double amp. (dpsc)	2	3	1
Azimuth of arrival (deg)	--	292.5	294
Apparent velocity (m/sec)	--	326	371

TABLE A.5

Results for Shot Charlie
30 October 1951, 0700 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	502	1755	2818
Start of signal (PST)	0729:05	0834:30	0928:40
Signal duration (min)	10 +	3	6
Signal double amp. (dpsc)	40 ± 10	>25	>20
Prominent periods (sec)	2 to 8, 13	9 to 16	7 to 16
Noise double amp. (dpsc)	6	11	2 to 4
Azimuth of arrival (deg)	--	294	295
Apparent velocity (m/sec)	--	368	340

TABLE A.6

Results for Shot Dog
1 November 1951, 0730 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	502	1755	2818
Start of signal (PST)	0754:33	0902:25	0954:50
Signal duration (min)	42	1.5	3
Signal double amp. (dpsc)	60	10	14
Prominent periods (sec)	1 to 8, 5[1]	12	9
Noise double amp. (dpsc)	12	3	2
Azimuth of arrival (deg)	--	300	Only two channels operating at signal time.
Apparent velocity (m/sec)	--	406	

TABLE A.7

Results for Shot Easy
5 November 1951, 0830 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	502	1755	2818
Start of signal (PST)	0857:55	0951:15	1048:00
Signal duration (min)	30	16	27
Signal double amp. (dpsc)	95	120	20
Prominent Periods (sec)	1 to 35,12[1]	3 to 10,15	7 to 20,15[1]
Noise double amp. (dpsc)	5	2	3
Azimuth of arrival (deg)	--	290	295
Apparent velocity (m/sec)	--	332	383

[1] Predominant

TABLE A.8

Results for Surface Shot
19 November 1951, 0900 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	508	1755	2818
Start of Signal (PST)	0930:00	1034	1130:29
Signal duration (min)	8	10	4.5
Signal double amp. (dpsc)	17	12	5
Prominent periods (sec)	1.5 to 6	3,5,7,10	3 to 8, 5[1]
Noise double amp. (dpsc)	4	3	3
Azimuth of arrival (deg)	--	290	287
Apparent velocity (m/sec)	--	354	365

TABLE A.9

Results for Underground Shot
29 November 1951, 1200 PST

	San Diego	Eagle Mt Lake	Eglin AFB
Distance (km)	512	1755	2818
Start of signal (PST)	No sig.	1335:30	1432:40
Signal duration (min)	--	5 1/2	10
Signal double amp. (dpsc)	--	13	10
Prominent periods (sec)	--	3 to 6	4-7 (5[1])
Noise double amp. (dpsc)	--	2	3
Azimuth of arrival (deg)	--	290	298
Apparent velocity (m/sec)	--	360	364

[1] Predominant

A.4.0 RECOMMENDATIONS

A.4.1 Further study should be made of the use of small arrays in tests of this type, as they are easier to install and maintain and appear to be less subject to trouble due to changing temperatures.

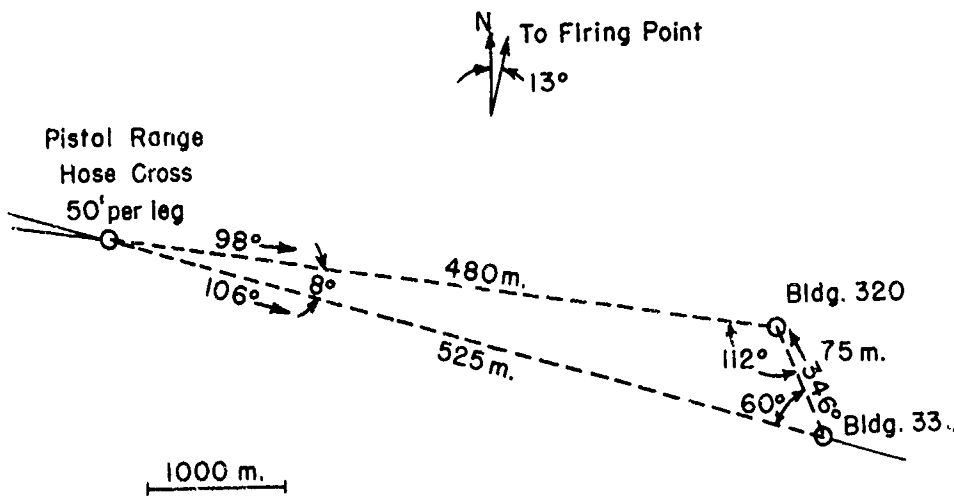
A.4.2 Recorders should be operated at sensitivities low enough so that the background level is not over one-fifth of full scale.

A.4.3 In case of further tests of this type, the Florida site should probably be abandoned in favor of a site somewhat inland.

A.4.4 If at all possible, sites should be chosen so that all equipment can be located within a fenced government reservation.

A.4.5 Joint operation of a station, and the analysis of all the records from that station by one activity, does not seem to be worthwhile. The analysis of records can be done efficiently only by the personnel familiar with the equipment used in obtaining the records.

Fig. A.1 Map of United States Showing Firing Point & Receiving Stations



NOTE: In Bldg. 320 and Bldg. 330, the closed buildings were the arrays.

Fig. A.2 Microphone Layout for NEL Station at San Diego, California.

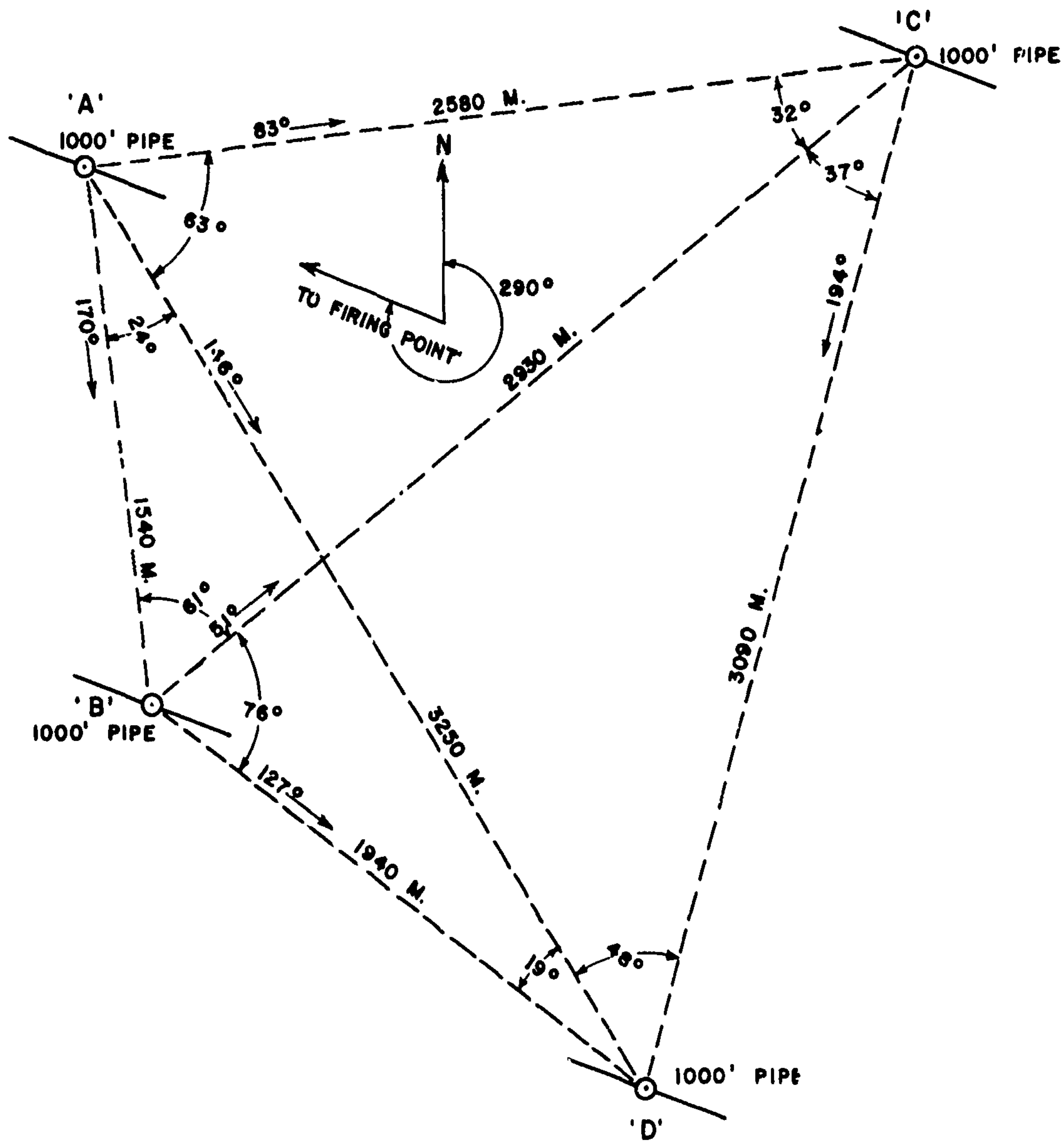


Fig. A.3 Microphone Layout for NEL Station
at Eagle Mt Lake, Newark, Texas.

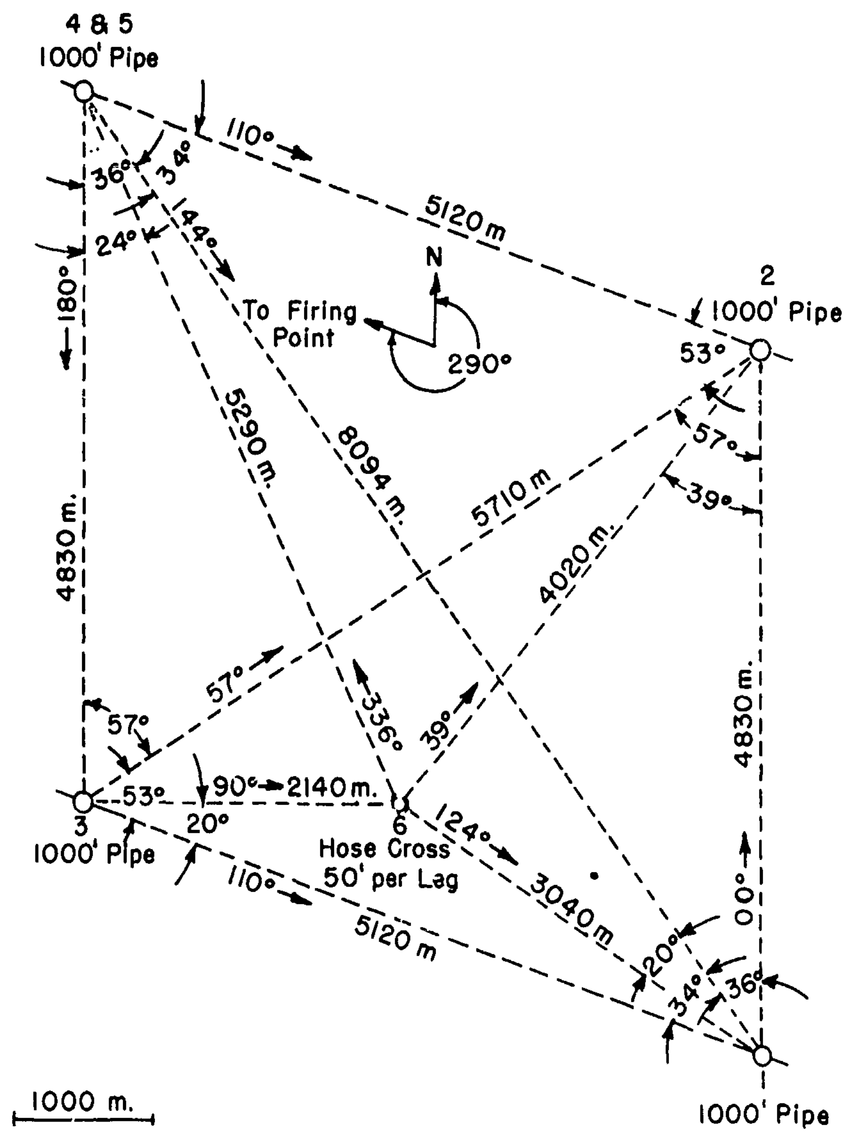


Fig. A.4 Microphone Layout for NEL Station at Eglin AFB, Valparaiso, Florida.

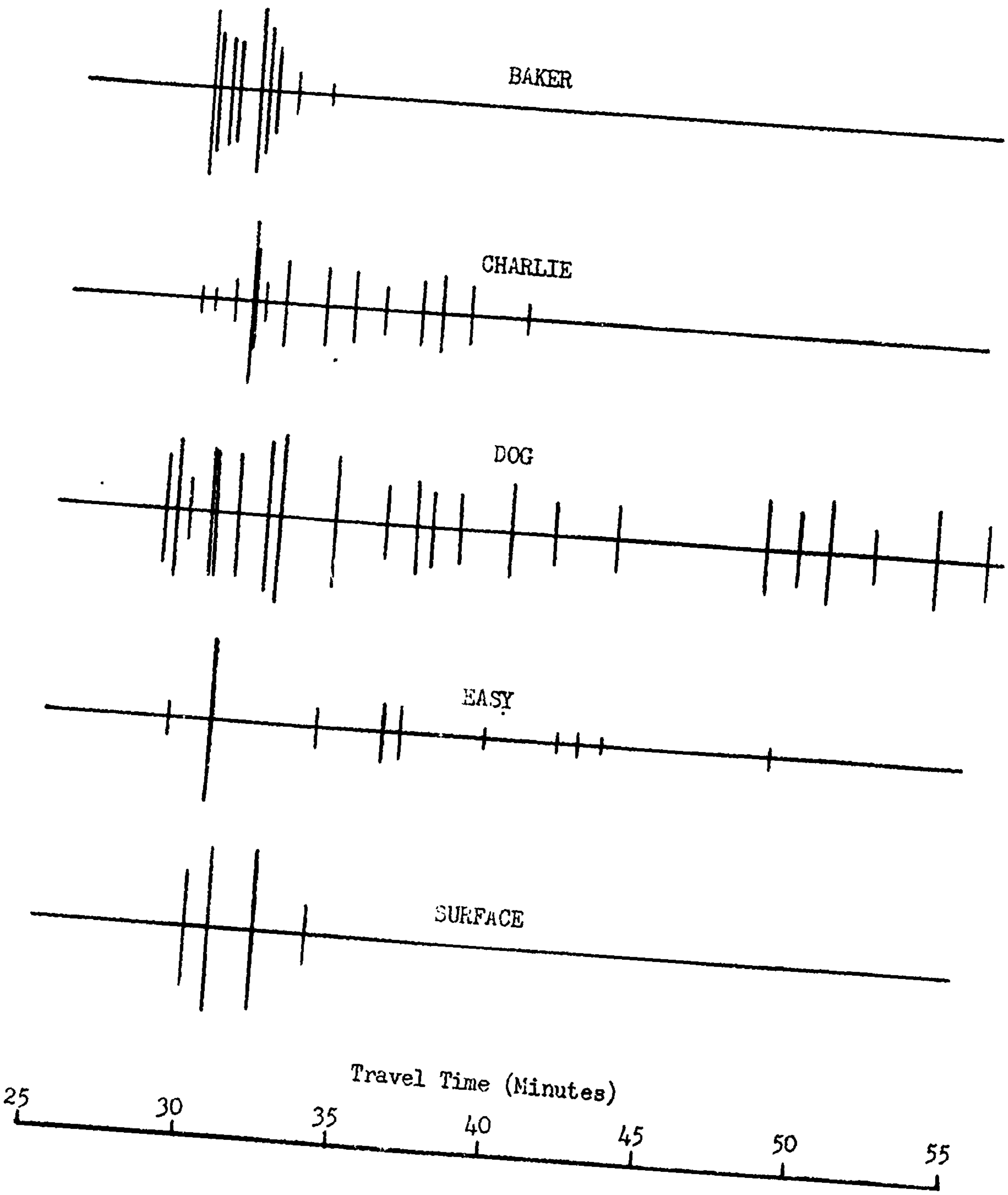


Fig. A.5. Travel Time and Relative Amplitudes of Major Acoustic Arrivals at San Diego, Cal.

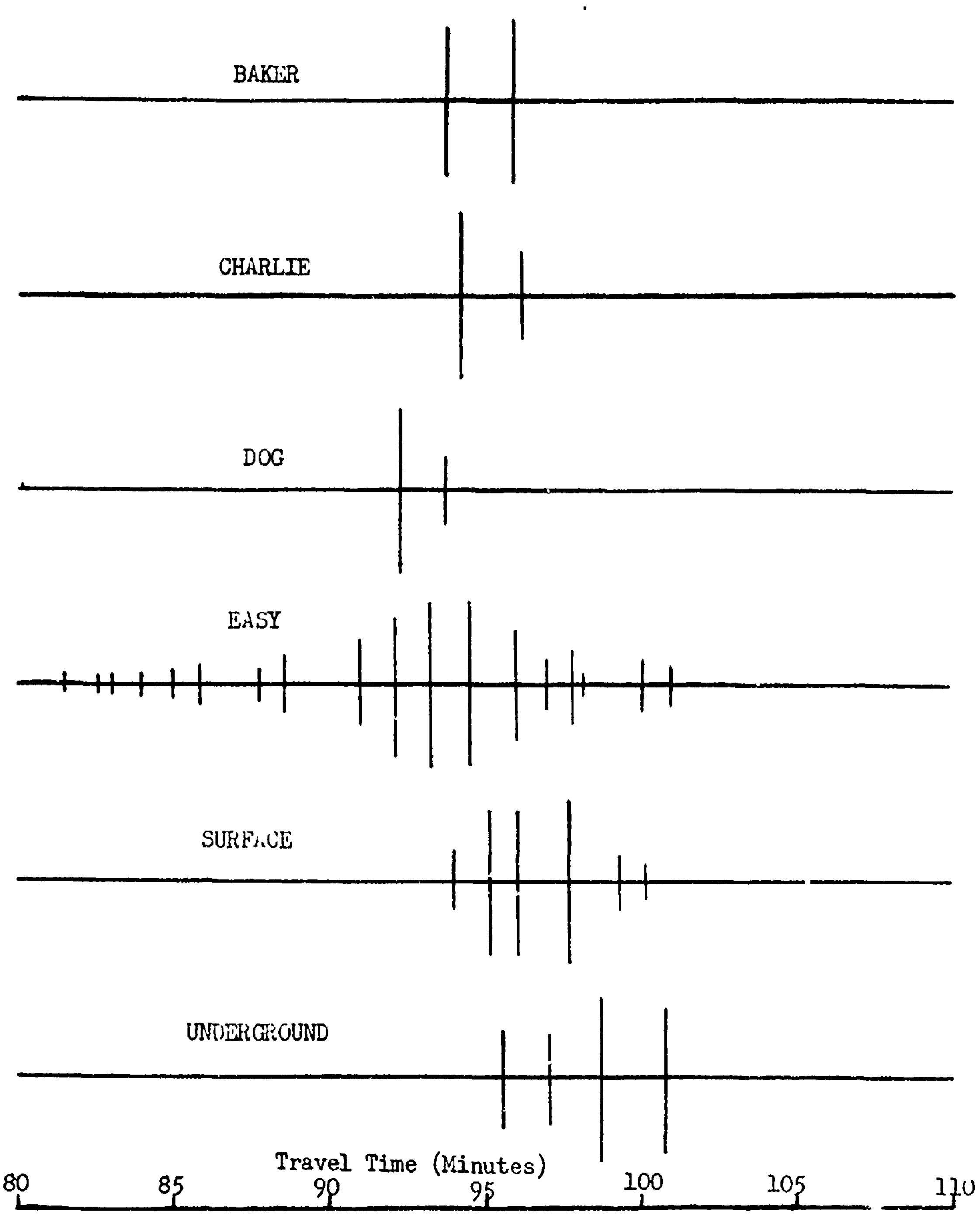


Fig. A.6 Travel Time and Relative Amplitude of Major Acoustic Arrivals at Eagle M.. Lake, Texas.

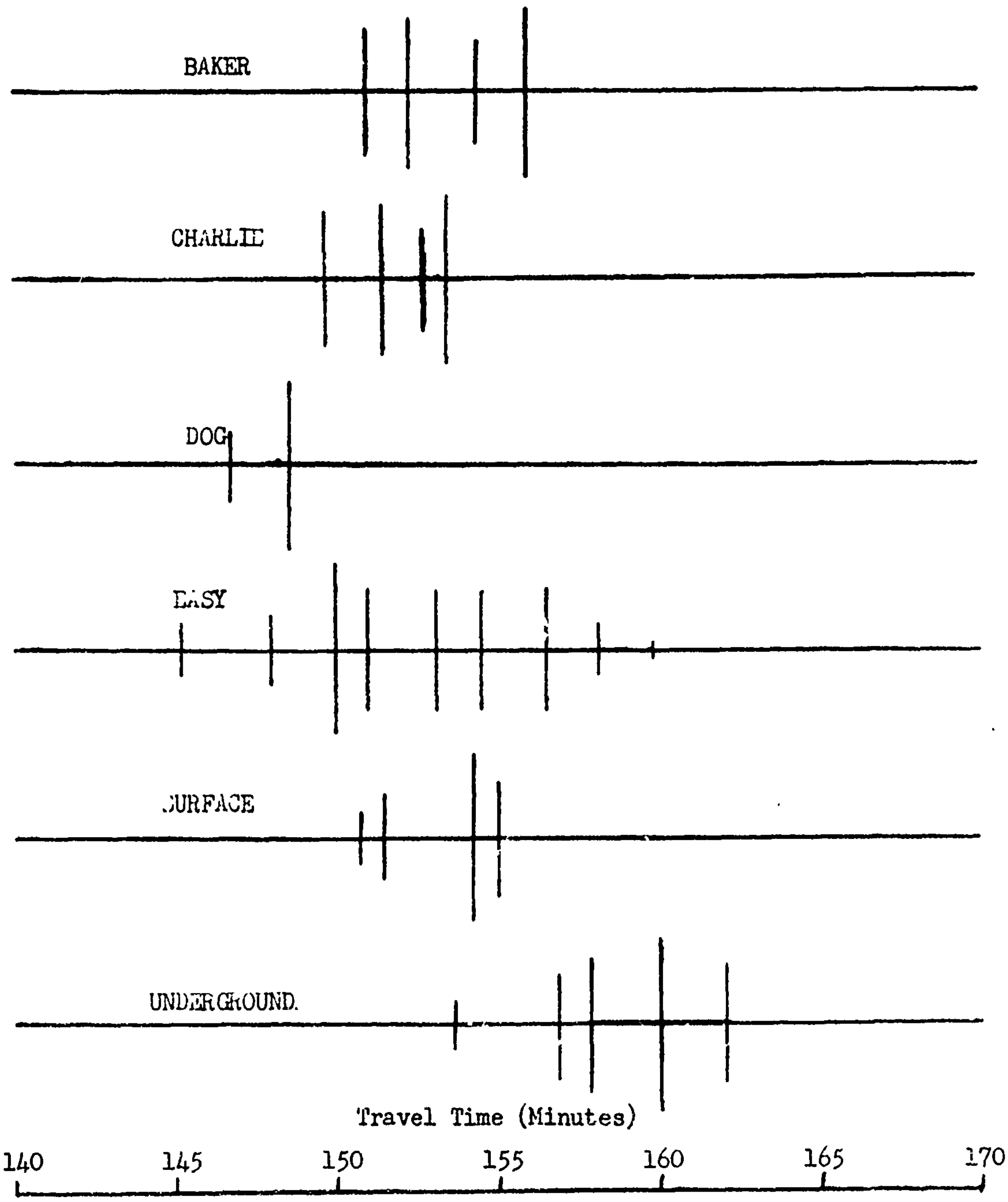


Fig. A.7 Travel Time and Relative Amplitudes of Major Acoustic Arrivals at Eglin AFB, Florida.

