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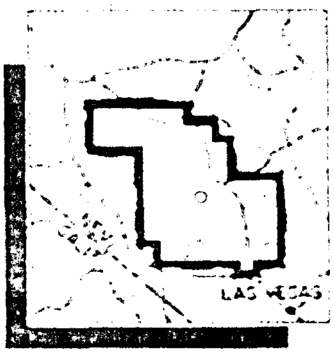
Operation UPSHOT-KNOTHOLE

NEVADA PROVING GROUNDS

March - June 1953

Project 7.3

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM NUCLEAR EXPLOSIONS



HEADQUARTERS FIELD COMMAND, ARMED FORCES SPECIAL WEAPONS PROJECT
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OPERATION UPSHOT-KNOTHOLE

Project 7.3

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM NUCLEAR EXPLOSIONS

REPORT TO THE TEST DIRECTOR

by

G. B. Olmsted
Major E. H. Nowak, USAF

15 February 1954

Headquarters United States Air Force
Office for Atomic Energy, DCS/O
AFOAT-1

[redacted]

ABSTRACT

Measurements of the airborne low-frequency sound from the UPSHOT-KNOTHOLE shots were made at 15 remote locations covering a variety of distances and directions from the Nevada Proving Grounds with the objective of supplementing available information on signal characteristics for shots of various sizes occurring in spring and early summer. Equipment was responsive to pressure variations of the order of a fraction of a dyne per square centimeter chiefly in the frequency range from 1.0 to 0.03 cycles per second. Each shot, except Shot 3 and Shot 6 was detected at distances of 4375 kilometers or more. Maximum distance for positive detection was 530 kilometers for Shot 3 and 1350 kilometers for Shot 6. Results generally verified results obtained during TUMBLER-SNAPPER. Similar measurements during future U. S. nuclear tests at the Nevada Proving Grounds during summer and fall conditions are recommended.

PREFACE

Conclusions and recommendations given in this report are those of AFOAT-1, Headquarters U. S. Air Force, and do not necessarily reflect the opinions of agencies participating in the project.

FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

ACKNOWLEDGEMENTS

The data presented in this report were the result of measurements and analyses by the Navy Electronics Laboratory, the National Bureau of Standards, and the Signal Corps Engineering Laboratories. Credit for the success of Project 7.3 is due to each of the participants listed below.

Navy Electronics Laboratory

A. B. Focke, Project Supervisor
C. T. Johnson, Project Leader
H. C. Silent, Consultant
J. R. Chiles, Jr.
W. D. Campbell
W. T. Hedrick
R. A. Waasted
A. J. Bloom
J. E. Rusconi
Joan F. Bennett
R. C. McLoughlin
C. P. Wiedow
D. D. Crowell
F. C. Foushee
A. E. Berndes, Jr.
D. E. Holcomb
W. E. Elms
Russell Smith
C. A. Potter

National Bureau of Standards

Peter Chrzanowski, Project Leader
R. C. Colbert
Irving Levine
K. T. Lemmon
R. E. Sacher
C. C. Walker
Mrs. E. M. Legate

Signal Corps Engineering Laboratories

C. M. Crenshaw, Project Director
E. J. W. Leinonen, Project Supervisor
W. P. Lonnie, Asst. Proj. Supervisor
Walter Pressman, Chief, Data Analysis
Maj C. F. Dietrich, CO, Military Personnel
S. E. Bania
Alphonse Bexmunt
R. B. Fishman
Capt C. A. Haycock
1st Lt L. M. Hodson
Mrs. D. D. Jacoby
Capt R. E. Kelly
Capt A. S. Montasser
S. A. Oliva
Capt W. B. Sullivan
Capt G. E. Summers
Mrs. M. A. Tate
1st Lt R. P. Ingalls
Capt L. R. Tipton
Miss E. D. Ulrich

Office of the Chief Signal Officer

Normand Stulman
T. E. Hedman

Office of Naval Research

J. W. Smith
J. J. Kane

Reproducible photographs for Figs. 4.1 and 4.2 were kindly supplied by the National Bureau of Standards.

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ILLUSTRATIONS

TABLES

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of Project 7.3 was to record and analyze the airborne acoustic waves from the nuclear shots at a number of remote locations covering a variety of distances and directions from the explosion site. These data, together with similar data from other nuclear blasts, will be used to evaluate the capabilities of acoustic detection stations under various combinations of source yield, source conditions, and atmospheric conditions. In addition, the data will be used in the interpretation of acoustic signals obtained from unknown sources during routine operation of acoustic detection stations.

1.2 BACKGROUND

Remote acoustic measurements have been made during all previous U. S. nuclear tests except TRINITY (July, 1945). Results during Operation CROSSROADS (July, 1946)[1,2] and Operation SANDSTONE (April and May, 1948)[3] were discouraging since they indicated a maximum distance for positive detection of 1900 kilometers. Improvements in detection equipment and techniques, however, resulted in increasing this distance to 4500 kilometers for Operation GREENHOUSE (April and May, 1951)[4,5,6,7]. Data obtained during Operation BUSTER-JANGLE (October and November, 1951)[8] and Operation TUMBLER-SNAPPER (April-June, 1952)[9] partially delineated the capabilities and limitations of acoustic detection techniques for explosions of small and medium yields detonated in the air, on the ground, and shallow underground. Results indicated limited but usable detection range for shots of small yield even though shallow underground. Seasonal shifts in preferred propagation direction, noted during tests using small TNT charges[10], were confirmed. Data obtained during Operation IVY (November, 1952)[11] permitted an extension of previous results to shots of larger yield.

The main interest in UPSHOT-KNOTHOLE was to verify and supplement data from sources of small and medium yield during spring and early summer propagation conditions.

[redacted]

CHAPTER 2

INSTRUMENTATION

2.1 GENERAL

The instrumentation used during UPSHOT-KNOTHOLE was essentially the same as that used for TUMBLER-SNAPPER and IVY. It consisted mainly of standard equipment responsive to minute pressure changes in the frequency range from 1.0 to 0.03 cps, approximately. In a few cases, equipment having extended low-frequency response was used. Most of the signals were recorded graphically on paper tape and in some cases magnetic tape recording was used. Timing with respect to world time was obtained by reference to radio station WWV and interval timing was obtained through use of various uniform rate devices - chronometers, constant speed motors, direct recording of WWV signals, etc.