OPERATIONS BUSTER AND JANGLE

PROJECT 7.6 BUSTER AND PROJECT 7.3 JANGLE

APPENDIX B

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF OPERATIONS BUSTER AND JANGLE - SIGNAL CORPS PARTICIPATION

by

CRAIG M. CRENSHAW
WILLIAM P. LONNIE
WALTER PRESSMAN

21 February 1952

Signal Corps Engineering Laboratories
Fort Monmouth, New Jersey

ABSTRACT

In conjunction with the BUSTER and JANGLE tests the Signal Corps operated four stations, which detect infrasonic signals with periods from 3 to 40 seconds. Three were to the east at ranges up to 2300 miles and the fourth to the west at 2700 miles. Positively identifiable arrivals were obtained from shots up to 2300 miles to the east except for two days when the high noise background level at Belmar precluded the detection. The signals to the east indicated that as the source size increases the periods increase from 4 to 14 seconds, and the amplitudes also increase. The travel velocity of the peak energy portion of the signal (9.8°/hour) is much more constant than that of the initial arrival for signals traveling to the east. At Oahu, 2700 miles to the west, a probable signal with a 30-second period and a low travel velocity (8.3°/hour) indicating travel via the 100-kilometer level, was detected on Dog Day. In general, the technique of strategic sound-ranging proved feasible and should be exploited as a means of surveillance.

B.1.0 OBJECTIVE

The purpose of the project was threefold: First, to determine additional information about the range to which airborne infrasonic signals from small atomic explosions are detectable; second, to investigate the appearance of the recorded signals at various ranges for possible information as to size and type (aerial, surface, or subsurface) of detonation; third, to obtain more data on the precision of a location by use of the airborne infrasonic signals detected at remote locations. The above data are necessary to augment the meager information now available in the field of acoustic surveillance, especially with reference to surface and subsurface shots and to low energy shots. As a result of this data, the feasibility of detection of small size air bursts and of underground blasts by acoustic means should be determined. A more reliable estimate of the accuracy of location by remote detection may be forthcoming.

B.2.0 HISTORICAL AND THEORETICAL BACKGROUND

B.2.1 Considerably prior to the CROSSROADS tests, the Signal Corps proposed the investigation of the feasibility of extending tactical sound ranging techniques to strategic sound ranging on atomic explosions. These proposals were implemented by the Signal Corps. Several other groups within the Armed Forces proposed and implemented similar tests. Similar measurements were made by the Signal Corps during the SANDSTONE, RANGER, and GREENHOUSE tests. The equipment used in the CROSSROADS tests (essentially a modification of the tactical sound ranging condenser microphone to respond to lower frequencies used with revised detection circuitry) has been progressively modified and improved for the successive tests. The many years background experience in acoustic propagation studies at tactical ranges has been of inestimable value in understanding the propagation vagaries of the atmosphere for these low frequencies. Some of these effects, which are well known, are listed as follows: (1) Signal intensities are not symmetrically distributed with respect to azimuth from the source; (2) In one direction there is no simple dependence of signal strength on range from a single source; (3) Even with the same source and detection point, large variations in amplitudes are observed for the same size source fired at time intervals as short as one minute; (4) Multiple arrivals, along different propagation paths, are commonly observed in directions where propagation factors are favorable; (5) The recorded wave shape can vary from a single pulse to multiple pulses occurring over a duration up to thirty times the time of a single pulse and showing large scale interference effects. All of these effects have their counterparts in strategic sound ranging, and corrections for meteorological effects can be devised analogous to those employed in tactical sound ranging. In the strategic case, however, the path travels above the known meteorological data and indirect methods must be used to obtain the meteorological structure. The accuracy of a location is directly dependent upon the path which the sound arrival travels and the meteorological conditions along this path. To obtain a more reliable estimate of the accuracy of a location, a long term study of all pertinent data from this and previous tests is necessary.

B.2.2 The previous Signal Corps results of sound ranging on atomic explosions can be summarized as follows: CROSSROADS, some positive results beyond 4000 miles, (these are subject to doubt because of possible alternate interpretations); SANDSTONE, no data under 2300 and negative beyond 2300 miles; RANGER, positive up to 750, negative at 2300 miles; GREENHOUSE, positive at all ranges up to the farthest station at 2700 miles. The usual theoretical scaling laws indicate a shift of the peak energy to longer periods as the size of the explosion increases proportional to the cube root of the size. The past data is approximately in qualitative agreement with this premise, however, since different propagation paths and meteorological structures attenuate the various frequencies differently a precise quantitative agreement of all arrivals is not to be expected. A long-range study is required to ferret out information about the source by this means.

B.3.0 INSTRUMENTATION

B.3.1 The equipment employed by the Signal Corps for these operations was similar to that used in SANDSTONE.[1] The increase in signal to noise ratio provided by noise reducing arrays, however, permitted the use of more sensitive equipment.

B.3.2 In brief, a typical acoustic detection station consisted of four outpost emplacements, each equipped with a noise reducing array, a condenser microphone, a calibrator, a capacitance bridge, and associated dry battery supply. The assembly of this equipment in the wooden shelter provided, is shown in Figure B.1. The output of each emplacement was connected by wire lines to the central station, where the signal was amplified and recorded on Esterline-Angus pen and ink recorders (Figure B.2). Certain modifications, designed to improve

[1] Appendix B, Secret Report of Operation FITZWILLIAM, Volume VI, Tab-D, Project BIRTHROOT, 27 May 1949.

the performance of the equipment employed for these operations, were incorporated and are described below.

B.3.2.1 The microphone and the associated circuitry were modified to increase the response to periods as long as one minute. The response of the system to pressure variations in the infrasonic region has been determined experimentally and is illustrated in graphical form in Figure B.3. A remotely controlled calibrator was installed at each outpost emplacement to check the system performance, as required.

B.3.2.2 Higher gain at the outpost emplacements was achieved by increasing the dry battery plate supply. Operating sensitivities as high as 10 mm deflection for one dyne per square cm pressure change resulted with the improved instrumentation.

B.3.2.3 In order to achieve optimum performance at all times, a means of remotely balancing the capacitance bridge from the central station was provided. This improvement was employed to compensate for the effect of the microphone drift experienced at the high operating sensitivities.

B.3.3 The noise reducing array employed for these tests, was a linear type based on previous Signal Corps design and experience.

B.3.3.1 The general linear array is electrically equivalent to a tapered transmission line and is similar to an inversion of the line microphone.[1] The array, which is constructed of pipes of increasing size, is designed to eliminate reflections of outgoing waves by matching the characteristic impedance of the small outer pipe sections to the atmosphere. The acoustical resistance required is provided by a thin hole drilled in a small brass plug. Equal resistance plugs are placed at equal intervals along the array. The lengths of the various diameter pipes are chosen such that the equivalent lumped impedence for each junction just matches the change in characteristic impedance for the change in pipe diameter at the junction. This provides several openings to sample the atmosphere at points uniformly spaced along a line. Since the pressure fluctuation of a signal is coherent at all openings and that of noise is usually

---

[1] H. F. Olsen, "Elements of Acoustical Engineering," 1st Ed. pp. 214 - 216. (Unclassified)

random the improvement in signal to noise ratio is equal to the square root of the number of openings.

B.3.3.2 A double-ended linear array, 1740 feet long with openings every five feet, was employed for these operations. For random noise, this array, with a total of 348 openings, would reduce the background noise by a factor of approximately 18. A schematic diagram is shown in Figure B.4.

B.3.4 The preliminary planning for the acoustic portion of Program 7 of Operations BUSTER and JANGLE required the Signal Corps to operate the instrumentation described above at three locations; one at an 800 mile range, and the others more than 2200 miles distant from the source. To obtain more data the Signal Corps supplemented the funds for these activities to permit operation of an additional station located at a range of 1500 miles. The relation of these four stations to the source, shown geographically in Figure B.5, is tabulated below.

LOCATION	DISTANCE FROM SOURCE Statute Miles	AZIMUTH FROM SOURCE
Pyote, Texas	826	115°
Camp Breckinridge, Ky.	1529	81°
Belmar, N.J.	2228	71°
Oahu, T.H.	2739	259°

B.3.5 The Signal Corps station at Oahu, T.H., was host to personnel from both the National Bureau of Standards and Navy Electronics Laboratory. Each group provided and supervised the operation of equipment of its own design for the tests. Since only one probable signal was detected at Oahu, T.H., during these tests it is felt that no comparison of equipmental performance is warranted.

B.4.0 DATA AND ANALYSIS

B.4.1 The basic data consists of recordings of airborne low-frequency sound waves identified as coming from the BUSTER and JANGLE atomic explosions. In Table B.1 the results of all Signal Corps monitoring installations are summarized, and in Table B.2 the salient signal characteristics are listed. Tables B.3 through B.8, B.9 through B.12, and B.13, present detailed shot by shot analyses of the signals detected at Pyote, Belmar, and Oahu, respectively. Similar analyses for the Camp Breckinridge[1] acoustic signals are presented in Tables B.14 through B.19. The details of the data reduction process are explained in a forthcoming Signal Corps final report on Operation GREENHOUSE. A portion of a typical recording at Pyote is presented in Figure B.6. Sections of the Belmar-Charlie and Belmar-Underground signals (Figures B.7 and B.8) have been included to show the difference in predominant periods on these two days. A section of the Camp Breckinridge-Easy recording, in which the equipment was strongly overloaded at the peak intensity of the signal, is included as Figure B.9.

B.4.2 At no Signal Corps installation was the Able Day detonation detected. All of the six subsequent explosions were identified without any difficulty whatsoever, at both Pyote, Texas, and Camp Breckinridge, Kentucky. At Belmar, New Jersey, four of the airborne waves, associated with the last six atomic detonations, were positively identified; two of these, Charlie and Easy, had exceptional clarity, while the remaining two, Baker and Underground, were not as obvious. Negative results were obtained for Dog and Surface at Belmar. At Oahu a poor quality signal, which is considered probable, was detected on Dog Day. Negative results were obtained on all the remaining days. As shown in paragraph B.4.7 below the negative results are attributed to background noise high enough to mask the probable signal level as determined from the associated positive results.

B.4.3 All recorded signals were found to be continuous rather than a series of discrete arrivals and to last anywhere from a minimum of 6 minutes (Breckinridge-Surface) to a maximum of 18 minutes (Pyote-Baker). The average duration was 13 minutes. The spreading in time of the transient, from several seconds at points a few miles from the source to about 10 or 15 minutes at points 1000 or 2000 miles from the source, is caused by the different travel times associated with multipath propagation and is in keeping with the Operation GREENHOUSE results. Although theoretically, signal duration should increase with range, the limitations of equipmental sensitivity and the influence of local background noise upon a continually weakening signal may cause an erratic variation of <u>measurable</u> signal duration with range such as was observed during the BUSTER and JANGLE events.

---

[1] The Signal Corps operated an acoustic monitoring station at Camp Breckinridge, Ky. in order to obtain data at an intermediate range. It was felt that this additional detection point, using the same instrumentation, was necessary in order to provide sufficient measurements to meet the objectives set forth in Section B.1.0, hence, the Signal Corps allocated necessary funds for its operation. With the exception of the first shot, on Able Day, the results were uniformly successful.

B.4.4 Predominant periods ranged from a minimum of 4 seconds to a maximum of 30 seconds; the maximum occurring on Dog Day at Oahu, the only signal detected to the west. The second largest predominant period was 14 seconds (Belmar-Easy).[1] For the easterly stations specific predominant periods appeared to be associated with each shot. The averages of the values of these stations (tabulated in Table B.2) are as follows:

	Baker	Charlie	Dog	Easy	Surface	Underground
Average Predominant Period (Seconds)	9.0	10.7	11.0	13.7	6.0	4.7

The marked short period values for the Surface and Underground tests are quite apparent. Exclusive of the single Oahu signal, the predominant periods correlate in a direct and positive sense with maximum amplitudes. Ratios of average predominant period and average maximum amplitude have been computed for each shot relative to the Baker Day shot. In no case was a station value used in the computations unless it had been recorded on both days. The computed ratios are:

	Underground	Surface	Baker	Charlie	Dog	Easy
Average Predominant Period (relative)	0.52	0.8	1	1.2	1.5	1.5
Average Maximum Amplitude (relative)	0.82	0.89	1	1.8	2.9	3.2

The above ratios show that the ordering of bomb yield both from predominant period and maximum amplitude are in good general agreement. Inasmuch as no marked meteorological change occurred in the sound paths during the test period, the above ordering is believed to be applicable to bomb yield.

B.4.5 Travel velocities (the great circle distance between source and detection point divided by the travel time) for the starting points of all signals have been extracted from individual tables and are presented in Table B.2. Travel velocities exhibited no significant

---

[1] Table B.2 shows no definite increase of predominant period with distance for a single shot.

variation from one shot to another at each of the stations, although slightly slower travel velocities were measured on Surface Day. However, a marked decrease in travel velocity with range is apparent. The average travel velocities for the initial arrival at each of the three easterly stations were:

Pyote:	11.2°/hour
Breckinridge:	10.4°/hour
Belmar:	10.1°/hour

Care must be exercised in the proper interpretation of these results. Listed below are the travel velocities for the <u>points of maximum energy</u>:

	Baker	Charlie	Dog	Easy	Surface	Under-ground	Average
Pyote	9.7	9.7	10.2	10.1	9.7	9.6	9.83
Breckinridge	9.8	9.9	10.1	10.0	9.6	9.8	9.86
Belmar	9.8	9.9		10.0		9.6	9.83
Oahu, T.H.			8.1				

Note that no variation in the average travel velocity at each of the stations to the east occurs for the points of maximum energies. Clearly then, the decrease in travel velocities with range for the leading edge of the transients must be caused by the fact that a smaller interval about the region of peak energy is discernible at greater distances from the source. The discussion of paragraph B.4.3 above on signal duration is pertinent.

B.4.6 Deviations of all computed azimuths from the true azimuths for each station and shot are tabulated below in degrees:

	Baker	Charlie	Dog	Easy	Surface	Under-ground	Average of all Days
Pyote	+2.2	+5.0	+3.4	+1.1	-0.8	-0.2	+1.8
Breckinridge	-4.0	+2.4	+1.3	-2.5	-6.0	+0.1	-1.4
Belmar	-1.0	-2.0		-2.1		+5.8	+0.2
Oahu, T.H.			+5.2				+5.2

Of the 17 entries, 11 (65%) were less than 3° and the remaining six (35%) ranged between 3° and 6°. Taking an average at each station over all test days considerably improved the azimuth determination. A deviation of 3° at a distance of 1000 miles is equivalent to a displacement of the source of about 50 miles; at 2000 miles the displacement would be about 100 miles. Similarly, doubling (halving) the azimuth deviations doubles (halves) the displacement of the source.

B.4.7 The background noise level varied appreciably for the various test days. At the distant stations, Belmar and Oahu, where the signal level was low, this variation probably was sufficient to influence the detectability of signals. At the closer stations where the peak signal was strong the signal would probably have been detectable even on much noisier days.

B.4.7.1 At Belmar, the noise backgrounds and maximum signal amplitudes (both in dynes/cm^2) were:

	Baker	Charlie	Dog	Easy	Surface	Underground
Noise Background	2.0	1.5	29.0	6.0	24.5	2.0
Signal Amplitude	2.8	12.0		26.0		5.8

Note how markedly the recorded background noise fluctuated from test day to test day and in particular the large values on Dog and Surface Days. Assuming relative consistency of meteorological structure along the propagation path to Belmar during the test period, and that signal amplitudes were in the order indicated in paragraph B.4.4 above, then the signal strength at Belmar on Dog Day should not have exceeded 26.0 dynes/cm^2 (the Easy Day value), and the probable signal to noise ratio would have been 26/29. Detection is improbable for such a ratio unless there is a marked differentiation between signal and noise in predominant period. If one assumes the signal strength on Surface Day to have been 5.8 dynes/cm^2 (the Underground Day value), then the probable S/N ratio would have been 5.8/24.5, which would have precluded any possibility of detection of the Surface signal. In fact, with the background level of Dog Day, neither the Baker nor Charlie signal could have been detected. The assumption of consistency of the meteorological structure and sound path to the east throughout the test is supported by the consistency of the travel velocity values, as discussed in paragraph B.4.5 above. Further, the period of the tests (about six weeks) lies entirely within the fall season and consequently it is expected that no major change occurs in the upper atmosphere.

B.4.7.2 At Oahu, the Dog Day signal was the only one detected. The slow travel velocity, 8.3°/hour, and long predominant period, 30 seconds, are indicative of a sound path to the 100 kilometer level. The recorded noise levels at Oahu for the six test days, and the maximum value of the signal amplitude (both in dynes/cm^2) were:

	Baker	Charlie	Dog	Easy	Surface	Underground
Noise Background	6.0	5.0	2.0	6.0	8.0	12.0
Signal Amplitude			5.0			

Again, assuming relative consistency of meteorological structure along the path of propagation to Oahu during the test period, and the ordering of maximum amplitudes as indicated in paragraph B.4.4 above, it is clear that the most favorable signal to noise ratio probably occurred on Dog Day. Since, on Dog Day, the peak signal to average noise ratio was 5/2, and the average signal to average noise was only 1.5/1, one may conclude that the high noise level precluded the detection of signals from any of the other tests.

B.5.0 CONCLUSIONS

B.5.1 In general the detection of the source was quite successful at ranges up to 2228 miles to the east and unsuccessful at a range of 2739 miles to the west. The influence of the size of the source on its detection was greater than the influence of burying the source.

B.5.1.1 Except for Test Able, which was not detected at any station, the following results were obtained:

a. At Pyote, Texas, 826 miles to the southeast, these signal amplitudes are in the same order as the source size. The period of the signals increases as the size of the sources increases. The influence of burying the source was insufficient to mask either of these effects.

b. At Camp Breckinridge, Kentucky (the Signal Corps supported station), the signal strengths are ordered according to source size. Except for the Dog Day shot the periods are ordered according to source size.

c. At Belmar, N.J., all signals were recorded except those on Dog and Surface Days. On these two days the background noise was sufficiently high to obscure a signal of the size of the next larger tests. (The most recent noise reducing arrays were not available for use at Belmar, N.J.) Thus, for source identification purposes, the results of these two days are best represented as no data. The recorded signal strengths and periods follow the trend of ordering with size of source but some discrepancies appear.

d. At Oahu, T.H., a signal (considered probable) was detected and attributed to the Dog Day shot even though its travel velocity was quite slow. This signal, with a period of 30 seconds and a low travel velocity, is typical of signals which travel to heights of 60 to 80 miles. The background noise level on the other shot days was three times that of Dog Day. This would have precluded detection of signals from the other shots unless a major change in the propagation characteristics of the atmosphere occurred.

B.5.1.2 The unsuccessful observations can be explained on the basis of increased background level at the remote stations. It also appears that careful analysis of the period and amplitude data can be used to give an estimate of relative source size of a series of shots to a factor of between two and ten, provided no gross change in propagation conditions has occurred. It may be possible to obtain an indication of absolute source size by coordination with test results of known firings under similar meteorological conditions.

B.5.2 Some interesting information, applicable to precision of location, is evident from this data:

B.5.2.1 The travel velocities to the east of the initial portion of the arrival show appreciable variation with distance whereas the travel velocities of the points of maximum energy show much less variation. This means that if due care is exercised to utilize the proper portion of a signal, considerable improvement in a location from the travel velocities can be made. The signal at Oahu is quite different from the others in that it has a very low travel velocity, however, its long period is sufficient to distinguish it.

B.5.2.2 The deviation of the computed azimuth from the true azimuth ranged up to 6 degrees. Two-thirds of the values were within three degrees. Since these values are both positive and negative, an average value from different days considerably improves the values.

B.6.0 RECOMMENDATIONS

B.6.1 It is recommended that a program of at least this scope be undertaken for any future test of atomic weapons in order to obtain sufficient data so that greater confidence in estimates of source location and size can be obtained. This is necessary to obtain information applicable to all seasons.

B.6.2 It is recommended that extreme caution be utilized in the determination of locations from acoustic arrival data to allow for the known effects of the various propagation paths.

B.6.3 It is recommended that the technique of strategic acoustic sound ranging on atomic bombs be exploited further for surveillance purposes.

B.6.4 It is recommended that in future tests the frequency response be extended to longer periods to allow for seasonal propagation effects and increased source yields.

TABLE B.1

Summary of Station Results

Station	Pyote, Texas	Camp Breckinridge, Kentucky	Belmar, New Jersey	Oahu, T.H.
Distance (statute miles)	826	1529	2282	2739
Azimuth to Source (degrees)	301.8	277.8	278.4	57.1
Shot Able 22 Oct 1951	Negative	Negative	Negative	Negative
Shot Baker 28 Oct 1951	Positive	Positive	Positive	Negative
Shot Charlie 30 Oct 1951	Positive	Positive	Positive	Negative
Shot Dog 1 Nov 1951	Positive	Positive	Negative (1)	Probable
Shot Easy 5 Nov 1951	Positive	Positive	Positive	Negative
Surface Shot 19 Nov 1951	Positive	Positive	Negative (2)	Negative
Underground 29 Nov 1951	Positive	Positive	Positive	Negative

(1) High background noise sufficient to prevent detection of signal of equivalent strength to Charlie.

(2) High background noise sufficient to prevent detection of signal of equivalent strength to Baker or Underground.

TABLE B.2

Summary of Signal Characteristics

Station	Baker	Charlie	Dog	Easy	Surface	Under-ground
Pyote 826 miles	7 18 16.0 11.4	10 14 27.0 11.4	12 15 51.0 11.6	13 10 50.0 11.1	4 10 15.3 10.2	4 17 11.5 11.2
Breckinridge 1529 miles	8 9 9.2 10.2	12 15 13(1) 10.7	10 11 23.0 10.7	14 11 12(2) 10.4	8 6 7.3 9.8	5 17 4.8 10.4
Belmar 2228 miles	12 7 2.8 9.9	10 12 12.0 10.4		14 10 26.0 10.3		5 14 5.8 9.9
Oahu, T.H. 2739 miles			30 11 5 8.3			

(1) Slightly overloaded (2) Strongly overloaded

Legend:
(Diagonally)

Predominant Period (seconds)
Duration (minutes)
Maximum Amplitude (dynes/cm^2, 0 to peak)
Travel Speed (degrees/hour)

TABLE B.3

Pyote Results - Baker Day
1521Z 28 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1623:54	11.40	308	391	1.7	10
	1627:02		302	418	1.5	10
	1629:49		303	381	3.8	7
	1631:32		305	358	7.4	6
	1634:28		307	365	15.0	8
Max. Amp.	1635:	9.73			16.0	8
	1636:59		301	378	8.3	5
	1638:44		300	392	4.4	16
End	1642:04	8.87	306	416	1.8	15

Average Computed Azimuth: 304.0°
Signal/Noise Ratio: 13:1
Signal Duration: 18 Minutes
Predominant Period of Signal: 7 Seconds

COMMENTS: Signal well above noise background; similarity in wave shapes among four channels excellent; detection obvious.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8°

TABLE B.4

Pyote Results - Charlie Day
1500Z 30 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1603:14	11.40	307	401	1.6	5
	1605:08		307	422	3.9	13
	1607:45		306	402	9.9	9
	1610:34		306	387	9.7	6
Max.Amp.	1614:07	9.73	304	378	27.0	10
End	1617:16	9.35	311	436	6.4	15

Average Computed Azimuth: 306.8°
Signal/Noise Ratio: 19:1
Signal Duration: 14 Minutes
Predominant Period of Signal: 10 Seconds

COMMENTS: Signal well above noise background; similarity in wave shape among four channels excellent; detection obvious; signal stronger than Baker Day.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8°

TABLE B.5

Pyote Results - Dog Day
1530Z 1 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1631:44	11.62	312	429	4.1	15
	1634:34		309	402	6.8	12
	1637:26		304	389	9.5	10
Max.Amp.	1640:02	10.23	304	389	51.0	12
	1641:24		302	398	22.0	10
	1643:04		303	413	6.1	8
	1645:32		307	417	2.8	7
End	1647:24	9.35	301	456	4.5	11

Average Computed Azimuth: 305.2°
Signal/Noise Ratio: 13:1
Signal Duration: 15 Minutes
Predominant Period: 12 Seconds

COMMENTS: Signal well above noise background; similarity in wave shape among four channels excellent; detection obvious; signal stronger than Charlie Day.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8°

TABLE B.6

Pyote Results - Easy Day
1630Z 5 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1734:46	11.08	308	413	16.0	7.0
	1736:51		298	381	16.0	9.0
	1737:54		299	389	22.0	9.0
	1739:11		304	378	38.0	18.0
	1740:46		302	379	46.0	10.0
Max. Amp.	1741:	10.14			50.0	13.0
	1742:01		306	374	30.0	11.0
	1743:24		301	392	31.0	11.0
End	1744:41	9.58	305	411	21.0	6.0

Average Computed Azimuth: 302.9°
Signal/Noise Ratio: 4:1
Signal Duration: 10 Minutes
Predominant Period of Signal: 13 Seconds

COMMENTS: Noise background high, but signal/noise ratio still good; similarity in wave shape among four channels excellent; detection obvious; signal has about same strength as Dog Day.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8°

TABLE B.7

Pyote Results - Surface Day
1700Z 19 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1810:13	10.23	301	379	2.3	6
	1812:20		298	394	9.8	4
	1813:45		300	385	12.0	5
Max.Amp.	1814:	9.73			15.3	4
	1815:29		300	400	3.1	6
	1818:00		302	397	2.0	8
End	1820:07	9.00	305	417	2.5	11

Average Computed Azimuth: 301.0°
Signal/Noise Ratio: 7:1
Signal Duration: 10 Minutes
Predominant Period of Signal: 4 Seconds

COMMENTS: Signal/noise ratio very good; similarity in wave shape among four channels excellent; detection obvious; signal has about same amplitude as Baker Day.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8°

TABLE B.8

Pyote Results - Underground Day
2000Z 29 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	2104:16	11.19	297	374	1.3	6
	2106:54		305	425	1.1	6
	2108:56		303	438	1.9	6
	2113:19		302	378	7.0	3
Max.Amp.	2115:	9.58			11.5	5
	2115:14		301	374	5.5	5
	2117:07		301	406	5.7	4
	2119:29		306	409	2.1	6
End	2120:59	8.87	301	406	1.4	6

Average Computed Azimuth: 302.0^{o}
Signal/Noise Ratio: 4:1
Signal Duration: 17 Minutes
Predominant Period of Signal: 4 Seconds

COMMENTS: Same as for Surface Day.