2.2 SIGNAL CORPS ENGINEERING LABORATORY (SCEL) INSTRUMENTATION

Signal Corps Data Recording System M-2,[12] responsive to frequencies from 1.0 to 0.03 cps, was operated at Ft. Lewis, Belmar, Fairbanks, Oahu, Thule, Hachinohe, Hanau, and Kyoto.* Modified M-2 equipment was used at Pyote and Barksdale. Briefly, this equipment consisted of a condenser microphone, an a.c. bridge circuit, a synchronous detector circuit, wire lines, amplifier circuits, and Esterline-Angus 0-1 Milliampere Graphic Recorders. Remotely-operated impulse-type calibrators and bridge balancing circuits were also employed. Each microphone was equipped with a linear pressure-averaging pipe array[4] approximately 1000 ft long in order to reduce unwanted background due to atmospheric turbulance.

At Barksdale, an improved version of the M-2 Recording System was used. The principle of operation was unchanged, but components were redesigned to attain improved sensitivity and stability. Microphones and recorders were unchanged.

* Fig. 2.1 shows the location of all acoustic stations.

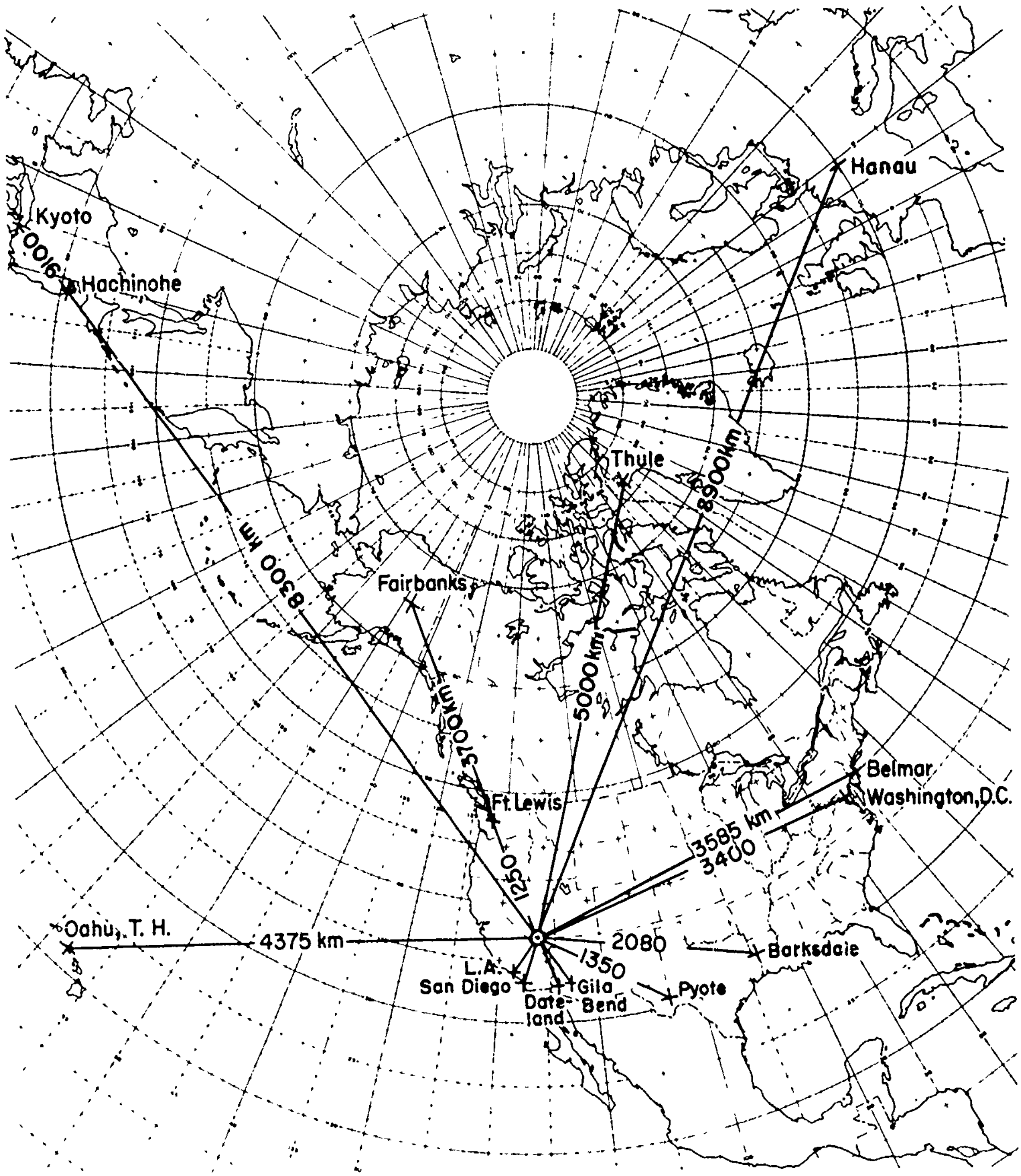

Fig. 2.1 Acoustic Stations for UPSHOT-KNOTHOLE

At Pyote, new bridges similar to those used at Barksdale were employed and, at one outpost, a laboratory model of a new microphone, similar in principle to the old one but made mainly of glass (including pressure-sensitive glass diaphragm), was tested.

2.3 NAVY ELECTRONICS LABORATORY (NEL) INSTRUMENTATION

Standard NEL equipment responsive to frequencies from 3.0 to 0.03 cps was employed at all locations in the California-Arizona Desert and at three locations in San Diego. This equipment, sometimes referred to as the "NEL Line-to-Pen Equipment," consisted of a Rieber Vibrotron Microphone,13/ a carrier oscillator and line amplifier, wire lines carrying the FM signal, a discriminator-amplifier, and a Brush six-channel graphic recorder.

The NEL equipment having extended low-frequency response (0.16 to 0.003 cps) was operated at San Diego and at Los Angeles. This equipment consisted of a T-21-B condenser microphone, equipped with acoustic leaks appropriate to the required response, an a.c. bridge circuit, a detector-amplifier circuit, and an Esterline-Angus Graphic Recording Milliammeter.

Each Rieber microphone was equipped with a Y-shaped pressure-averaging hose array consisting of three 25-ft sections of garden hose into which were inserted brass capillary tubes at 5-ft intervals. No arrays were used with the extended low-frequency equipment.