Distance to Source: 826 statute miles
11.97 degrees

True Azimuth to Source: 301.8^{o}

TABLE B.9

Belmar Results - Baker Day
1521Z 28 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1837:27	9.88	277	389	1.6	7
Max.Amp.	1838:56	9.79	276	409	2.8	11
	1840:22		276	369	1.9	10
	1842:03		282	413	1.8	10
End	1844:03	9.56	276	426	2.0	12

Average Computed Azimuth: 277.4°
Signal/Noise Ratio: 1:1
Signal Duration: 7 Minutes
Predominant Period of Signal: 12 Seconds

COMMENTS: Signal/noise ratio poor; similarity of wave shape among four channels fair; signal identified mainly by change in frequency from background noise which had predominant period of one minute.

Distance to Source: 2228 statute miles
32.30 degrees

True Azimuth to Source: 278.4°

TABLE B.10

Belmar Results - Charlie Day
1500Z 30 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1806:42	10.35	276	397	4.3	18
	1808:49		276	412	8.9	20
	1810:55		275	437	3.6	10
	1812:06		276	454	7.9	14
	1813:32		277	435	10.2	11
Max.Amp.	1815:00	9.94			12.0	11
	1815:04		274	424	8.7	12
	1817:25		278	431	5.9	14
End	1818:38	9.73	279	429	3.8	10

Average Computed Azimuth: 276.4°
Signal/Noise Ratio: 5:1
Signal Duration: 12 Minutes
Predominant Period of Signal: 10 Seconds

COMMENTS: Signal/noise ratio very good; similarity in wave shape among four channels excellent; detection obvious; peak amplitude about four times Baker Day.

Distance to Source: 2228 statute miles
32.30 degrees

True Azimuth to Source: 278.4°

TABLE B.11

Belmar Results - Easy Day
1630Z 5 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1939:26	10.25	273	380	16.0	11
	1941:05		277	366	7.0	9
	1943:09		278	410	18.0	11
Max.Amp.	1944	10.00			26.0	18
	1945:56		278	400	18.0	19
	1947:52		277	407	20.0	15
End	1949:28	9.73	275	376	6.8	13

Average Computed Azimuth: 276.3°
Signal/Noise Ratio: 3.5:1
Signal Duration: 10 Minutes
Predominant Period of Signal: 14 Seconds

COMMENTS: Signal/noise ratio very good; similarity in wave shape among four channels excellent; detection obvious; highest recorded peak amplitude of all four Belmar signals.

Distance to Source: 2228 statute miles
32.30 degrees

True Azimuth to Source: 278.4°

TABLE B.12

Belmar Results - Underground Day
2000Z 29 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	2315:53	9.88	287	377	1.2	6
	2317:39		286	371	4.8	6
	2320:20		285	368	3.3	7
	2322:15		284	363	5.3	5
Max.Amp.	2323	9.56			5.8	6
	2324:41		282	363	2.7	4
	2326:15		285	362	5.1	7
	2328:11		284	379	4.5	7
End	2329:33	9.23	281	380	1.6	5

Average Computed Azimuth: 284.2°
Signal/Noise Ratio: 1.5:1
Signal Duration: 14 Minutes
Predominant Period of Signal: 5 Seconds

COMMENTS: Signal/noise ratio poor; similarity in wave shape among four channels fair; signal initially identified by high frequency pattern relative to low frequency background.

Distance to Source: 2228 statute miles
32.30 degrees

True Azimuth to Source: 278.4°

TABLE B.13

Oahu Results - Dog Day
1530Z 1 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	2018:30	8.27	61	378	3.3	50
	2019:39		61	393	[illegible].1	30
	2021:02		63	391	3.8	25
Max. Amp.	2023:51	8.10	59	390	5.0	30
	2027:36		65	394	3.2	20
End	2029:40	7.96	65	393	3.9	45

Average Computed Azimuth: 62.3°
Signal/Noise Ratio: 1.5:1
Signal Duration: 11 Minutes
Predominant Period of Signal: 30 Seconds

COMMENTS: Signal/noise ratio poor; similarity in wave shape among four channels fair; character of pressure fluctuations changes from 6 second microbarometric pattern to 30 second pattern average.

Distance to Source: 2739 statute miles
39.70 degrees

True Azimuth to Source: 57.1°

TABLE B.14

Breckinridge Results - Baker Day
1521Z 28 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1732:22	10.17	272	395	2.0	8
	1733:42		273	384	3.8	10
	1734:44		272	388	4.5	9
	1735:49		276	397	4.4	8
Max.Amp.	1737:02	9.77	273	393	9.2	7
	1738:33		274	405	8.4	6
	1740:15		274	419	6.6	9
End	1740:38	9.52	276	397	2.6	8

Average Computed Azimuth: 273.8°
Signal/Noise Ratio: 5.5:1
Signal Duration: 9 Minutes
Predominant Period of Signal: 8 Seconds

COMMENTS: Signal well above noise background; similarity of wave shape among four channels excellent; detection obvious.

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

TABLE B.15

Breckinridge Results - Charlie Day
1500Z 30 October 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1704:56	10.66	283	387	3.1	19
	1706:48		274	363	4.1	18
	1710:18		284	395	11.0	15
	1711:42		280	361	12.0	16
	1713:25		278	386	11.0*	10
Max.Amp.	1714:	9.94			13.0*	18
	1714:23		280	391	12.0*	7
	1715:54		277	432	4.5	10
	1717:23		281	446	5.2	8
End	1719:42	9.52	283	449	2.1	9

* Slightly saturated

Average Computed Azimuth: 280.2°
Signal/Noise Ratio: 14:1
Signal Duration: 15 Minutes
Predominant Period of Signal: 12 Seconds

COMMENTS: Signal well above noise background; similarity in wave shape among four channels excellent; equipment slightly overloaded at peak intensities; detection obvious.

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

TABLE B.16

Breckinridge Results - Dog Day
1530Z 1 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1733:47	10.71	282	429	6.5	13
	1736:05		279	420	7.6	12
	1738:26		280	406	11.0	13
	1740:24		277	369	16.0	11
Max. Amp.	1742:	10.08			23.0	12
	1743:13		280	392	15.0	9
	1743:04		276	388	20.0	18
End	1745:16	9.85	280	403	14.0	10

Average Computed Azimuth: 279.1°
Signal/Noise Ratio: 4:1
Signal Duration: 11 Minutes
Predominant Period of Signal: 10 Seconds

COMMENTS: Signal/noise ratio good; similarity in wave shape among four channels excellent; detection obvious; peak amplitude about 2.5 times Baker Day.

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

TABLE B.17

Breckinridge Results - Easy Day
1630Z 5 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1838:17	10.41	272	351	4.5	10
	1840:01		271	372	8.9	12
	1842:20		275	386	7.2*	7
Max. Amp.	1843:	9.99			12.0*	14
	1845:16		278	419	9.8*	23
	1847:15		276	416	9.8*	16
End	1848:42	9.56	280	432	9.8*	15

*Strongly saturated

Average Computed Azimuth: 275.3°
Signal/Noise Ratio: 9+:1
Signal Duration: 11 Minutes
Predominant Period of Signal: 14 Seconds

COMMENTS: Equipment strongly overloaded by signal; similarity of wave shape among four channels excellent; detection obvious.

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

TABLE B.18

Breckinridge Results - Surface Day
1700Z 19 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	1916:19	9.77	272	400	3.5	5
	1917:46		275	358	1.9	7
Max.Amp.	1919:05	9.56	270	380	7.3	8
	1920:32		272	371	7.1	7
End	1921:50	9.35	270	354	4.1	6

Average Computed Azimuth: 271.8°
Signal/Noise Ratio: 2.5:1
Signal Duration: 6 Minutes
Predominant Period of Signal: 8 Seconds

COMMENTS: Signal/noise ratio good; similarity in wave shape among four channels excellent; frequency of signal higher than background; detection obvious.

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

TABLE B.19

Breckinridge Results - Underground Day
2000Z 29 November 1951

	Time (Z)	Travel Velocity Degrees/ Hour	Azimuth (Degrees)	Trace Velocity (yards/ second)	Amplitude 0 to peak (Dynes/ cm^2)	Period (Sec)
Start	2208:11	10.41	281	341	1.3	6
	2210:11		280	374	1.9	3
	2212:59		279	377	3.6	4
Max.Amp.	2216:11	9.77	277	354	4.8	9
	2219:07		275	419	3.6	6
	2221:38		272	388	3.9	9
	2223:45		277	393	3.1	6
End	2224:46	9.16	274	386	1.2	5

Average Computed Azimuth: 277.9°
Signal/Noise Ratio: 2.0:1
Signal Duration: 17 Minutes
Predominant Period of Signal: 5 Seconds

COMMENTS: Same as for Surface Day

Distance to Source: 1529 statute miles
22.17 degrees

True Azimuth to Source: 277.8°

Fig. B.1 Outpost Microphone Installation

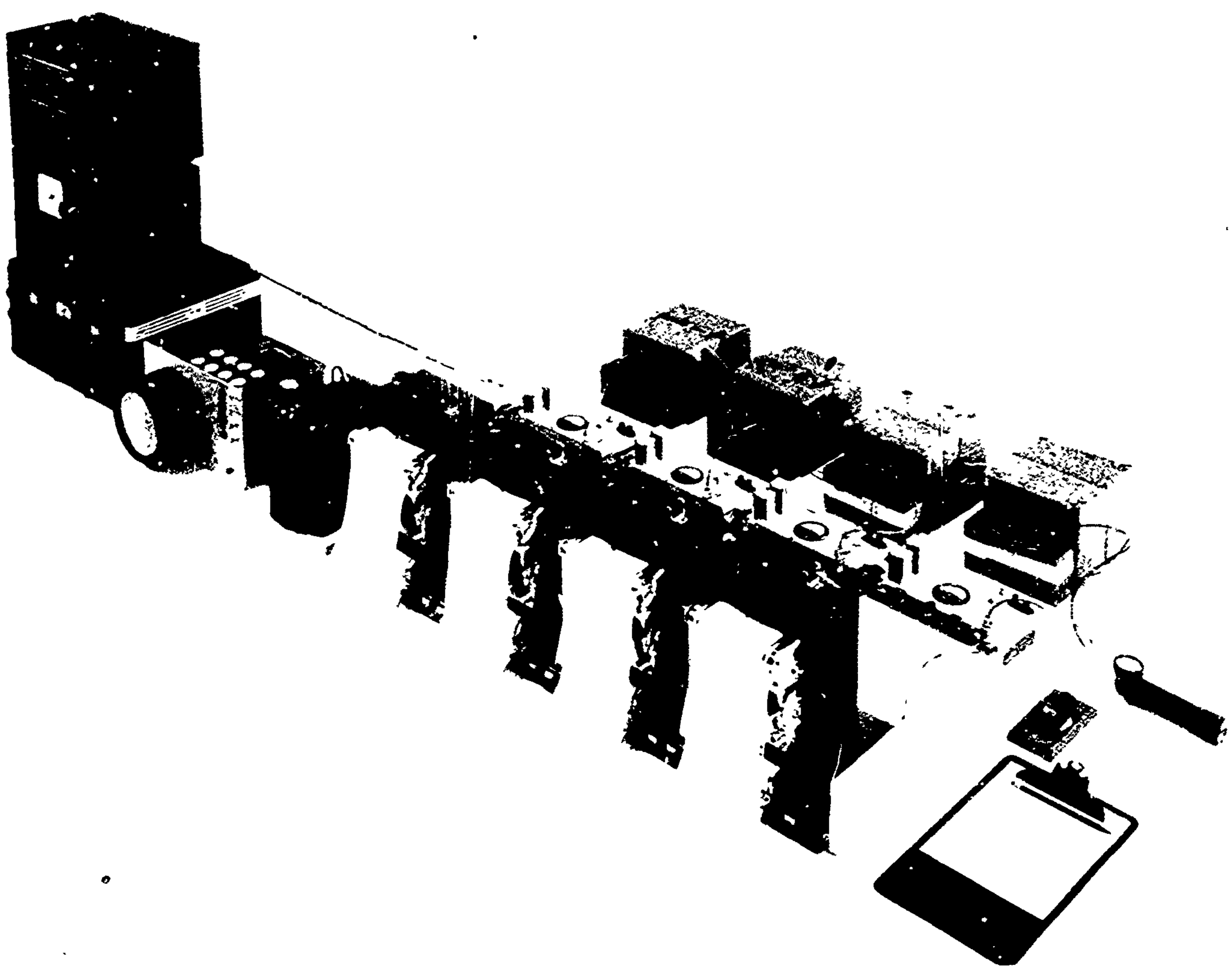


Fig. B.2 Central Station Installation (Idealized)

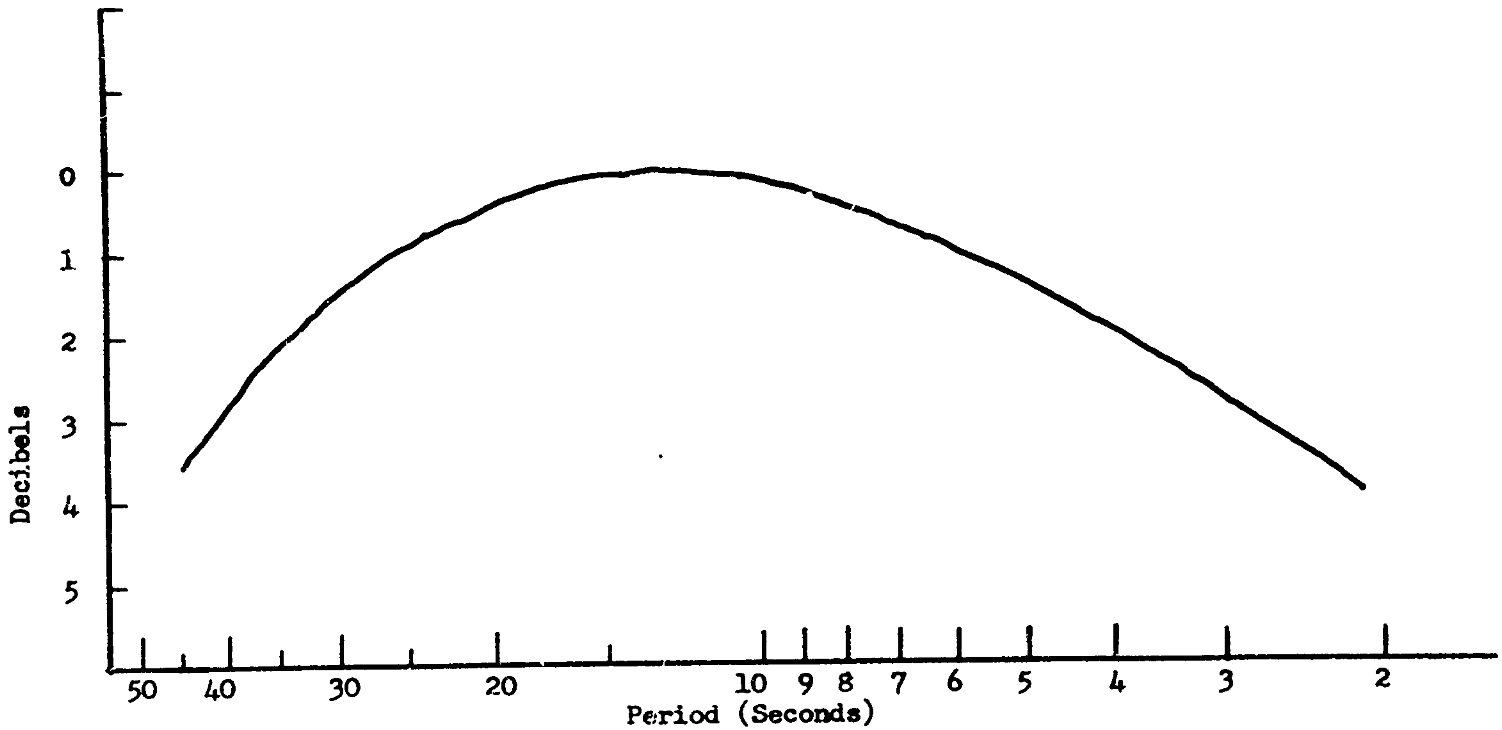


Fig. B.3 Frequency Response of the Improved Infra-Sonic System M-2

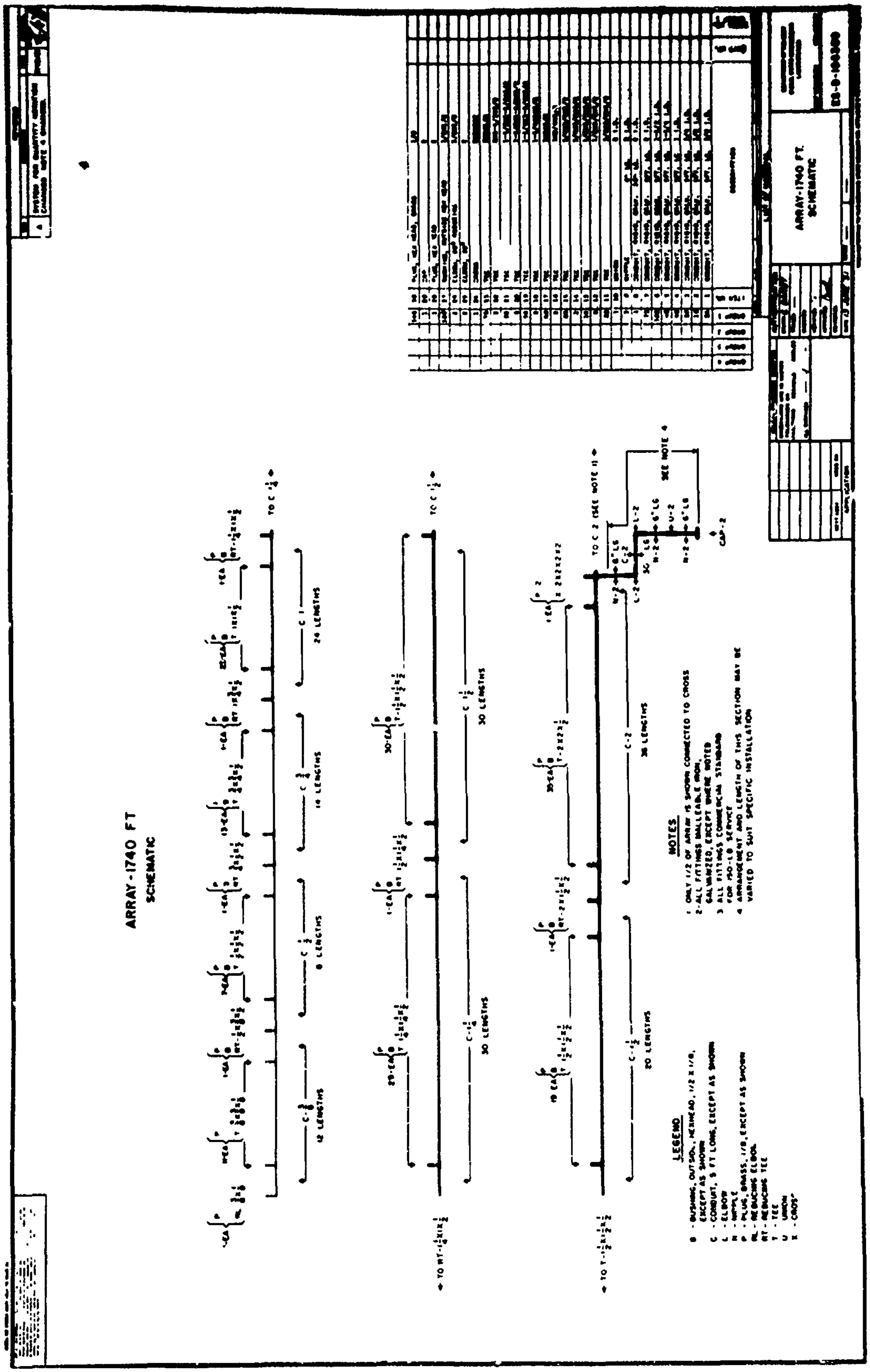


Fig. B.4 Schematic Diagram of 1740-ft. Noise-Reducing Array

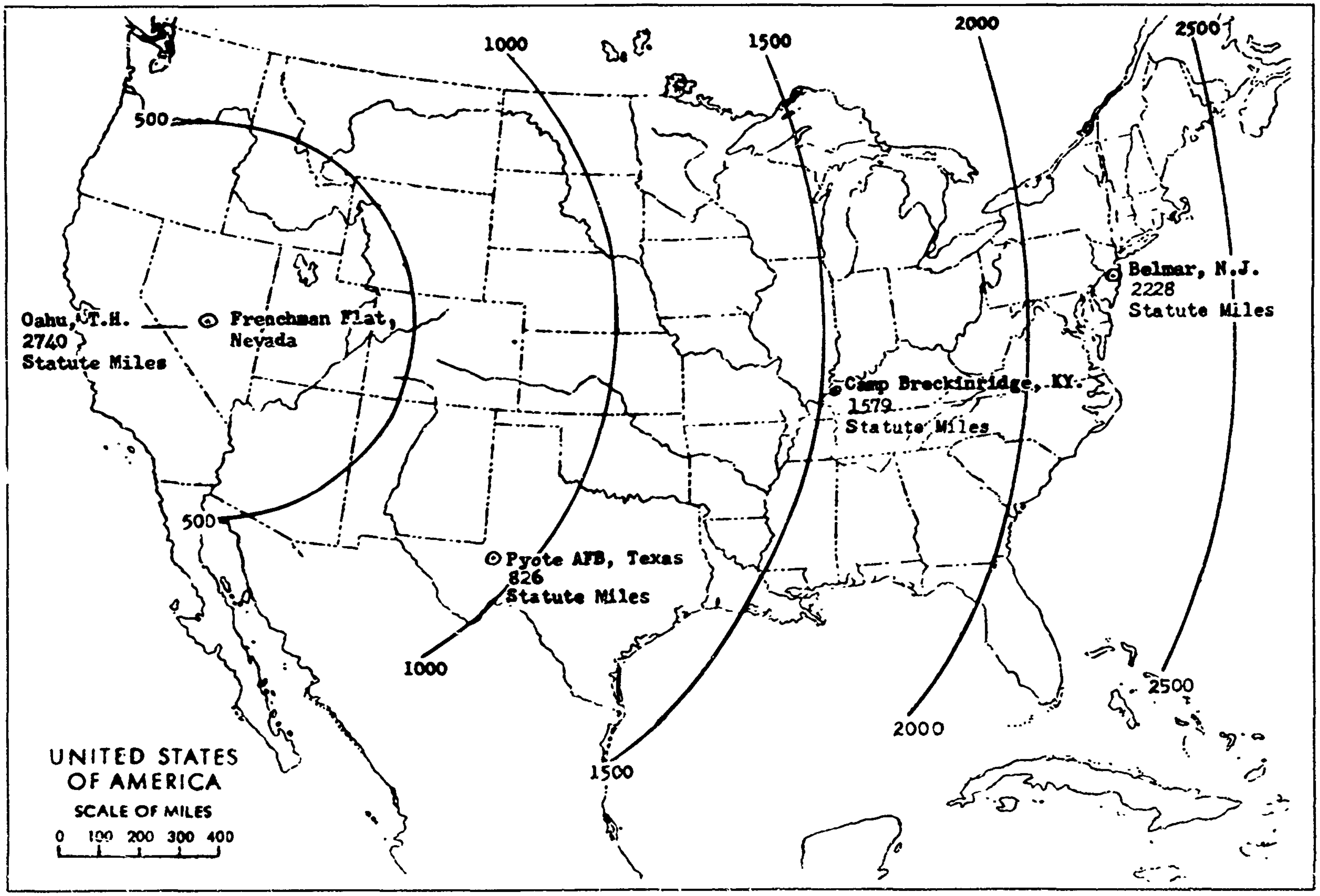
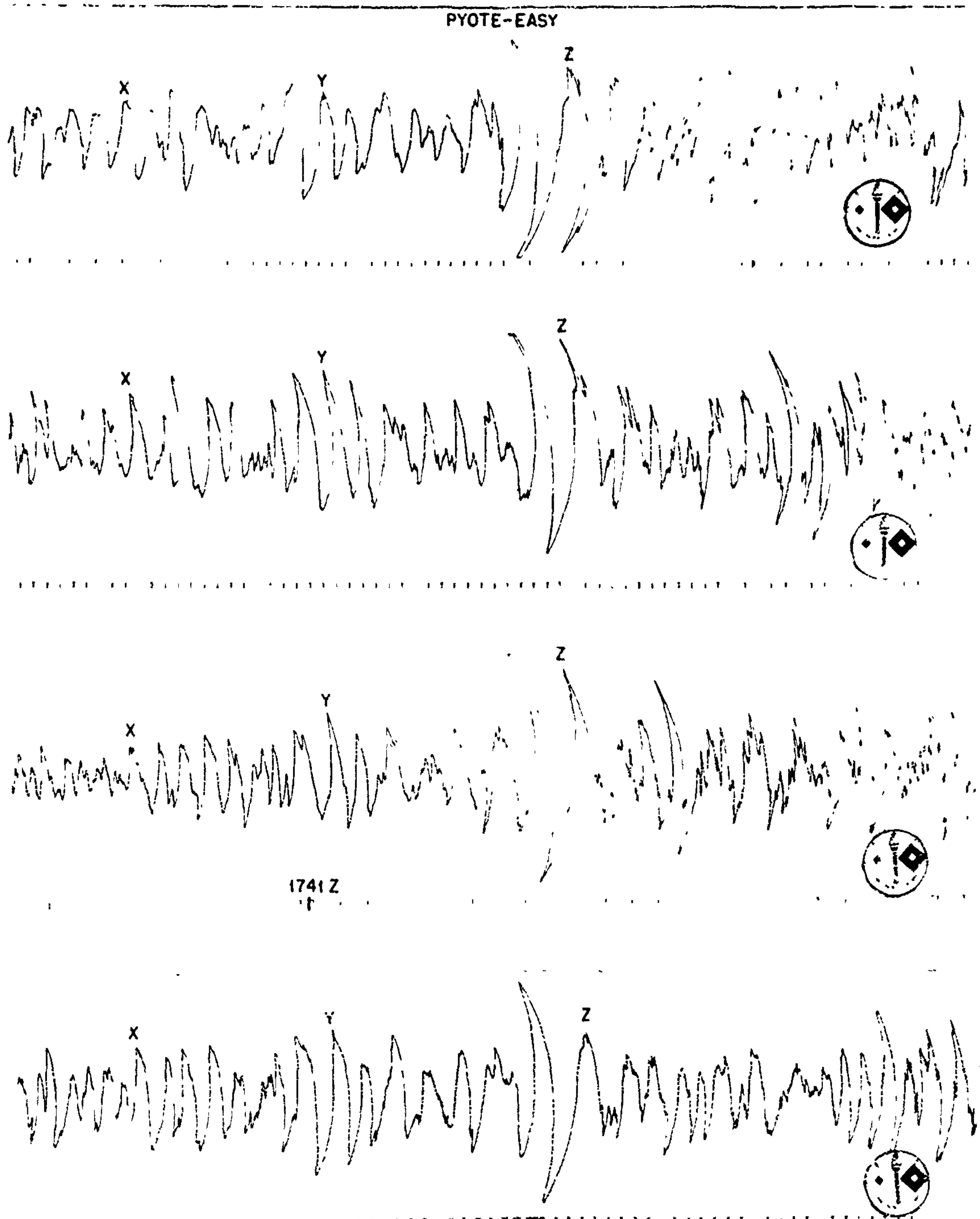


Fig. B.5 Locations of Signal Corps Stations



SECRET

Fig. B.6 Graphic Record for Shot Easy at Pyote AFB, Texas

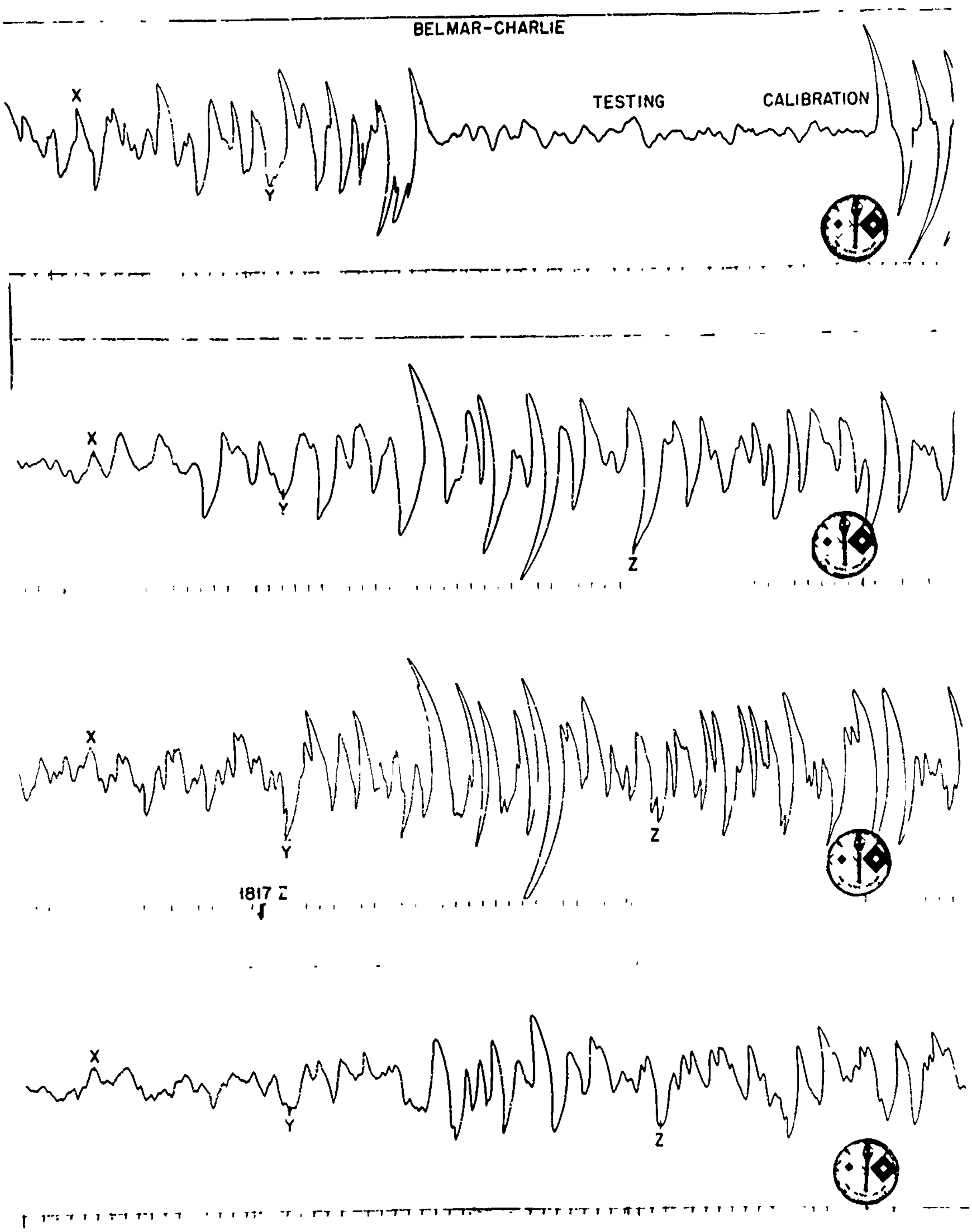


Fig. B.7 Graphic Records for Shot Charlie at Belmar, N.J.

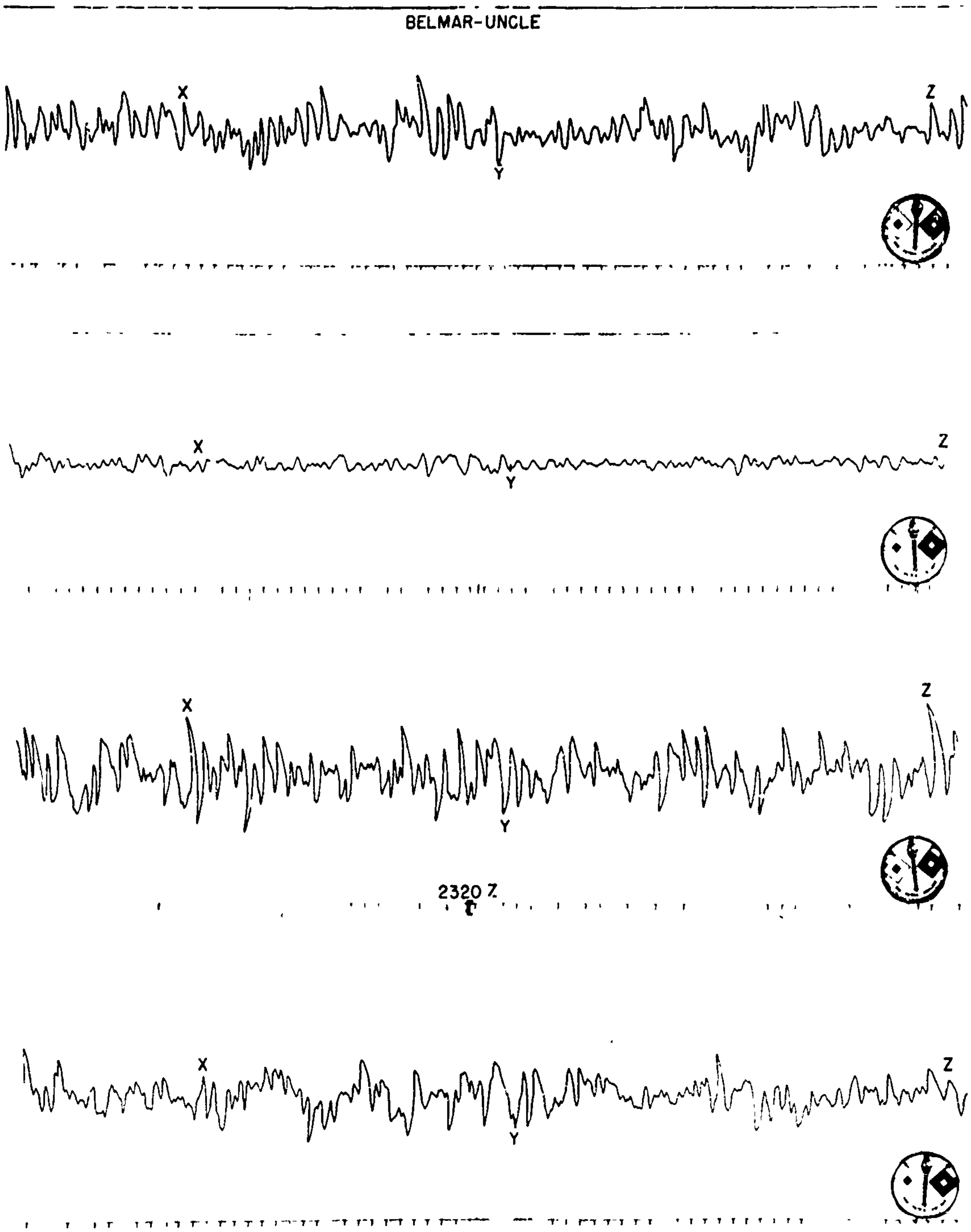


Fig. B.8 Graphic Records for the Underground Shot, Belmar, N.J.

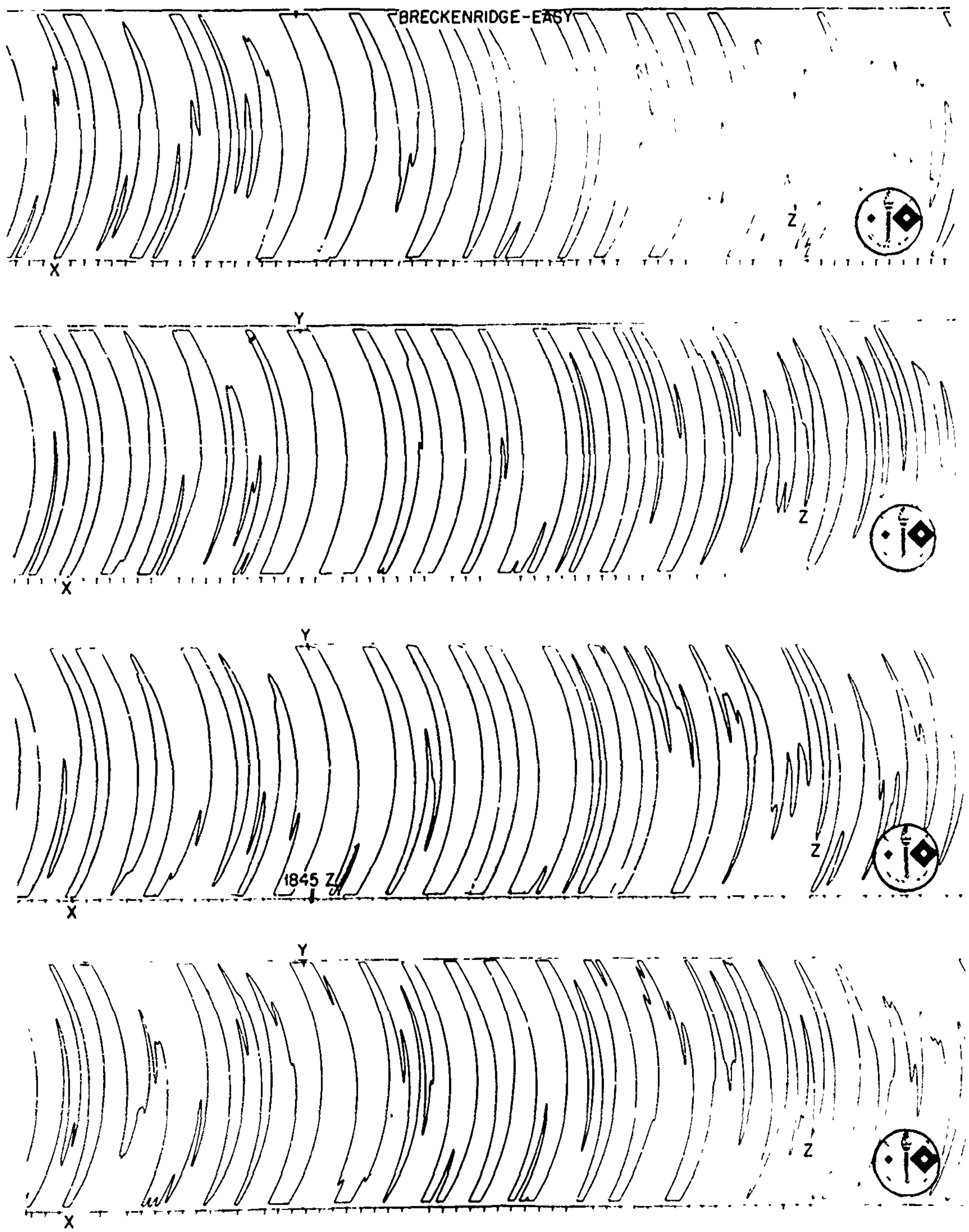


Fig. B.9 Graphic Records for Shot Easy at Breckinridge, Ky.

OPERATIONS BUSTER AND JANGLE

PROJECT 7.6 BUSTER AND PROJECT 7.3 JANGLE

APPENDIX C

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF OPERATIONS BUSTER AND JANGLE - NATIONAL BUREAU OF STANDARDS PARTICIPATION

by

Peter Chrzanowski, Daniel P. Johnson, Irving Levine,
Harry Matheson, Horace A. Bowman

3 March 1952

U. S. Department of Commerce
National Bureau of Standards

PRECEDING PAGE BLANK-NOT FILMED

ACKNOWLEDGMENTS

NBS Project Personnel were:

Horace A. Bowman
Peter Chrzanowski
Hilbert W. Frey
Vernon H. Goerke
Charles C. Walker
Richard P. DeAgro
Edward T. Woolard
Kenneth L. Lemmon
Daniel P. Johnson
Irving Levine
Harry Matheson
Robert E. Sacher

PRECEDING PAGE BLANK-NOT FILMED

CONTENTS

CHAPTER C.1

INTRODUCTION

C.1.1 SCOPE

This report covers the work done by the National Bureau of Standards on Operations BUSTER and JANGLE for the United States Air Force under AFOAT-1 Project Authorization No. B/92/W/NBS. The project was authorized by secret letter dated 22 March 1951, from Headquarters, USAF, to the National Bureau of Standards, subject: National Bureau of Standards Participation in Project 7.3, Operation WINDSTORM (Secret) (Short Title B/92)." Due to a change in plans, Operations BUSTER and JANGLE were substituted for the originally scheduled Operation WINDSTORM.

C.1.2 GENERAL

Acoustic ranging on an extended scale is a possible approach to the problem of monitoring other countries for atomic explosions. Consequently, a knowledge of the character of acoustic signals at great distances from such explosions is of paramount importance to the design of instrumentation for detecting them. Also, only through study of the atmospheric factors which affect long distance propagation of sound will it be possible to establish the limits for reliable detection of atomic explosions.

Operations BUSTER and JANGLE provided a series of signals for study from advantageous locations. The Bureau was one of three agencies which participated in the study. For its part, the Bureau established an acoustic detection station at Fort Lewis-McChord AFB, Washington, and furnished instrumentation and personnel to the station operated at Oahu, T.H., by the Signal Corps Engineering Laboratories. The Bureau also maintained a small experimental station at Washington, D.C., which was operated during these tests.

At each station the Bureau acoustic instrumentation was used with graphic recorders of the recording milliammeter type. In addition, magnetic tape recorders were used for Shots Baker, Charlie, Dog, and Easy at Fort Lewis-McChord station and for the Surface and the Underground[1] shots at the Washington, D.C., station. The magnetic

---

[1] Hereafter, tests are referred to as A, B, C, D, E, S, and U.

tape recorder was a part of a recorder-correlator system now being developed to determine automatically the time, azimuth, and vertical angle of arrival of acoustic signals at monitoring stations.

Shot A was not received. Shots B, C, D, E, S, and U and Shots B, C, D, E, and U were recorded successfully on graphic recorders at the Fort Lewis-McChord and at the Washington, D.C. stations, respectively. No successes were reported from the Oahu station from field inspection of the graphic records obtained with Bureau equipment. However, analysis of the data from Shot D obtained at Oahu after it was transcribed to magnetic tape indicates the presence of a late arrival. Arrivals from other shots may be found after the remaining records are transcribed.

Analysis of a magnetic tape record from Fort Lewis-McChord shows that the duration and character of the acoustic signals received at long range are very different from the duration and character visualized from inspection of the graphic records.

CHAPTER C.2

INSTRUMENTATION

C.2.1 GENERAL

The acoustic detection instrumentation employed by the Bureau during Operations BUSTER and JANGLE was developed at the Bureau under AFOAT-1 Project Authorization No. W/67/DC/BS. It was first field tested during Operation GREENHOUSE in the spring of 1951. With only minor modifications, it was placed in service for Operations BUSTER and JANGLE. The instrumentation is described in considerable detail in progress reports to AFOAT-1 and in a preliminary technical manual. A final manual and complete specifications for the detecting and graphic recording portion of the equipment are being prepared. A very brief resume of principles of operation and acoustic characteristics of the equipment are included below for purposes of orientation.

C.2.2 CHANNEL CHARACTERISTICS

C.2.2.1 Microphone Capsule

The pressure sensitive element of the microphone was a flexible diaphragm which formed one plate of a variable condenser. The other plate was fixed. Both the diaphragm and the fixed plate were mounted in an arrangement called a capsule. To provide a suitable reference pressure for the diaphragm, one side of the capsule was connected to a one-gallon glass bottle. The necessary acoustic bypass between front and back of the diaphragm was an 18-in. length of stainless steel tubing of 0.035 in. bore. The bottle was mounted in a large galvanized can and suitably insulated against thermal changes. By filling the bottle with expanded mica, troublesome convection currents in the bottle, which might produce undesirable noise, were prevented.

The variable condenser, or capsule, was part of the frequency determining network of an electronic oscillator. Motions of the diaphragm in response to pressures acting on it produced changes in the frequency of the oscillator. Thus, the microphone furnished a frequency modulated signal whose frequency deviations were a function of the pressures acting on the diaphragm.

C.2.2.2 Single-Unit Microphone

The Bureau developed two types of microphones for the acoustic detection system. While they used the same diaphragm, capsules, and cans, they employed different electronic oscillator circuits. However, the parameters were so adjusted that the oscillators produced about the same carrier frequency. Also, they were designed for different noise reducing array systems.

The so-called single-unit microphone employed only a single transducer and so was a single-point pickup device. It could be coupled to a noise-reducing array at only one point. Usually, the microphone was connected to the center of a 1,000-foot pipe array of Signal Corps design.

In the single-unit microphone, the capsule functioned as a variable condenser in the shunt RC leg of a Wien bridge oscillator. Since the frequency of such an oscillator is inversely proportional to the square root of the variable shunt capacitance, it was necessary to "tailor" the diaphragms by corrugating them in such a way that the pressure vs. frequency relation for the diaphragm compensated in part for the non-linear frequency vs. inverse capacitance characteristic.

C.2.2.3 Ring Microphone

The second type, called a "ring" microphone, was designed for use with a two-dimensional noise-reducing array. In the ring microphone four (although three or more are practical) capsules formed the variable capacitances in a four-section phase shift oscillator. With this arrangement, the effects of pressures acting on the capsules were algebraically additive. Thus, the ring microphone was a multiple-point pickup device with the property that, with a spacing of several hundred feet between the microphone sections, the capsules plus the electronics of the microphone behaved as one oscillator. The sensitivity of the ring microphone was about 1.5 times that of the single-unit microphone.

The multiple pickup feature of the ring microphones permitted their use with a number of arrays disposed in any convenient configuration. Although other arrangements were possible, the one used at Fort Lewis during Operations BUSTER and JANGLE was a double W (WW) arrangement.