2.4 NATIONAL BUREAU OF STANDARDS (NBS) INSTRUMENTATION

Both standard and extended low-frequency response equipment were operated by NBS at Washington, D. C. Standard equipment, NBS Infrasonic Single Microphone System,14/ responsive to frequencies from 3.0 to 0.02 cps, consisted of a condenser microphone, an oscillator, wire lines carrying FM signal, a pulse-count type discriminator, an amplifier, and an Esterline-Angus 0-3 Milliampere Graphic Recorder. This equipment is frequently termed "Amplitude Response" equipment.

Extended low-frequency response equipment, responding to rate-of-change of pressure in the range 0.1 to 0.001 cps and lower, consisted of standard microphones and wire lines combined with a multivibrator type discriminator, a low-pass filter-amplifier, and an Esterline-Angus 0-3 Milliampere Graphic Recorder. This equipment operated normally at a sensitivity of 50 millimeters deflection for a rate-of-change of pressure of 1 dyne/cm^2/sec.

A number of channels were recorded directly on magnetic tape. These recordings were played back at high speed and analyzed for spectral content using a vibralyzer and a panoramic analyzer.

CHAPTER 3

OPERATIONS

3.1 PARTICIPATING AGENCIES

Project 7.3 was conducted jointly by the Signal Corps Engineering Laboratories, the National Bureau of Standards, and the Navy Electronics Laboratory under the sponsorship of Headquarters U. S. Air Force, AFOAT-1. The Office of the Chief Signal Officer coordinated the Army effort and the Office of Naval Research coordinated the Navy effort.

3.2 STATION LIST

Table A.1 lists the acoustic stations operated for UPSHOT-KNOTHOLE and indicates the location of the station, the azimuth from the station to the Nevada Proving Grounds measured in degrees clockwise from true north, and the great-circle distance from the station to the Nevada Proving Grounds. Figure 2.1 shows the geographical distribution of stations.

3.3 STATION LAYOUT

3.3.1 SCEL Stations

All stations operated by the Signal Corps consisted of four microphone outposts, one at each corner of a quadrilateral, nearly square, 4 to 10 miles on a side. Each outpost was connected by wire lines to a recording center.

3.3.2 NEL Stations

The station at Los Angeles consisted of a single microphone with local recording.

At San Diego, the station consisted of six microphone outposts located at the corners of two roughly equilateral triangles, one 10 miles on a side and the other 3 miles on a side. Local recording was accomplished in the vicinity of each outpost making up the large triangle, and central recording was employed for the small triangle.

At Dateland, Arizona, five microphone outposts were located at approximately 11-mile intervals on an east-west great-circle path. In addition, six microphone outposts were located at the corners of two roughly equilateral triangles, one approximately 3 miles on a side and the other approximately 1.5 miles on a side. Each outpost was connected by wire lines to a central recording van.

At Gila Bend, Arizona, five microphone outposts were located at approximately 11-mile intervals on the extension of the same east-west great-circle path noted above. Again each outpost was connected by wire lines to a central recording van.

3.4 STATION PARTICIPATION

All stations were operational for each of the UPSHOT-KNOTHOLE series* except as follows: Gila Bend for Shots 5, 7, 8, 9, 10, and 11; Dateland for Shot 10; and Pyote for Shot 11.

* See Table A.2 for a complete list of shots, shot locations, times, and type of shot.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Graphic Records

The more important characteristics of the acoustic signals from UPSHOT-KNOTHOLE are summarized in Tables A.3 through A.13. These data resulted from analysis of graphic records. The tabulation includes: the time at which the first correlatable signal was detectable, the time of arrival of the signal having maximum amplitude, the azimuth of the incoming acoustic wave measured in degrees clockwise from true north, the range in horizontal phase velocities computed at various points throughout the signal train, the maximum zero-to-peak pressure-amplitude of the signal, the signal duration, the prominent signal periods noted in the wave train, and the average zero-to-peak noise pressure-amplitude appearing just before and just after the acoustic signal. Noise levels are also included for stations at which no signal was detected.

Table A.14 lists the difference between the true azimuth from the station to the explosion site and the computed azimuth for the recorded acoustic wave.

The average speed of travel of the acoustic wave, computed by dividing the great-circle distance from source to station by the total elapsed time from the time of the explosion to the time of arrival at the station, is presented in Table A.15.

4.1.2 Magnetic Tape Records

Vibragrams showing the power spectrum versus time were made by NBS for individual standard channels for each shot. In addition, composite vibragrams were made by superposing individual vibragrams in the proper phase so that the signal was enhanced and the noise reduced. Figure 4.1 illustrates the results for Shot 2. "CARD," "DALE," "BURO," and "BAFB" refer to individual microphones in Washington, D. C. station. The same scale of signal periods applies to each vibragram. The signal appears as a strong band of blackening, persisting for