C.2.2.4 Discriminator and Amplifier

The signal from the microphone was transmitted over telephone lines to a central recording site where the signal was demodulated in a discriminator of the pulse counting type to produce an electrical signal proportional to the pressure acting on the microphone. After amplification in an amplifier with appropriate frequency cut-off characteristics, the electrical signal was recorded on either an Esterline-Angus ink-on-paper recorder or on a magnetic tape recorder. The amplifier was equipped with an eight step sensitivity control of five db per step and a five position band control for the low-frequency cut-off. Thus, the operator could set the sensitivity and the low-frequency cut-off for optimum conditions for signal reception at his station. The choice of sensitivity and band settings depended on the level of the background noise and the anticipated frequency of the expected acoustic arrival.

Typical sensitivities for a complete Bureau channel, including a single-unit microphone and recorder, when the microphone was subjected to a constant sinusoidal pressure were as follows:

Sensitivity Control Step	Sensitivity, Dynes/cm^2 per inch, peak-to-peak, EA Recorder, 3 milliampere movement
1	71
2	40
3	23
4	13
5	7.1
6	4.0
7	2.3
8	1.3

However, the sensitivities of the capsules used at the Washington, D.C., station were about double those given in the table.

C.2.2.5 Response-Frequency Characteristics

A response-frequency characteristic of a typical channel (microphone-discriminator-amplifier-EA recorder) is given in Figure C.1. The curves of different channels are nearly identical when the curves are normalized for the differences in mid-band sensitivity.

The acoustic resistance of the by-pass between the front and back of the microphone diaphragm was chosen so that the microphone itself would have the response-frequency characteristic of an analogous single RC high-pass filter with the three db point at 0.02 cycles per second.

It should be noted that all field calibrations of the microphone channels were made at a single frequency (approximately 0.13 cycles per second) as produced by the field calibrator. Thus, the field calibration yields a mid-band sensitivity value at any amplifier low-frequency cut-off setting except Band 1.

The recognizable periods reported in Tables C.1 and C.2 were obtained by visual inspection of the records and are determined usually from the time interval between consecutive peaks of a correlatable signal trace. The amplitudes of arrivals as given in these tables represent the pressures at the inlets to the microphones. They are obtained from the maximum peak-to-peak displacements of consecutive dominant peaks on the record after the amplitudes are converted to dynes/cm^2 using the measured mid-band values of sensitivity of the microphone channel producing the record. No attempt was made to assign an amplitude to any particular frequency.

The upper frequency cut-off for the channels was governed by the response of the recorders as well as by the unknown frequency response characteristics of the noise-reducing arrays.

C.2.2.6 Recorders

All acoustic arrivals were recorded on Esterline-Angus recording milliammeters with a sensitivity of three milliamperes for full scale deflection. These furnished graphic ink-on-paper records. The upper frequency cut-off of these recorders was about two cycles per second and determined the upper frequency cut-off of the entire channel exclusive of the array.

See Chapter 5 for the report on magnetic recorders.

C.2.2.7 Timing

Two sets of time marks were recorded on the graphically recorded paper tapes. For relative timing purposes, time pips from a Nardine chronometer were recorded on one side of the tapes. For absolute time measurements and for rating the chronometer, time marks obtained from WWV radio time signals were recorded on the other side of the tapes. Thus, each paper tape had time marks at 10-second intervals with a pattern repeating at intervals of one, and 10 minutes at Fort Lewis and 1 and 5 minutes at Washington, D.C.

C.2.2.8 Calibrations

All of the equipment except that at Oahu, T.H. was re-calibrated after it was returned from Operation GREENHOUSE and before it was placed in service for Operations BUSTER and JANGLE. The capsules were re-calibrated using a static pressure calibrator. The discriminator-amplifiers were re-calibrated electrically. At both the Washington, D.C., and Fort Lewis-McChord AFB stations the capsules and oscillators were brought in from the field and calibrated using a constant-pressure variable-frequency generator.

Periodically, the various channels were re-calibrated using a portable field calibrator which generated a pressure of about 9.5 dynes/cm^2 at about 0.13 cycles per second when it was coupled to Bureau microphones.

C.2.2.9 Noise-Reducing Arrays

Two types of noise-reducing arrays were employed by the Bureau. The 1000-foot pipe noise-reducing array developed by the Signal Corps was always used with the single-unit microphones. This type of array was made up of pipe in 10-foot lengths tapering from 1 1/2-inch diameter at the center to 1/2-inch diameter pipe at the ends. At 10-foot intervals, inlet plugs provided communication to the atmosphere. Each inlet was provided with a rain shield made of a 180 degree bend of 3/8-inch diameter tubing.

The inlet plugs on the pipe arrays at the Fort Lewis-McChord AFB and at the Washington, D.C., stations were inadvertantly drilled with a No. 53 drill instead of a No. 63 drill as required by the Signal Corps Engineering Laboratory design. Consequently, instead of 400 ohms, each inlet had an acoustic resistance of approximately 23 ohms. The effect of the much smaller acoustic resistance was to make the array behave as if it were much shorter, especially with regard to the higher frequency components of the signal.

The ring-microphones were used with two-dimensional arrays made up of 3/4-inch internal diameter garden hose. This came in convenient 50-foot lengths and could be easily arranged in any desired configuration. At Fort Lewis-McChord, where ring-microphones were installed for BUSTER and JANGLE, the arrays were arranged in a double W (WW) with the microphone sections connected to the bases of the W's. The straight lines composing the W's were about 250 feet long. Inlets to the hose were provided by inserting No. 18 gage hypodermic needles, 1 1/2-inch long, into the hose at appropriate intervals. The measured resistance of the needles was 585 acoustic ohms. To give equal weight to each interval of the hose, the needles were spaced about 16 feet apart near the microphone cans and about 8 feet apart near the end of a 250-foot hose.

C.2.2.10 Transcriber

A device was constructed which makes it possible to transcribe the information from EA paper records onto magnetic tape. The paper is moved over a 6-in. diameter drum either by hand or by a slow-speed clock motor. A magnetic tape is driven by an appropriate capstan which is integral with the drum shaft. The operator traces the "wiggly-line" record with a stylus which moves the arm of a potentiometer in a bridge circuit. Deflections of the stylus are thus converted into fluctuating current in the magnetic recording head. The resulting record is a magnetic copy of the EA paper record and can be used for refined high speed analysis.

CHAPTER C.3

STATIONS AND SITES

C.3.1 FORT LEWIS-MCCHORD AFB

C.3.1.1 General

Fort Lewis lies in the western part of the State of Washington on Puget Sound. The area is a coastal plain with the Cascade Mountains about 50 miles to the east and the Olympic Mountains about the same distance to the northwest. The area is relatively quiet meteorologically -- strong winds are infrequent. During the fall, winter, and spring seasons it is subject to considerable rain. The climate is mild with infrequent snow.

Six microphone sites were located on Fort Lewis and one on McChord AFB which adjoins Fort Lewis. Both single-unit and ring-microphones were used at this station. The single-unit microphones were coupled to the 1000-ft Signal Corps type noise-reducing arrays. Arrays for the ring-microphones were of 3/4-inch internal diameter garden hose. See Section C.2.2.9.

All of the microphones were locally powered and only the signals were transmitted to the recording site over the local telephone system.

The recording site was located at the Signal Corps Radio Compound at North Fort Lewis.

C.3.1.2 Coordinates of Sites

The coordinates given below for the microphone sites located on the Fort Lewis Reservation were established as follows:

a. Easily identifiable landmarks near each site were pin-pricked on aerial survey photographs of the area. The coordinates of the pin-pricked points were determined photogrammetrically by the Army Map Service at Washington, D.C. The AMS also supplied the photographs. The coordinates of these points were determined relative to the Universal Transverse Mercator Grid, Zone 10, and were estimated by the Army Map Service to be accurate to within 25 ft.

b. The coordinates of the microphone sites relative to the chosen landmarks were found by transit surveys. Since the distances between landmarks and sites were short, it is estimated that the error in the coordinates given below does not exceed 25 ft.

c. For the sites equipped with Signal Corps type pipe arrays, the coordinates are given for the center of the pipe. For the sites employing hose arrays, the coordinates are for the geometrical center of the double W (WW).

d. The coordinates of Site 3 on McChord AFB were determined independently by traverse relative to the U.S. Polyconic Grid, Zone G, and were translated into the Universal Transverse Mercator Grid, Zone 10.

Microphone Site Coordinates

Ft. Lewis-McChord Station

Site Number	Type Microphone	Type Array	Grid North(1) (Feet)	Grid East(1) (Feet)
1	Single-Unit	Pipe	17126562	1741658
2	Ring-Unit	WW Hose	17110040	1728463
3	Single-Unit	Pipe	17121096	1773677
4	Ring-Unit	WW Hose	17077098	1750006
5	Single-Unit	Pipe	17099058	1744691
6(2)	Ring-Unit	WW Hose	17089467	1772571
7(2)	Single-Unit	Pipe	17089575	1772521
8	Ring-Unit	WW Hose	17117644	1760225

(1)Universal Transverse Mercator Grid, Zone 10

(2)Sites 6 and 7 have approximately the same coordinates. The coordinates for the single-unit microphone were taken for the center of the 1000-ft pipe array, whereas the coordinates for the ring-microphone were for the center of the double W (WW).

The geodetic positions of the centroid of all seven primary microphone site locations were 17,105,868 feet, grid North, 1,753,034 feet, grid East, referred to the Universal Transverse Mercator Grid, Zone 10, and 47° 4' 46.4" North, 122° 32' 52.2" West. The coordinates for the center of the pipe array were used as the coordinates for Sites 6 and 7 in computing the centroid and the latitude and longitude.

C.3.1.3 Description of Sites

Site 1, Radio Compound, Single-Unit Microphone.

This site was located in a field adjacent to the fenced-in compound where the recording equipment was located. It was almost entirely open and completely devoid of trees. There were some bushes about 2 to 3 feet high. This site was the most noisy one.

Site 2, Trailer Camp, Ring-Unit Microphone.

This site was located in woods made up largely of second growth fir, closely spaced, and with a great deal of dead fallen wood. It was within about 1/3 mile of U.S. Highway No. 99, between the golf course and the trailer camp. This was a rather quiet site, second only to Site 4.

Site 3, McChord AFB, Single-Unit Microphone.

This site was located in rather dense woods on the McChord Air Force Base reservation. This site was rich in microbaroms.

Site 4, Beacon Hill, Ring-Unit Microphone.

This, the quietest site, was located on the northern slope of Beacon Hill. The ground cover was very dense growth with a few tall fir trees. The growth contained many deciduous plants, a great deal of it being not more than 15 feet tall with some taller trees. It was a typical second growth after a forest fire.

Site 5, Fort Lewis Cemetery, Single-Unit Microphone.

This site was located in a wooded area with relatively tall trees. There was very little underbrush and the low limbs of trees were few in number. The ground itself had been cleared for a military training area. The microbarom level here was higher than at any other site.

Site 6, Radio Range Station, Ring-Unit Microphone.

This site is in a wooded area adjacent to a radio range station. The woods are for the most part made up of fir trees with branches extending down to the ground, and with small grassy clearings. Noise of the microbarom type became objectionable at times at this site.

Site 7, Radio Range Station, Single-Unit Microphone.

Same location as Site 6. The difference was that Site 6 referred to the ring-unit microphone and Site 7 referred to the single-unit microphone.

Site 8, McCall Woods, Ring-Unit Microphone

This site was located on the south side of McCall Hill. The hill had steep sides and the base of the array was located within fifty feet of the base of the hill. The array was on relatively open ground with a sparse cover of scrub oaks and a few firs. The array itself was on essentially level ground. This site was satisfactory. However, it was more likely to be noisy in sunlight than sites in heavily wooded areas. Due to the excessive cost of running 110-volt, 60-cycle, a-c power lines to this site, it was operated from batteries.

C.3.2 WASHINGTON, D.C.

C.3.2.1 General

At Washington, D.C., three sites were set up forming a nearly equilateral triangle approximately 2 1/2-miles on a side. Only single-unit microphones were used at this station. Sites 1 and 2 had 1000-ft pipe arrays. The array at Site 3 was 800 ft long.

C.3.2.2 Coordinates of Sites

Microphone Site Coordinates

Washington, D. C. Station

Site Number	Type Microphone	Type Array	Grid North (Feet)	Grid West (Feet)
1	Single-Unit	Pipe	9230	23070
2	Single-Unit	Pipe	18550	29360
3	Single-Unit	Pipe	20015	17255

The coordinates are referred to the National Capitol Dome.

The coordinates of the centroid of the microphone site locations were 15,932 feet grid North, and 23,228 feet grid East.

The longitude and latitude of the centroid were 77° 5' 24.5" W, 38° 55' 59.5" N.

C.3.2.3 Description of Sites

Site 1, First High Reservoir

This site is located at the reservoir at Foxhall Road and Whitehaven Parkway. The noise-reducing array was of the 1000-ft Signal Corps type. The microphone was connected to the lineal center of the array. This reservoir is of the covered type with an embankment about 8 ft high on three sides. The array, in the form of an open U, with moderately sharp corners, open to the north, was placed at the base of a chain link fence at the bottom of the embankment. The microphone is locally powered with the output signal transmitted to the recording station over commercial telephone lines.

Site 2, Dalecarlia Reservoir

A 1000-ft array of the Signal Corps type, approximately straight, was laid at the high water mark nearly parallel to McArthur Boulevard, on the south side of the Dalecarlia Reservoir. During the summer and early fall this array is well concealed by high weeds, bull-rushes, etc., typical of swampy terrain. During the winter this cover dies down but is never cleared so that the array is somewhat protected even from a north wind.

The microphone at this site was connected to the center of the array, was locally powered, and was connected to the recording station by commercial telephone lines.

Site 3, National Bureau of Standards

This site was located on the grounds of the National Bureau of Standards, at the base of the chain link boundary fence along 36th Street. The noise-reducing array consisted of an 800-ft pipe array of the Signal Corps type laid parallel to 36th Street and about 25 feet from the center of the street. The microphone was powered from the recording site. The recording site was set up in a building near Site 3. The signal from each of the microphones was fed to each of two discriminator-amplifiers. The discriminator-amplifiers were arranged in two groups so that the sensitivity and bandwidth controls on each group could be adjusted to different values to make reception of the arrival more certain. Each of the discriminator-amplifiers was connected to its own EA recorder.

One group of three discriminator-amplifiers was also connected to three of the five channels of a magnetic tape recorder for the Operation JANGLE shots.

C.3.3 OAHU, T.H.

This station was a permanent acoustic detection station maintained by the Signal Corps. During Operations BUSTER and JANGLE it was to serve the two-fold purpose of (1) providing data on the westward propagation of the BUSTER-JANGLE signals, and (2) as a location for making intercomparison tests between the acoustic instrumentation developed by the Bureau, Signal Corps Engineering Laboratories, and Navy Electronics Laboratory.

CHAPTER C.4

ACOUSTIC RESULTS AND DISCUSSION

C.4.1 TABULATIONS

The results pertaining to the acoustic arrivals from Operations BUSTER and JANGLE are presented in Tables C.1 and C.2. Definitions and methods for arriving at the values of the various characteristics are given in the remainder of this section.

C.4.1.1 Time of First Recognizable Arrival

The times of arrival shown in Tables C.1 and C.2 are for the first event in the record which observers consider to be correlatable. These values are not precise since their choice is influenced markedly by the subjective preferences of different observers.

C.4.1.2 Time of Onset of Main Arrival

These times are for the beginning of the region of high correlatability. For a high signal-to-noise ratio, the onset was usually very abrupt and could be determined to within two or three minutes.

C.4.1.3 Duration of Arrival

This is essentially the length of the time over which the records show continual correlatability. No exact figure can be assigned to this value since the ends, and often the starts, of the arrivals are lost in the noise background.

C.4.1.4 Maximum Amplitude of Arrival

This is the peak-to-peak amplitude of two or more correlatable waves in the arrival. The value given may have been influenced by fortuitous summation of noise and signal energies.

TABLE C.1

Summary of Acoustic Results From Operations BUSTER and JANGLE
Station: Fort Lewis-McChord AFB, Washington

Shot	Able	Baker	Charlie	Dog	Easy	Surface	Underground
Time of first recognizable arrival (GCT)	—	1627	1618	1645	1745	1815	2111
Time of onset of the main arrival (GCT)	—	1639	1618	1645	1745	1821	2120
Duration of recognizable signal, minutes	—	13	22	23	35	8	3
Maximum amplitude of arrival, dynes/cm^2, peak-to-peak	—	5	8.2	10	10	5	6
Signal-to-noise ratio	No arrival	2.5	4.1	5	10	2.5	2
Periods recognized in arrival, seconds		15,<u>30</u>,50	5-19,<u>16</u>	7-23	5-40	15-40	15-40
Horizontal phase velocity, ft/sec(2)		1192	1058	1158	1164	1227	1097
Azimuth of arrival, computed, degrees(2)	—	153.6	145.2	145.3	148.2	149.3	145.4
Transit time, minutes	—	79	78	75	75	81	80
Transit velocity, Ft/Sec	—	856	868	902	902	835	846
Number of channels operating(1)	8	8	8	8	8	8	8

(1) One site contained both a single-unit and ring-unit microphone
(2) Average for two independent observers.
Distance from ground zero = 769 statute miles
Azimuth (angle of departure to ground zero) = 151° 8'

TABLE C.2

Summary of Acoustic Results from Operations BUSTER and JANGLE
Station: Washington, D. C.

Shot	Able	Baker	Charlie	Dog	Easy	Surface	Underground
Time of first recognizable arrival (GCT)	—	1818.30	1752	1823	1927	—	2257
Time of onset of the main arrival (GCT)	—	1820	1755	1826	1929	—	2302
Duration of recognizable signal, minutes	—	18	19	9	16	High background noise - no arrival recorded	16
Maximum amplitude of arrival, dynes/cm^2, peak-to-peak	No arrival	8.5	8.8	10.1	30		2.5
Signal-to-noise ratio		3.5	8.8	3.4	6		2.5
Periods recognized in arrival, seconds		7, 13	11, 20	10,13,30	5,15,45		2.5,4,10
Horizontal phase velocity ft/sec		1172	1226	1324	1207		1270
Azimuth of arrival, computed, degrees	—	282	283	282	280		280
Transit time, minutes	—	180	175	176	179	—	182
Transit velocity, ft/sec	—	1032	1061	1055	1038	—	1021
Number of channels operating	3	3	3	3	3	3	3
Distance from ground zero = 2111 statute miles Azimuth (angle of departure to ground zero) = 276.5°							

C.4.1.5 Signal-to-Noise Ratio

This figure is based on an estimate of the average noise level before and after an arrival and the maximum amplitude of the arrival.

C.4.1.6 Periods Recognizable in Arrival

These were estimated from the time intervals between consecutive major and/or consecutive minor peaks. The values for individual periods are perhaps the most difficult of the characteristics to determine. The character of the arrivals is greatly influenced by the noise background and the periods which are recognizable by eye persist usually for only a few cycles before being displaced by others.

C.4.1.7 Horizontal Phase Velocity

The figure is the distance between two sites, measured in the direction of the received ray, divided by the difference in the time of arrival at the two sites as determined by the tape displacements of correlatable features.

C.4.1.8 Computed Azimuth of Arrivals

By any of several methods, a correlatable arrival on any three records may be used to compute the azimuth of the signal. With an arrival having, in general, many correlatable points the computations may be made for each point and then averaged, or, one may so position the records that maximum correlation of all features of the arrival are obtained and use the time displacements of the records for further computation. The first method gives weight only to maxima, both positive and negative, the exact times of which are subject to displacement by noise. The second method allows for consideration of such features as wave forms and is much easier to compute.

At the Fort Lewis-McChord station the azimuth for arrivals with a high signal-to-noise ratio was computed by the first method from three convenient records. The second method was used at the Washington, D.C., station and at the Fort Lewis-McChord station for arrivals with a low signal-to-noise ratio.

C.4.2 PHOTOGRAPHS OF GRAPHIC RECORDS

Photographs of portions of representative records showing the arrivals received with Bureau instrumentation are shown in Figures C.2 through C.8.

Several corresponding prominent peaks have been circled on the records to assist the reader in studying the traces. The records have been displaced in time so that correlatable points on the different traces in any one photograph will be on a vertical line. The circled prominences are <u>not</u> the only correlatable points on the records. There are many more which can be easily found.

Some of the ring data photographs have been displaced in time with respect to the corresponding single unit data photographs by several minutes. Consequently, there is no relation between circles on the different figures. The numbers identifying the minute mark above the traces may be illegible. Corresponding times on ring and single unit tapes for a given shot may still be found by referring to the WWV code patterns immediately below the traces.

The arcs at the left ends of the records give the amplitude scale in dynes/cm^2 peak-to-peak for the particular trace. It will be noted that the arcs for the Washington, D.C., station indicate sensitivities approaching 3 dynes/cm^2 for full scale deflection on some traces. See Section C.2.2.4.

The symbols like B3S8 on each trace near the arcs identify the bandwidth and sensitivity control settings on the amplifier for the given arrival. See Section C.2.2.4.

C.4.2.1 Graphic Records From Fort Lewis-McChord

On the whole, the graphic tape records obtained with the ring-microphones appear to be more suitable for correlation purposes by visual observation than do the records obtained with the single-unit microphones. This may be in part subjective, since it is not possible at this time to show quantitatively that a ring-microphone system has a substantially better signal-to-noise ratio than a single-unit microphone system. The apparent superiority of the ring system may arise from the differential frequency response of the two types of noise-reducing arrays. The inadvertent error which led to the use of 23-acoustic-ohm instead of 400-ohm inlets in the 1000-ft pipe arrays may be in part responsible for the apparent difference. It may be due in part to the different cover at the ring and single-unit sites.

Figures C.2 and C.3 for Shot B show the difference in an arrival received with the ring-microphone system with a hose array fitted with 585-ohm acoustic inlets, and a single-unit microphone system with a 1000-ft pipe array with 23-ohm acoustic inlets. The amplifier bandwidth and sensitivity were adjusted to the same values. The response to higher frequencies is much greater with the single-unit system. This may be largely due to the incorrect inlet acoustic resistance.

The sudden onset of Shot D is illustrated in Figure C.4. This should be compared with Figure C.11 which shows the power level obtained from the magnetic tape recording of the same shot at Site 5, after it was filtered by means of band pass filters. The onset in both presentations is seen to be quite abrupt. However, because of the higher noise due to microbaroms registered with the single-unit system, the onset is not quite so spectacular as it was when recorded with the ring-microphone system as shown in Figure C.5.

The richness of microbaroms in the Fort Lewis-McChord area is shown in Figure C.6. These records were obtained with the single-unit microphone system. Figure C.6 also shows an example of an arrival consisting of only one large pulse. Unfortunately, this shot was not recorded on magnetic tape so that acoustic analysis for this type of an arrival is not available.

C.4.2.2 Graphic Records from Washington, D.C.

The signal-to-noise ratio at Washington, D.C., was favorable for reception of all BUSTER and JANGLE shots except Shot S. From the amplitude of arrivals at this station it is inferred that the eastward propagation of sound during these shots was very favorable.

Figure C.7 shows an arrival for Shot B at Washington, D.C., at 2100 miles from ground zero under very quiet conditions. The noise level was somewhat over 1 dyne/cm^2 peak to peak. The signal itself was about 8 dynes/cm^2. The first set of circled points on the left side of the figure appears to be due to a precursor which can be found only under quiet conditions of reception. The onset of the arrival, although quite abrupt, is still slow enough to make the determination of the time of onset doubtful by 2 or 3 minutes. This is true of other arrivals of this character.

Figure C.8 shows the arrival from Shot U recorded at Washington, D.C. Until this record was made it was felt that the upper frequency cut-off at 2 seconds was set too high for optional reception of signals at long range. This record shows that the arrival is very rich in frequencies of 2.5 and 4 cycles per second. From visual examination it would appear that these frequencies predominate. However, this arrival was also recorded on magnetic tape at Washington, D.C., and the analysis of the magnetic tape data indicates that there is considerable energy in the 10- to 20-second period band.

C.4.2.3 Results From Oahu, T.H.

No clear-cut arrivals were recorded on pen-and-ink recorders at this station with Bureau instrumentation. However, a probable arrival for Shot D was found after the information on a paper record was transcribed to magnetic tape and analyzed. Further study may reveal other arrivals. The magnetically recorded arrival for Shot D is discussed in Section C.5.4.

The station was about 2700 miles from the shot point for Operations BUSTER and JANGLE. It was about the same distance from the shot point for Operation GREENHOUSE, during which all four shots were received successfully. The inference was that transmission westward was not favorable during Operations BUSTER and JANGLE.

CHAPTER C.5

MAGNETIC RECORDING

C.5.1 MAGNETIC RECORDERS

In addition to the graphic recorders, magnetic tape recorders. were used to record four arrivals at the Fort Lewis-McChord station, and two arrivals at the Washington, D.C., station. The two shots recorded magnetically at Washington, D.C., have not yet been fully analyzed and, consequently, are not discussed in this report.

Two magnetic recorders were used. The first was a five-channel recorder which will ultimately be used for automatic correlation of signals from several channels. The second recorder was a single-channel Magnecorder suitably modified for low tape-speed operation. The following paragraphs are concerned with the data provided by the latter recorder.

The recording speed was 1/2 in/min, and the recorder at the Fort Lewis-McChord station was operated continuously from October 25 to November 5, 1951, to include Shots B through E. The microphone Site 5 was in a wooded area. It was decided to use this site for magnetic recording because of the exceptionally strong microbaroms present. It was felt that much could be learned about this phenomenon through analysis of the magnetic recording.

C.5.2 METHOD OF ANALYSIS

To make the analysis, the recording was played back at a speed of 15 in/sec, which compressed half-an-hour of original data into one second during playback. The original frequency band was thus multiplied by a factor of 1800 and was translated into the audio spectrum where analysis using filters, etc., could be readily accomplished.

The first analysis was made by ear. The output of the magnetic tape was amplified and fed into a loudspeaker. Each shot was distinctly audible above the background noise. The duration of Shot D was audible for three to six seconds. This led to the conclusion that the signal received was actually of the order of one-and-a-half to three hours duration. The microbaroms were audible as a component of fairly definite medium pitch while daytime noise reproduced as irregular rumble.

The next step was to feed the output of the tape through a band-pass filter and then into a high-speed level recorder which plots the power level in the signal vs. time. Photographs of the records obtained with the recorder for various filter pass bands are shown in Figures C.9 through C.12. The whole band was separated by filters into octaves corresponding to periods in the original signal of 20-40 sec, 10-20 sec, etc., up to .625-1.25 sec. Four Spencer-Kennedy continuously adjustable filters were used in cascade with the maximum attenuation outside the pass band being 36 db/octave. Level recordings were made for the whole spectrum and for each octave band.

C.5.3 DISCUSSION OF THE DATA

Perhaps the most striking fact from the photographs shown in Figures C.9 through C.12 is the duration of each signal. It can be seen that durations of up to three hours were recorded, thus confirming the aural analysis mentioned above. Also, it can be seen that the signal decays approximately exponentially with the possibility of two or more slopes in some of the decay curves.

There are two things worth noting in connection with Shot C displayed in Figure C.10. First, it should be pointed out that the pips which occur 2 hours after the onset of the signal are due to a sinusoidal acoustic signal field calibrator connected to the microphone. The last positive pip is caused by the calibrating signal which was a sine wave lasting 10 minutes and which had a period of about 8 sec, and an amplitude of about 8 dynes/cm^2 peak-to-peak. Secondly, the 20-40 sec band shows what appears to be an arrival 3 hours and 40 minutes after the onset of the main arrival. This indication is also present in the 10-20 sec band. Further investigation of this apparent arrival would seem desirable. This can be made with the five-channel correlator when it is completed.

Shot D, lasting at least 3 hours, was the longest in duration. In the photograph of the 0.625-1.25 sec band for Shot D there are present a series of about six spikes which closely resemble arrivals since their leading edges are steep and they have a straight-line decay. They are audible as crackling sounds during the shot. Whether or not they are indeed separate arrivals is a very interesting question which remains to be answered.

Unfortunately, a series of power failures occurred during Shot E so that only the onset and about 1/2 hour are undisturbed and can be used for comparison purposes.

It is worth noting here that, for the four shots received at this location, the 2.5-5 sec band shows minimum signal-to-noise ratio.

It is also noteworthy that improvements in signal-to-noise ratio of up to 10 db are obtained in the 10-20 sec band. This indicates that the proposed correlator, which will operate in the audio spectrum, can achieve up to 10 db additional improvement in signal-to-noise ratio by proper filtering.

Using the data provided by the level recorder, the relative power on the tape in each octave was computed and plotted at 1/2 hour intervals for each shot, Figures C.13 through C.16. In these graphs the vertical distance between any two lines gives the relative power in the octave bounded by those lines. From the graphs it can be seen that over 50 percent of the power in the arrivals was concentrated in the 5-10 and 10-20 sec bands with the next greatest contribution being from the 20-40 sec band. The energy in the 20-40 sec band, however, decays more rapidly than any of the others. The 10-20 sec band gave the longest duration. This fact is especially noticeable in Shot C.

Further work is being done on these and other records to determine the character of the received signals. Although analysis by other methods has also been attempted, difficulties with interpretation of the data obtained precludes further discussion of the results at this time.

C.5.4 SUMMARY OF ANALYSIS OF MAGNETIC TAPE DATA

Several things have been found by the experiment with the magnetic tape recorder. When the proposal to use magnetic tape recording was first made, it was felt that listening to an infrasonic signal which has been translated to the audio range would be a powerful method of detecting such signals in the presence of noise. This has been amply confirmed by our experience. A signal from an atomic explosion seems to have a characteristic sound which can be detected even when the background noise is strong. The sound is very roughly similar to that which one hears in a train when another train passes, going in the opposite direction. The power of the aural analysis is best demonstrated by the fact that Shot D at Oahu was detected from a single channel transcribed onto magnetic tape and confirmed by two other transcriptions of the same shot and by re-examination of the original paper tape records.

The magnetic records have also shown that the disturbance produced at a microphone site by an atomic burst may last several hours and has a fast onset. It will be extremely interesting to see how the azimuth and velocity behave during this interval. It is felt that the automatic correlator now under construction offers the best method of investigating this phenomenon.

Data provided by the magnetic recorder show that, at the Fort Lewis-McChord station, the frequency spectrum of an infrasonic signal from an atomic explosion is fairly uniform in the range of 5-40 sec periods. The background noise, on the other hand, can be seen to have a spectrum which contains more high-frequency energy. This fact enabled us to improve the signal-to-noise ratio by more than 10 db for two arrivals, by using octave filters in the low-frequency region. The uniformity of the signal spectrum together with its sudden onset probably accounts for the fact that the ear recognizes it so easily.

CHAPTER C.6

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn immediately from the Bureau's results obtained during Operation BUSTER and JANGLE:

1. Under favorable conditions, a distance of 2100 statute miles still appears to be within the zone of reliable reception of acoustic arrivals from atomic explosions.

2. There is no conclusive evidence of distinct multiple arrivals at Fort Lewis-McChord or at Washington, D.C.

3. The present evidence on the relative merits of the Bureau ring-microphone used with the hose array and the single-unit microphone used with the Signal Corps pipe array system is inconclusive.

4. Magnetic tape data indicates that the onset of arrivals is abrupt and that the duration of the signals is much longer than the duration of arrivals recognizable on ink-on-paper records.

5. The results obtained with magnetic recording are favorable to the development of a correlator for automatic determination of time, azimuth, and phase velocity of long-range signals.

Two general recommendations can be made on the basis of the Bureau's experience during Operations BUSTER and JANGLE.

1. Long-range signals should be recorded magnetically at every opportunity to provide data for further study.

2. Further studies should be conducted on systems for noise reduction.

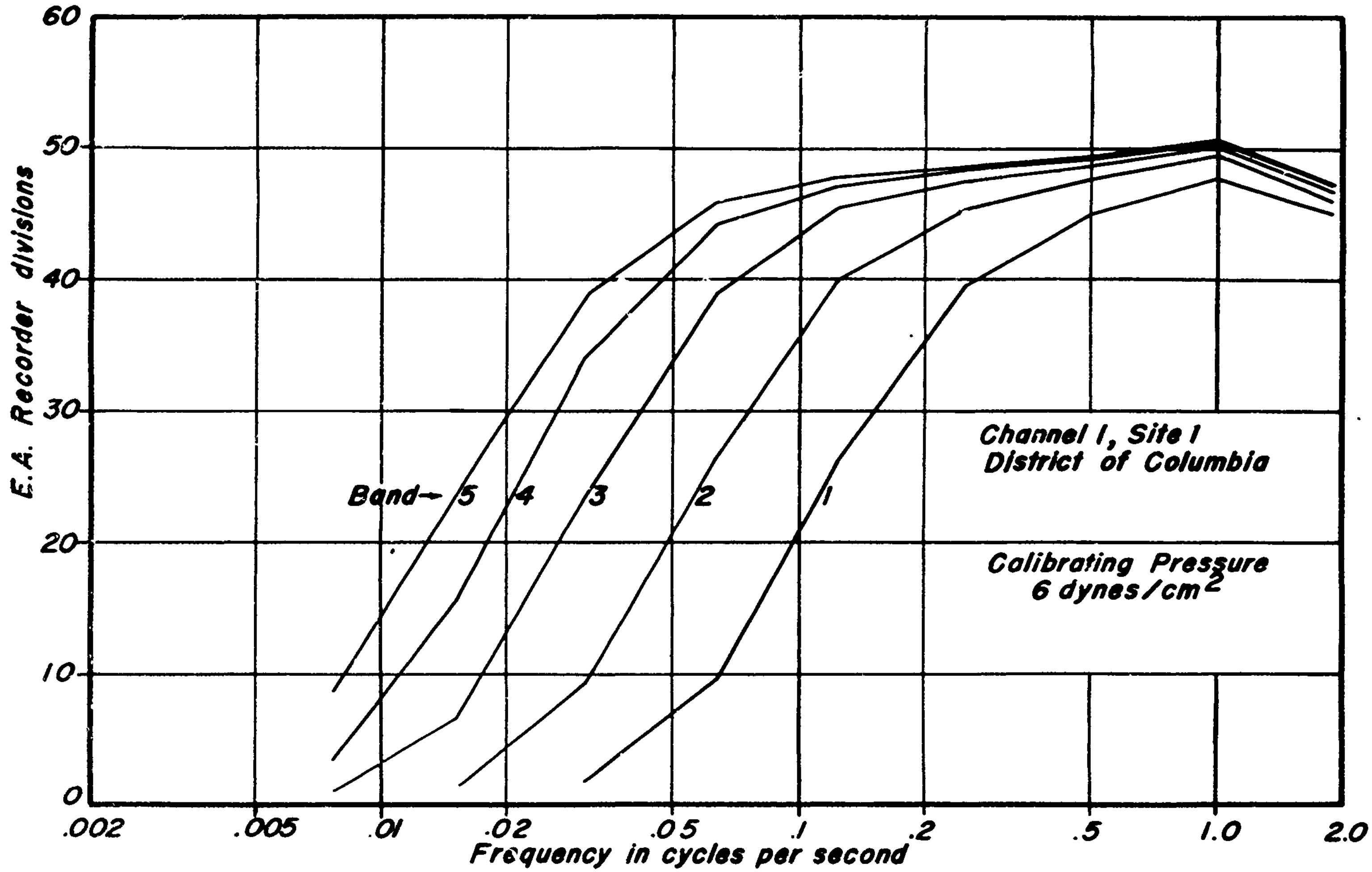


Fig. C.1 Over-all Response-Frequency Characteristics of a Typical NBS Microphone Channel

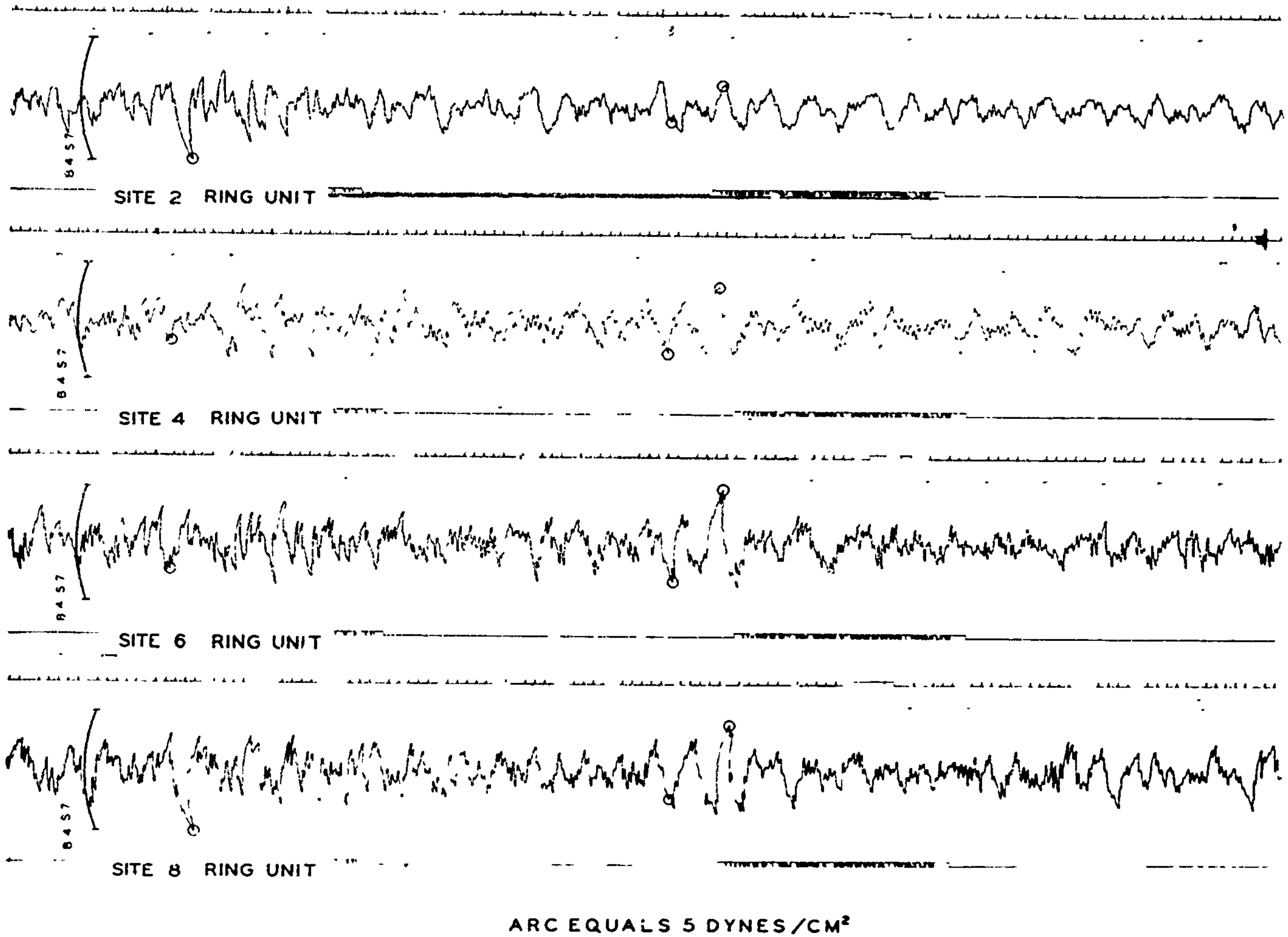
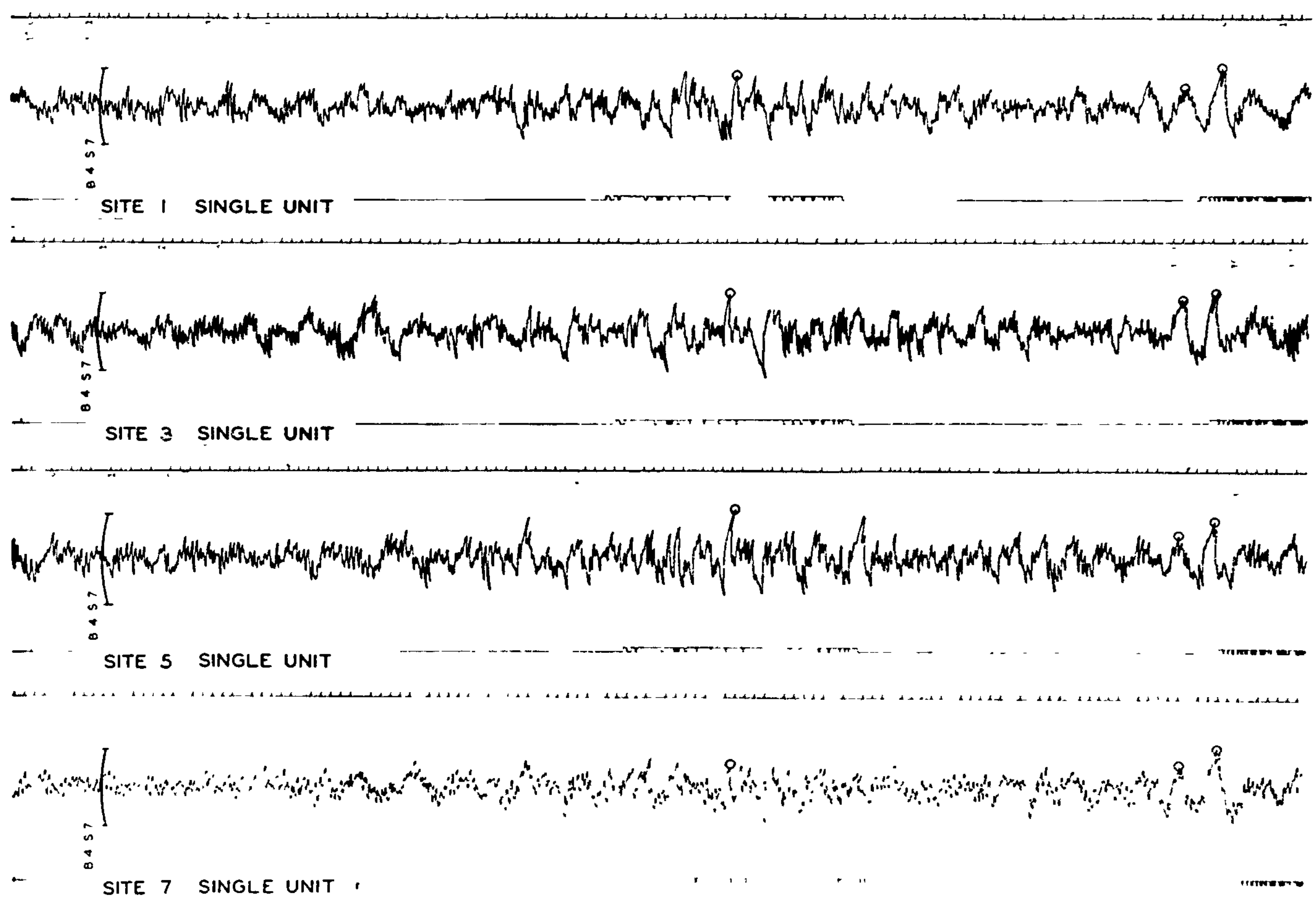


Fig. C.2 Typical Records from NBS Ring Unit Microphone at Fort Lewis–McChord AFB, Shot B, October 28, 1951



ARC EQUALS 5 DYNES/CM²

Fig. C.3 Typical Records of NBS Single Unit Microphone at Fort Lewis-Mc Chord AFB, Shot B, October 28, 1951

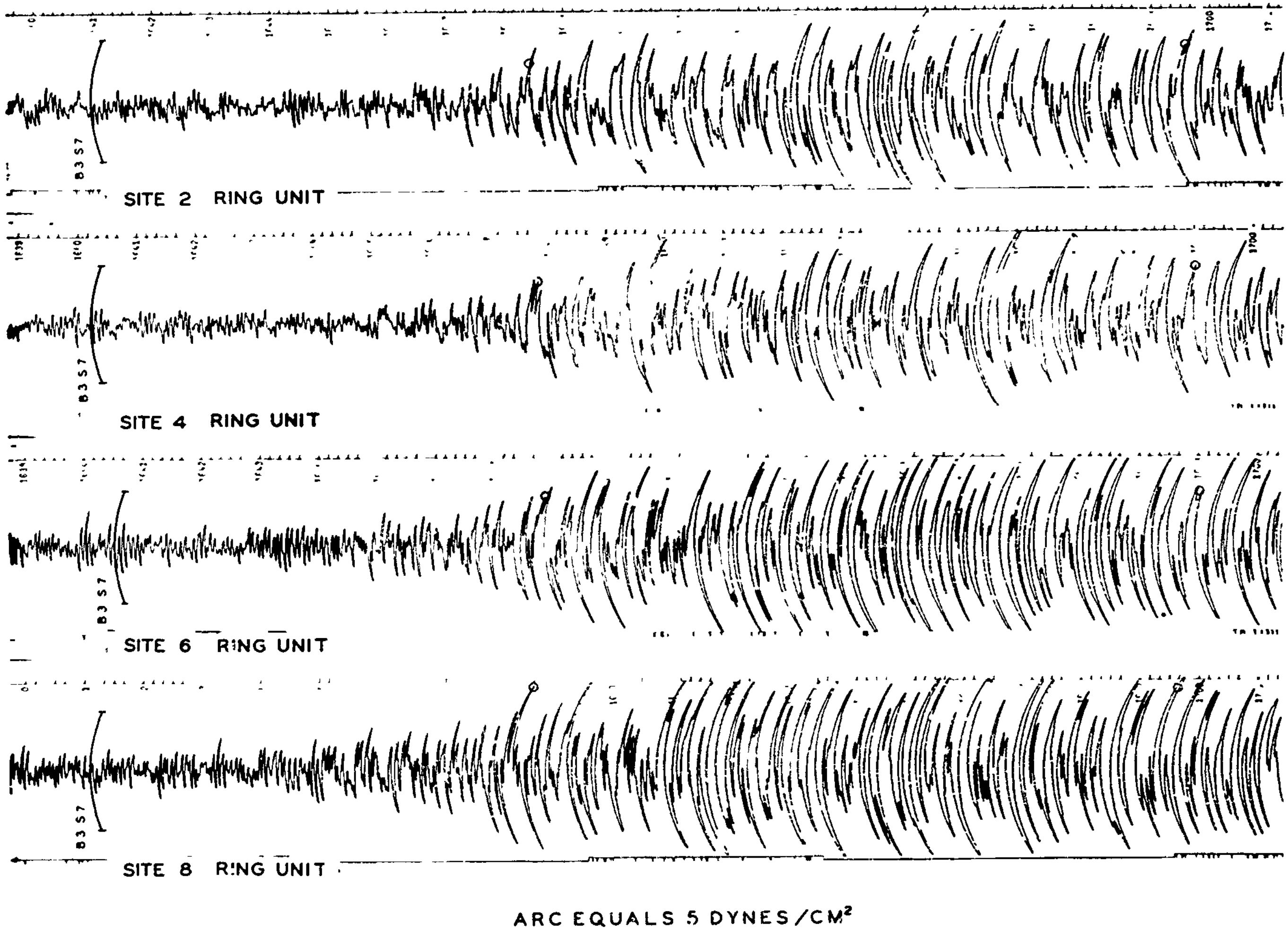


Fig. C.4 A Sharp Onset Arrival received with a Ring Microphone under High Signal to Noise Ratio conditions. Shot D, November 1, 1951, Fort Lewis-Mc Chord AFB