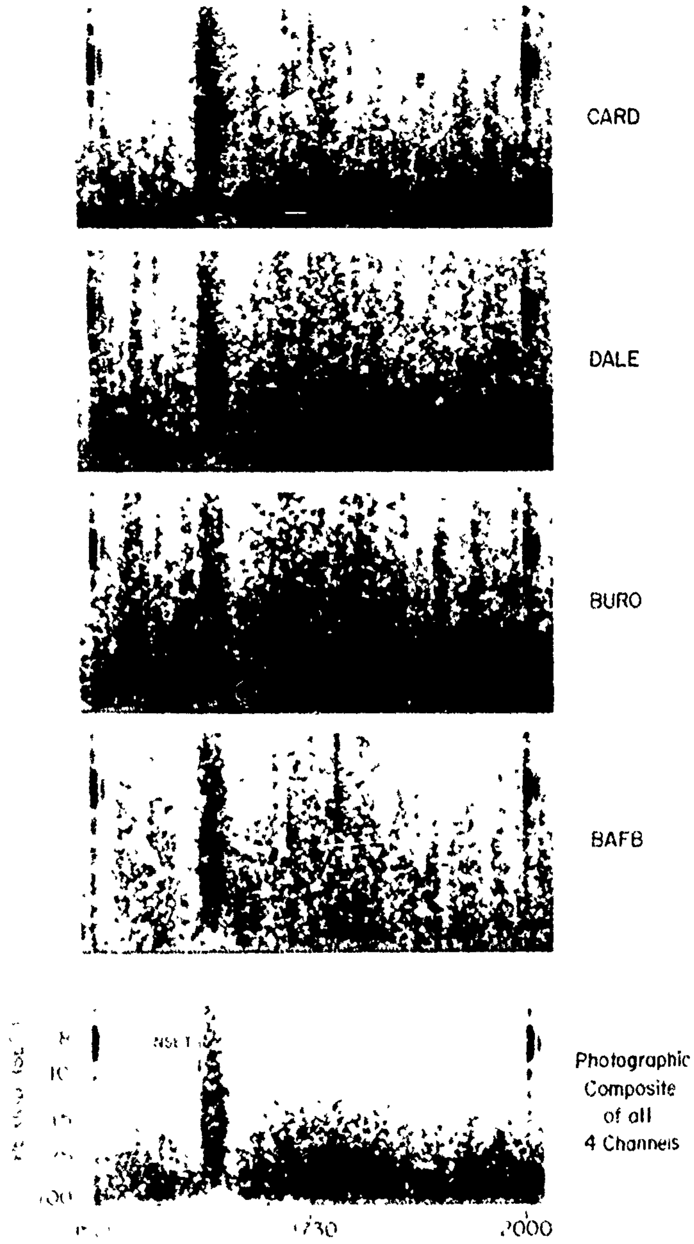

Fig. 4.1 Composite and Individual Vibragrams Obtained from Magnetic Tape Records of the Acoustic Arrival from UPSHOT-KNOTHOLE, Shot 2 and Recorded on NBS Amplitude Response Instrumentation at Washington, D. C.

roughly 20 min, standing out on all channels and appearing more markedly in the composite. The sharp onset of the signal is marked on the composite vibragram.

4.2 DISCUSSION

4.2.1 Detection Range

The maximum distance at which positive detection occurred was 9100 km (Kyoto) for Shot 11. Shots 1, 2, 4, 5, 7, and 9 were detected at a maximum range of 5000 km (Thule). The maximum for Shot 8 was 4375 km (Oahu), that for Shot 3 was 1350 km (Pyote), and that for Shot 6 was 530 km (Gila Bend).

Of the stations within 4000 km of the shot for Shot 3, only Ft. Lewis and Fairbanks had favorable noise levels, 1.3 and 0.3 dynes per square centimeter, respectively. Since it is usually possible to detect a signal equal to noise when the approximate time of arrival is known, it appears that signal levels toward the north did not exceed 1.3 dynes at 1230 km and 0.3 dyne at 3710 km. Levels of 12, 7.2, and 12.5 dynes at Barksdale, Washington, and Belmar, respectively, made detection at these stations unlikely.

For Shot 6, background levels were quite favorable for detection. Most significant is the fact that signal level at 1350 km to the east of the source apparently did not exceed 0.4 dyne/cm^2 and signal at 1230 km to the north did not exceed about 2.2 dynes. To the west, the closest station (4375 km) failed to detect the signal although the noise was only 1.2 dynes/cm^2.

4.2.2 Signal Characteristics

4.2.2.1 General

In general, signal characteristics observed for UPSHOT-KNOTHOLE were similar to those observed for BUSTER-JANGLE and TUMBLER-SNAPPER. The signal rose rapidly out of the background, reached a maximum usually within 3 or 4 minutes, then gradually diminished. Obvious separate wave arrivals at a single station were observed only in a few instances at stations within a few hundred kilometers of the source. No definite frequency pattern was observable on the graphic records and signals at different locations for the same shot and at the same location for different shots showed large differences in appearance.

Figure 4.2 illustrates a rather unusual arrival at Washington, D. C. for Shot 2. This signal shows a very high amplitude at the end of the arrival, dropping abruptly into the background. Signals of this type, commonly observed for underwater sound, are attributed to channel-type transmission. They are observed rarely in atmospheric propagation.