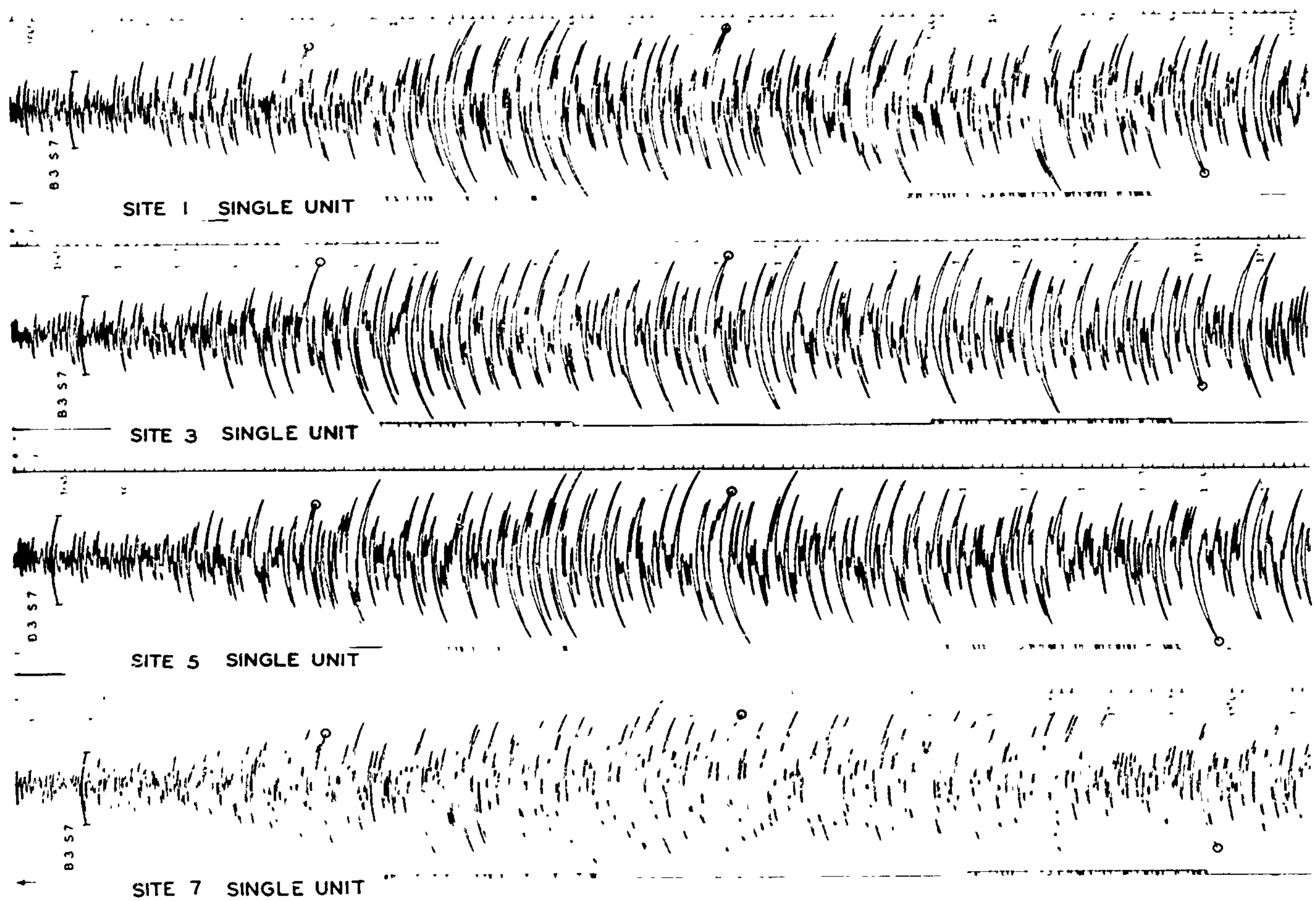


Fig. C.5 A Sharp Onset Arrival received with a Single Unit Microphone under High Signal to Noise Ratio conditions. Shot D, November 1, 1951, Fort Lewis—Mc Chord AFB

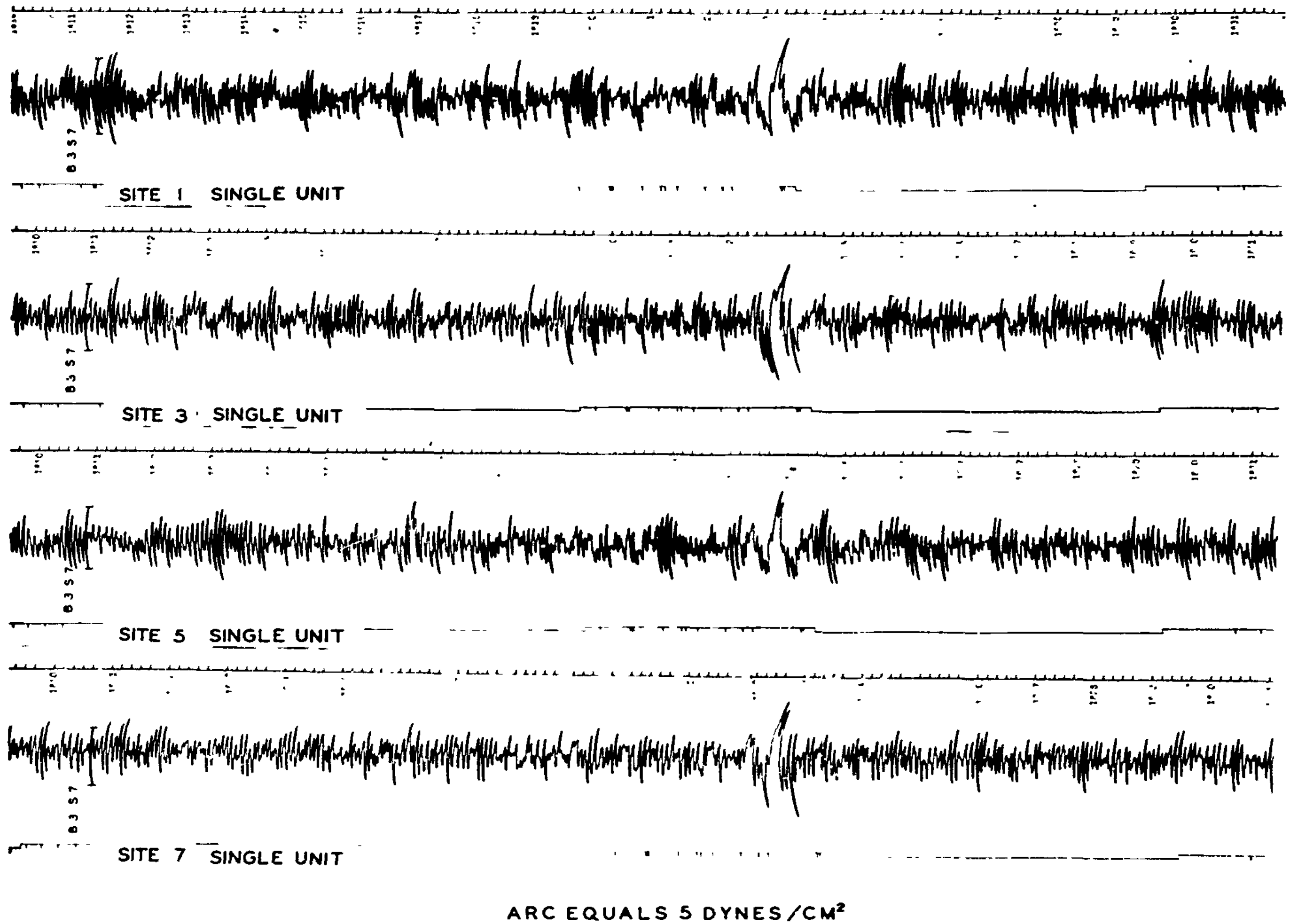


Fig. C.6 A Pulse Type of Arrival for Shot S, November 19, 1951, received at Fort Lewis—Mc Chord AFB. Record also shows typical Microbaroms for this Area

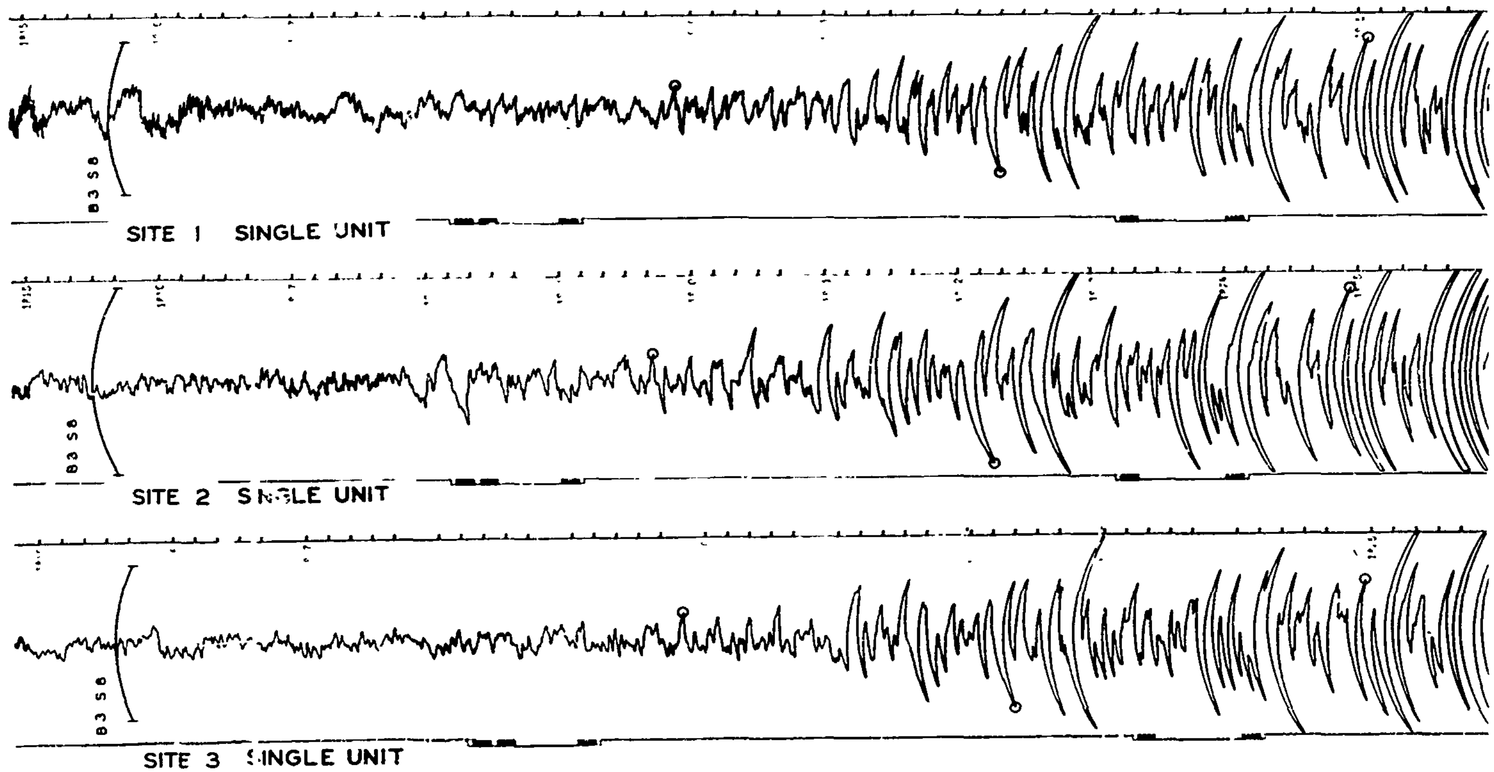


Fig. C.7 Record showing Precursors often found under Quiet Reception conditions. Shot B, October 28, 1951, received at Washington, D.C.

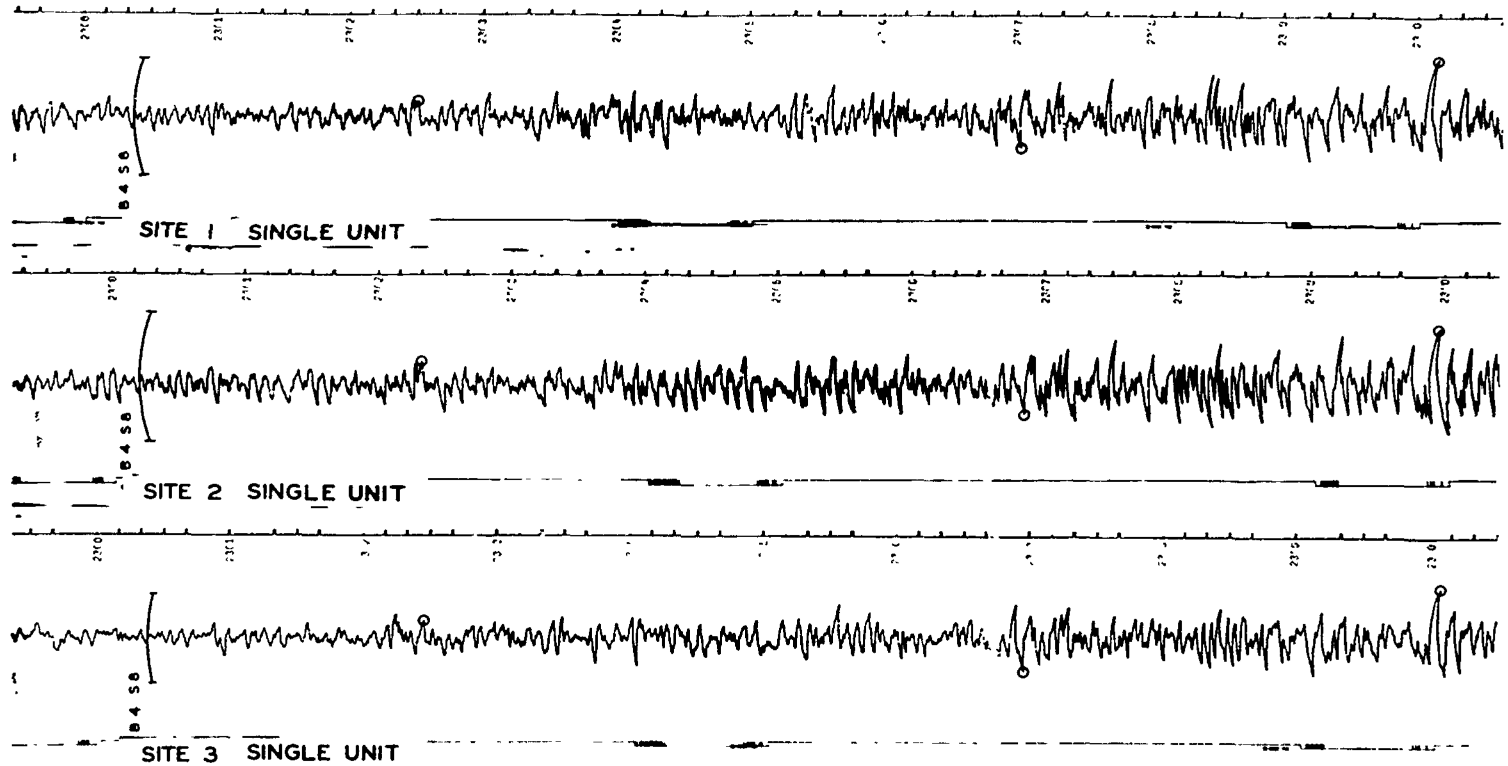


Fig. C.8 A High Frequency Arrival for Shot U, November 29, 1951, received at Washington, D.C.

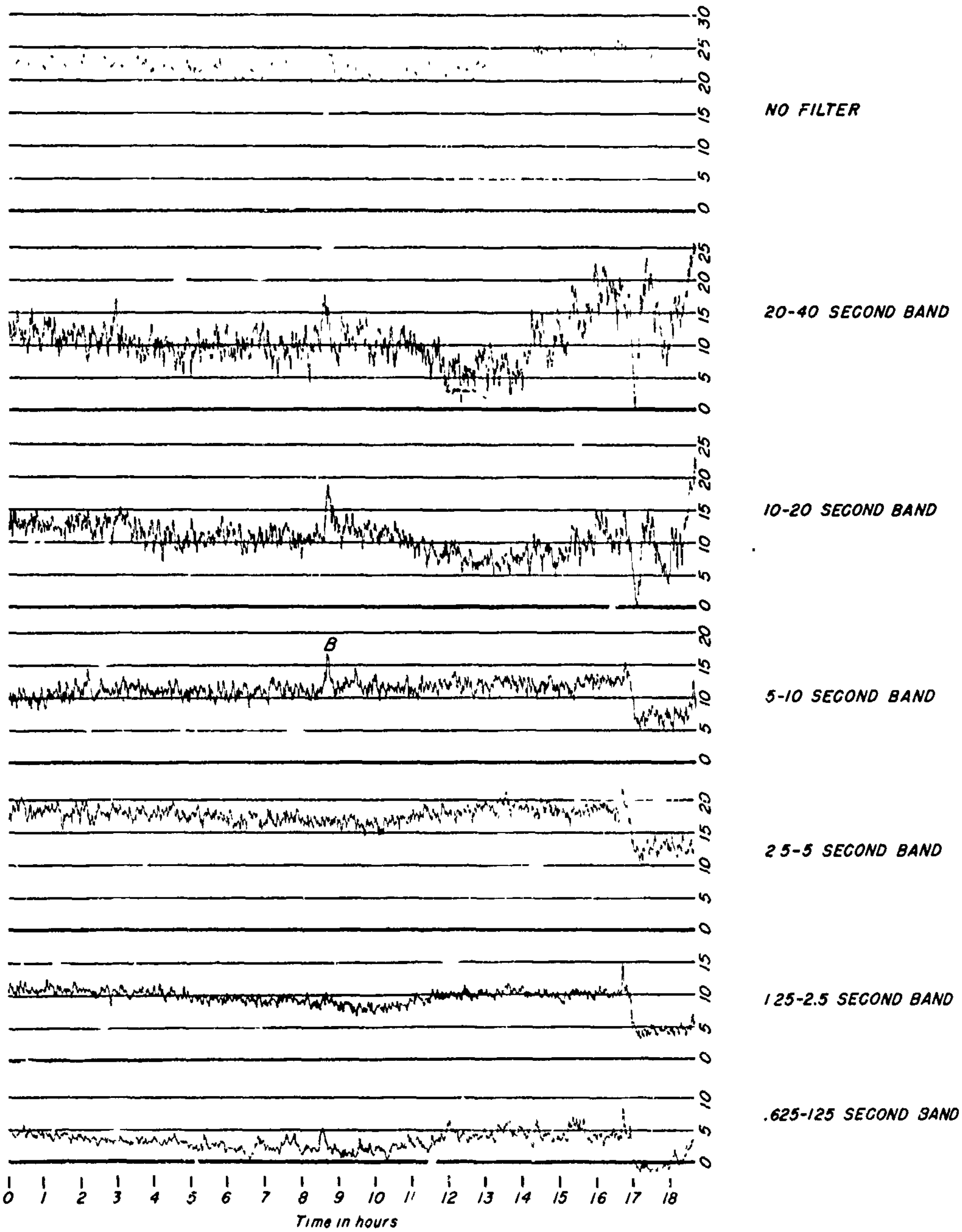


Fig. C.9 *High Speed Level Recorder Records of Magnetic Tape Data passed through Octave Filters of Shot B, October 28, 1951 received at Fort Lewis-Mc Chord AFB*

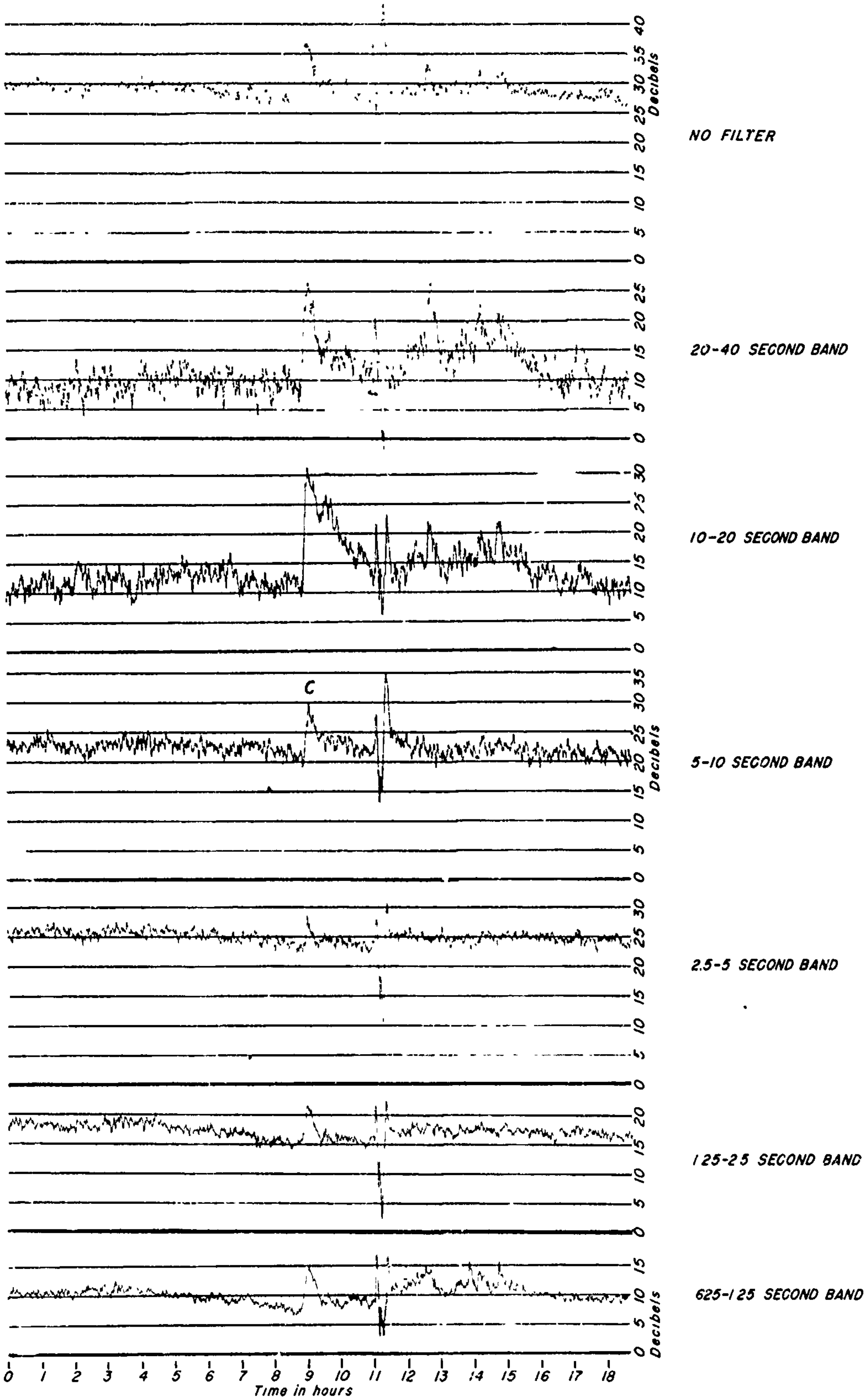


Fig. C.10 *High Speed Level Recorder Records of Magnetic Tape Data passed through Octave Filters of Shot C, October 30, 1951 received at Fort Lewis-McChord AFB*

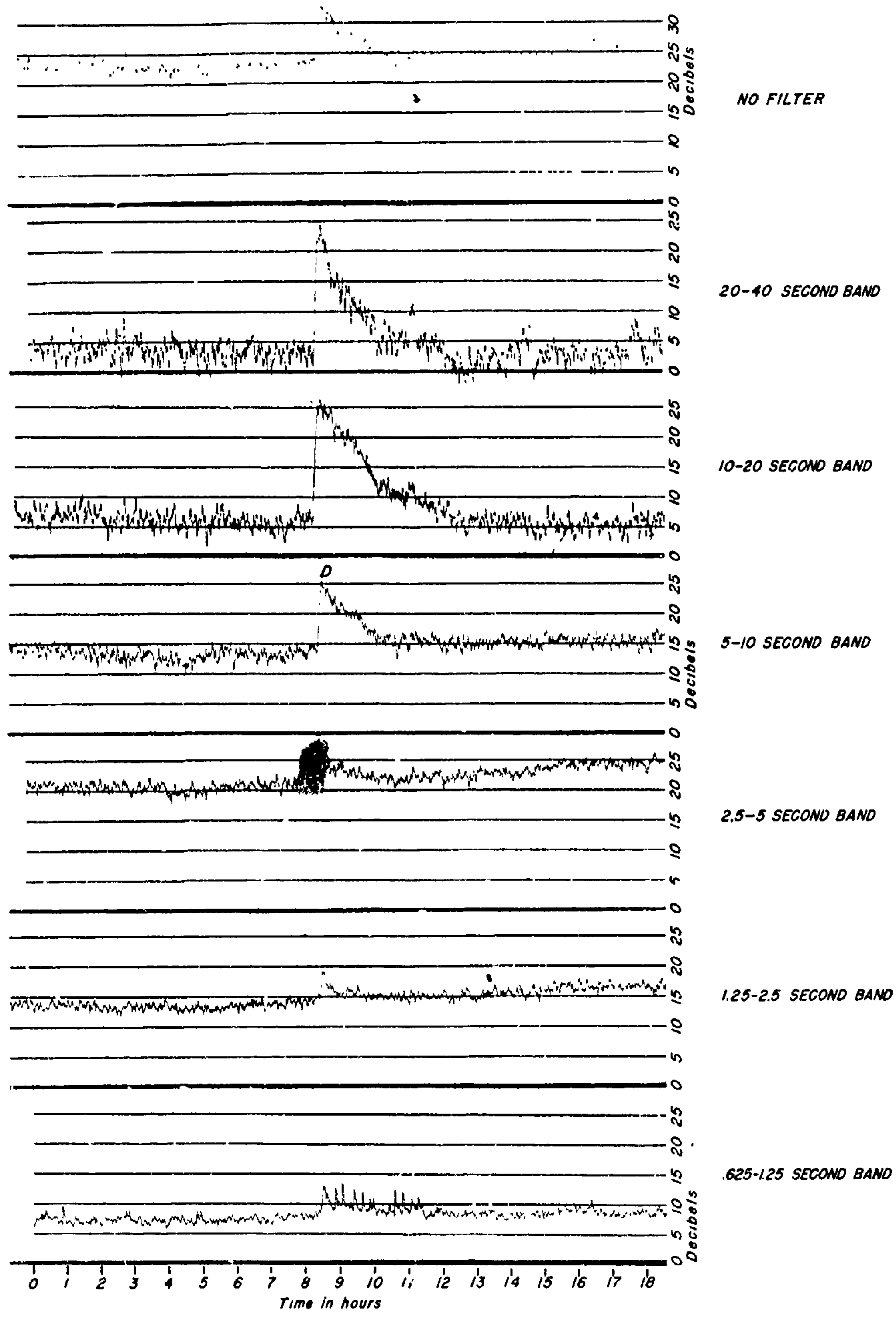


Fig. C.11 *High Speed Level Recorder Records of Magnetic Tape Data passed through Octave Filters of Shot D, November 1, 1951 received at Fort Lewis-Mc Chord AFB*

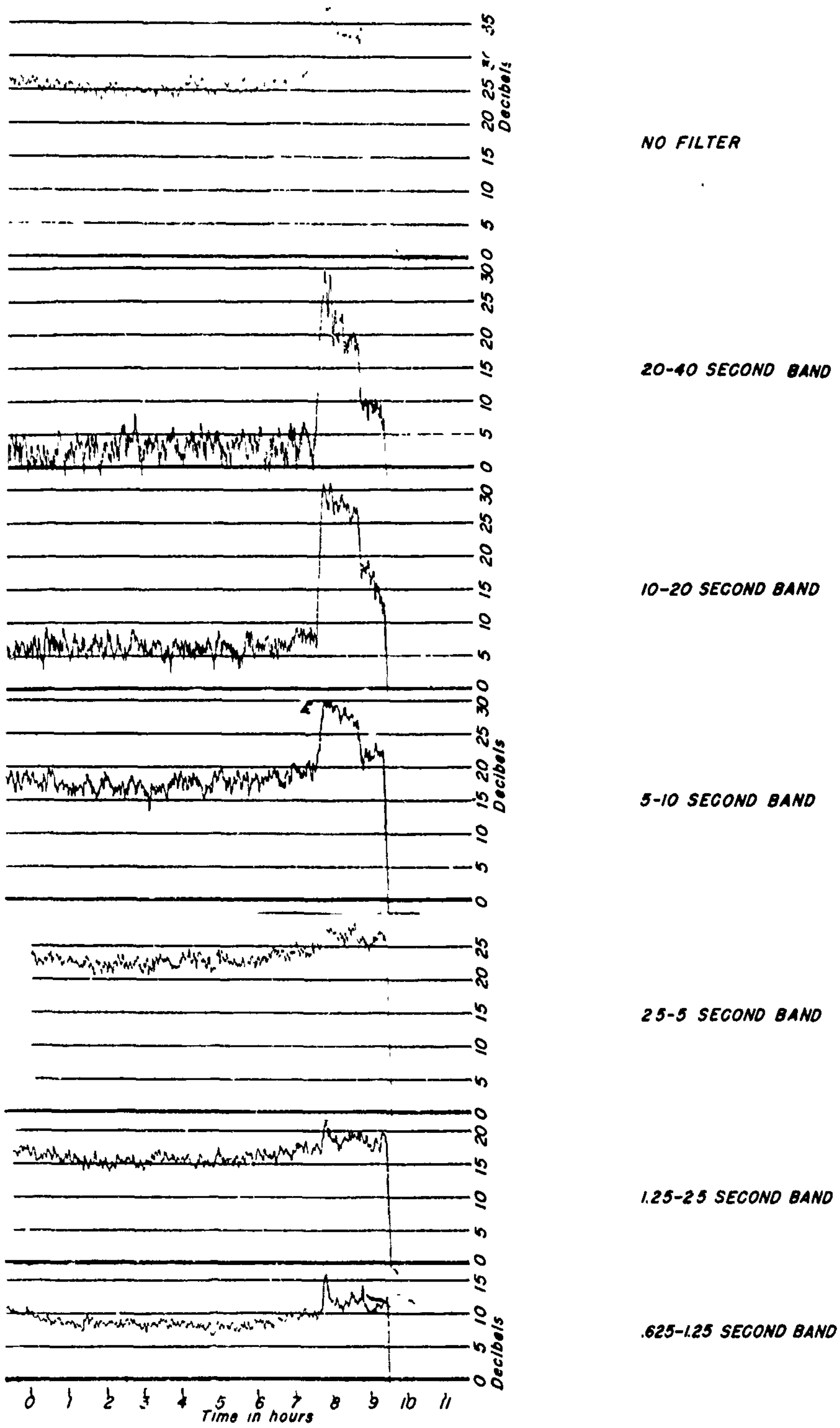


Fig. C 12 *High Speed Level Recorder Records of Magnetic Tape Data passed through Octave Filters of Shot E, November 5,1951 received at Fort Lewis-Mc Chord AFB*

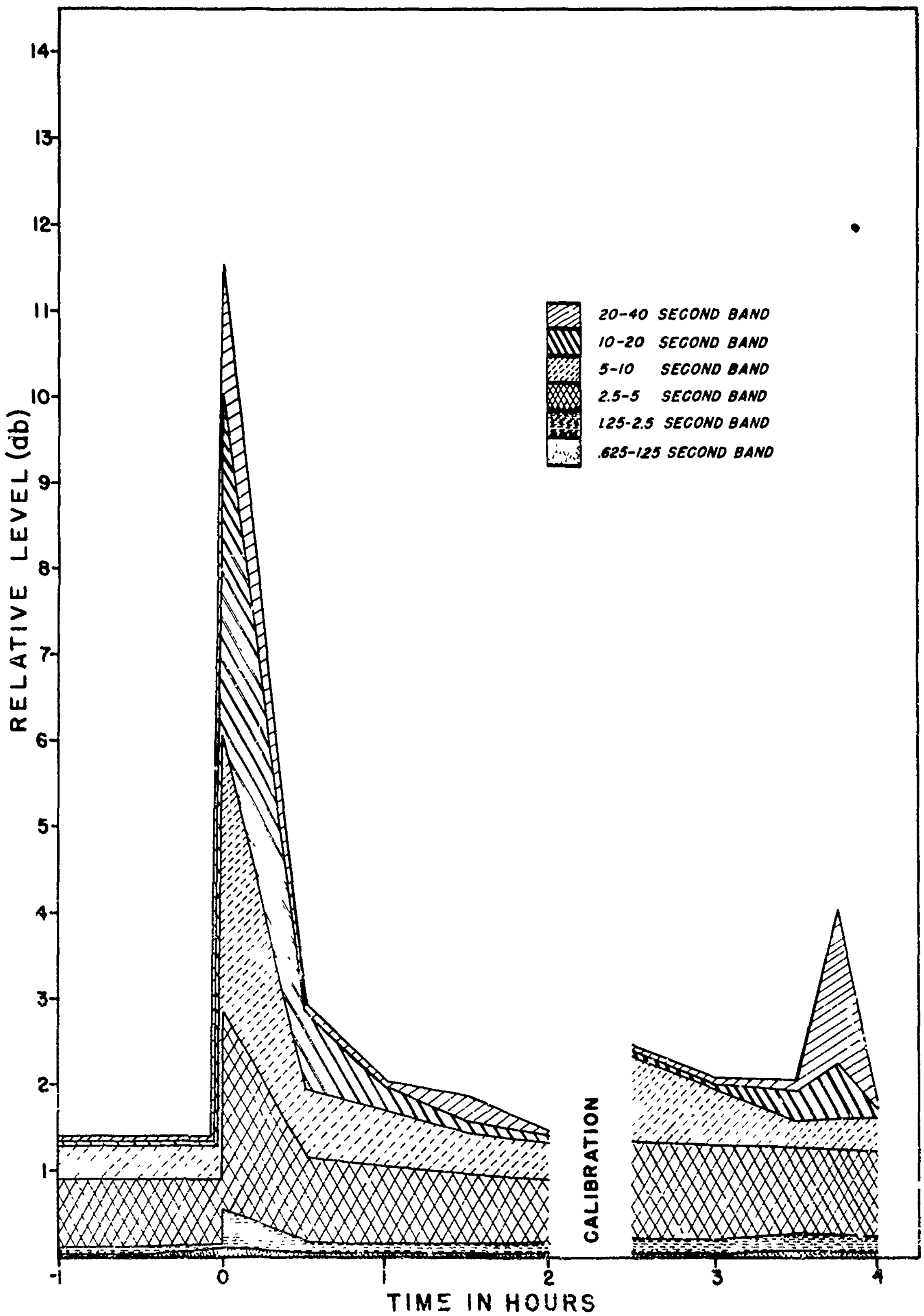


Fig. C.14 Relative Power in various Octaves of Arrival from Shot C, October 30, 1951, and Recorded on Magnetic Tape at Fort Lewis—Mc Chord AFB

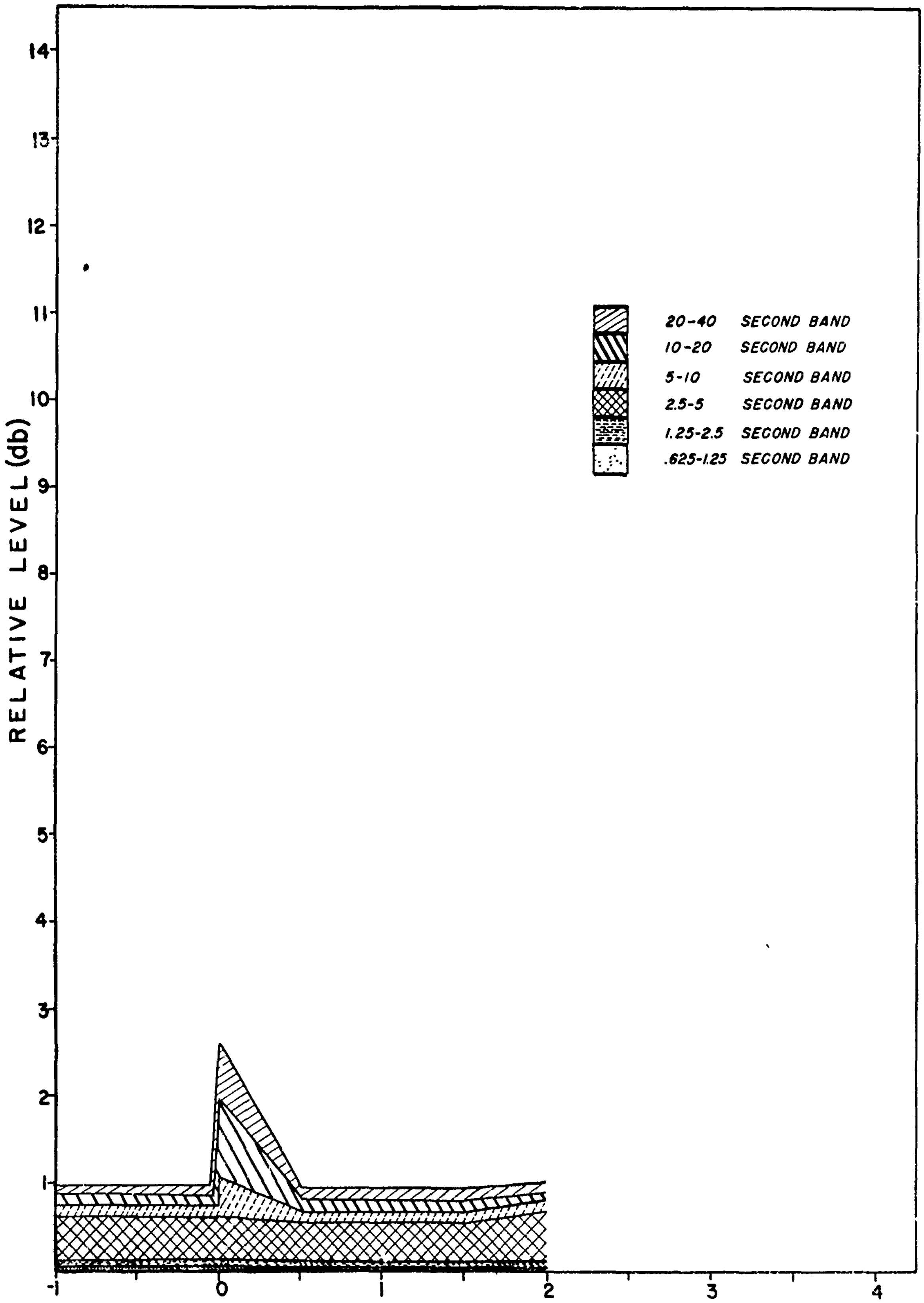


Fig. C.13 Relative Power in various Octaves of Arrival from Shot B, October 28, 1951, and Recorded on Magnetic Tape at Fort Lewis-Mc Chord AFB

[redacted]

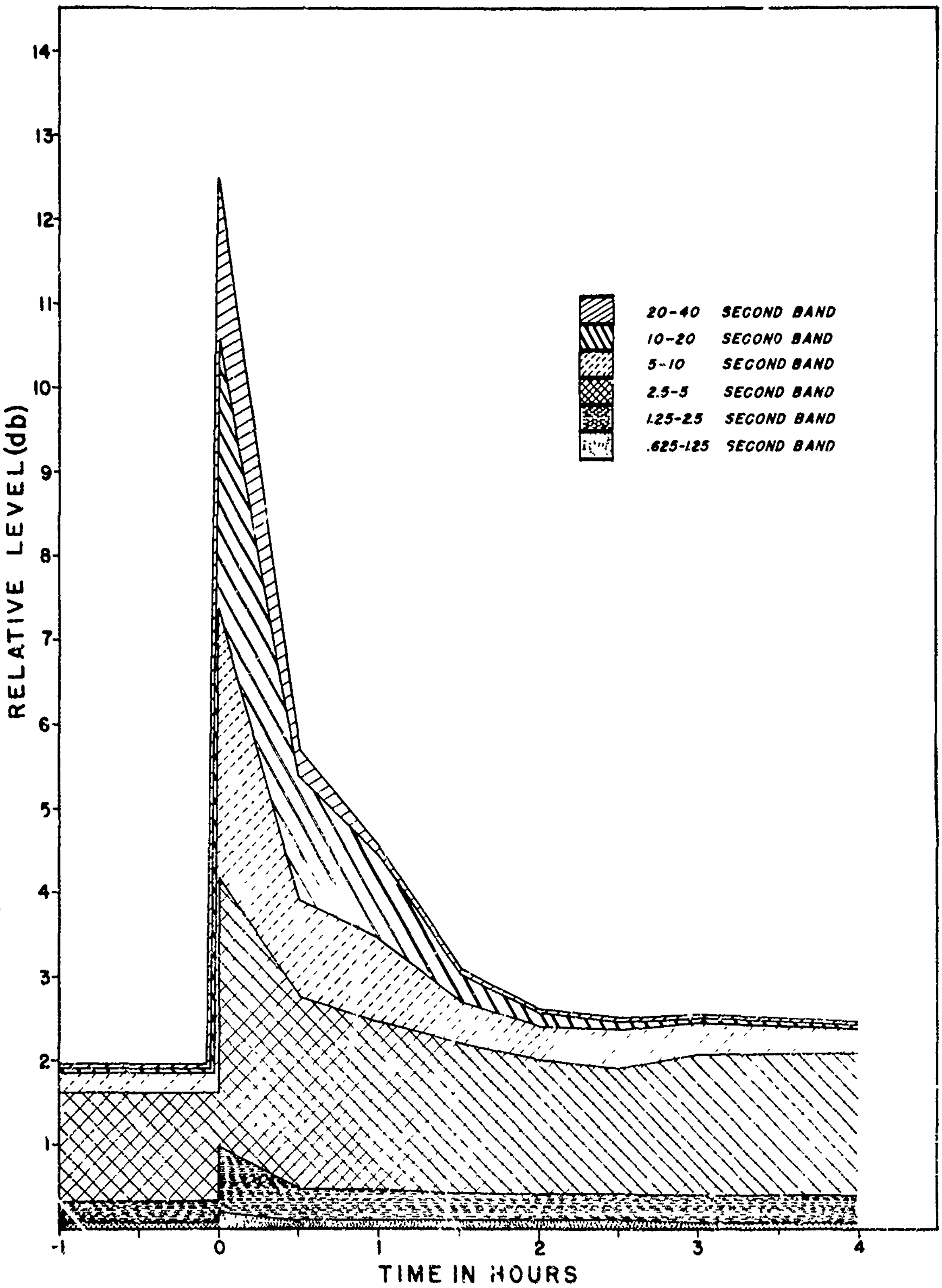


Fig. C.15 Relative Power in various Octaves of Arrival from Shot D, November 1, 1951, and Recorded on Magnetic Tape at Fort Lewis--Mc Chord AFB

[redacted]

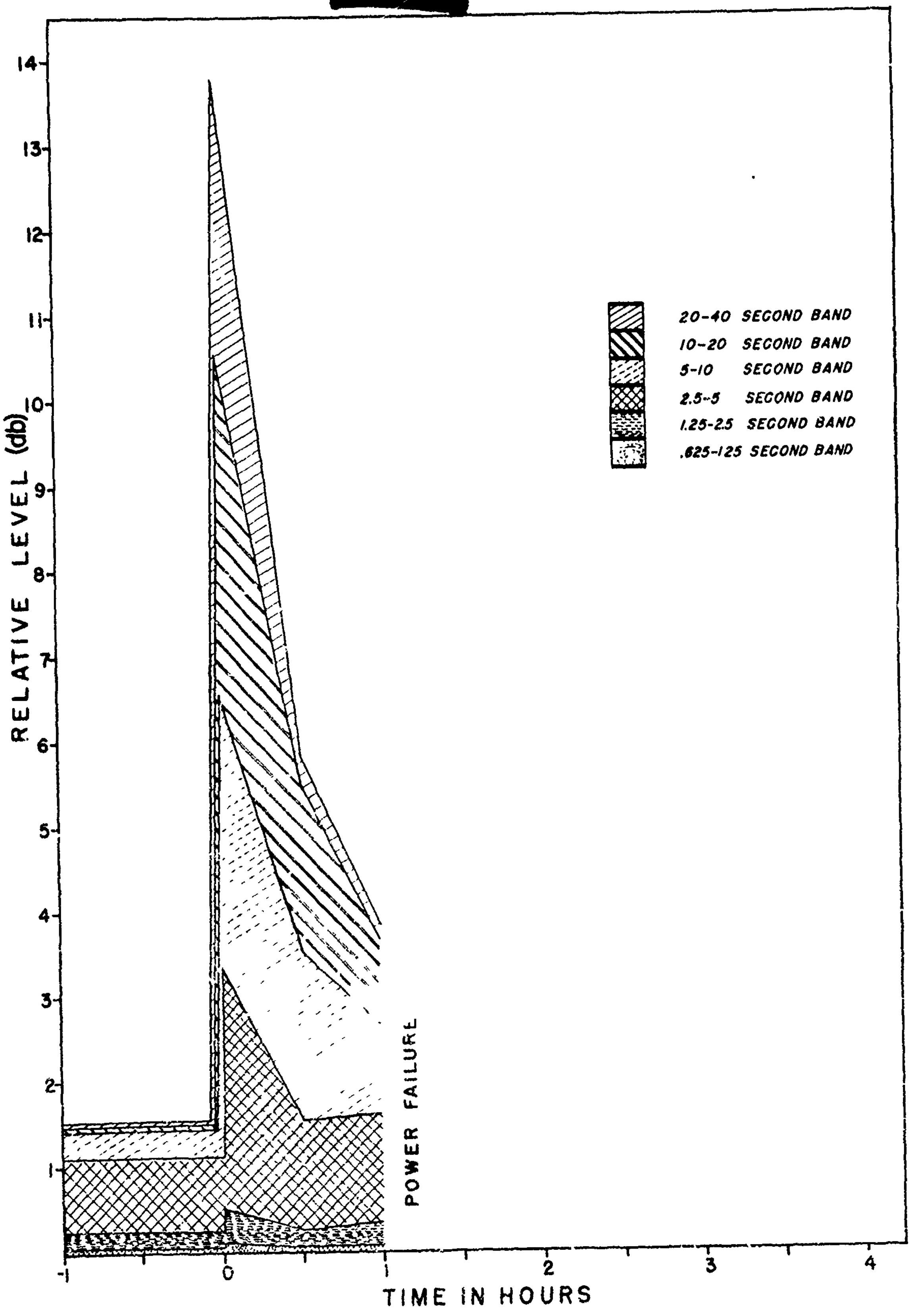


Fig. C.16 Relative Power in various Octaves of Arrival from Shot E, November 5, 1951, and Recorded on Magnetic Tape at Fort Lewis-Mc Chord AFB

DISTRIBUTION

ARMY ACTIVITIES

Asst. Chief of Staff, G-4, Department of the Army, Washington 25, D. C. ATTN: Research and Development Division	1 - 2
Chief, Army Field Forces, Fort Monroe, Va.	3
Director, Operations Research Office, 6410 Connecticut Ave., Chevy Chase, Md.	4

NAVY ACTIVITIES

Chief of Naval Operations, Department of the Navy, Washington 25, D. C. ATTN: Op-36	5
Chief, Naval Research, Department of the Navy, Washington 25, D. C.	6
Director, U. S. Naval Research Laboratory, Washington 25, D. C.	7

AIR FORCE ACTIVITIES

Commanding General, Air Research and Development Command, P.O. Box 1395, Baltimore 3, Md.	8
Commanding General, 1009th Special Weapons Squadron, 1712 G St. NW, Washington 25, D. C.	9 - 40
Assistant for Atomic Energy, Headquarters, U. S. Air Force, Washington, D. C.	41
Director of Research and Development, Headquarters, U. S. Air Force, Washington 25, D. C.	42

AFSWP ACTIVITIES

Chief, Armed Forces Special Weapons Project, P.O. Box 2610, Washington 13, D. C.	43 - 51
Commanding General, Field Command, Armed Forces Special Weapons Project, P.O. Box 5100, Albuquerque, N. Mex.	52 - 54
Commanding Officer, Test Command, Armed Forces Special Weapons Project, P.O. Box 5600, Albuquerque, N. Mex.	55 - 57

OTHER ACTIVITIES

Surplus in TISOR for AFSWP	58 - 278
Weapon Test Reports Group, TIS	279

[redacted] AEC, Oak Ridge, Tenn , A-34376