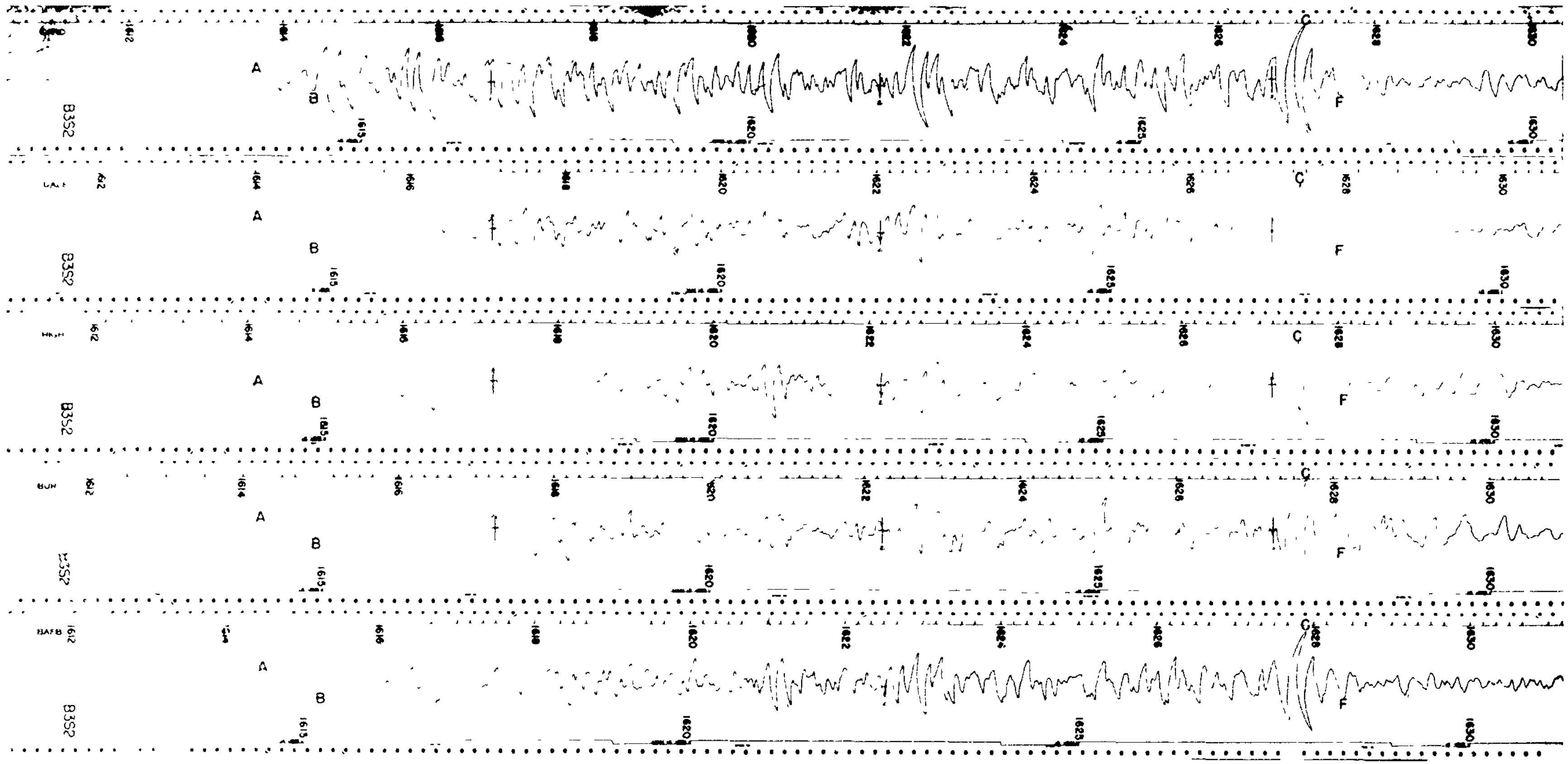

Fig. 4.2 Graphic Records of the Complete Acoustic Arrival from Shot 2 Recorded on NBS Amplitude Response Instrumentation at Washington, D. C.

4.2.2.2 Horizontal Phase Velocity

The maximum horizontal phase velocity reported at any station for any shot was 460 meters/sec at Dateland for Shot 5 and the minimum was 281 meters/sec at Thule for Shot 9. The velocity spread from each recording, where the signal-to-noise ratio was two or more, covered at least some part of the range 315 to 385 meters/sec.

4.2.2.3 Amplitude

Since the determination of amplitude in absolute pressure units depends on the accuracy of field calibrations, the stability of the equipment, the accuracy of frequency response curves and the signal-to-noise ratio, no claim for a high degree of accuracy can be made. No attempt was made to correct for equipment response except in the case of long-period signals observed at Washington, D. C. for Shots 8, 10, and 11. Most of the recorded signals were within the pass-band of the equipment.

Considering all shots except Shots 3 and 6, the maximum reported amplitude at distances greater than 3000 km was 20 dynes/cm^2 (zero-to-peak) at Oahu for Shot 11. The average amplitude at ranges between 3000 km and 5000 km was 6.9 for Shot 11, 3.3 for Shot 10, 3.1 for Shot 8, 3.4 for Shot 9, 2.6 for Shot 7, 3.8 for Shot 5, 2.1 for Shot 4, 9.7 for Shot 2, and 5.0 for Shot 1.

Data for Shots 3 and 6 imply that the distance from the source had to be reduced to less than 2000 km in order to obtain amplitudes equivalent to those obtained from the other shots at ranges between 3000 and 5000 km.

4.2.2.4 Duration

Graphic signals from all stations persisted for a minimum of 2.5 min and a maximum of 60 min. At distances greater than 3000 km, the minimum duration was 5 min, the average was 19.4 min, and the maximum was 60 min.

4.2.2.5 Period

Visually observed prominent signal periods ranged from 0.5 to 90 sec.

Analyses of magnetic tape recordings at Washington, D. C. showed a lack of periodic structure in the vibragrams. For Shots 1, 2, and 5 shorter periods (up to 3 sec) were observed than for Shots 8, 9, 10 and 11. This was consistent with results from the graphic records.

4.2.3 Azimuth Errors

The over-all range of azimuth errors was 0.1 to 10.2° and the average was 3.2°. Over 96 per cent of the reported errors were less than 7.2°.

4.2.4 Travel Speed

Travel speeds for all arrivals ranged from 262 to 343 meters per second. The highest speeds were reported at the stations closest to the source. At stations beyond 3000 kilometers, the speeds ranged from 262 to 325 meters/sec with an average of 301. In general, speeds for stations to the east of the source decreased as the tests progressed and those to the west increased. At stations beyond 2000 km, the speed changed from above 300 meters/sec to below that value or vice versa during the period from 11 to 25 April.

4.2.5 Directional Effects

Evidence of directional effects in propagation provides qualitative information regarding high altitude winds. These effects generally are apparent in the detection range, the amplitude, the azimuth error, the transit speed, and the signal period.

Results indicate a more or less gradual shift in directional character of the propagation throughout the test series. The most marked effects were noted in the travel speeds and signal periods. Note, for example, that at Washington, D. C. three of the four shots in May and June gave velocities lower than 275 meters/sec whereas velocities observed in March and April were 300 meters/sec or more. The 303 meters/sec recorded on 19 May is not consistent with the pattern, but it is noted that the maximum amplitude for this signal occurred much later in the wave train than is usually the case. In this case, very poor signal-to-noise ratio and very poor correlation between channels were noted prior to the main arrival. Of particular interest is the fact that the prominent signal periods observed in the arrivals having velocities in the 270's were considerably longer than for those having velocities in the 300's.

All of the data show a fairly consistent pattern indicating relatively higher speeds, shorter periods, and higher amplitudes to the east of the source for shots in March and early April when compared with results to the northwest and west. This shifts to a reverse pattern showing relatively lower speeds, longer periods, and lower amplitudes to the east in later April, increasing in evidence in May and early June.

The azimuth shift noted for north-south stations in TUMBLER-SNAPPER was not as marked for UPSHOT-KNOTHOLE. Thule and Ft. Lewis, for example, gave east errors in March shifting to west errors in April, but Fairbanks gave west errors for all shots except for the 19 May arrival which yielded an east error. San Diego and Dateland gave east errors for all except the 4 June shot.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Detection Range

The extremely limited detection ranges for Shots 3 and 6 confirm results from TUMBLER-SNAPPER and BUSTER-JANGLE indicating that considerable improvement in signal detection capability is required in order to permit reasonable assurance of detection of shots of this size at usable ranges. There is added evidence that detection is more limited in range in spring than in summer or winter.

As expected, standard equipment showed considerably greater detection capability than did extended low-frequency response equipment. This is attributed partly to the larger noise levels observed at very low frequencies and the concentration of signal energy at the higher frequencies.

5.1.2 Azimuth Accuracy

Azimuth errors were roughly the same as noted for previous tests.

5.1.3 Signal Characteristics

No outstanding differences in character were noted between the UPSHOT-KNOTHOLE signals and the TUMBLER-SNAPPER signals.

5.1.4 Seasonal Effects

Directional effects generally support previous observations that a shift in stratosphere winds from winter westerlies to summer easterlies occurs in the spring, usually in April. UPSHOT-KNOTHOLE results were not as consistent in this respect as were the TUMBLER-SNAPPER results.

5.2 RECOMMENDATIONS

Further measurements during atomic tests at the Nevada Proving Grounds are required for shots occurring in summer and fall propagation conditions (July through September). In addition, measurements are recommended during tests conducted at higher altitude than previously or under other unusual circumstances.

APPENDIX A

TABLES

TABLE A.1 - UPSHOT-KNOTHOLE Acoustic Station List

Agency*	Station	Location		Approx. Azimuth to NPG** (degrees)	Approx. Distance to NPG# (km)
		Latitude (deg.min.)	Longitude (deg.min.)		
NEL	Los Angeles	34 07 N	118 17 W	034	380
NEL	San Diego	32 49 N	117 15 W	013	475
NEL	Dateland, Ariz	32 53 N	113 37 W	337	505
NEL	Gila Bend, Ariz	32 52 N	112 40 W	328	530
SCEL	Ft. Lewis, Wash	47 05 N	122 35 W	152	1230
SCEL	Pyote AFB, Texas	31 30 N	103 15 W	301	1350
SCEL	Barksdale AFB, La	32 30 N	093 45 W	290	2080
NBS	Washington, D. C.	38 57 N	077 04 W	279	[illegible]
SCEL	Belmar, N. J.	40 12 N	074 05 W	278	3585
SCEL	Fairbanks, Alaska	64 50 N	147 40 W	131	3710
SCEL	Oahu, T. H.	21 31 N	158 05 W	057	4375
SCEL	Thule, Greenland	76 32 N	068 40 W	237	5000
SCEL	Hachinohe, Japan	40 35 N	141 25 E	054	8300
SCEL	Hanau, Germany	50 07 N	008 59 E	318	8900
SCEL	Kyoto, Japan	34 55 N	135 41 E	050	9100

* NEL - Navy Electronics Laboratory
SCEL - Signal Corps Engineering Laboratories
NBS - National Bureau of Standards

** Azimuth measured in degrees clockwise from true north.
NPG - Nevada Proving Grounds

Distance measured on a great circle path at the earth's surface.

TABLE A.2 - UPSHOT-KNOTHOLE Shot Data

Shot No.	Shot Code Name	Time of Occurrence (GMT)		Location		Type of Shot
		Date	Hr.Min.Sec.	N. Latitude (deg.min.sec.)	W. Longitude (deg.min.sec.)	
1	ANNIE	17 Mar	1320:00	37 02 52.3	116 01 15.7	300' tower
2	NANCY	24 Mar	1310:00	37 05 43.9	116 06 09.9	300' tower
3	RUTH	31 Mar	1300:00	37 04 57.9	116 01 25.7	300' tower
4	DIXIE	06 Apr	1529:38	37 05 04.7	116 01 11.3	Air - 6022' above target. 10,216' MSL.
5	BADGER	18 Apr	1235:00	37 08 18.4	116 07 04.0	300' tower
6	RAY	11 Apr	1245:00	37 05 56.2	116 05 32.9	100' tower
7	SIMON	25 Apr	1230:00	37 03 11.1	116 06 09.5	300' tower
8	HARRY	19 May	1205:00	37 02 25.4	116 01 31.4	300' tower
9	ENCORE	08 May	1529:55	36 47 52.7	115 55 44.1*	Air - 2423' above target. 5493' MSL.
10	GRABLE	25 May	1530:00	36 47 52.7	115 55 44.1*	Air - shell 525' above target. 3595' MSL.
11	CLIMAX	04 Jun	1114:57	37 05 04.7	116 01 11.3*	Air - 1334' above target. 5528' MSL.

* Refers to aiming point.

TABLE A.3 - Acoustic Data for Shot 1

(Source Time: 17 March 1953, 1320:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude O-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise O-peak (dynes/cm^2)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1341	1345	--	--	81	4	10,35	< 5
San Diego	1346	1348	--	285-320	45	4	17,8,11	< 2.5
Dateland	1348	1349	--	340-380	66	6	0.5,1,3.5	0
Gila Bend	1349	1352	--	--	125	9	9	< 2.5
Ft. Lewis	1430	1435	150.3	311-352	7	12	15-20	1.5
Pyote	1429	1432	301.5	324-379	15	16	9-22	1.3
Barksdale	1512	1515	288.6	355-372	10	12	10-17	1.8
Wash., D. C.	1615	1623	280.0	340	7.4	16	20	4.1
Belmar	1630	1636	274.7	352-361	6	8	[illegible]-23	5.6
Fairbanks	1703	1705	135.3	360-398	1.6	22	6-12	0.3
Thule	1758	1818	232.8	311-365	4.0	38	8-24	1.2

Stations reporting negative results and the noise level (dynes/cm^2): Oahu - 7.0, Hachinohe - 0.9, Hanau - 1.4, Kyoto - 0.6

TABLE A.4 - Acoustic Data for Shot 2

(Source Time: 24 March 1953, 1310:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm^2)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1332	1336	--	--	62	13	60	< 2.5
San Diego	1337	1349	--	--	25	12	30,50,70,90	< 2.5
Dateland	1337	1339	--	345-370	52	7	4,13,2	0
Gila Bend	1339	1341	--	--	160	7	15,0.6	0
Ft. Lewis	1422	1425	151.3	330-354	> 15	10	16-28	1.0
Pyote	1417	1423	301.5	342-411	> 62	12	6-20	1.7
Barksdale	1454	1500	297.3	379-409	> 81	30	8-23	2.3
Wash., D. C.	1614	1628	280.0	348	19.1	14	14	4.6
Fairbanks	1648	1653	133.0	293-335	1.0	12	10-18	0.3
Thule	1757	1804	226.7	316-350	9	33	5-15	1.3

Stations reporting negative results and the noise level (dynes/cm^2): Belmar - 30, Oahu - 3.3, Hachinohe - 0.5, Hanau - 1.7, Kyoto - 0.6

TABLE A.5 - Acoustic Data for Shot 3

(Source Time: 31 March 1953, 1300:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak ($dynes/cm^2$)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak ($dynes/cm^2$)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1322	1325	--	--	9	3	6,14	< 0.5
San Diego	1327	1330	--	320-380	5	10	3-5,12	< 0.5
Dateland	1327	1329	--	350-435	40	10	2,13	< 0.5
Gila Bend	1329	1330	--	--	40	10	1.2,12	< 0.5
Pyote	1411	1413	302.3	346-358	3.4	3	2-4	1.0

Stations reporting negative results and the noise level ($dynes/cm^2$): Ft. Lewis - 1.3, Barksdale - 12, Washington - 7.2, Belmar - 12.5, Fairbanks - 0.3, Oahu - 2.5, Thule - 0.9, Hachinohe - 0.9, Hanau - 0.8, Kyoto - 0.6

TABLE A.6 - Acoustic Data for Shot 4

(Source Time: 6 April 1953, 1529:38 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm^2)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1551	1555	--	--	85	5	6,18	< 0.5
San Diego	1555	1559	--	--	26	11	9,24,55	< 2.5
Dateland	1555	1555	--	335-350	64	4.5	5	< 2.5
Gila Bend	1557	1557	--	--	120	12	7,20	< 2.5
Ft. Lewis	1638	1644	150.6	325-346	7	14	12-20	0.5
Pyote	1638	1642	300.0	347-372	3.8	8	7-18	1.5
Fairbanks	1859	1911	132.0	302-320	2.4	30	6-12	1.6
Thule	2011	2015	237.0	315-323	1.9	24	15-19	0.9

Stations reporting negative results and the noise level (dynes/cm^2): Barksdale - 2.2, Washington - 3.0 to 13.4, Belmar - 9.5, Oahu - 1.4, Hachinohe - 1.4, Hanau - 1.0, Kyoto - 0.8

TABLE A.7 - Acoustic Data for Shot 5

(Source Time: 18 April 1953, 1235:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak ($dynes/cm^2$)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak ($dynes/cm^2$)
	Start (hr.min.)	Max. Ampl. (hr.min.)						
Los Angeles	1256	1256	--	--	63	4	11,35	< 1.5
San Diego	1301	1305	--	330-350	75	14	10,20,36	< 1.5
Dateland	1303	1303	--	350-460	75	17	8,4,0.5	< 5
Ft. Lewis	1342	1347	155.5	321-343	6.5	11	16-20	0.3
Pyote	1343	1349	301.8	335-370	9.5	11	8-14	3.2
Wash, D. C.	1544	1555	281.0	355	1.9	18	10-12	2.4
Fairbanks	1600	1600	135.0	320-357	2.5	15	5-15	1.4
Thule	1709	1716	238.0	338-351	7.0	14	11-14	1.1

Stations reporting negative results and the noise level ($dynes/cm^2$): Barksdale - 12, Belmar - 2.5, Oahu - 3.7, Hachinohe - 0.6, Hanau - 0.5, Kyoto - 0.4
Not operating: Gila Bend

TABLE A.8 - Acoustic Data for Shot 6

(Source Time: 11 April 1953, 1245:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm^2)
	Start (hr.min.)	Max. Ampl. (hr.min.)						
Los Angeles	1308	1308	--	--	8	2.5	2,6,16	< 0.5
San Diego	1313	1313	--	--	8	4	2.5	< 5
Dateland	1311	1311	--	350-365	8	6	1,3	0
Gila Bend	1313	1313	--	--	40	6	2	0

Stations reporting negative results and the noise level (dynes/cm^2): Ft. Lewis - 2.2, Pyote - 0.4, Barksdale - 1.7, Washington - 4.6, Belmar - 17.5, Fairbanks - 0.2, Oahu - 1.2, Thule - 0.9, Hachinohe - 0.9, Hanau - 0.6, Kyoto - 3.8

TABLE A.9 - Acoustic Data for Shot 7

(Source Time: 25 April 1953, 1230:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm^2)
	Start (hr.min.)	Max. Ampl. (hr.min.)						
Los Angeles	1251	1254	--	--	100	8	10,60	< 0.5
San Diego	1256	1257	--	335-410	60	15	10,60	< 0.5
Dateland	1257	1259	--	345-415	55	13	10,60	< 0.5
Ft. Lewis	1338	1346	154.0	314-372	11	15	9-35	0.6
Pyote	1342	1345	300.2	337-360	12.5	10	20-30	4.7
Barksdale	1419	1433	294.7	368-381	14.5	29	8-20	1.2
Fairbanks	1555	1604	134.8	321-347	2.2	22	16-20	0.5
Oahu	1640	1658	62.2	334-367	2.5	35	15-26	1.4
Thule	1709	1715	241.3	334-366	3.0	41	12-60	0.7

Stations reporting negative results and the noise level (dynes/cm^2): Washington, D. C. - 5.5, Belmar - 2.5, Hachinohe - 0.4, Hanau - 1.2, Kyoto - 1.1
Not operating: Gila Bend

TABLE A.10 - Acoustic Data for Shot 8

(Source Time: 19 May 1953, 1205:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm^2)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1225	1226	--	--	160	--	--	15
San Diego	1231	1235	--	325-375	75	14	6,14,40,55	< 2.5
Dateland	1231	1231	--	340-370	44	15	6,7,9	< 0.7
Ft. Lewis	1309	1314	154.8	332-380	6	23	8-18	0.4
Barksdale	1400	1413	285.0	370-411	6.5	12	13-44	1.8
Wash, D. C.	1512	1526	283.0	350	1.2	60	33	0.6
Fairbanks	1531	1533	130.0	322-354	0.5	7	16-17	0.5
Oahu	1611	1614	64.0	343-356	7.5	15	10-28	4.5

Stations reporting negative results and the noise level (dynes/cm^2): Pyote - 2.2, Thule - 3.8, Hachinohe - 0.6, Hanau - 2.9, Kyoto - 0.4, Belmar - 0.9
Not operating: Gila Bend

TABLE A.11 - Acoustic Data for Shot 9

(Source Time: 8 May 1953, 1529:55 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm2)
	Start (hr.min.)	Max.Ampl. (hr.min.)						
Los Angeles	1550	1550	--	--	150	--	--	20
San Diego	1555	1555	--	--	45	10	4,6,10,20	23
Dateland	1557	1557	--	--	53	4	7,10	8.5
Ft. Lewis	1640	1642	152.8	327-401	38	11	11-30	8
Pyote	1642	1648	299.0	341-373	5.5	10	8-30	1.9
Barksdale	1731	1737	288.0	364-393	> 5.5	25	9-20	1.3
Wash, D. C.	1906	1909	273.0	358	3.4	7.5	25	2.2
Oahu	1937	1947	56.3	324-350	3.8	13	15-25	1.7
Thule	2007	2016	239.7	281-361	2.9	28	12-35	1.4

Stations reporting negative results and the noise level (dynes/cm^2): Belmar - 4.2, Fairbanks - 3.3, Hachinohe - 1.0, Hanau - 0.3, Kyoto - 4.3
Not operating: Gila Bend

TABLE A.12 - Acoustic Data for Shot 10

(Source Time: 25 May 1953, 1530:00 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude O-peak (dynes/cm^2)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise O-peak (dynes/cm^2)
	Start (hr.min.)	Max. Ampl. (hr. min.)						
Los Angeles	1550	1552	--	--	120	5	2.5,5,7,24	< 3
San Diego	1555	1557	--	305-345	102	5	8,16,21	< 2.5
Ft. Lewis	1634	1637	158.0	293-352	15	30	9-45	1.5
Pyote	1651	1654	292.5	283-360	3.6	6	30-45	1.4
Wash, D. C.	1854	1900	282.0	360	2.0	14	30	0.6
Fairbanks	1850	1854	135.0	329-365	1.9	11	15-24	0.7
Oahu	1933	1939	57.8	332-366	6	12	10-19	2.9

Stations reporting negative results and the noise level (dynes/cm^2): Barksdale - 7.5, Belmar - 2.4, Thule - 1.3, Hachinohe - 2.9, Hanau - 0.3, Kyoto - 2.0
Not operating: Dateland, Gila Bend

TABLE A.13 - Acoustic Data for Shot 11

(Source Time: 4 June 1953, 1114:57 GMT)

Station	Time of Arrival (GMT)		Average Computed Azimuth (degrees)	Range of Horizontal Phase Velocities (meters/sec)	Maximum Signal Amplitude 0-peak (dynes/cm²)	Signal Duration (minutes)	Prominent Signal Periods (seconds)	Average Noise 0-peak (dynes/cm²)
	Start (hr.min.)	Max. Ampl. (hr.min.)						
Los Angeles	1135	1136	--	--	185	5	2,5,25	< 1
San Diego	1141	1143	--	330-415	> 125	20	15-25	< 1
Dateland	1144	1148	--	340-440	20	20	7,25	< 1
Ft. Lewis	1218	1223	155.3	321-330	> 39	7	3-20	1.3
Barksdale	1321	1330	294.4	344-373	5.5	14	30-48	1.5
Wash, D. C.	1438	1445	282.0	344	2.1	42	35	1.0
Fairbanks	1432	1436	133.2	340-357	1.8	22	12-20	0.3
Oahu	1514	1518	55.3	347-388	20	16	15-25	3.0
Thule	1552	1553	244.0	297	3.8	5	19-25	3.8
Hachinohe	1855	1857	45.5	327-352	0.4	6	7-20	0.2
Kyoto	1946	1950	45.5	307-333	2.5	6	13-20	1.1

Stations reporting negative results and the noise level (dynes/cm²): Belmar - 5.5, Hanau - 0.2
Not operating: Gila Bend, Pyote

TABLE A.14 - Azimuth Errors

Station	Error (degrees)										
	17 Mar	24 Mar	31 Mar	6 Apr	11 Apr	18 Apr	25 Apr	8 May	19 May	25 May	4 Jun
San Diego	1.4E*	-	4.8E	-	-	1.5E	2.1E	-	0.1E	4.2E	2.0W
Dateland	5.0E	7.7E	5.4E	4.7E	5.0E	4.3E	5.0E	-	4.2E	-	0.7W
Ft. Lewis	1.7E	0.9E	-	1.4E	-	3.3W	2.7W	0.8W	2.8W	6.0W	3.3W
Pyote	1.0N*	0.9N	1.6N	0.7S	-	1.0N	0.2S	1.0S	-	7.1S	-
Barksdale	1.5S	7.1N	-	-	-	-	4.6N	1.3S	5.1S	-	4.2N
Wash, D. C.	1.0N	1.0N	-	-	-	2.0N	-	5.4S	4.1N	3.6N	3.0N
Belmar	3.5S	-	-	-	-	-	-	-	-	-	-
Fairbanks	4.8W	2.3W	-	1.5W	-	4.4W	4.2W	-	0.5E	4.4W	2.7W
Oahu	-	-	-	-	-	-	4.9S	1.4N	6.7S	0.1S	2.0N
Thule	4.0E	10.2E	-	0.2W	-	1.1W	4.4W	3.1W	-	-	7.2W
Hachinohe	-	-	-	-	-	-	-	-	-	-	8.3N
Kyoto	-	-	-	-	-	-	-	-	-	-	4.4N

* E means indicated source to the east of the real source, N means indicated source to the north of the real source, etcetera.

TABLE A.15 - Travel Speeds for First Acoustic Arrivals, UPSHOT-KNOTHOLE

Station	Speed (meters/sec)										
	17 Mar	24 Mar	31 Mar	6 Apr	11 Apr	18 Apr	25 Apr	8 May	19 May	25 May	4 Jun
Los Angeles	303	293	298	311	287	307	308	304	313	307	317
San Diego	311	303	301	322	-	318	318	312	318	311	319
Dateland	315	324	319	343	337	320	321	312	337	NIO	298
Gila Bend	320	328	323	339	337	NIO*	NIO	NIO	NIO	NIO	NIO
Ft. Lewis	295	285	-	302	-	305	303	302	322	330	326
Pyote	324	336	315	329	-	332	312	306	-	272	NIO
Barksdale	315	340	-	-	-	-	325	290	287	-	280
Wash, D. C.	325	306	-	-	-	300	-	262	303	277	274
Belmar	317	-	-	-	-	-	-	-	-	-	-
Fairbanks	278	284	-	296	-	301	302	296	301	312	314
Oahu	-	-	-	-	-	-	292	300	297	301	306
Thule	297	288	-	296	-	301	296	-	-	-	299
Hachinohe	-	-	-	-	-	-	-	-	-	-	301
Hanau	-	-	-	-	-	-	-	-	-	-	-
Kyoto	-	-	-	-	-	-	-	-	-	-	297

* Not in operation.

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